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National health services: Efficiency, welfare and economy

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National health services: Efficiency, welfare and economy

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Editorial: National health services: Efficiency, welfare and economy

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Editorial on the Research Topic
National health services: Efficiency, welfare and economy

The national health service (NHS) forms a crucial part of a country for improving the health and lives of its citizens (1, 2). It contributes toward increasing life expectancy and improving the quality of life of the population and allows for better control of mortality rates resulting from various diseases. In addition, it is a key element in promoting social equity and improving the efficiency of a country's economy. Health managers face significant challenges, such as the growing demand for higher quality service, the increase in life expectancy leading to population aging, rising costs due to advances in medical technology, and limited and scarce resources, especially as a result of the economic crisis (3–5). Nowadays, it is also necessary to consider the impact of the COVID-19 pandemic, which further complicates the context (6).

The quality of an NHS differs according to the country and geographical area in question (7, 8). It is essential to display the NHS's strengths, identify its weaknesses, and provide helpful information for practitioners, administrators, politicians, and citizens. The control of medical procedures, action protocols, cost management, and resource allocation must be analyzed from a purely medical and managerial perspective. The COVID-19 pandemic has highlighted how differences in management lead to very different health outcomes (9, 10). While some health systems have been able to manage the situation effectively, others have experienced major collapses at the most difficult times, resulting in higher mortality, more negative consequences for survivors, and a deepening economic crisis. The wellbeing and health of its population should be the primary objective of a country. Moreover, health resources management is essential for reducing inequalities in the population's health status and providing a stable and robust economy.

This Research Topic has contributed to providing empirical evidence in the field of health management as well as knowledge for enhancing both the efficiency of an NHS and the welfare of a country's population through research conducted worldwide, specifically in China, Japan, the United States, and Europe.

Shi et al. have revealed spatial and temporal differences in health expenditure efficiency in China based on the background of the COVID-19 pandemic. They used a meta-frontier data envelopment analysis (DEA) based on the number of health workers and beds in medical institutions as well as per capita fiscal health expenditure as the input variables, and GDP and life expectancy as the output variables. The results show a large difference between the eastern and western regions of China, with the former having the most efficient technical level of efficiency.

Guo et al. evaluated unified healthcare efficiency in China using a meta-frontier non-radial directional distance function analysis. The number of health technicians and beds were used as inputs, while the number of outpatient and inpatient visits, as well as the maternal, perinatal, and contagious mortality rates were used as outputs. These authors determined how efficiency is linked to technological progress, such that the more technologically developed regions have a more evolved healthcare system. In addition, the less developed areas follow the path of the more developed regions to reduce the efficiency gap.

Based on a non-parametric additive model, Wang Y. et al. established that the amount of public health spending is crucial not only for the survival and quality of life of a population but also for economic development. Therefore, especially during periods of economic crisis, governments should increase the percentage of GDP allocated to health resources to improve the health of human capital and, consequently, the performance of the economy.

Yang et al., using the two-stage network DEA model, showed how the efficiency of the Chinese healthcare system has increased, but also that there are notable differences between different regions. The factors that most affect efficiency are economic development, fiscal decentralization, and the old-age dependency ratio. Efficiency can be improved by establishing mechanisms for sharing resources and forming medical alliances between the most and least efficient areas. Governments should encourage technological innovation in the medical field and also increase technical medical research. It is also important to implement training programs that improve the skills of health technicians, further the education of resident physicians, and increase the population's health literacy.

Yin et al. analyzed efficiency in Chinese county hospitals based on DEA and a fuzzy-set qualitative comparative analysis. A combination of many factors determines efficiency. In this sense, achieving efficiency requires structural optimization, capacity enhancement, and government support. In contrast, inefficiency is determined by insufficient capacity, aggressive expansion, and poor decision-making.

Chen et al. studied the case of China and highlighted the difficult work performed by village doctors in developing countries, which often causes job burnout and turnover intention. Governments should develop policies to improve the situation of these doctors, such as reducing their workload by employing more doctors, training students for this particular position, and improving the harsh working conditions.

Life expectancy can be considered to be the fundamental determinant of wellbeing. Therefore, it is a critical element of government policies for achieving the United Nations Sustainable Development Goals. However, life expectancy differs greatly between countries, as well as between regions within the same country. In this vein, Valls Martínez et al. have revealed the inequalities in regional wellbeing arising from public healthcare expenditure policies in Spain. First, using a PLS-SEM model, the authors showed how public health spending has a decisive influence on the population's wellbeing as measured by life expectancy. Second, based on a hierarchical cluster analysis and a principal component analysis, they established a clear division of the country into areas according to the overall health of their citizens as well as basic spending. Therefore, public health spending policies make a difference even within the same country and are decisive for the wellbeing of citizens.

Moga Rogoz et al. have shown the positive effects of economic freedom and education on life expectancy in the new EU member states. Economic freedom leads to adequate legal structures, sound monetary and fiscal policies, financial development, trade liberalization, innovation, and competitiveness, which implies greater wellbeing. Moreover, better-educated individuals are more likely to adopt healthier lifestyles and have greater access to higher-paying jobs, allowing them to use improved health services. Analyzing the case of China, Wang S. et al. established that fiscal policy is a fundamental macroeconomic tool for boosting economic development, especially in times of crisis, such as that resulting from the COVID-19 pandemic. The expansionary fiscal spending policy failed in the economic control of the crisis, with the effectiveness of the revenue-based fiscal policy being much faster.

Carrasco-Aguilar et al. analyzed the literature on the Affordable Care Act in the United States, colloquially known as Obamacare. This law was intended to allow all U.S. citizens access to healthcare services at a time when most were provided by the private sector, representing a change in the country's mentality toward free and universal healthcare. This was a significant reform, with legal, political, economic, administrative, and health repercussions, and has brought about significant progress in preventing and treating illnesses. However, Yuda, in a study of Japan, demonstrated that free health care entails an excessive use of public health

services, which can be moderated by establishing a co-payment system.

On the other hand, Hao et al., through an evaluation of a program for controlling hypertension in China, showed how public programs for the prevention, control, and treatment of certain illnesses have proven to be efficient. In this vein, Bosch-Frigola et al. (a), in a study on diabetes mellitus in the different European healthcare systems, showed how an increased awareness among the population of this disease, as well as improvements in national health plans, can improve the quality of life of patients, influencing the management of the disease and healthcare expenditure. The multiplier effect of specific prevention campaigns must also be considered. For example, considering the direct relationship between certain psychopathologies and increased rates of smoking, Nieto-González et al., showed that campaigns aimed at the prevention of mental illness may reduce tobacco consumption among patients. Finally, in a study conducted by Bosch-Frigola et al. (b) on diabetes mellitus in Spain, it has become clear how access to information and communication technologies is considered a social determinant of health, as it can generate inequalities in access to information and health services.

The editors believe that this Research Topic has advanced the understanding of the efficiency and welfare of an NHS, as well as how the healthcare system is related to the national economy and to a country's citizens.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Spatial and Temporal Differences in the Health Expenditure Efficiency of China: Reflections Based on the Background of the COVID-19 Pandemic

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The outbreak of the COVID-19 pandemic has brought several challenges to China's national health services, causing great risks and uncertainties to people's lives. Considering China's huge population and relatively small medical investment and its good performance in the COVID-19 pandemic, this research utilizes the hybrid meta-frontier model to analyze health expenditure efficiencies of 30 provinces in China from 1999 to 2018 and compares spatial and temporal differences of the efficiencies in regards to regional forward position and national common frontier. The results show an obvious difference in health expenditure efficiency in different provinces along the regional frontier, in which the efficiency gap in the eastern region is the largest. Moreover, the room for improvement in health expenditure efficiency varies from region to region. For the national common frontier, Beijing is the most efficient, while Guizhou is the least. The eastern region owns the most efficient technical level of health expenditure efficiency, and there is a large efficiency distance between it and the western region. The findings offer effective guidance for elevating the expenditure structure and spatial resource allocation of public health and for promoting the equalization of high quality basic medical services.

Keywords: hybrid meta-frontier DEA, health expenditure efficiency, spatial-temporal difference, policy recommendations, COVID-19 pandemic

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INTRODUCTION

Public health events caused by highly infectious diseases are sudden and more harmful, easily causing serious damage to public health and bringing more serious losses to a national economy in the short term. The outbreak of COVID-19 has severely impacted the defense line of China's health care industry. COVID-19 continues to sweep around the world, bringing serious threats to the safety of people's lives and property. Health is crucial to human beings and to the future development of any country. The practice of developed countries or regions has shown that government expenditure on health not only helps residents enjoy health welfare, but also reduces residents' health expenditure, promotes their physical and mental health, and induces the accumulation of human capital, which has the effect of promoting economic growth (1). To better solve people's requirements for health problems, China attaches great importance to public health expenditure.

The country's relatively effective response to the shock of COVID-19 relates to the operational efficiency of its health care system and the effectiveness of national governance. The vast size of China, the large differences in the level of economic development and government revenue across the country, and the great differences in public health investment in health care services by local governments have resulted in the performance in coping with COVID-19 varying from place to place. Since health services have certain public good attributes, it is more efficient for the government to provide most of such services from the perspective of social equity and efficiency, but conversely, relying entirely on government tax revenue to provide health resources to residents puts enormous pressure on fiscal expenditures. After the occurrence of COVID-19, people are thinking more deeply about the adequacy and effectiveness of government public health investment and discussing how the structure and allocation of it should be rationalized by effectively improving the efficiency in the use of both financial funds and health care funds.

In the 1990s China proposed that provincial and local governments shall increase their health expenditures year by year along with the continuous development of the overall economy, and the growth of health expenditure must be much faster than fiscal expenditure, especially after China's Medicare Reform in 2009, which aims to create a safe, effective, convenient, and low-cost basic universal service system that makes health care costs affordable to everyone (2). From 2009 to 2018, total health expenditure in China grew at a rate of 14.61% per annual, which is higher than that of GDP (10.55%), leading to an increase in total health expenditure (THE) share of GDP from 1.19 to 1.71% during the same period. The Healthy China 2030 Plan released by the 18th Chinese National Congress has established the "big health concept" centered on "health promotion". However, the majority of medical expenses in China are still borne by individual residents. As such, the problem of difficult and expensive medical treatment has not been effectively solved. However, as shown in **Figure 1**, although the percentage of China's health expenditure has increased in recent years, it is still far from enough compared to developed economies such as the United States, Japan, etc. It is clear that health services provided by the government do not meet the increasing health expenditure needs of its citizens, especially in response to events such as the COVID-19 pandemic.

Public service expenditure accounts for a relatively small proportion of fiscal expenditure in China, resulting in insufficient public services such as health, education, and social security, although it has gradually increased since the Reform and Opening-up in 1978. In addition to the lack of public service expenditures, the China government also exhibits low efficiency or inefficiency in the process of public service supply. There are still widespread medical care problems such as high medical costs and medical difficulties, and the number of people who become poor due to illness or even turn from wealth to poverty is on the rise. Thus, a study on the efficiency of health expenditure plays an important role in health economics.

China is a populous country, especially with its population density reaching 150 people per square kilometer in 2018. Therefore, the increased efficiency of health spending will help China fully implement its health strategy. Under the realistic constraint of insufficient health inputs, it is expected that relative departments can propose effective policies and appropriate health services that improve the efficiency of health-care costs. One pre-condition for improving and enhancing the efficiency of public health expenditure is to scientifically evaluate such efficiency and understand its makeup in China. We thus apply the hybrid meta-frontier DEA model to evaluate the health expenditure efficiencies of 30provinces (Tibet, Hong Kong, Macao, and Taiwan are not include, due to serious data deficiencies) from 1999 to 2018 and to explore the spatial and temporal variation rules of their health expenditure efficiency. We expect to provide theoretical support for the government to formulate a strong policy based on the background of COVID-19 that can promote health expenditure efficiency.

The remaining structure of this paper runs as follows. Section Literature Review, which states the main studies on health expenditure efficiency and their methods. Section Methodology, which introduces methods used herein and explains the index selection and data sources. Section Empirical Results, which discuss the results of efficiency calculation as well as spatial and temporal evolution characteristics. Section Research Conclusions and Policy Recommendations.

LITERATURE REVIEW

Scholars around the world have conducted a great deal of research in the field of health. Newhouse (3), who studied the determinants affecting health-care spending, pointed out that the main factor in health-care spending is actually the affluence of a country. The presentation of some health programs has largely applied data on health issues, leading to an enormous array of studies that support the result of Newhouse (3–7). In recent decades, however, studies on the relationship between health expenditure efficiency and energy consumption (8–11) are gradually increasing. Grasso et al. (12) used the bibliometric method to evaluate research areas that used patient satisfaction as a basis for health policy, thereby providing recommendations for healthcare policy makers to develop policies in the face of a changing and evolving environment.

Most studies on the health expenditure efficiency, have focused on the determinants and allocation of local health care services, such as gross domestic product (GDP) per capita, fiscal structure, revenue, etc. Akca et al. (13) identified the main variables in the health expenditure estimates of OECD member states, and GDP per capita was found to be a major estimated factor in regards to medical expenses. Kim et al. (14) used the method of Eikemo et al. (15) to examine the relationship between income and forgone care across a multinational sample of 28 countries, and the empirical results mostly corresponded with the study of Apouey and Geoffard (16). This suggests a strong social gradient and statistically significant linkage between income and forgone care. Most studies employ transnational samples to see to what extent income (measured by GDP) and other determinants, such as demographics and unequal investment in

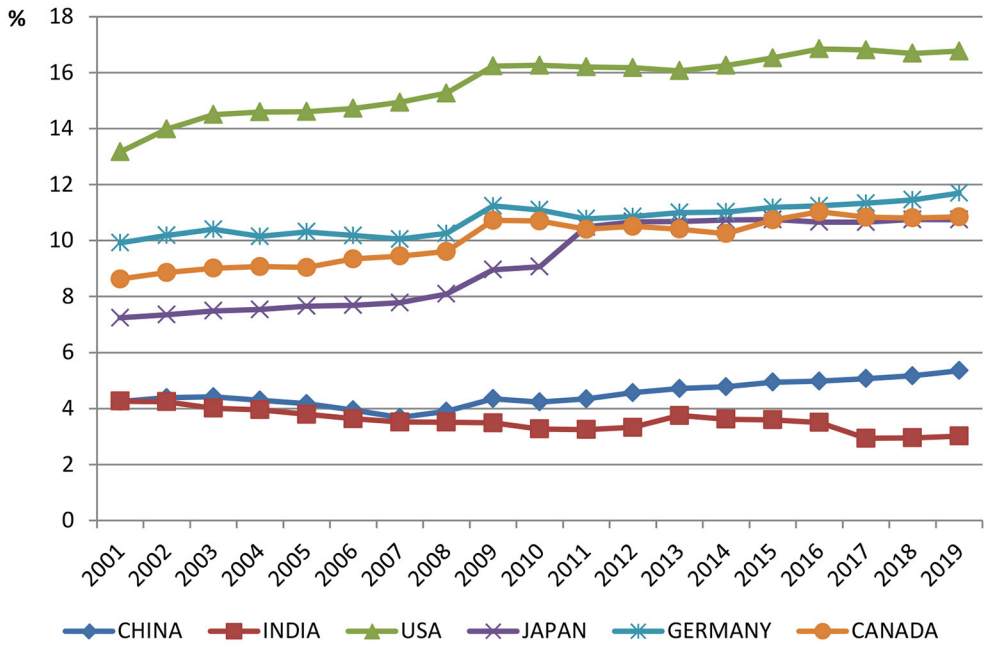

FIGURE 1 | Current health expenditure (% of GDP) of some countries in the world.

health funding, explain differences in health expenditure (17–19). Sun and Luo (20) used the Concentration index and Data Envelopment Analysis (DEA) to evaluate the fairness of health services utilization and employed a relative assessment toward the efficiency of health resources allocation. They found that the distribution of medical resources in China is uneven and exhibits regional differences. The allocation efficiency of health resources in most provinces is generally low and still needs to be improved.

Scant research exists on the spatiotemporal performance of health expenditure, and most studies are based on the spatial econometric model. In fact, the spatial-temporal characteristics of health expenditure efficiencies are crucial issues in any attempt to optimize the situation for the supplying entities, especially during post-COVID-19 period. Costa-Font and Pons-Novell (21) found that the national public health expenditure in Spain showed significant spatial heterogeneity caused by the difference between health sector investment and the economic dimension. Wang and Tao (22) applied DEA and the spatial Durbin model to analyze the static overall efficiency and spatial spillover effect of local government health expenditure across China. Jeetoo (23) researched the public health-care cost in Sub-Saharan Africa (SSA) through balanced panel data that consist of 43 SSA countries from 2000 to 2015. The empirical results indicated that the public healthcare expenditure of these countries has a positive spatial dependence.

The most widely applied methods for the evaluation of innovation efficiency are parametric techniques, among which DEA is the most popular. The basic concept of DEA dates back to Farrell (24). In one DEA model, Nunamaker (1985) believed that increasing potential efficiency scores are followed by the addition of empirical variables and new data. Following that, the methods and conceptions of DEA employed by scholars have gradually increased. For example, the two-stage DEA proposed in the measurement of efficiencies (25–28), Super Slacks-based Measure DEA applied in the calculation of efficiency score (29–32), and three-stage DEA are now used in empirical analysis (33–35).

Scholars arguably have studied health expenditure efficiency through the DEA method mostly based on the health expenditure status and its influencing factors. Jakovljevic et al. (36) analyzed the health expenditure efficiency in East Europe based on life expectancy perspectives, differences-in-differences (DID) analysis, and DEA methods. Cetin and Bahce (37) employed DEA to calculate health expenditure efficiency in OECD countries. Eriksen and Wiese (38) then took their results to estimate the relationship between private healthcare financing and total health expenditure efficiency of OECD countries through DEA and the Tobit Panel data. Feng et al. (39) applied modified Meta-Frontier Dynamic Network DEA to investigate the impact of energy consumption on health expenditure efficiencies of environmental pollution in 15 old EU states and 13 new EU countries in 2010–2014. They found differences in groups and calculated overall efficiency scores and technical gap ratios as well as health expenditure efficiencies.

Many scholars have focused on China's efficiency of health spending based on various perspectives and methods of DEA. Liu and Liu (40) took Chinese panel data from 2002 to 2009 and used the DEA-Tobit method to evaluate out-of-pocket healthcare expenditure efficiency. The results showed that the total efficiency of health expenditure has not increased since the health reform, with national health expenditure efficiency rising and personal health expenditure efficiency dropping. Liu et al. (41) applied

the super-slack-based measure (SBM) model to focus on static and dynamic health expenditure efficiencies in rural China from 2007 to 2016. Their findings showed that the health expenditure efficiencies present unstable trends during the period. Shi et al. (42) merged the efficiencies of energy, environmental pollution, and human health and analyzed them in a two-stage framework to measure the influence of pollutant emissions in 30 provinces of China from 2013 to 2016. The data indicate that the average efficiency of health expenditure is undesirable. Wang and Tao (22) employed DEA to measure the static overall efficiency of the each local government health expenditure in China from 2007 to 2016. The empirical results presented that the overall efficiency score increased 0.11 during the decade.

Scholars have certainly increased their research in health care after the COVID-19 outbreak. Radenovic et al. (43) analyzed the efficiency of health systems and the response to the COVID-19 pandemic in 27 European Union (EU) countries, examining the interdependence between their health expenditures and health system efficiency as well as the key determinants of improvement. The interdependence between health expenditure and health system efficiency in these countries and the key determinants of health system efficiency in the EU were examined, and recommendations were made for building an efficient and comprehensive health system that can respond to public health emergencies. Considering China's economic status and huge population, their health expenditure is not so huge, but they can achieve effective control of infectious diseases like COVID-19 pandemic, which makes it necessary to study the efficiency of their health expenditure efficiency and its spatial and temporal differences, because other countries can gain experience in improving national health care services, especially emerging economies such as India and Brazil, which also have large populations. However, the efficiency of health systems in China has been rarely studied. In particular, their evaluation results may not be able to reflect the actual situation of China's health expenditure efficiency, because the methods in the literature ignore regional heterogeneity and the performance of each province is not simply comparable.

Hayami (44) and Hayami and Ruttan (45, 46) proposed the meta-frontier DEA. On the basis of a fundamental concept of the meta-production function, it is used to solve the problem of incomparability between different Decision Making Units (*DMUs*) under different technologies (47). Since then, the approach has been used in a variety of studies analyzing efficiency by comparing different regions' technical efficiency and gap ratios, such as O'Donnell et al. (48), Zou et al. (49), Yu and Chen (50), and Sun et al. (51). The hybrid meta-frontier DEA model was used to measure the efficiencies of health expenditure for 30 provinces in China and to compare the health expenditure efficiencies between the regional forward position and national common frontier. Technical gap ratios were introduced to analyze the gap between the efficiency of health input and the most likely level of excellence in the country.

METHODOLOGY

The level of economic development varies greatly across China, and the eastern coastal provinces have a great degree of such development and health care than the central and western provinces due to them having developed transportation systems and rich natural resource endowments. Simply measuring the efficiency of health care spending in a particular province or comparing the efficiency of health care spending among provinces without collation does not reflect the overall level of health care spending in China well. To address these issues, the research conducted in this paper proposes to construct the following model.

Hybrid DEA Model

Charnes et al. (52) built DEA by exploiting the existing assumption of scale return being invariant (CCR model). Banker et al. (53) incorporated variable returns to the scale, extended the CCR model, and developed the BCC model. The main shortcoming of these traditional DEA models is that they ignore non-radial relaxants when scoring efficiency, especially when these slacks have a big impact on management efficiency. Alternatively, SBM (54) captures non-radial slacks directly, and the non-radial slacks that are not in the radial model can now be analyzed from the optimal efficiency values.

We let the observed data matrices of inputs and outputs respectively be $X \epsilon R_+^{m \times n}$ *and* $Y \epsilon R_+^{s \times n}$. Here, n, m, and s are respectively the number of DMUs, inputs, and outputs. We decompose below the inputs' matrix into radial components, $X^R \epsilon R_+^{m_1 \times n}$, *and the non − radial into* $X^{NR} \epsilon R_+^{m_2 \times n}$, where $m = m_1 + m_2$:

$$x = \begin{pmatrix} X^R \\ X^{NR} \end{pmatrix}$$

As above, we decompose the outputs' matrix Y into the radial components, $Y^R \epsilon R_+^{s_1 \times n}$, *and non−radial,* $Y^{NR} \epsilon R_+^{s_2 \times n}$, *where* $s = s_1 + s_2$:

$$Y = \begin{pmatrix} Y^R \\ Y^{NR} \end{pmatrix}$$

We now assume that the dataset is positive, $X > 0$, $Y > 0$. Here, P as a production possibility set is subsequently defined as:

$$P = \{(x, y) | x \geq X\lambda, y \leq Y\lambda, \lambda \geq 0\}$$

Where is a non-negative vector in R^n, such that:

$$DMU(x_0, y_o) = (x_0{}^R, x_0^{NR}, y_0^R, y_0^{NR}) \in P$$

$$\theta x_0^R = X^R\lambda + s^{R-}$$

$$X_0^{NR} = X^{NR}\lambda + s^{NR-}$$

$$\varnothing y_0^R = Y^R\lambda - s^{R+}$$

$$y_0^{NR} = Y^{NR}\lambda - s^{NR+}$$

Here, $\theta \leq 1$, $\varnothing \geq 1$, $\lambda \geq 0$, $s^{R-} \geq 0$, $s^{NR-} \geq 0$, *and* $s^{NR+} \geq 0$, and $s^{R-} \in R^{m_1}$ and $s^{NR-} \in R^{m_2}$, respectively are the excess of

radial and non − radial components, and $s^{R+} \in R^{s_1}$ and $s^{NR+} \in R^{s_2}$ denote the slacks of *radial and non − radial and slacks*. If $\theta = 1,\ \varnothing = 1, and\ \lambda_0 = 1, \lambda_j = 0(\forall_j \neq 0)$, then the slacks are equal to 0.

We define efficiency index ρ as:

$$\rho = \frac{1 - \frac{N}{R} \times (1-\theta) - \frac{1}{R} \times \sum_{m=1}^{M} s_m^{NR}/x_{em}^{NR}}{1 + \frac{s_1}{s}(\varnothing - 1) + \frac{1}{s} \times \sum_{q=1}^{Q} s_q^{NR+}/y_{eq}^{NR}}$$

Here, $DMU(x_0, y_o) = (x_0{}^R, x_0^{NR}, y_0^R, y_0^{NR}) \in P$ is hybrid efficient if $\rho = 1, \theta = 1, \varnothing = 1,\ s^{NR-} = 0$, and $s^{NR_+} = 0$. This state can be determined by solving the following procedure:

$$\underset{\theta, \varphi, \lambda, s^{NR-}, s^{NR+}}{Min} : \rho^* = \frac{1 - \frac{N}{R} \times (1-\theta) - \frac{1}{R} \times \sum_{m=1}^{M} s_m^{NR}/x_{em}^{NR}}{1 + \frac{s_1}{s}(\varnothing - 1) + \frac{1}{s} \times \sum_{q=1}^{Q} s_q^{NR+}/y_{eq}^{NR}}$$

$$s.t. \sum_{j=1}^{J^i} x_{jn}^R \mu_j \leq \theta \times x_{en}^R, \quad \mathrm{n} = 1, \ldots, \mathrm{N}$$

$$\sum_{j=1}^{J^i} x_{jm}^{NR} \mu_j + S_m^{NR-} = x_{em}^{NR}, \ \mathrm{m} = 1, \ldots, \mathrm{M}$$

$$\sum_{j=1}^{J^i} y_{jp}^R \mu_j \geq y_{ep}^R, \qquad \mathrm{p} = 1, \ldots, \mathrm{P}$$

$$\sum_{j=1}^{J^i} y_{jp}^{NR} \mu_j - S_q^{NR+} = y_{ep}^{NR}, \ \mathrm{q} = 1, \ldots, \mathrm{Q}$$

$$\sum_{j-1}^{J^i} \mu_j = 1\theta \leq 1, \mu_j \geq 0, s^{R-} \geq 0,\ s_m^{NR-} \geq 0,\ S_q^{NR+} \geq 0$$

We note that θ is the efficiency score measured from the radial inputs; $s_m^{NR-}\ (m = 1, \ldots, M)$ and $S_q^{NR+}(q = 1, \ldots, Q)$, respectively are the mth non-radial inputs' slack and qth non-radial outputs' slack that are evaluated based on the dataset; and μ_j is the composed weight of benchmarks for DMU_e.

Through the optimal solution, we decompose the hybrid efficiency indicator into four factors:

$$\text{Radial input inefficiency}: \ \alpha_1 = \frac{m_1}{m}(1 - \theta^*)$$

$$\text{Non} - \text{radial input inefficiency}: \ \alpha_2 = \frac{1}{m} \sum_{i=1}^{m2} S_m^{NR-*}/x_{i0}^{NR}$$

$$\text{Radial output inefficiency}: \ \beta_1 = \frac{s_1}{s}(\varnothing^* - 1)$$

$$\text{Non} - \text{radial output inefficiency}: \ \beta_2 = \frac{1}{s} \sum S_r^{NR+*}/y_{r0}^{NR}$$

The input and output inefficiencies are defined as:

Input inefficiency: $\alpha = \alpha_1 + \alpha_2$

Output inefficiency: $\beta = \beta_1 + \beta_2$

The hybrid efficiency measure is then:

$$\rho^* = \frac{1 - \alpha}{1 + \beta} = \frac{1 + \alpha_1 - \alpha_2}{1 + \beta_1 - \beta_2}.$$

The resulting expressions help find the sources of inefficiencies and the extent of their influence on the efficiency scores.

Meta-Frontier DEA Model

Battese et al. (55) noted that the meta-frontier can estimate the technology gap by specifying a non-random frontier. O'Donnell et al. (48) determined technical disparity by means of the radial DEA model. We further develop gap measurements of hybrid techniques from the hybrid DEA model and examine the operational technical differences in different regions.

We separate the *DMU*s into I groups by different operating technologies. The sample size of the ith group is J^i and satisfies $\sum_{i=1}^{I} J^i = J$. The formula is thus rewritten as:

$$\underset{\theta, \varphi, \lambda, s^{NR-}, s^{NR+}}{Min} \cdot \rho^*.$$

$$s.t. \sum_{i=1}^{I} \sum_{j=1}^{J^i} x_{jin}^R \lambda_{ji} \leq \theta \times x_{en}^R, \ \mathrm{n} = 1, \ldots, \mathrm{N}$$

$$\sum_{i=1}^{I} \sum_{j=1}^{J^i} x_{jin}^{NR} \lambda_{ji} + S_m^{NR-} = x_{em}^{NR}, \mathrm{m} = 1, \ldots, \mathrm{M}$$

$$\sum_{i=1}^{I} \sum_{j=1}^{J^i} y_{jip}^R \lambda_{ji} \geq y_{ep}^R, \qquad \mathrm{p} = 1, \ldots, \mathrm{P}$$

$$\sum_{i=1}^{I} \sum_{j=1}^{J^i} y_{jiq}^{NR} \lambda_{ji} - S_q^{NR+} = y_{eq}^{NR}, \ \mathrm{q} = 1, \ldots, \mathrm{Q}$$

$$\sum_{i=1}^{I} \sum_{j=1}^{J^i} \lambda_{ji} = 1, \mathrm{I} = 1, \ \ldots, \mathrm{I}$$

$$\theta \leq 1, \lambda_{ji} \geq 0, s^{NR-} \geq 0, \ S_q^{NR-} \geq 0, \ S_q^{NR} \geq 0$$

O'Donnell et al. (48) identified the optimal objective value of ρ^* as meta-efficiency. Solving this procedure helps us calculate the efficiency score of DMU_e (labeled ρ^i) based on the ith group-namely, group-efficiency:

$$\underset{\theta, \varphi, \lambda, s^{NR-}, s^{NR+}}{Min} : \rho^{i*} = \frac{1 - \frac{N}{R} \times (1 - \theta^i) - \frac{1}{R} \times \sum_{m=1}^{M} S_m^{iNR-}/x_{em}^{NR}}{1 + \frac{s_1}{s}(\varnothing^i - 1) + \frac{1}{s} \times \sum_{q=1}^{0} S_q^{iNR+}/y_{eq}^{NR}}$$

$$s.t. \sum_{j=1}^{J^i} x_{jn}^R \mu_j \leq \theta^i \times x_{en}^R, n = 1, \ldots, N$$

$$\sum_{j=1}^{J^i} x_{jm}^{NR} \mu_j + S_m^{iNR-} = x_{em}^{NR}, m = 1, \ldots, M$$

$$\sum_{j=1}^{J^i} y_{jp}^R \mu_j \geq y_{ep}^R, \qquad p = 1, \ldots, P$$

$$\sum_{j=1}^{J^i} y_{jq}^{NR} \mu_j - s_q^{iNR} = y_{eq}^{NR} \quad , q = 1, \ldots, Q$$

FIGURE 2 | The three regions of China divided in this paper.

$$\sum_{j=1}^{j^i} \mu_j = 1$$

$$\theta^i \leq 1, \mu_j \geq 0, S_q^{iNR-} \geq 0, S_q^{iNR} \geq 0$$

To extricate the technical differences, we define the technology gap ratio (TGR) of productiveness for i^{th} group's j^{th} DMU (i.e.,DMU_{ij}) as $TGR_{ij} = \rho^*/\rho^{i*}$. Technological progress or regression of countries (or companies) relative to technological changes in different regions can explain the TGR growth index. This growth index is below one when the disparity between the group frontier and the meta-frontier is decreasing.

EMPIRICAL RESULTS

Data and Variables

The study's data cover 30 provinces in China during the period 1999–2018. Based on geographical differences, we divide them into three regions: Eastern, Central, and Western. The eastern region includes Beijing, Tianjin, Hebei, Liaoning, Shandong, Shanghai, Jiangsu, Zhejiang, Fujian, and Guangdong. The central part includes Inner Mongolia, Heilongjiang, Jilin, Shanxi, Anhui, Jiangxi, Henan, Hunan, and Hubei. The western area includes Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang, Chongqing, Sichuan, Yunnan, Guizhou, Guangxi, and Hainan (as shown in **Figure 2**).

In this investigation we have five variables divided into two categories to evaluate each province's efficiency scores. These two classes are the input variables and the output variables, with three and two, respectively. The input variables are the number of health workers, beds in medical institutions, and per capita fiscal health expenditure per thousand citizens. The corresponding output variables are per capita GDP and life expectancy (as **Table 1**). The data are from ***"China Statistical Yearbook"*** and ***"China Health Statistical Yearbook"***.

The following results about the variables can be obtained from **Table 2**. (1) The average number of health workers per thousand citizens from 1999 to 2018 is 4.17. Beijing has the greatest number of health workers per thousand citizens at 9.48 in 2018, while the province with the lowest is Qinghai at 3.58 in 1997. (3) The average number of beds in medical institutions per thousand citizens from 1999 to 2018 is 6.58. The province with the highest number is Beijing at 13.52 in 2018, while Ningxia at 4.23 in 1996 has the lowest amount. (4) The per capita fiscal health expenditure for the 30 provinces increased from 1999 to 2018 at an average annual rate of 6.85%. Beijing has the highest per capita fiscal health expenditure at 1205.31 CNY in 2018, with Gansu the lowest at 82.69 CNY in 1999. (5) The per capita GDP for the 30 provinces increased from 1999 to 2018 at an average rate of 11.26% every year. Tianjin has the highest per capita GDP at

TABLE 1 | Input and output variables.

Input variables	Output variables
1. The number of health workers per thousand citizens	1. Per capita GDP
2. The number of beds in medical institutions per thousand citizens	2. Life expectancy
3. Per capita fiscal health expenditure	

TABLE 2 | Descriptive statistics.

	Variables	AVE	MAX	MIN	STDEV
Input	Number of health workers per thousand citizens	4.17	9.48	3.58	1.82
	Number of beds in medical institutions per thousand citizens	6.58	13.52	4.23	2.65
	Per capita fiscal health expenditure	363.35	1205.31	82.69	189.36
Output	Per capita GDP	16,583	93,173	2,215	3,721
	Life expectancy	71.37	80.19	60.61	4.57

93173 CNY in 2018, with Guizhou being the lowest at 2215 CNY in 1999. (6) Life expectancy increased from 1999 to 2018 at an average rise of 7.23% every year. The highest is Beijing at 80.19 years in 2018, while the lowest is 60.61 years for Qinghai in 1999.

This study used DEA-Solver software 9.0 to assess efficiency *via* the Hybrid DEA model of Tone (56). Each of efficiency value improves toward the efficient frontier according to its own specifications to identify the relationship between health expenditure and health outcome. We denote the above variables as the radial category and the other parameters (the number of health workers and beds in medical institutions per thousand citizens, and per capita GDP) as the non-radial category.

Analysis of Differences in Health Expenditure Efficiency Under the Regional Frontier

This study estimates the health expenditure efficiency of each province under the country's three regional frontiers. The left side of **Table 3** and **Figure 3** shows the results. The average health expenditure workpiece ratio of the sample period that is under the eastern frontier is 0.669, suggesting that potentially using the best production technologies in the east could yield an improvement of 33.1%. The efficiency gap in the eastern provinces is large. Shanghai has the highest average efficiency at 0.893, while Hebei has the lowest efficiency at 0.561. The average health expenditure efficiency for the sample period that is under the central frontier is 0.734. Hunan has the highest efficiency at an average level of 0.761, while Jiangxi has the lowest efficiency at 0.713. The inter-provincial efficiency gap in the central provinces is narrower than that in the east, and there is room to hit the best efficiency level. The average health expenditure efficiency that is under the western frontier is 0.718, with the highest efficiency in Chongqing and the lowest in Guizhou. Therefore, the difference in health expenditure efficiency is significant when comparing the three regional frontiers. By comparing the potential optimal production technologies across regions, the likelihood of improvement is 33.1% in the east, 26.6% in the central, and 28.2% in the west.

Analysis of Differences in Health Expenditure Efficiency Under the National Common Frontier

This study next estimates the health expenditure efficiency of each province under a common national frontier, **Table 3** and **Figure 4** shows the results. The health expenditure efficiencies under the national common leading edge represent the relative efficiencies of provinces compared to the others. The gap in the efficiency of average health expenditures is even more pronounced under the common leading edge of the whole country. The average efficiency of Shanghai is 0.893, while Guizhou is only 0.446. In terms of the overall level of each region, the east has the highest average health expenditure efficiency, and the central region has a higher efficiency than the west. In other words, the regional efficiency model of China's provinces does coincide with a gradient in the pattern of economic development in the three different regions. Therefore, the results suggest that the efficiency of health expenditure in a province highly correlates with the degree of economic development. In the central and west, the study finds differences in the efficiency of health-care cost estimated along the national common frontier and the efficiency estimated along the regional frontier. For example, Sichuan's average efficiency under the regional frontier is 0.736, while it is 0.487 under the common frontier, because of the different setting reference technology. The regional frontier is the potential optimal technology for the west area only, and the common frontier is the potential optimal production technology for the whole country. The east exhibits the highest level in China.

Analysis of Health Expenditure Efficiency's Technology Gap

The technology gap ratio is the most significant indicator of the common frontier analysis method. It is able to inspect the gaps in potential optimal production technologies between the three regions.

From **Table 4**, there are significant technological gaps in the efficiency of health-care spending in the three areas of China during the sample period. The eastern region had the highest TGR of 1 in previous years. For health expenditure utilization, it has reached 100% of the country's potentially best production technology. This region is the most economically developed in China, and its general level of efficiency in health expenditure is better than that of the other two regions. The average TGR for the central region is 0.774, showing 22.6% room for improvement compared to the country's potentially best production technology. The western region's TGR is 0.683, denoting room for improvement of 31.7% compared to the potential optimal production technology for the country.

This study shows that the technical difference ratio of health expenditure efficiency in the central area is increasing,

TABLE 3 | Health expenditure efficiency under the regional and national common frontiers.

	Regional frontier				National common frontier			
	Min	**Max**	**Ave**	**SD**	**Min**	**Max**	**Ave**	**SD**
Eastern	0.456	1.000	0.669	0.101	0.456	1.000	0.669	0.101
Beijing	0.696	0.907	0.864	0.132	0.696	0.906	0.864	0.132
Tianjin	0.598	0.867	0.655	0.098	0.598	0.867	0.655	0.098
Liaoning	0.474	0.798	0.604	0.086	0.474	0.798	0.604	0.086
Hebei	0.465	0.791	0.561	0.091	0.465	0.791	0.561	0.091
Shandong	0.456	0.848	0.585	0.104	0.456	0.848	0.585	0.104
Shanghai	0.702	1.000	0.893	0.107	0.702	1.000	0.893	0.107
Jiangsu	0.511	0.875	0.652	0.132	0.511	0.875	0.652	0.132
Zhejiang	0.505	0.837	0.617	0.145	0.505	0.837	0.617	0.145
Fujian	0.523	0.812	0.629	0.092	0.523	0.812	0.629	0.092
Guangdong	0.517	0.823	0.635	0.128	0.517	0.823	0.635	0.128
Central	0.381	1.000	0.734	0.142	0.346	0.731	0.511	0.101
Inner Mongolia	0.421	1.000	0.753	0.067	0.361	0.675	0.521	0.081
Heilongjiang	0.464	0.911	0.726	0.117	0.385	0.731	0.503	0.078
Jilin	0.412	0.903	0.728	0.078	0.390	0.718	0.518	0.097
Shanxi	0.462	0.887	0.719	0.102	0.387	0.703	0.498	0.077
Anhui	0.398	0.903	0.731	0.115	0.362	0.682	0.512	0.103
Jiangxi	0.381	0.896	0.713	0.103	0.353	0.712	0.505	0.136
Henan	0.459	0.919	0.742	0.102	0.346	0.684	0.523	0.078
Hunan	0.408	0.936	0.761	0.072	0.363	0.719	0.531	0.102
Hubei	0.397	0.902	0.736	0.095	0.361	0.675	0.491	0.102
Western	0.408	1.000	0.718	0.090	0.249	0.731	0.460	0.143
Shaanxi	0.473	0.766	0.723	0.087	0.307	0.672	0.464	0.102
Gansu	0.407	0.735	0.698	0.137	0.262	0.663	0.452	0.032
Qinghai	0.461	0.727	0.713	0.110	0.256	0.647	0.460	0.095
Ningxia	0.442	0.708	0.709	0.126	0.278	0.652	0.427	0.090
Xinjiang	0.436	0.724	0.717	0.082	0.263	0.630	0.425	0.087
Chongqing	0.503	1.000	0.824	0.108	0.306	0.721	0.532	0.117
Sichuan	0.427	0.843	0.736	0.152	0.297	0.687	0.487	0.153
Yunnan	0.419	0.746	0.706	0.089	0.284	0.628	0.453	0.088
Guizhou	0.408	0.705	0.673	0.074	0.249	0.626	0.446	0.094
Guangxi	0.411	0.716	0.697	0.114	0.260	0.639	0.457	0.101
Hainan	0.415	0.712	0.703	0.127	0.276	0.642	0.435	0.108

meaning that the gap between its health expenditure efficiency and that of the east is narrowing. The western area's TGR first increases and then decreases gradually, and the gap in health expenditure efficiency between the west and the east does not change much over the sample period.

CONCLUSIONS AND POLICY RECOMMENDATIONS

COVID-19 has given people much to contemplate about, not only on the importance of life and health rights, but also on how to effectively improve the allocation of public goods for all human beings as well as at the national level. The need to raise the overall level of health care services and the efficiency of government spending on health care is essential so as to provide people with better quality health care services without wasting too much financial investment. This research applies the hybrid meta-frontier DEA model to measure the efficiencies of health expenditure for 30 provinces in China, compares the health expenditure efficiencies between the regional and national common frontiers, and introduces the technology gap ratio to analyze the disparity between health expenditure efficiencies and the country's most potential excellent levels. The results show differences in health expenditure efficiency among provinces under the regional frontier, with the largest gap in the east. The space for improvement in the health expenditure efficiency for the three regions is clearly different. Along the national common frontier, the efficiency of Beijing is the greatest, while that of Guizhou is the smallest. The east represents the highest technical

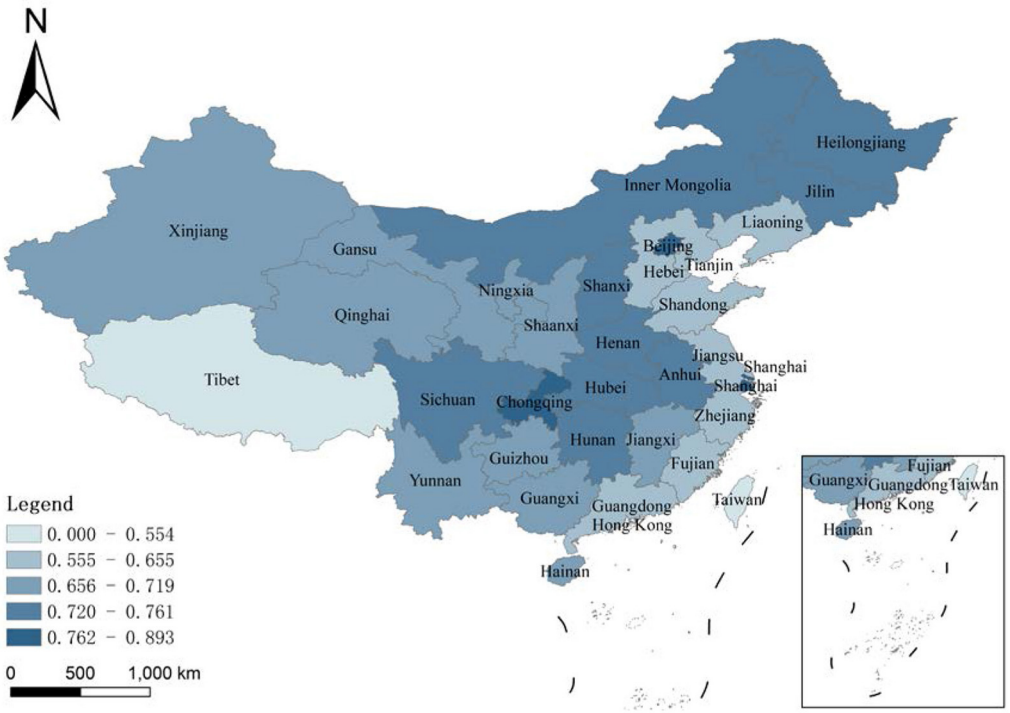

FIGURE 3 | Average innovation efficiency of the high-tech industry under the regional frontier in 1999–2018.

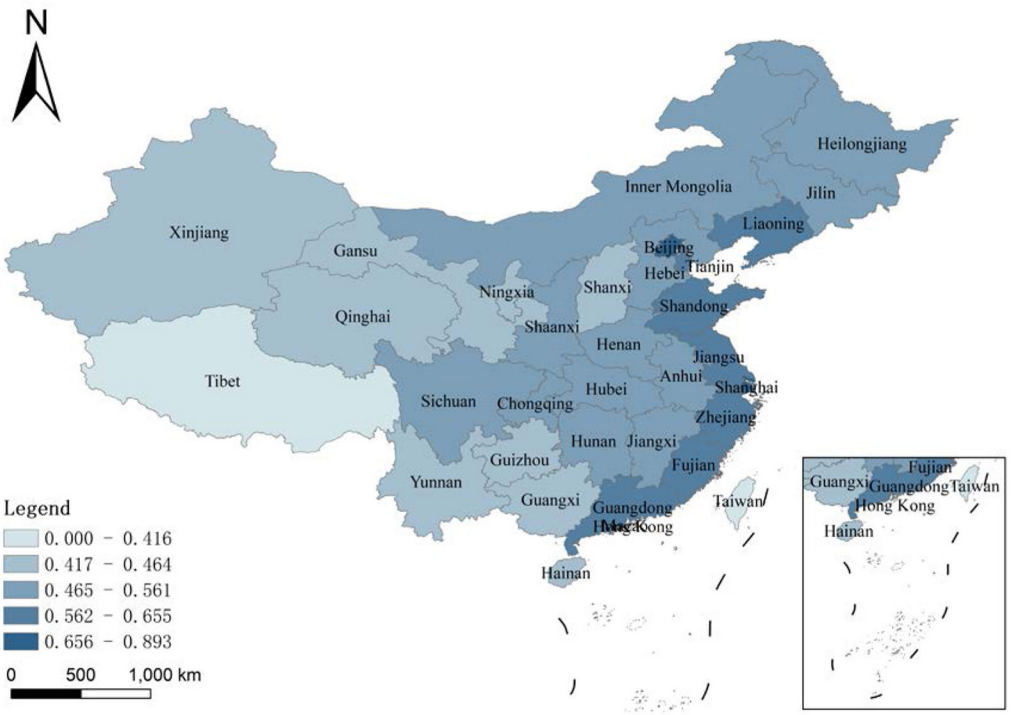

FIGURE 4 | Average innovation efficiency of the high-tech industry under the common frontier in 1999–2018.

TABLE 4 | Technology gap ratio of health expenditure efficiency.

Year / Regional	TGR		
	Eastern	Central	Western
1999	1.000	0.683	0.651
2000	1.000	0.696	0.662
2001	1.000	0.709	0.655
2002	1.000	0.721	0.661
2003	1.000	0.738	0.674
2004	1.000	0.754	0.678
2005	1.000	0.743	0.676
2006	1.000	0.758	0.689
2007	1.000	0.765	0.702
2008	1.000	0.756	0.713
2009	1.000	0.771	0.716
2010	1.000	0.775	0.707
2011	1.000	0.784	0.705
2012	1.000	0.781	0.689
2013	1.000	0.778	0.710
2014	1.000	0.789	0.683
2015	1.000	0.814	0.672
2016	1.000	0.808	0.681
2017	1.000	0.811	0.676
2018	1.000	0.817	0.669
Average	1.000	0.774	0.683

level of health expenditure efficiency, while the western and the central regions have a long way to catch up with it.

Conclusions of this study imply that to improve health expenditure efficiency, the China government must solve the following issues. First of all, the government should adjust the expenditure structure of public finance and sustainably increase public health expenditure. Insufficient expenditure on public health is an important reason for restricting China's health expenditure efficiency. Therefore, improving the fiscal expenditure scale of the health sector and exploiting economies of scale are effective ways to improve health expenditure efficiency. The government should continue reforming medical services, accelerate the progress of the reform results in public pilot hospitals, and begin to reform the management of private hospitals. At the same time, it should increase investment in disease prevention to ensure meeting the growing demands of high-quality basic health care and medical services of citizens.

The government can also target to optimize public service awareness. Currently, China's actions in regards to government public service awareness are weak, and public service efficiency is low. Thus, the central government should build government performance evaluation and monitoring mechanisms and urge all levels of governments to improve public service awareness. Local governments should improve their responsibility mechanism. During the process of improving the medical and health service system, it is necessary to strengthen the responsibility of local governments over healthcare supply, so as to ensure fairness and efficiency of public health care and to safeguard the interests of the masses, especially disadvantaged groups. In addition, China should help guide the sharing of public health service resources and promote regional cooperation on public health service. The government should establish an "Integrated medical service and health system", which aims to improve the economies of scale and realize better use of capital and operational resources based on the integration of different levels of medical institutions. Coordinated actions for the integration of medical institutions can helps improve the productiveness of the health system and cut down on unit costs.

There are still gaps between the health expenditure efficiencies of the various provinces. Therefore, it is necessary to promote inter-provincial cooperation in public health services, narrow regional disparities within public health service, and improve health expenditure efficiencies of backward provinces. The public health expenditure of a province does not exist in isolation, and it will affect adjacent or similar provinces, presenting geographic relevance and overflow features. Therefore, the central government should guide local governments to share public health resources and give full play to the spatial spillover effect of public medical treatment expenditure. For the development of regional health-care, local governments should supervise the flow of regional health resources through financial policy and optimize the layout of regional health service centers. At the same time, the use of spatial spillovers to break down administrative barriers has made it easier for people to access health services in different places. Strengthening medical exchanges and cooperation with surrounding areas can also result in better local medical services.

Finally, China's government should appropriately allocate public health resources and improve the overall health expenditure efficiency of the country. An inappropriate allocation of its limited public health resources is an important cause of low health expenditure efficiency. There is clearly a big gap in regional public health technology between the eastern and western regions. Thus, the central government should guide public health resources to the central and western regions through financial transfer payments, while at the same time increase general transfer payments, reduce special transfer payments, and adjust tax returns. Local government should promote the equalization of high quality basic medical services and also take the initiative to carry out the Wagner adjustment in response to the pressure from increasing demand for medical and health care when facing the reality of a narrow increase in fiscal revenue. Last but not least, the central and local governments should work together to optimize their budget systems, promote fairer budget disclosure, improve annual budget control, and further clarify powers and expenditure responsibilities.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

AUTHOR CONTRIBUTIONS

WZ and HC: conceptualization, writing—original draft preparation, supervision, project administration, and funding acquisition. YS: methodology, data curation, and visualization. WZ: software. HC: validation and investigation. YS and YX: formal analysis and writing—review and editing. WZ and YX: resources. All authors have read and agreed to the published version of the manuscript.

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Evaluation of Unified Healthcare Efficiency in China: A Meta-Frontier Non-radial Directional Distance Function Analysis During 2009–2019

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In this study, we analyze the unified healthcare efficiency in China at the regional level from 2009 to 2019. To accurately evaluate the evolution of unified efficiency from both static and dynamic perspectives, we combine the non-radial directional distance function and the meta-frontier method to evaluate the unified healthcare efficiency and its dynamic changes. This new approach allows for regional heterogeneity and non-radial slack simultaneously. The decomposition of the meta-frontier non-radial Malmquist unified healthcare efficiency index (MNMHEI) can be used to identify the driving factors of dynamic changes. The results show that the unified healthcare efficiency in eastern China is generally higher than that in non-eastern China from the static perspective, implying significant regional differences. Moreover, the unified efficiency in both eastern and non-eastern regions shows similar time trends and reaches the maximum in 2012. From the dynamic perspective, the unified healthcare efficiency increases annually by 2.68% during the study period. This increase in eastern China as a technology leader is mainly driven by technological progress, whereas the increase in non-eastern China is mainly driven by a better catch-up effect. In addition, the impact of the reform on the non-eastern region is more significant for the decreasing technology gap, the stronger growth momentum of technological progress, and global innovative provinces.

Keywords: healthcare efficiency, non-radial directional distance function, meta-frontier, data envelopment analysis, regional heterogeneity

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INTRODUCTION

After a series of reforms, the healthcare system in China has experienced significant changes. A country's healthcare services are influenced by interrelated political, economic, social, and cultural factors. The continuous changes in these conditions guide the development of healthcare services (1). A well-designed healthcare system can improve the population health conditions, which is conducive to the improvement of national competitiveness. With the economic development and rising overall living standards, China has shown great progress in improving the health status since the reform and opening-up policy in 1978. From 1978 to 2019, life expectancy rises from 66.5 to 77.3 years, and infant mortality drops from 53 to 5.6‰ (2). In the early stages of reform, the strategies compatible with the market economy have brought about the improvement in medical services and also a series of problems, such as the growing inequality among provinces and a rapid

increase in healthcare expenditure (3). According to the report on healthcare reform in 2005, the market-oriented healthcare reform was declared unsuccessful for the increasing inequity and decreasing efficiency in health care. The Chinese government started a new round of healthcare reform in 2009, known as the "new healthcare reform." The fundamental objective of the new reform was to establish a basic medical and healthcare system, supported by four systems, namely, public health, medical service, health care, and drug supply system. To deepen the reform, the government tries to make full use of the advantages of marketization and government intervention. One of the most remarkable achievements of the "new healthcare reform" is that it takes only 3 years for China to achieve universal health insurance coverage. After 2011, the coverage of medical insurance in urban and rural areas has stabilized at above 95%, which increases access to medical services, especially for poor people. Considering problems in the previous unsuccessful reform, it is necessary to examine the evolution of healthcare efficiency, explore regional differences, and identify potential drivers of changes during the post-reform period.

The efficiency evaluation in the healthcare sector after the implementation of the new healthcare reform has attracted considerable attention from scholars. These studies show that although the healthcare efficiency in China has significantly improved since 2009, regional differences always exist (4–6). There is a geographical distribution of healthcare efficiency in China. YU suggests that the regional healthcare efficiency in China is roughly consistent with the level of economic development (7). Economic development may lead to more effective ways of production or management. While China's economy has developed rapidly in the past decade, there remain the challenges, such as unbalanced improvement across different provinces. Thus, the imbalance of economic development may induce significant differences in medical technology levels (8). Despite numerous studies on the evaluation of healthcare efficiency across provinces, we identify a gap in previous research. From a methodological perspective, prior research mainly assesses the healthcare efficiency and explores the regional differences under the assumption of the same production technology, neglecting the technology heterogeneity. Thus, the aim of the study was to evaluate the evolution of unified healthcare efficiency during 2009–2019 through both static and dynamic perspectives based on the technology heterogeneity.

This study has the following contributions. First, we propose an approach combining meta-frontier method and non-radial directional distance function to conduct static and dynamic analyses in unified healthcare efficiency. This approach evaluates the efficiency more accurately by considering the regional technology heterogeneity and the potential non-radial slack simultaneously. Second, we can identify the sources of the changes in unified healthcare efficiency through the decomposition of dynamic indicator (MNMHEI). In addition to the two traditional subcomponents, namely, technological change and efficiency change, we also explore the technology gap change among different regions. Third, we analyze the impact of reforms on unified efficiency changes and explore the emphasis of future policies based on different regions.

The rest of this article is organized as follows. Section Literature Review provides the literature review relevant to our research. Section Methodology introduces the method and data sources. Section Results and Discussion presents the empirical results to analyze both the static and dynamic unified healthcare efficiencies over the period from 2009 to 2019. Section Conclusion concludes the article.

LITERATURE REVIEW

Healthcare efficiency has been widely studied in different countries using data envelopment analysis (DEA) and Malmquist index from both static and dynamic perspectives. DEA, a nonparametric analysis method developed by Charnes et al. (9), has advantages in evaluating the relative efficiency of decision-making units (DMUs) with multiple outputs and inputs, without assuming a specific functional form. To conduct a temporal analysis of healthcare efficiency, the Malmquist index is generally used to evaluate dynamic changes and identify sources of changes through decomposition, such as "catching up" effect and technological change. Many studies have employed the DEA and Malmquist method to analyze the efficiency in the healthcare sector (10–14).

Recent studies have extended the healthcare efficiency analysis to include the minimization of undesirable outputs, such as mortality and readmissions (15–17). Directional distance function (DDF) is proposed to measure efficiency by maximizing desirable outputs and minimizing undesirable outputs at the same rate. Correspondingly, Chung et al. developed the Malmquist–Luenberger (ML) index to measure the dynamic changes in efficiency evaluated by DDF (18). This ML index has been widely used in measuring environmental performance changes, such as Nakano et al. (19) and Sueyoshi and Goto (20). In terms of healthcare, some scholars have extended the DDF and ML. For example, Falavigna et al. adopted DDF to assess the Italian healthcare efficiency and investigated the influencing factors (21). Gimenez et al. employed the global Malmquist–Luenberger index (GML) to assess the evolution of hospital performance for the post-reform period (22).

However, conventional DDF is considered as a radial model, which may overestimate efficiency when there is slack (23). In addition, it cannot identify the sources of inefficiency for specific indicators (24). In view of the above limitations, non-radial DDF (NDDF) has been developed by allowing for the adjustments of inputs, desirable outputs, and undesirable outputs non-proportionally (25, 26). This novel method has been employed to conduct efficiency analysis in Taiwan's hospitals (15) and Emergency Obstetric of public hospitals in India (27).

With regard to the evolution of efficiency in China's healthcare sector, scholars have explored geographical differences in healthcare efficiency with the development of China's medical reform. Hu suggested that the healthcare efficiency in coastal areas was higher than that in non-coastal areas from 2002 to 2008, but the gap gradually narrowed due to the implementation of the New Rural Cooperative Medical System (NRCMS) in 2003 (28). After the "new healthcare reform" in China, scholars mainly

explored the regional differences in healthcare efficiency based on the traditional regional division of the eastern, central, and western areas. By investigating the treatment quality of hospitals in China from 2009 to 2014, Li et al. indicated that the treatment quality in the eastern region was significantly higher than that in the central and western regions, whereas the treatment quality gap between the central region and western region was small (6). Gong et al. assessed the healthcare efficiency from 2009 to 2016 corresponding to the post-reform period, finding a positive correlation between healthcare efficiency and socioeconomic development. He also reported that the eastern region had higher healthcare efficiency than the central region, which in turn had higher healthcare efficiency than the western region (29).

However, a general method in the existing research to explore the regional differences is under the assumption of the same production technology set, neglecting the technology heterogeneity. The neglect of technology heterogeneity may lead to biased results (30). Meta-frontier method is usually proposed to deal with group heterogeneity issue. Therefore, the study examines the healthcare efficiency based on the group heterogeneity to provide comprehensive information.

Through the review of the previous literature, we can find that the healthcare efficiency in China exhibited regional differences. Compared with central and western regions, the efficiency in the eastern region showed better performance due to the advantages in technology, talent, and infrastructure. However, previous studies assessed the healthcare efficiency across different provinces under the assumption of the same production technology set. The neglect of technology heterogeneity may lead to biased results due to China's significant regional gaps. Considering both non-radial slacks and group heterogeneity, this study combines the meta-frontier method and non-radial directional distance function to estimate the unified healthcare efficiency from both the static and dynamic perspectives.

METHODOLOGY

The Production Technology

Suppose there are N decision-making units (DMUs) with information available (in this article, meaning "provinces"), each DMU generates desirable and undesirable outputs through the consumption of inputs. We denote inputs by $x \in R_+^N$, desirable outputs by $y \in R_+^M$, and undesirable outputs by $b \in R_+^I$. In general, we can define the production technology set as follows:

$$T = \left\{(x, y, b) : \ x \ can \ produce \ (y, b)\right\} \tag{1}$$

One can refer to Fare and Grosskopf for the standard axioms of production theory (31). In this study, referring to the method of Zhou et al. (26), we can formulate the production sets T with constant returns to scale in the following way.

$$T = \left\{ \begin{array}{l} (x, y, b) : \sum_{n=1}^{N} z_n x_n \le x, \sum_{n=1}^{N} z_n y_n \ge y, \\ \sum_{n=1}^{N} z_n b_n = b, z_n \ge 0, n = 1, 2, \ldots\ldots, N \end{array} \right\} \tag{2}$$

where the row vector Z_n is an intensity variable, which constructs a set of production technologies using a convex combination. Based on Tulkens and Vanden Eeckaut (32) and Oh and Lee (33), we distinguish three production technology sets according to the concepts of meta-frontier and group frontier: contemporary production technology, intertemporal production technology, and global production technology.

Suppose there are H groups showing technological heterogeneity, the contemporary production technology indicates the specific technology of the group frontier at a specific time. For the group h at a specific period t, the contemporary production technology can be defined as follows:

$$T_{Rh}^C = \left\{ \begin{array}{l} (x^t, y^t, b^t) : \\ (x^t) \ can \ produce \ (y^t, b^t) \ where \ t = 1, \ldots T. \end{array} \right\} \tag{3}$$

The intertemporal production technology consists of all the observations that cover the whole period for the specific group h. It indicates the specific technology of the group frontier over the whole period. We define the above technology as follows:

$$T_{Rh}^I = T_{Rh}^1 \cup T_{Rh}^2 \cup \ldots T_{Rh}^T \tag{4}$$

The global production technology contains observations from all groups during all sample periods, representing the technology of meta-frontier. It is the aggregation of all intertemporal production technology sets and can be defined as follows:

$$T^G = T_{R1}^I \cup T_{R2}^I \cup \ldots T_{Rh}^I \tag{5}$$

Variables

The purpose of an efficient healthcare system was to provide more medical services and improve the residents' health status with limited resources. Death is inevitable in the process of providing services.

In addition, the improvement in health level manifests in the improvement in maternal and child hygiene levels, and disease control levels (34). Thus, it is important to consider deaths as undesirable outputs.

According to the literature review of healthcare efficiency from the study of Kohl et al. (35) and Ozcan (36), previous studies mainly select labor, capital investment, operating expenses as input variables, and outpatient visits, inpatient visits as output variables. The capital investment can generally be proxied by beds in previous studies. However, some scholars have criticized the mixed-use of economic indicators and quantitative indicators due to the confusion between technical efficiency and allocative efficiency (9, 37). Thus, the economic indicators have not been adopted into the input–output indicators. Based on the importance and availability of indicators, the inputs, desirable outputs, and undesirable outputs are specified as follows. The inputs x selected in our study include the number of health technicians (E) and the number of beds (B). Healthcare output is complicated, which reflects the level of health service delivery,

disease control, maternal and perinatal hygiene, and so on. Accordingly, the number of outpatient visits (O) and the number of inpatient visits (I) are measured as desirable outputs y. Undesirable outputs b selected are three types of death to reflect the competitiveness of each province in the health care: maternal mortality (M), perinatal mortality (P), and contagious mortality (C).

Non-radial Directional Distance Function

This article applies the non-radial directional distance function (NDDF) to the healthcare efficiency evaluation in China (26, 38). The description of the NDDF in the case of healthcare sector can be specified as follows:

$$\vec{D}(x,y,b;g) = \sup\{w^T\beta : ((x,y,b) + g \cdot diag(\beta)) \in T\} \quad (6)$$

Here, $w^T = (w_x, w_y, w_b)^T$ is the vector of exogenous weights assigned to inputs and outputs; $g = (-g_x, g_y, -g_b)$ denotes the directional vector in which the inputs, desirable outputs, and undesirable outputs will be scaled. $\beta = (\beta_x, \beta_y, \beta_b)^T \geq 0$ represents the vector of scaling factors. The calculation of NDDF value for a specific province n' can be obtained by solving the following linear program.

$$\begin{aligned} \vec{D}(x,y,b;g) = \max\ & w_x\beta_x + w_y\beta_y + w_b\beta_b \\ s.t.\ & \sum_{n=1}^{N} z_n x_n \leq x_{n'} - \beta_x g_x \\ & \sum_{n=1}^{N} z_n y_n \geq y_{n'} + \beta_y g_y \\ & \sum_{n=1}^{N} z_n b_n = b_{n'} - \beta_b g_b \\ & z_n \geq 0, \beta_x, \beta_y, \beta_b \geq 0 \end{aligned} \quad (7)$$

If $\vec{D}(x,y,b;g)$=0, it means that the inefficiency level of this DMU is zero in the g direction and the DMU is located on the best-practice frontier.

Because there are two inputs (health technicians, beds), two desirable outputs (outpatient visits, inpatient visits), and three undesirable outputs (maternal mortality, perinatal mortality, contagious mortality), we set the directional vector $g = (-E, -B, O, I, -M, -P, -C)$ and the weight vector w^T equal to$(\frac{1}{6}, \frac{1}{6}, \frac{1}{6}, \frac{1}{6}, \frac{1}{9}, \frac{1}{9}, \frac{1}{9})$. This study employs the method introduced by Zhou et al. (26) to construct a static unified efficiency index. We define a unified healthcare efficiency index (HEI) to carry out static analysis in China. If $\beta_E^*, \beta_B^*, \beta_O^*, \beta_I^*, \beta_M^*, \beta_P^*, \beta_C^*$ are optimal solutions in the model (7), then HEI can be expressed as Equation (8). The HEI ranges from zero to unity. The higher the HEI value, the higher the unified healthcare efficiency is. If the HEI equals to unity, it means that the DMU is located on the best-practice frontier.

$$\text{HEI} = \frac{1 - \frac{1}{5}(\beta_E^* + \beta_B^* + \beta_M^* + \beta_P^* + \beta_C^*)}{1 + \frac{1}{2}(\beta_O^* + \beta_I^*)} \quad (8)$$

Meta-Frontier Non-radial Malmquist Unified Healthcare Efficiency Index

In the Section The Production Technology, we described three production technology sets according to the concepts of meta-frontier and group frontier. Then, we incorporate the three production technology sets into the NDDF model (7) and obtain corresponding NDDF models. Suppose there are H groups, then, the contemporary NDDF model for a specific group R_h at a specific time t is given by:

$$\vec{D}^C(x,y,b;g) = \sup\{w^T\beta^C : ((x,y,b) + g \cdot diag(\beta^C)) \in T_{Rh}^C\} \quad (9)$$

The intertemporal NDDF for a specific group R_h covering the whole periods is given by:

$$\vec{D}^I(x,y,b;g) = \sup\{w^T\beta^I : ((x,y,b) + g \cdot diag(\beta^I)) \in T_{Rh}^I\} \quad (10)$$

Analogously, the global NDDF covering all groups and sample periods is given by:

$$\vec{D}^G(x,y,b;g) = \sup\{w^T\beta^G : ((x,y,b) + g \cdot diag(\beta^G)) \in T^G\} \quad (11)$$

We define the meta-frontier non-radial Malmquist unified healthcare efficiency index (MNMHEI) to conduct the dynamic analysis by incorporating the NDDF model into the meta-frontier Malmquist index. To evaluate the dynamic changes in the unified efficiency and decompose the MNMHEI, we need to solve NDDF models under three different production technology sets $\vec{D}^C(x,y,b)$, $\vec{D}^I(x,y,b)$, $\vec{D}^G(x,y,b)$ during two adjacent periods, i.e., t and $t+1$. The calculation of $\vec{D}^d(x^t, y^t, b^t)$ corresponding to three types of technology sets at a specific time t is made by solving the following linear program.

$$\begin{aligned} \vec{D}^d(x^t, y^t, b^t; g) = \max\ & w_x\beta_x^{d,t} + w_y\beta_y^{d,t} + w_b\beta_b^{d,t} \\ s.t.\ & \sum_{con} z_n^{d,t} x_n^{d,t} \leq x_{n'}^t - \beta_x^{d,t} g_x^t \\ & \sum_{con} z_n^{d,t} y_n^{d,t} \geq y_{n'}^t + \beta_y^{d,t} g_y^t \\ & \sum_{con} z_n^{d,t} b_n^{d,t} = b_{n'}^t - \beta_b^{d,t} g_b^t \\ & z_n^{d,t} \geq 0, \beta_x^{d,t}, \beta_y^{d,t}, \beta_b^{d,t} \geq 0 \end{aligned} \quad (12)$$

The superscript d indicates three types of NDDF models mentioned above. Here, $d = (C, I, G)$. The symbol con under $\sum$ represents conditions corresponding to three different production technology sets. If $d = C$, we can obtain the contemporary NDDF and $con = T_{Rh}^C$. If $d = I$, we can obtain the intertemporal NDDF and $con = T_{Rh}^I$. If $d = G$, the global NDDF is defined with $con = T^G$. Based on Equations (8) and (12), the HEI^{d} of a DMU corresponding to three different NDDFs at period t can be generated, denoted as $\text{HEI}^{\text{C}}(t)$, $\text{HEI}^{\text{I}}(t)$, and $\text{HEI}^{\text{G}}(t)$.

$$HEI^d(x^t, y^t, b^t) = \frac{1-\frac{1}{5}(\beta_E^{d*,t}+\beta_B^{d*,t}+\beta_M^{d*,t}+\beta_P^{d*,t}+\beta_C^{d*,t})}{1+\frac{1}{2}(\beta_O^{d*,t}+\beta_I^{d*,t})} \quad d = (C, I, G) \tag{13}$$

Analogously, we can also generate three kinds of HEI at period $t+1$ by replacing t with $t+1$ in Equation (13), denoted as $HEI^C(t+1)$, $HEI^I(t+1)$, and $HEI^G(t+1)$, respectively. Then, we define the meta-frontier non-radial Malmquist index for unified healthcare efficiency (MNMHEI) based on the global production technology set (T^G) in the following way. It is used to measure the dynamic changes of the unified healthcare efficiency from time t to $t+1$.

$$MNMHEI(t, t+1) = \frac{HEI^G(x^{t+1}, y^{t+1}, b^{t+1})}{HEI^G(x^t, y^t, b^t)} \tag{14}$$

If MNMHEI is greater than unity, the DMU in $t+1$ is closer to the global frontier than that in t, which represents an improvement in unified efficiency. If MNMHEI is less than unity, the DMU in $t+1$ is farther away from the global frontier than that in t, implying a deterioration during the corresponding period. Referring to Oh and Lee (33), Equation (14) can be decomposed into three parts to identify potential drivers as follows:

$$\begin{aligned} MNMHEI(t, t+1) &= \frac{HEI^G(.^{t+1})}{HEI^G(.^t)} \\ &= \left[\frac{HEI^C(.^{t+1})}{HEI^C(.^t)}\right] * \left[\frac{HEI^I(.^{t+1})/HEI^C(.^{t+1})}{HEI^I(.^t)/HEI^C(.^t)}\right] * \left[\frac{HEI^G(.^{t+1})/HEI^I(.^{t+1})}{HEI^G(.^t)/HEI^I(.^t)}\right] \\ &= \left[\frac{TE^{t+1}}{TE^t}\right] * \left[\frac{BPR^{t+1}}{BPR^t}\right] * \left[\frac{TGR^{t+1}}{TGR^t}\right] \\ &= EC^{t,t+1} * BPC^{t,t+1} * TGC^{t,t+1} \end{aligned} \tag{15}$$

where $EC^{t,t+1}$ (efficiency change) captures the technical efficiency changes relative to contemporary frontier from time t to $t+1$. $EC^{t,t+1} > 1$ represents an improvement in technical efficiency, since the inefficiency distance from a DMU to the contemporary frontier in $t+1$ is smaller than that in t. If $EC^{t,t+1} < 1$, it indicates an efficiency decrease. $BPC^{t,t+1}$(the best-practice gap change) measures frontier shifts between contemporary technology frontier and intertemporal technology frontier from t to $t+1$. $BPC^{t,t+1} > 1$ indicates that the contemporary frontier moves toward the intertemporal frontier, representing technological progress and innovation effect. $BPC^{t,t+1} < 1$ represents that the contemporary frontier shifts far away from the intertemporal frontier, implying technological deterioration.

$TGC^{t,t+1}$ (technology gap change) measures changes in technology gap between intertemporal frontier and global frontier during two periods. This indicator is the ratio of TGR in year $t+1$ to that in year t. If TGR =1, the HEI calculated by the intertemporal frontier NDDF is equal to that calculated by the global frontier NDDF, implying the leading position in inventing new technologies. The group which has more DMUs with TGR = 1 is the leading group (33). Correspondingly, $TGC^{t,t+1}$ collects the changes in technology leadership. If $TGC^{t,t+1} > 1$, it represents a decrease in the technology gap between the aforementioned two frontiers. $TGC^{t,t+1} < 1$ is interpreted conversely.

Data

We adopt the method mentioned above to evaluate the unified healthcare efficiency in China from 2009 to 2019. The sample consists of 31 provinces which can be divided into two large groups (eastern region and non-eastern region) based on geographical and economic characteristics. The eastern region includes eleven relatively developed coastal provinces: Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan. The remaining 20 provinces belong to the relatively underdeveloped non-eastern region. The data for this study are drawn from China Health Statistic Yearbook.

Table 1 presents the statistical description results of the input and output variables. For the input variables and desirable output variables, the average values in eastern region are markedly higher than those in non-eastern region. Both groups show significant growth during the sample period. Except outpatient visits (O), other inputs and desirable outputs in non-eastern region have higher annual growth rates than those in eastern region. In addition, we should pay more attention to the undesirable output variables because of the noticeable differences between the two groups. For all the undesirable outputs, the average values in non-eastern region are significantly higher than those in the eastern region. Annual growth rates of maternal mortality (M) and perinatal mortality (P) in two groups are both negative, representing the improvement in health level. In comparison with the eastern region, non-eastern China experiences a more obvious decline. Contagious mortality (C) shows the greatest differences in annual growth rate. Average annual growth rate in eastern region is −1.86%, while that in non-eastern region is 6.2%. It can be found that the contagious mortality in the non-eastern region has a clear upward trend, which is different from the slight downward trend in eastern region.

RESULTS AND DISCUSSION

Analysis of the Static HEI^d

Healthcare efficiency index is generated to evaluate the static unified healthcare efficiency. As explained above, we consider three categories of HEI^d: HEI^G, HEI^I, and HEI^C, which are measured under global frontier, intertemporal frontier, and contemporary frontier, respectively. Since the three different production technology sets satisfy the following relationship: $T_{Rh}^C \subseteq T_{Rh}^I \subseteq T^G$, the inefficiency distance between a DMU and global frontier is greater than or equal to that between a DMU and intertemporal frontier. Analogously, the inefficiency distance between a DMU and intertemporal frontier is not less than that between a DMU and contemporary frontier. Then, $HEI^G \leq HEI^I \leq HEI^C$ always holds.

Figure 1 provides the empirical results of three average HEI in two regions from 2009 to 2019. In **Figure 1A**, HEI^G values in the eastern region are obviously higher than those in non-eastern region during the whole study period, implying significant

TABLE 1 | Descriptive statistics of input and output data (2009–2019).

Type	Variables	Unit	Groups	Mean	SD	Min	Max	Annual growth rate
Inputs	E	Thousand people	ES	307.10	193.16	37.86	792.59	6.19%
			NE	213.49	132.20	9.34	653.89	6.28%
	B	Thousand	ES	237.50	157.73	23.53	629.72	6.34%
			NE	198.68	131.81	8.35	640.15	7.69%
Desirable outputs	O	10 thousand people	ES	33636.97	22290.68	3127.32	89179.77	5.08%
			NE	17970.96	13215.42	959.19	61020.29	4.40%
	I	10 thousand people	ES	693.75	497.54	63.54	1849.93	6.84%
			NE	617.54	438.74	14.40	2013.22	7.30%
Undesirable outputs	M	Per 100 thousand people	ES	9.07	4.58	1.1	25.8	−5.03%
			NE	24.73	28.75	6.4	232.2	−8.42%
	P	‰	ES	4.94	1.73	1.8	9.61	−5.79%
			NE	7.22	3.84	2.28	24.04	−6.59%
	C	Per 100 thousand people	ES	0.64	0.31	0.22	1.69	−1.86%
			NE	1.62	1.64	0.26	8.2	6.2%

ES, eastern; NE, non-eastern.

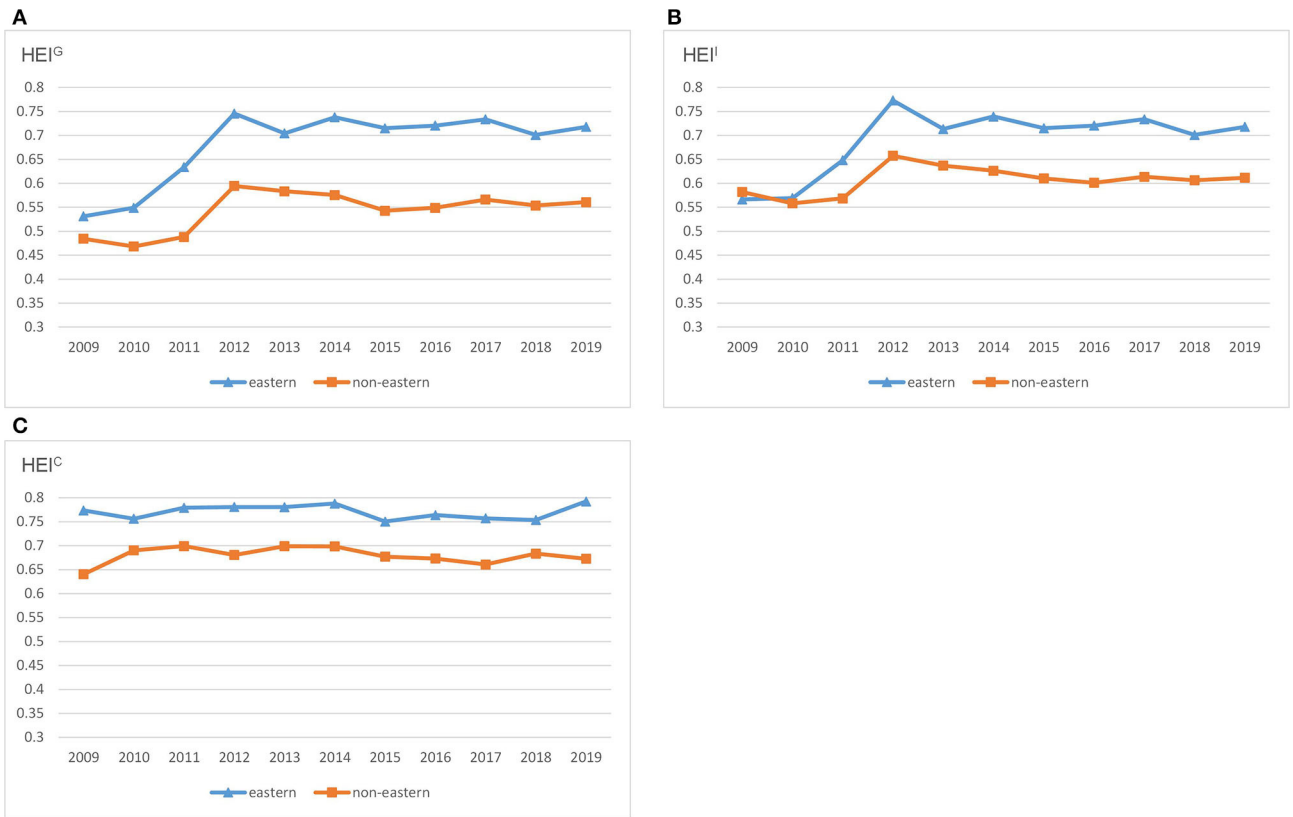

FIGURE 1 | HEI^{d} across regions in China. **(A)** HEI^{G}. **(B)** HEI^{I}. **(C)** HEI^{C}.

regional differences. It is interesting to find that HEI^{G} values in eastern region show similar time trend to that in non-eastern region. HEI^{G} in two regions exhibits the largest increase from 2011 to 2012 and reaches the maximum in 2012 simultaneously. The most likely reason is the whole coverage of basic health insurance of China in 2011 (39), which improves the access to health services for people with health insurance. After 2012, the HEI^{G} values remain stable with the trend of fluctuation.

These results are consistent with Gong et al. (29) who indicate that the healthcare efficiency in 2012 is the highest during

2009–2016 due to the universal health insurance coverage. With respect to the regional differences, they also show that the healthcare efficiency in the eastern region is the highest among the three regions in China (29). Even though the time trend of healthcare efficiency in the two regions is similar, the gap always exists and remains stable, which is different from the study on the gradual narrowing of regional gap during 2002–2008.

As shown in **Figure 1B**, the spatial and temporal distribution patterns of HEI^I are similar to those of HEI^G. **Figure 1C** describes the time trend of HEI^C under contemporary frontier. HEI^C in the two regions keeps stable with less fluctuation during 2009–2019. Moreover, HEI^C values in eastern region are higher than those in non-eastern region. Overall, the two regions show similar time trends of HEI under the influence of policies.

Analysis of MNMHEI and the Decomposition

MNMHEI and the Decomposition at the Regional and Provincial Level

The dynamic changes in unified healthcare efficiency are evaluated by MNMHEI. **Table 2** reports the results of average MNMHEI and its decomposition for each of the provinces. The average MNMHEI in China is 1.0268, implying that the unified healthcare efficiency under the global frontier increases annually by 2.68% from 2009 to 2019. Both eastern and non-eastern regions show an upward trend, with an average growth rate of 3.53 and 2.22%, respectively. At the provincial level, one province (9.1%) in eastern China and four provinces (20%) in non-eastern China exhibit a decline. Among all provinces, Hubei shows the largest increase (8.67%) whereas Guizhou is the province that demonstrates the largest decrease (−4.26%).

To reveal the sources of the unified healthcare efficiency changes, the MNMHEI is decomposed into efficiency change (EC), best-practice gap change (BPC), and technology gap change (TGC). EC reveals how a DMU's proximity to the contemporary frontier changes during the sample period, implying the catch-up effect. The average EC has a value of 1.013, indicating an average annual growth of 1.3%. This means that the provinces generally move toward the contemporary frontier from 2009 to 2019. At the regional level, non-eastern China shows more significant growth than does eastern China, with the average growth rate of 1.53 and 0.88%, respectively. At the provincial level, the province with the best catch-up effect is Ningxia (16.65%), whereas Guizhou shows the poorest catch-up effect (−5.63%). A number of two provinces (18%) in eastern China and three provinces (20%) in non-eastern China experience a decline in EC.

Best-practice gap change measures frontier shifts, implying technological change during the period. The average BPC is 1.018, larger than unity, which means that technological progress has taken place on average. Contrary to EC at the regional level, the average BPC value in eastern region (1.0297) is higher than that in non-eastern region (1.0115). It indicates that eastern China shows better performance in innovation compared with the non-eastern region. For individual provinces, a total of 24 provinces experience technological progress, whereas only 7 provinces show a technological decline. The BPC in Shanghai has the highest value (1.0758), whereas the BPC in Ningxia has the lowest value (0.9411). For most provinces in eastern China, the improvement in unified healthcare efficiency is accompanied by technological progress. However, provinces that experience technological deterioration are mainly located in the non-eastern region.

The average TGC in China is 1.0081, implying less change in the gap between the intertemporal frontier and the global frontier. An interesting result is that the average TGC values in most eastern provinces are equal to unity, which means that the technology gaps in those provinces between intertemporal frontier and global frontier keep stable. However, the information provided by TGC only includes the dynamic changes in the technology gap, but not the static values of technology gap. To solve this argument, we plot the histogram of TGR for each

TABLE 2 | Average MNMHEI and the decomposition of provinces in China.

Province	Area	MNMHEI	EC	BPC	TGC
Beijing	ES	1.0704	1.1299	0.9776	1.0000
Tianjin	ES	1.0318	1.0163	1.0159	1.0000
Hebei	ES	1.0411	1.0033	1.0419	1.0000
Liaoning	ES	1.0113	0.9839	1.0300	1.0000
Shanghai	ES	1.0758	1.0000	1.0758	1.0000
Jiangsu	ES	1.0438	1.0000	1.0438	1.0000
Zhejiang	ES	1.0646	1.0000	1.0646	1.0000
Fujian	ES	0.9912	0.9607	1.0210	1.0548
Shandong	ES	1.0453	1.0000	1.0453	1.0000
Guangdong	ES	1.0050	1.0000	1.0050	1.0000
Hainan	ES	1.0077	1.0022	1.0060	1.0000
Shanxi	NE	1.0128	1.0001	1.0248	0.9915
Inner Mongolia	NE	1.0132	1.0161	1.0089	0.9982
Jilin	NE	1.0109	1.0049	1.0099	0.9967
Heilongjiang	NE	1.0105	0.9830	1.0232	1.0061
Anhui	NE	1.0434	1.0345	1.0339	1.0035
Jiangxi	NE	0.9930	1.0000	0.9906	1.0004
Henan	NE	1.0679	1.0000	1.0389	1.0298
Hubei	NE	1.0867	1.0249	1.0360	1.0270
Hunan	NE	1.0437	1.0113	1.0219	1.0129
Guangxi	NE	1.0718	1.0000	1.0171	1.0485
Chongqing	NE	1.0186	1.0959	0.9786	1.0062
Sichuan	NE	1.0092	1.0000	1.0072	1.0002
Guizhou	NE	0.9574	0.9437	1.0434	1.0001
Yunnan	NE	1.0372	0.9551	1.0338	1.0709
Xizang	NE	0.9951	1.0163	0.9857	0.9978
Shaanxi	NE	1.0178	1.0160	1.0347	0.9977
Gansu	NE	1.0299	1.0205	1.0059	1.0087
Qinghai	NE	0.9843	0.9981	0.9962	0.9904
Ningxia	NE	1.0058	1.1665	0.9411	0.9927
Xinjiang	NE	1.0347	1.0185	0.9981	1.0180
Eastern region		1.0353	1.0088	1.0297	1.0050
Non-eastern region		1.0222	1.0153	1.0115	1.0099
China		1.0268	1.0130	1.0180	1.0081

ES, eastern; NE, non-eastern.

region, reflecting the distribution of static technology gap. If TGR equals to unity, there is no gap between intertemporal frontier and global frontier for the specific group. The smaller the value of TGR, the larger the gap between intertemporal frontier and global frontier. According to the distribution of TGR in **Figure 2A**, the TGR values in most eastern provinces are equal to unity, indicating that eastern China is the leading group. In **Figure 2B**, the distribution of TGR in non-eastern provinces is more dispersed than that in eastern provinces. In addition to a large number of data aggregations around 1, there is also some aggregations around 0.8. This evidence means that the gaps between intertemporal frontier and global frontier in non-eastern provinces are larger than those in the eastern provinces. Even though non-eastern China is considered as the technology follower, the average TGC values of most provinces (65%) in this region are greater than unity, indicating a decreasing technology gap between this group intertemporal frontier and global frontier during the sample period (as shown in **Table 2**).

Temporal Analysis of MNMHEI and the Decomposition

We also examine time trends of dynamic changes in the unified healthcare efficiency and its decomposition under the MNMHEI framework. **Figure 3** reports time trends of MNMHEI at the regional level. Both eastern and non-eastern China share similar time trends of MNMHEI during the sample period. Between 2011 and 2012, the MNMHEI in two regions shows the greatest values. As mentioned above, the notable growth in unified healthcare efficiency is a combined result of universal health insurance coverage and a low comparison base. In the following years, the MNMHEI in two regions experiences a significant decline from 2012 to 2013 with values less than unity, followed by a slight fluctuating trend.

Figure 4 reports average EC values in eastern and non-eastern regions from 2009 to 2019. Time trends of EC values in two regions fluctuate both up and down, without obvious upward or downward trends. It is found that there is a slightly competitive relationship of EC values between eastern China and non-eastern China since the ranking changes each period. For example, the eastern group shows higher values in six periods whereas the non-eastern group performs better in four periods.

In **Figure 5**, the BPC values in eastern China show a similar time trend with those in non-eastern China. In addition, the BPC time trends in two regions approximately coincide with the changes in MNMHEI according to the results in **Figures 3**, **5**. Both MNMHEI values and BPC values show a marked increase from 2011 to 2012. The phenomenon may emerge from China's policy of universal health insurance coverage which has a positive impact on technological progress. The eastern region shows higher BPC values from 2009 to 2012, whereas there is no significant difference in BPC between eastern and non-eastern China from 2012 to 2018. After 2018, the BPC in the non-eastern region performs better. It is interesting to note that even though the average BPC value in eastern region is higher during the whole study period (as shown in **Table 2**), the BPC in non-eastern region shows a stronger growth momentum from the perspective of time trend.

As mentioned above, TGC measures the changes in technology gap for the specific group. **Figure 6** describes TGC values of eastern and non-eastern China during 2009–2019. On the whole, TGC values in the non-eastern region show a greater fluctuation trend than those in the eastern region. From 2009 to 2013, we observe almost opposite time trends between eastern and non-eastern regions. Non-eastern region during 2011–2012 shows the greatest value of TGC, implying a significant decreasing technology gap between the intertemporal frontier and the global frontier. However, the eastern region experiences a widening technology gap in the same time frame. It seems that the policy of universal health insurance coverage achieved in 2011 has a more positive effect on reducing the

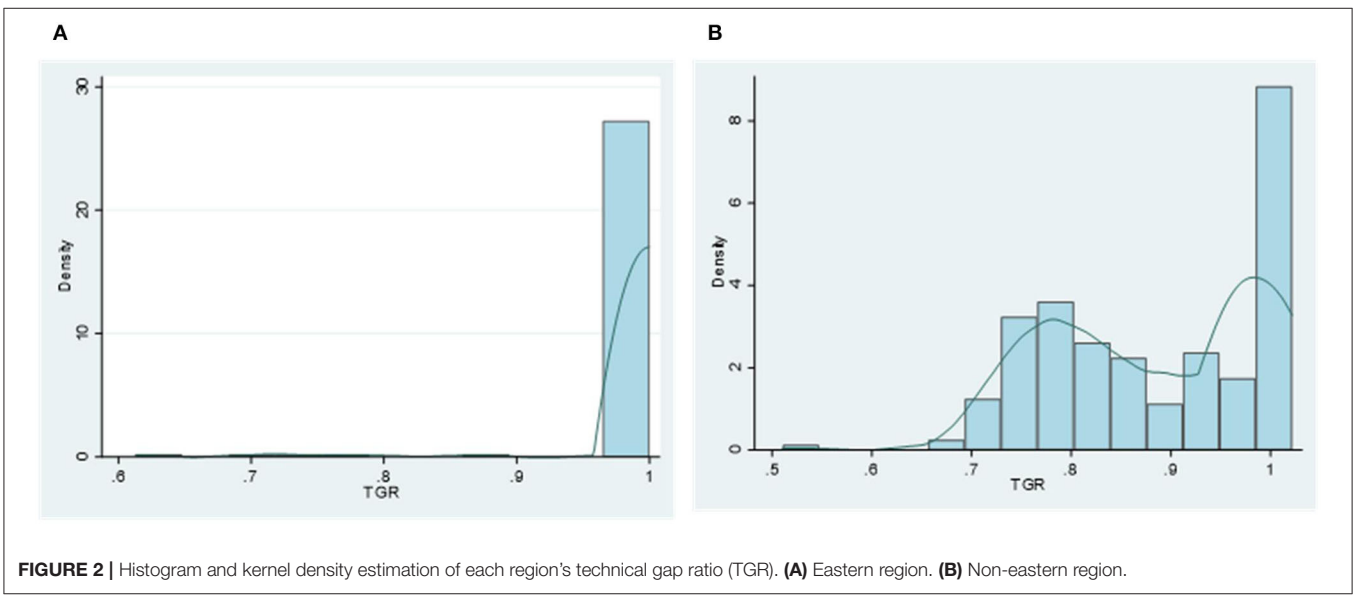

FIGURE 2 | Histogram and kernel density estimation of each region's technical gap ratio (TGR). **(A)** Eastern region. **(B)** Non-eastern region.

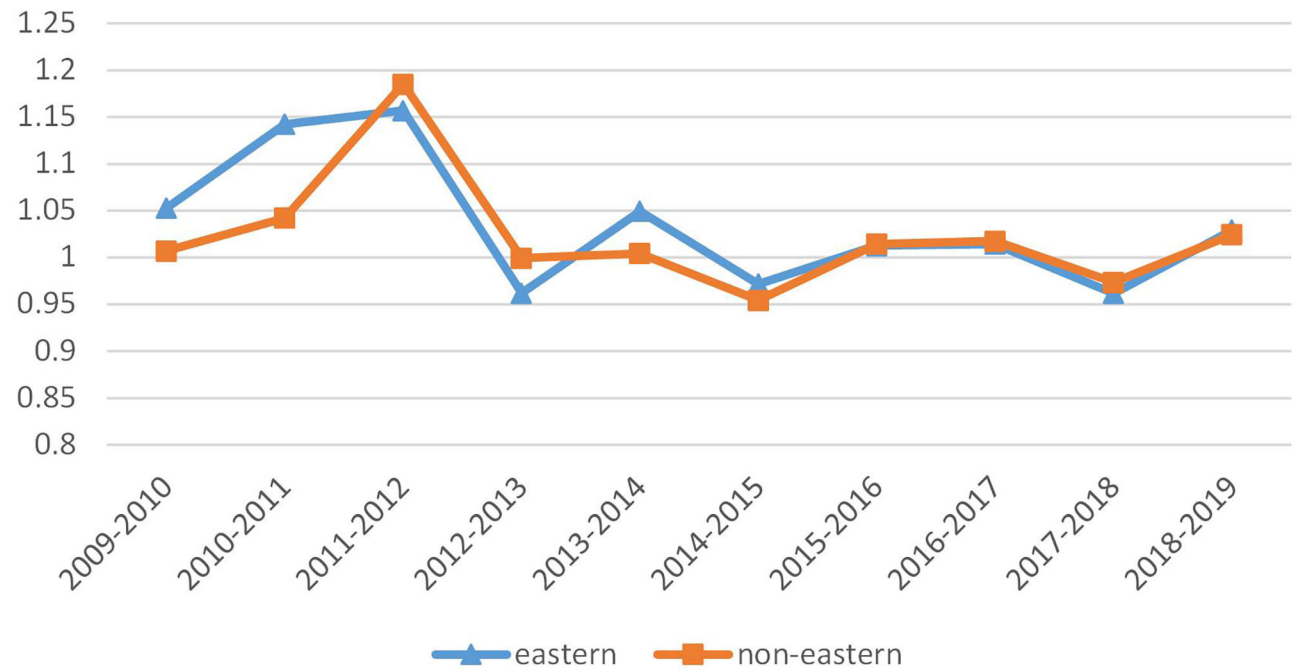

FIGURE 3 | Trends of MNMHEI at the regional level.

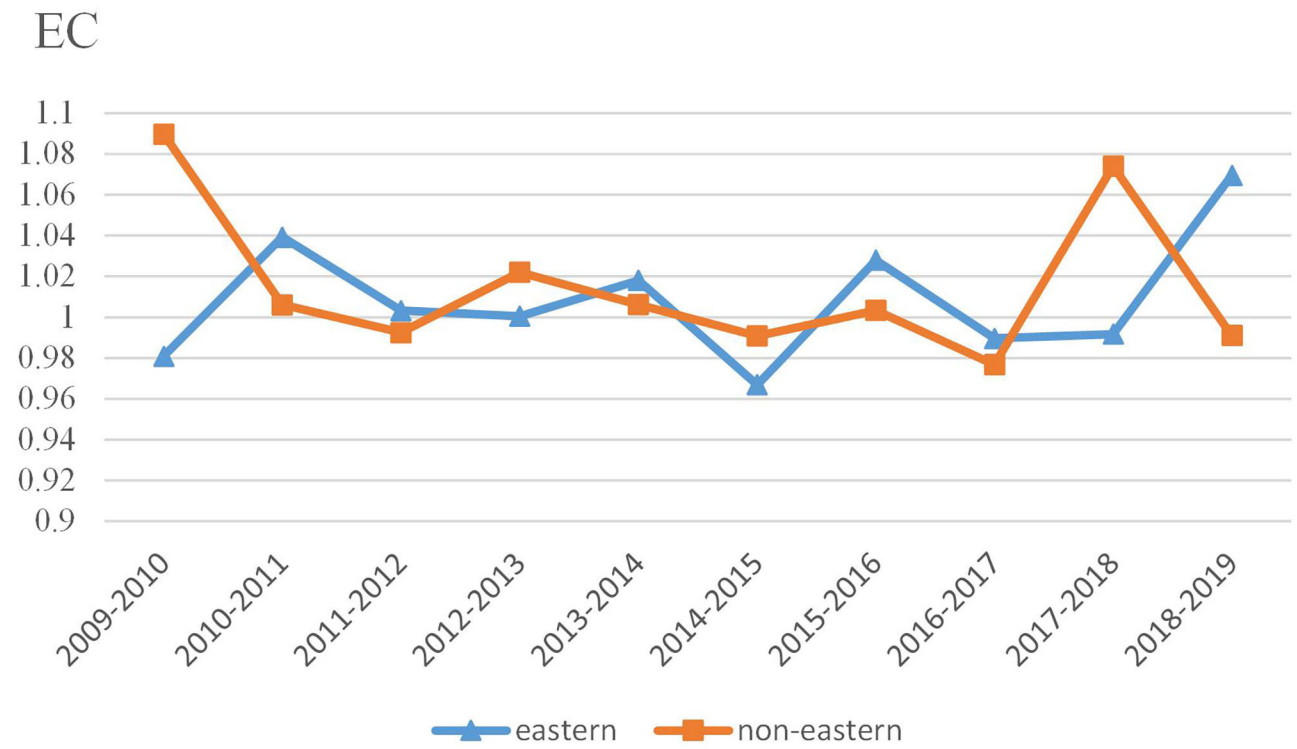

FIGURE 4 | Trends of EC at the regional level.

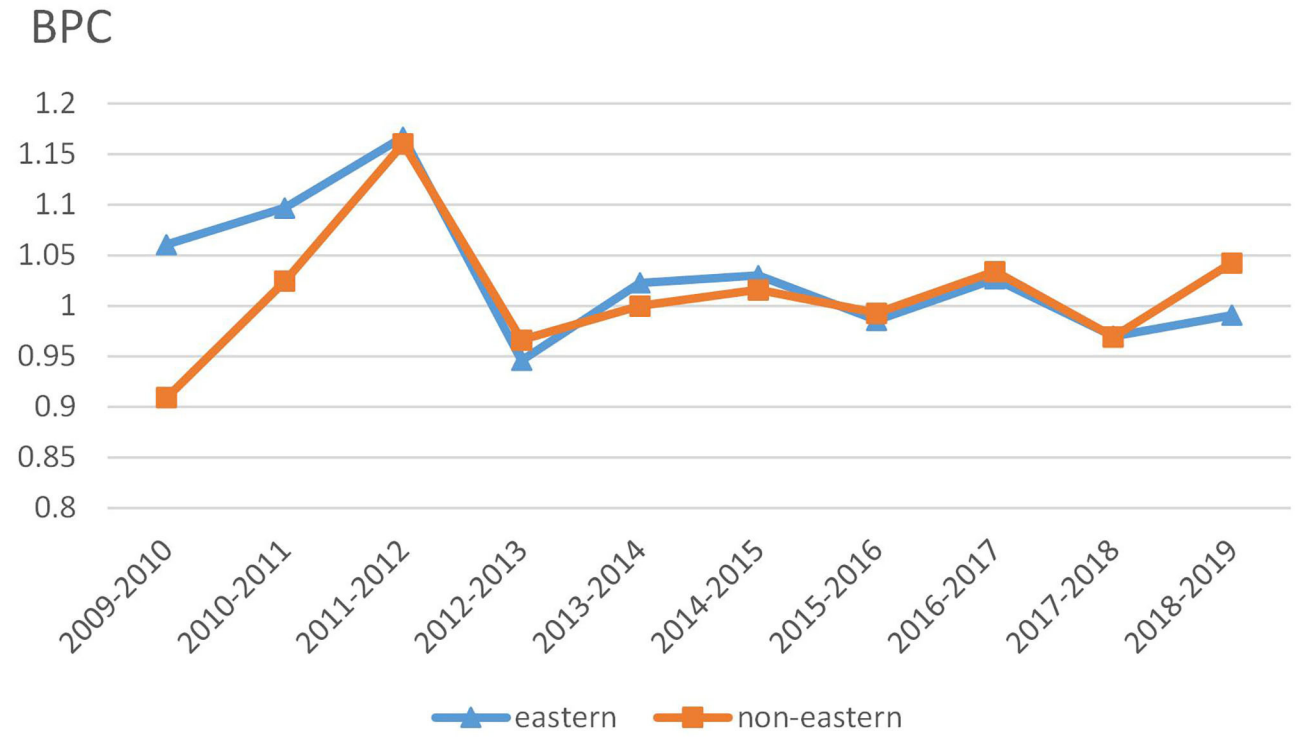

FIGURE 5 | Trends of BPC at the regional level.

technology gap in the relatively underdeveloped non-eastern region. After 2014, the TGC values in the eastern region remain relatively stable, whereas there is still a large fluctuation trend of TGC in the non-eastern region. Although the TGC values in the eastern region fluctuate slightly in the early stage of the sample period, the eastern region has maintained the leader of technology due to the existence of a large number of TGR values equal to 1. For the non-eastern region, the TGC values are larger than unity in most cases regardless of the obvious fluctuation, implying the decreasing technology gap during the whole study period.

Innovative Provinces

Referring to Oh and Lee (33) and Zhang and Choi (40), we identify two types of innovative provinces that can be targeted by those inefficient provinces: the regional innovative provinces and the global innovative provinces. Regional innovative provinces can be regarded as innovators within a specific group, and global innovative provinces include a subset of regional innovators from an integrated perspective. A total of three conditions for identifying regional innovative provinces are described as follows:

$$BPC > 1 \tag{16a}$$

$$\vec{D}^{t}(T^{t+1}, B^{t+1}, O^{t+1}, I^{t+1}, M^{t+1}, P^{t+1}, C^{t+1}) < 0 \tag{16b}$$

$$\vec{D}^{t+1}(T^{t+1}, B^{t+1}, O^{t+1}, I^{t+1}, M^{t+1}, P^{t+1}, C^{t+1})=0 \tag{16c}$$

As described earlier, Equation (16a) indicates that the contemporary frontier in $t+1$ shifts closer to the intertemporal frontier than that in t, representing an innovation effect. Equation (16b) suggests that the production of innovative provinces in period $t+1$ should be outside of the contemporary production possibility set of period t. It also means that the technology in period t cannot satisfy the required production activity in period $t+1$. Equation (16c) indicates that the regional innovative provinces in period $t+1$ should be completely efficient under the contemporary frontier in period $t+1$.

In addition to the three conditions mentioned above, we add two additional conditions to identify the global innovative provinces.

$$TGC > 1 \tag{17a}$$

$$\vec{D}^{G}(T^{t+1}, B^{t+1}, O^{t+1}, I^{t+1}, M^{t+1}, P^{t+1}, C^{t+1})=0 \tag{17b}$$

Equation (17a) indicates a decrease in the technology gap between the intertemporal frontier and the global frontier, implying technology convergence toward the global frontier. Equation (17b) suggests that the global innovative provinces in period t+1 should be completely efficient under the global frontier.

Table 3 lists the regional innovative provinces and global innovative provinces. In eastern China, most of the regional innovation provinces are mainly concentrated in the Yangtze

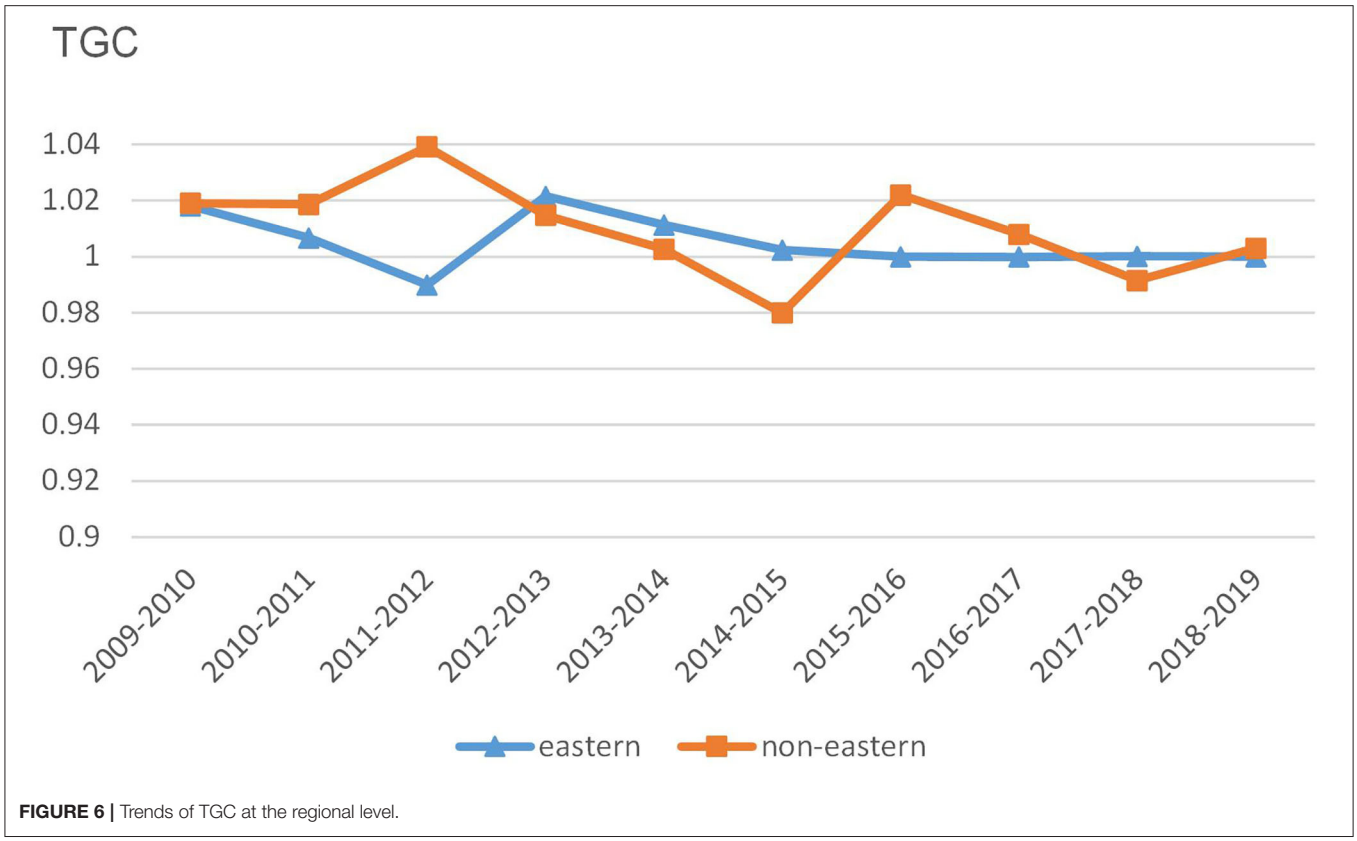

FIGURE 6 | Trends of TGC at the regional level.

River Delta region, such as Shanghai, Jiangsu, and Zhejiang. Among them, Zhejiang appears seven times as the province with the highest frequency. Shanghai and Jiangsu appear five and four times, respectively. In addition, Shandong and Guangdong are also identified as regional innovative provinces four and three times, respectively. In non-eastern China, regional innovative provinces vary across periods. Hubei, Sichuan, Guangxi, Henan, and Anhui are found to be the regional innovative provinces with relatively high frequency. Hubei is registered six times, followed by Sichuan, Henan, and Guangxi (four times). From the global frontier perspective, all the global innovative provinces come from non-eastern China. In the above study, we have identified the eastern region and the non-eastern region as the technology leaders and followers, respectively. An examination of the phenomenon reveals that the global innovative provinces from the non-eastern region are also technologically leading provinces due to a decreasing technology gap and location on the global frontier. Non-innovative provinces can benchmark the regional innovative provinces and global innovative provinces to improve their unified healthcare efficiency.

CONCLUSION

Research in healthcare efficiency has increasingly focused on regional differences based on the assumption of the same production technology. Yet, less research considers the technology heterogeneity. In this study, we combine the non-radial directional distance function and the meta-frontier method to construct the static indicator (HEI) and dynamic indicator (MNMHEI). Through the temporal analysis of those indicators and the decomposition of MNMHEI, we evaluate the evolution of the unified healthcare efficiency at the regional level from 2009 to 2019 and identify the sources of unified efficiency changes. The main conclusions are as follows:

The findings of the HEI support the general argument that the unified healthcare efficiency in China's economically developed eastern region is significantly higher than that in the relatively underdeveloped non-eastern region. From the perspective of temporal analysis, 2012 is considered as a watershed in the development of unified healthcare efficiency. Due to the successful coverage of universal health insurance in 2011, the unified healthcare efficiency in both eastern and non-eastern China shows notable growth from 2011 to 2012 and reaches the maximum in 2012. In addition, the two regions share similar time trends of HEI and MNMHEI during the whole study period.

The result of the average MNMHEI indicates a 2.68% annual increase in unified healthcare efficiency from 2009 to 2019. Both eastern and non-eastern regions show an upward trend, with an average growth rate of 3.53 and 2.22%, respectively. The decomposition of MNMHEI reveals that the increase in unified healthcare efficiency in eastern China is mainly driven by technological progress, measured by BPC. On the contrary, the main reason for the increase in unified healthcare efficiency in non-eastern China is the better catch-up performance, measured by EC. According to TGC, the eastern region maintains the leader of technology, and the non-eastern region, as a follower, shows a narrowing technology gap.

TABLE 3 | Group and metafrontier innovators.

Year	Group innovator		Metafrontier innovator
	Eastern region	Non-eastern region	
2009–2010	Shanghai Jiangsu Zhejiang Shandong	Henan	
2010–2011	Shanghai Jiangsu Zhejiang Shandong Guangdong	Anhui Jiangxi Henan Hubei	Jiangxi
2011–2012	Hebei Shanghai Zhejiang Fujian Shandong Guangdong	Hubei Guangxi Sichuan Guizhou Yunnan	Sichuan Yunnan
2012–2013	–	–	–
2013–2014	Shanghai Jiangsu Shandong	Hubei Hunan	Hubei
2014–2015		Anhui Hunan	
2015–2016	Hebei Zhejiang	Henan Hubei Guangxi Sichuan	
2016–2017	Shanghai Zhejiang Guangdong	Jiangxi Hubei Chongqing Sichuan	Jiangxi Guangdong
2017–2018	Zhejiang	Anhui Guangxi	
2018–2019	Jiangsu Zhejiang	Henan Hubei Guangxi Sichuan Ningxia	Henan Hubei

The temporal analysis of dynamic indicator shows that the BPC time trends approximately coincide with the MNMHEI time trends in two regions, implying that technological progress has made a greater contribution to the changes in MNMHEI. Time trends of EC values in two regions show fluctuations, without obvious upward or downward trends. BPC values show similar temporal trends in the eastern and non-eastern regions and reach the maximum during 2011–2012. With the universal health insurance coverage in 2011, the increase in medical services may promote technological progress. Compared with the EC and TGC, the impact of policies on technological progress is more significant. The BPC values of the eastern region are higher than those of the non-eastern region from 2009 to 2011, whereas this gap has disappeared gradually after 2012. Interestingly, although the non-eastern region has a lower average value of BPC, it shows better growth momentum from the perspective of time trends. In general, the reform has a greater impact on the technological progress in the non-eastern region than in the eastern region.

On the whole, eastern China and non-eastern China share similar time trends of HEI and MNMHEI under the influence of policies. The unified healthcare efficiency has increased significantly from 2009 to 2019, but there are notable differences between the two regions. The emphasis on policies adopted by the two regions should be different. The eastern region is considered as a technology leader, with higher unified healthcare efficiency, better technological progress performance, and the production technology closest to the meta-frontier technology. According to the results, the eastern region should focus more on the improvement in resource management level in the production process and plays a leading role nationwide.

It cannot be ignored that the production technology in non-eastern China lags behind that in eastern China. However, the impact of the reform on the non-eastern region is more significant, as shown in the following. As a technology follower, the non-eastern region shows a decreasing technology gap and a stronger growth momentum of technological progress during the study period. We also have an interesting finding that all the global innovative provinces come from non-eastern China. From the perspective of time trends, EC shows uncertainty whereas BPC experiences a stable growth momentum. The non-eastern region should commit to improving innovation and introducing advanced technologies that are common in the eastern region. In addition, more attention should be paid to the radiation and the leading role of innovative provinces.

This study has some limitations that can be further researched. First, the group classification is based on the previous research that the eastern region shows better performance in healthcare efficiency. Future research can consider a wider range of group classifications to explore the regional heterogeneity. Second, the bootstrap methods can be incorporated to perform the statistical inference for the unified healthcare efficiency and its dynamic changes as well as the decompositions.

DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. This data can be found at: https://data.cnki.net/yearbook/Single/N2022010155.

AUTHOR CONTRIBUTIONS

BG contributed to conceptualization and writing—original draft. XF contributed to data curation and policy suggestions. JZ contributed to writing, reviewing, and editing the manuscript. All authors contributed to the article and approved the final manuscript.

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Evaluation of the Community-Based Hypertension Management Programs in China

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Purpose: The National Essential Public Health Services Package (NEPHSP), a set of community-based hypertension management programs, was launched by the Chinese government in 2009. However, the data are limited for the comprehensive evaluation of NEPHSP on hypertension management. This study was to estimate the effect of NEPHSP on hypertension control nationwide in China.

Methods: Data were from China Hypertension Survey (CHS). The participants ($n = 119{,}412$) aged ≥35 years with hypertension were included in the analysis. Further, a subset of 64,188 diagnosed hypertensive patients were analyzed to evaluate the effect of NEPHSP by comparing the ones covered and not covered by NEPHSP. Blood pressure (BP) was measured by trained staff using a validated digital portable monitor in local communities or clinics.

Results: Among adults aged ≥35 years with hypertension, the coverage of NEPHSP was 25.6% and increased with age. The coverage was significantly higher in women than in men ($P < 0.001$). Among the 64, 188 diagnosed hypertensive patients, compared to the control group (not covered by NEPHSP), the mean systolic and diastolic BPs were 2 mmHg and 1.6 mmHg lower in NEPHSP group, respectively. The rate of treatment for hypertension was significantly higher in NEPHSP group than the control group (93.0% vs. 81.4%, $P < 0.001$), and the rate of BP control was also significantly higher in NEPHSP group than the control group (35.9% vs. 29.6%, $P < 0.001$). Furthermore, similar trends were found in rural and urban, as well as in men and women.

Conclusions: Our results showed that NEPHSP is effective in improving hypertension treatment and control in hypertensive patients in China. However, the coverage of NEPHSP was still low.

Keywords: hypertension, community-based program, control, China, public health

INTRODUCTION

Hypertension is the leading modifiable risk factor for cardiovascular (CV) disease, which is a major cause of mortality and morbidity in China and worldwide (1, 2). In China, the prevalence of hypertension has reached 23.2% in adults (3). Although safe and effective antihypertensive medications have been available for decades, treatment and control of hypertension remain low in China. Moreover, only 46.9% hypertensive patients were aware of their condition, 40.7% were treated with antihypertensive medications, and 15.3% had controlled blood pressure (BP) (3). The burden of hypertension and CV disease in China is expected to continue increasing along with rapid urbanization, economic growth, and aging of the population (2, 4, 5).

To address current health challenges, including obesity, diabetes, and other non-communicable diseases, and to reduce the disparities for the Chinese population in accessing essential public health services, the Chinese government issued the National Essential Public Health Services Package (NEPHSP) in 2009 (6, 7). The benefit of NEPHSP included physical examination, health education, chronic disease screening, management, etc. For hypertension, the services of NEPHSP include establishing health records, screening and following-up, and routine physical examinations of identified hypertension (8). A recent study showed that coverage of NEPHSP program was associated with increases of 7.9% in BP control, 10.3% in medication, and 10.5% in BP monitoring among adults aged ≥45 years. This study also showed that NEPHSP program helped to equalize the geographic disparities in access to health services such as BP monitoring (7). However, data are still limited for a comprehensive evaluation of NEPHSP on hypertension control in Chinese adults. This study used the China Hypertension Survey (CHS) data to examine the progress and impact of NEPHSP on hypertension control nationwide in China.

METHODS

The CHS study design was published elsewhere (9). Briefly, a stratified, multistage random sampling method was used to obtain a nationally representative sample of the Chinese population. A total of 487,349 participants aged ≥15 years were recruited, with a response rate of 66.4%. After excluding 7,507 participants due to missing information on major risk factors, 479,842 were eligible and completed the survey. The participants (n = 119,412) who were aged ≥35 years with hypertension were included in the analysis. Further, a total of 64,188 hypertensive patients who were aware of having hypertension were included to evaluate the effect of NEPHSP (33,946 patients covered by NEPHSP were considered as the intervention group, and 30,242 patients not covered by NEPHSP were considered as the control group) (**Supplementary Figure S1**). The written informed consent was signed by each participant. The Ethics Committee of Fuwai Hospital (Beijing, China) approved the study (Approved number: 2012-402).

A comprehensive operational manual was developed to ensure standardization and high quality of data. All study investigators completed a training program that oriented them both to the aims of the study and the specific tools and methodologies

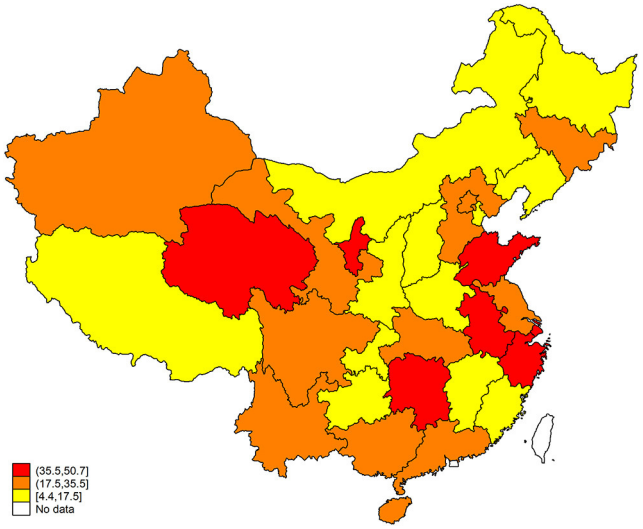

FIGURE 1 | Coverage of the National Essential Public Health Services Package by Province.

TABLE 1 | Coverage of the National Essential Public Health Services Package by Region and Sex, and Province.

Province	Region		Sex		Total	*P*-value for region	*P*-value for sex
	Urban	Rural	Men	Women			
N	56,037	63,375	56,888	62,524	119,412		
Age							
35–44	13.4 (9.6–18.4)	11.8 (8.8–15.6)	11.0 (8.5–14.1)	14.5 (11.8–17.7)	12.3 (9.8–15.2)	0.553	0.002
45–54	24.1 (18.9–30.0)	22.0 (16.4–28.7)	20.4 (16.8–24.5)	25.3 (20.6–30.6)	22.7 (18.7–27.3)	0.608	<0.001
55–64	31.1 (25.4–37.4)	26.7 (20.5–34.1)	25.8 (21.6–30.6)	30.8 (25.9–36.2)	28.3 (23.8–33.4)	0.334	<0.001
65–74	35.4 (28.2–43.4)	31.7 (24.1–40.3)	31.5 (26.0–37.5)	34.3 (28.7–40.5)	33.0 (27.5–39.0)	0.492	0.001
≥75	37.4 (29.7–45.7)	30.8 (22.5–40.6)	32.1 (26.2–38.6)	33.8 (27.4–40.9)	33.1 (26.9–39.9)	0.282	0.09
Overall	28.2 (22.5–34.7)	24.1 (18.3–31.2)	22.9 (18.9–27.4)	28.5 (23.6–33.8)	25.6 (21.2–30.5)	0.361	<0.001

All values were weighted to represent the total population of Chinese aged 18 years or older based on Chinese census 2010.

TABLE 2 | Difference between the intervention and control groups.

Characteristics	Control	Intervention	*P*-value
n (%)	30,242 (47.1)	33,946 (52.9)	
Mean age, yr	58.6 (58–59.2)	61 (60.6–61.5)	<0.001
Sex (Female, %)	50 (48.3–51.8)	53.8 (52.5–55)	<0.001
Mean BMI, kg/m^2	26 (25.5–26.4)	25.7 (25.3–26)	0.137
<18.5	1.6 (1.1–2.1)	2.1 (1.6–2.8)	
18.5–23.9	28.7 (25.4–32.3)	31.3 (27.7–35.1)	0.143
24.0–27.9	41.8 (40.5–43.1)	41.6 (40.3–43)	
≥28.0	27.9 (23.8–32.4)	25 (21.7–28.6)	
Mean SBP—mmHg	149.1 (147.6–150.6)	147.1 (145.4–148.8)	0.009
Mean DBP—mmHg	85.6 (84.8–86.4)	84.2 (83.3–85)	0.001
Ethnicity (Han, %)	93.1 (89–95.7)	90.7 (80.9–95.8)	0.359
Educational attainment, %			
Elementary school	52 (48.1–55.8)	58.1 (52.7–63.2)	
Elementary middle school	43.6 (40.3–46.9)	38.1 (33.9–42.5)	0.021
High school or above	4.4 (3.6–5.5)	3.8 (2.7–5.4)	
Smoking status, %			
Non-smokers	69.9 (67.5–72.2)	74.3 (72.1–76.4)	
Past smokers	6.8 (5.6–8.2)	6 (5.1–7)	0.001
Current smokers	23.3 (21.7–25)	19.8 (18.2–21.5)	
Consumption of alcohol, %	19.5 (17.5–21.5)	16.5 (14.3–19)	0.018
Family history of hypertension, %	46 (41.3–50.7)	43.8 (39.5–48.2)	0.353
Rural, %	62.6 (49–74.5)	61.4 (48.1–73.3)	0.881

BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure.
Data are represented as value (95% CI).
All values were weighted to represent the total population of Chinese aged 18 years or older based on Chinese census 2010.

employed. The questionnaire was filled and checked for completeness on site. All data were checked for inconsistencies in the entries and outlying values (9). Demographic characteristics and social-economic factors were collected using a standardized questionnaire. Bodyweight with light clothes was measured using an OMRON body fat and weight measurement device (V-body HBF-371, OMRON, Kyoto, Japan). Height was measured without shoes (to the nearest 0.5 cm). Body mass index (BMI) was calculated as weight divided by the square of height (kg/m^2). After the participant was sitting at rest for 5 min, BP was measured three times on the right arm positioned at heart level using the OMRON HBP-1300 Professional Portable Blood Pressure Monitor (OMRON, Kyoto, Japan). The accuracy of the Omron HBP-1300 had been verified in our previous study (10).

According to 2010 Chinese guidelines for the management of hypertension (11), hypertension was defined as systolic blood pressure (SBP) ≥140 mm Hg, and/or diastolic blood pressure (DBP) ≥ 90 mm Hg, and/or use of antihypertensive medicine within 2 weeks. Awareness of hypertension was defined as self-report of any previous diagnosis of hypertension by a doctor, treatment as self-reported use of antihypertensive medication within 2 weeks, control as SBP <140 mmHg and DBP < 90 mm Hg. Coverage of NEPHSP was defined as the number of hypertensive patients covered by NEPHSP divided by the number of hypertensive patients.

Overweight and obese were defined as BMI between 24.0 and 27.9 kg/m^2 and 28.0 kg/m^2 or above, respectively (12). Participants who consumed at least one serving of alcoholic beverage per week in the past month were defined as drinkers. Participants who smoked at least 20 packets of cigarettes in their lifetime and currently smoke cigarettes were defined as current smokers; participants who smoked at least 20 packets of cigarettes in their lifetime, and quit smoking for at least 1 month were defined as former smokers, and other participants were defined as never smokers.

Antihypertensive drugs were classified as diuretics, β-blockers, α-β-blockers, calcium channel blockers, angiotensin-converting enzyme inhibitors (ACEIs), angiotensin II receptor blockers (ARBs), centrally acting drugs, vasodilators, and traditional Chinese medicine. Single-pill combinations (SPCs), which normally contain ≥2 active ingredients, were separated into their generic components (3).

Statistical Analysis

Survey weights were calculated according to the 2010 China population census data and the complex sampling scheme including oversampling for specific age subgroups, non-response, and other demographic between the sample (13).

Variables were summarized using means with 95% confidence intervals (CI) for continuous data; using frequencies, percentages, or proportions for categorical data. Two-tailed

TABLE 3 | Antihypertensive medicine use in participants with hypertension.

Variables	Control	Intervention	*P*-value
Drug Type for monotherapy[†]			
β-blockers	4.2 (3.3–5.4)	4.1 (2.9–5.8)	0.910
Diuretics	6.6 (4.6–9.3)	7.6 (5.7–10.2)	0.423
CCBs	42.0 (35.9–48.3)	41.7 (35.6–48)	0.925
ACEIs	14.6 (12.7–16.7)	17.3 (13.7–21.5)	0.169
ARBs	9.1 (6.3–12.8)	11.5 (6.8–18.7)	0.284
α-β-blockers	0.1 (0.0–0.1)	0.1 (0.0–0.5)	0.633
CADs	9.3 (6.4–13.3)	9.6 (5.2–17.0)	0.916
Vasodilators	0.4 (0.1–1.7)	0.2 (0.1–0.5)	0.417
TCMs	5.5 (3.9–7.6)	3 (2.2–4.1)	<0.001
Single-pill combinations			
ACEIs and Diuretics	0.1 (0.0–0.3)	0.5 (0.2–1.3)	<0.001
ARBs and Diuretics	0.5 (0.2–1.0)	0.3 (0.2–0.5)	0.108
CADs/Vasodilators/Diuretics[‡]	17.4 (14.3–21.0)	15.7 (12.4–19.6)	0.157
ARB and CCBs	0.0 (0.0–0.2)	0.1 (0.0–0.1)	0.781
Combination of TCMs	0.7 (0.1–2.9)	0.6 (0.2–1.4)	0.633
Number of drugs for combination therapy[§]			
1	83.8 (79.0–87.7)	87.7 (82.1–91.8)	0.547
2	3.7 (2.5–5.3)	3.1 (2.4–3.9)	
≥3	11.9 (8.4–16.4)	9 (5.3–14.9)	

ARBs, angiotensin II receptor antagonists; ACEIs, angiotensin-converting-enzyme inhibitors; CCBs, calcium-channel blockers; TCMs, Traditional Chinese medications; CADs, Centrally acting drugs.

[†] *The classes of drugs were used as monotherapy, not pooled with the ingredients of the single-pill combinations.*

[‡] *Considered Chinese traditional antihypertensive combinations, which normally contain reserpine, hydralazine, and diuretics.*

[§] *Single-pill combinations (SPCs), which normally contain ≥2 active ingredients, were separated into their generic components.*

Student *t*-tests with the Wilcoxon rank-test when necessary and *Chi*-squared tests were used to compare continuous and categorical variables, respectively. Logistic regression, applied with "svy: logit," was used to test the differences in hypertension treatment and control between the intervention and control group after adjusting for age, sex, BMI, ethnicity, education attainment, smoking status, consumption of alcohol, family history of hypertension, and region (rural/urban). $P < 0.05$ was the threshold for statistical significance. Statistical analyses were conducted with Stata 12.1 (STATA Corp., TX, USA).

RESULTS

A total of 119,412 participants with hypertension aged ≥ 35 years (52.8% women and 53.1% rural) completed the survey and were included in the analysis. Overall, the coverage of NEPHSP was 25.6% and increased with age (**Table 1**). The coverage of NEPHSP was significantly higher in women than men ($P < 0.001$), while the coverage of NEPHSP between urban and rural populations was similar ($P = 0.361$). The coverage of NEPHSP varied considerably among provinces (**Figure 1**). Three provinces or province-level municipalities, Shandong, Zhejiang, and Shanghai, ranked in the top 3 for coverage of NEPHSP at 50.7, 46.9, and 41.1%, respectively; whereby, Xizang had the lowest coverage of NEPHSP (4.4%) (**Supplementary Table S1**).

A total of 64, 188 hypertensive patients who were aware of having hypertension were included to evaluate the effect of NEPHSP. Compared to the control group, the mean SBP and DBP were 2 mmHg and 1.6 mmHg lower in NEPHSP group, respectively (**Table 2**). The mean age and percentage of women were higher in NEPHSP group, while the percentages of participants with higher education levels, smokers, and alcohol drinkers were lower in NEPHSP group ($P < 0.05$).

The overall prescribing patterns of antihypertensive drugs in intervention and control groups were similar except for Traditional Chinese medications and single-pill combinations of ACEIs and diuretics, which were more commonly used in the intervention group ($P < 0.001$) (**Table 3**).

After adjusting for other covariates, the treatment rate of hypertension was significantly higher in the intervention group than the control group (93.0% vs. 81.4%, $P < 0.001$), and the BP control rate was also significantly higher in the intervention group than the control group (35.9% vs. 29.6%, $P < 0.001$). Furthermore, similar trends were found in both rural and urban, as well as in men and women (**Figure 2**).

DISCUSSION

This large survey from a national representative sample showed that only 25.6% of hypertensive patients aged

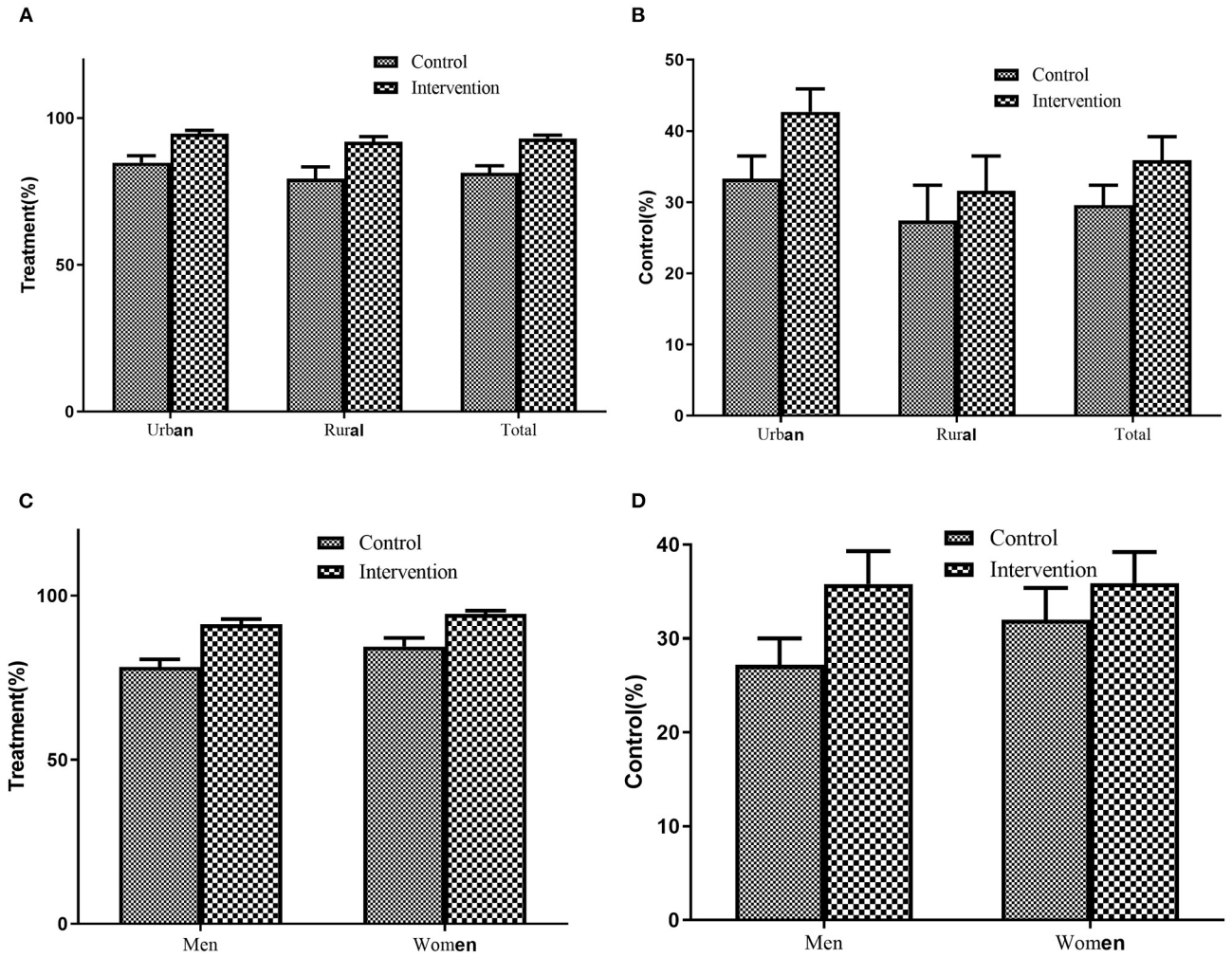

FIGURE 2 | Treatment and Control of Hypertension between intervention and control group. **(A)** Treatment by region, **(B)** Control by region, **(C)** Treatment by sex, **(D)** Treatment by sex. Adjusting for age, sex, BMI, ethnicity, education attainment, smoking status, consumption of alcohol, family history of hypertension, and region (rural/urban).

≥ 35 years in China were covered by NEPHSP, and the coverage was significantly higher in women than men, similar in urban and rural populations. Compared to the control group, the mean SBP and DBP were 2 mmHg and 1.6 mmHg lower in NEPHSP group, respectively. Furthermore, the treatment and control of hypertension were significantly higher in the intervention group than in the control group.

Studies show that even a 1-mm Hg decrease in SBP could prevent substantial numbers of CV events, including heart failure, coronary heart disease, and stroke (14). Framingham Heart Study reported that a 2-mm Hg population-wide DBP reduction was associated with a 17% decrease in the risk of hypertension and a 6% reduction in coronary heart disease (15). In NEPHSP group, the treatment, and control of hypertension were significantly higher, and the mean SBP and DBP had a 2 mmHg and 1.6 mmHg decrease, which can be translated to a significant reduction in CV diseases. The Chinese government provided a subsidy of 15 yuan ($2.14) per capita for primary care providers to deliver NEPHSP since 2009. From 2011 to 2013, increased public funding ($4.61) had been invested to expand NEPHSP services including annual physical examination for all residents aged ≥65 years, regular health check-ups, and follow-up services for patients with hypertension or type 2 diabetes aged ≥35 years (7). We roughly estimated the cost of NEPHSP and saving from only CV disease events prevented by NEPHSP according to the data from the Felodipine Event Reduction (FEVER) study and China Health Statistics Yearbook (16, 17). The results indicated that if all hypertensive patients aged ≥35 years in China were covered by NEPHSP, the cost would be 0.55 million US dollars/year, and the saving would be 0.37 million US dollars/year. Considering NEPHSP covers multiple health services, NEPHSP is very likely expected to be cost-effective, although future health economic analysis is required.

The previous study indicated that high-risk strategies have a major impact on CV disease in the population (18). Our results showed that only 25.6% of hypertensive patients aged ≥ 35 years in China were covered by NEPHSP. This result is in line with the previous study (7), which reported that only 8.1% of the middle-aged and older population took the EPHS-covered physical examination between 2011 and 2013, suggesting a great potential if NEPHSP scales up to a higher coverage. Therefore, national-wide health education, increase primary care providers and budget should be considered (19–21). There is a significant geographical diversity for coverage of NEPHSP. Shandong, Zhejiang, and Shanghai with relatively higher gross domestic products in China (22) ranked in the top 3. These results suggest that more attention should be paid to specific geographical regions.

Hypertension is a condition of long duration and slow progression that is largely preventable through the improvement of their unhealthy lifestyles, including smoking, unhealthy diet, physical inactivity, and alcohol consumption (23). A growing body of evidence supports the feasibility and benefits of implementing community-based programs for the prevention of CV disease (24, 25). Research shows that increasing the awareness of hypertension is one of the most effective ways to control BP and reduce related CV diseases (26, 27). Increasing the awareness of hypertension helps people increase their opportunity for receiving high-quality care, and helps them to lead healthy lifestyles (26). Consistent with previous results, we also found that the smoking and drinking rate was lower in hypertensive patients covered by NEPHSP.

One of the major strengths is that our study sample represented all the target population of NEPHSP and it represented the overall hypertensive population in China. There are several limitations in this study. The first limitation is that our data on NEPHSP were based on self-report, which may be subject to recall bias. Second, hypertension was diagnosed based on only 3 times BP measurements at one visit. Third, the low response rate may produce a non-response bias. Finally, more studies with randomized design will be needed to confirm our findings.

CONCLUSIONS

Our results showed that NEPHSP is efficient in hypertension treatment and control in hypertensive patients aged ≥ 35 years in China. However, the coverage of NEPHSP was still lower. These results suggest that NEPHSP has the potential for hypertension management in China and other developing countries, thus, it should be extended.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because rights of use were only granted to the authors. Requests to access the datasets should be directed to wangzengwu@foxmail.com.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethics Committee of Fuwai Hospital. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

ZW and RG contributed to the conceptualization of the study. GH performed the statistical analysis, interpreted the results, and wrote the first draft of the manuscript. ZC, XW, LZ, YK, CZ, and LC critically reviewed the manuscript. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

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Configurational Paths to Higher Efficiency in County Hospital: Evidence From Qualitative Comparative Analysis

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Background: The efficient operation of county-level medical institutions is a significant guarantee in constructing Chinese rural tertiary care service networks. However, it is still unclear how to increase the efficiency of county hospitals under the interaction of multiple factors. In this study, 35 county general hospitals in China were selected to explore the configuration paths of county hospitals' high and poor efficiency status under the Environment-Structure-Behavior (ESB) framework and provide evidence-based recommendations for measures to enhance its efficiency.

Methods: Data envelopment analysis with the bootstrapping procedure was used to estimate the technical efficiency value of case hospitals. A fuzzy-set qualitative comparative analysis approach was carried out to explore the configuration of conditions to the efficiency status.

Results: Antecedent configurations affecting the efficiency status of county hospitals were identified based on the ESB analytical framework. Three high-efficiency configuration paths can be summarized as structural optimization, capacity enhancement, and government support. Another three types of paths, namely insufficient capacity, aggressive expansion, and poor decision-making, will lead to inefficient configurations.

Conclusion: Qualitative comparative analysis is necessary when exploring complex causality. The efficiency situation of county hospitals results from a combination of influencing factors instead of the effect of a single one. There is no solitary configuration for high efficiency that applies to all healthcare units. Any measures aimed at efficiency promotion should be discussed within the framework of a case-specific analysis.

Keywords: county hospital, hospital efficiency, configurational paths, qualitative comparative analysis, QCA

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INTRODUCTION

The three-tier medical and health service system in rural China, consisting of county hospitals, township hospitals, and village clinics, guarantees country-dwellers essential health services. As the pinnacle of the service network, county hospitals represent the local top level of medical care delivery. It could be argued that the efficiency of county hospital medical services is directly

related to the medical and health security of hundreds of millions of Chinese rural residents (1–3). However, in terms of service capacity and efficiency, county-level hospitals are still far from urban tertiary hospitals, and the development levels of county hospitals are also uneven (3–5). Improving the delivery efficiency of county-level hospitals can effectively improve the economy of regional health resource allocation. From a worldwide perspective, a large number of empirical studies show that the low efficiency of grass-roots medical institutions is a common situation, especially in a region with lower medical and health development, which leads to the unreasonable allocation of health services and the waste of medical resources (4–7). This dilemma has perplexed the central and local health administrative departments. In China, the central administration released the action plan for the Promotion of High-Quality Development (PHQD) of public hospitals in 2021, which proposes to enhance the comprehensive capabilities of county-level hospitals further and achieve PHQD (8). Service efficiency has become an essential issue in PHQD for public hospitals. Therefore, research on service efficiency's key factors can help provide decision-makers references for policymakers, thus providing the evidence-based basis for determining regional health policies.

Many scholars have studied the efficiency of health institutions in different countries, focusing on the measurement methods of hospital efficiency and its determinants (9). The Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA) are widely used in terms of efficiency measurement (10–12). As a non-parametric method, DEA is particularly suitable for discussing the efficiency measurement of multi-input and multi-output scenarios (13–15). For example, the undesirable output model (16), bootstrapping approach (17–20), multi-stage analysis (7, 21, 22), and other DEA methods are often used in the literature on hospital efficiency research. In discussing the key factors of hospital efficiency, regression models were the prevailing integrated approach with DEA. Since the value calculated by the DEA was between 0 and 1 and most of the scores mainly concentrated on their boundary, most scholars used Tobit regression to explore the influence of variables on efficiency (23). However, the literature review shows that the research on the factors influencing hospital efficiency still has the following deficiencies.

Firstly, there is a lack of a systematic discussion framework on the variables affecting efficiency. It is not noticed that efficiency factors exist in the internal organizational structure, medical behavior, and the complex external environment (24). Secondly, most studies use the method of Tobit regression to discuss the contributing factors, ignoring the multiple causalities between these factors and efficiency results (23, 25). However, the actual situation is that various factors affect each other and influence operation efficiency. There were existing limitations in exploring the net effect of a single variable on outcomes. It is challenging to explain causality using correlation analysis. Finally, the study only tells readers which factors are significant and lacks specific suggestions for the efficiency improvement of different hospitals (10). The environment and organizational structure of various hospitals may be highly heterogeneous, and the efficiency improvement measures of each hospital may be other.

Therefore, based on the case-oriented Qualitative Comparative Analysis (QCA) method, this study explores the multiple configuration paths of the contributing factors to county-level hospitals' efficiency and provides evidence-based suggestions for efficiency progress. To the best of our knowledge, this is the first study to analyze the antecedent configuration of county-level hospital efficiency. Thus, this paper sheds new light on the discussion of influencing elements of hospital efficiency and efficiency improvement measures from a holistic perspective.

The rest of the study is organized as follows. Section Methods and Materials introduces the theoretical basis and analysis methods of this study and explains the samples, variables, and data sources. Section Results reports the efficiency measurement results of the case hospital and the critical steps in the qualitative comparative analysis, including efficiency value calibration, necessary condition analysis, standard analysis, and robustness test. Section Discussion discusses the configuration path of county-level hospital efficiency influencing factors. Section Conclusion summarizes these findings and clarifies the highlights and limitations of this study.

METHODS AND MATERIALS

Bootstrap-DEA Model

The measurement of hospital efficiency is a classic topic in Health Economics. In terms of methodology, the current academia divided it into two categories, namely parametric and non-parametric methods (10). The non-parametric approach, represented by the DEA method, was widely used because of the multi-input and multi-output nature of the healthcare system (26), which originated from Farell's concept of technical efficiency and was proposed by Charnes et al. (27). So far, the method has been widely used in measuring the efficiency of healthcare delivery systems in both developed and developing countries (28–32). Since the DEA approach creates an efficiency frontier based on available data, the efficiency values calculated using this method are inherently biased in a positive and or at least non-negative direction (13). The bootstrapping and jackknife methods were often used as a means of repeated sampling to solve the problem of serially correlation estimates (14, 23, 26, 33). In this study, the output-orientated Constant Returns to Scale (CRS) DEA method was used to measure the sample hospitals' original technical efficiency because the demand for quality medical resources exceeds the supply at the county level in China. Subsequently, the bootstrapping technique (34) was used to correct the efficiency values, and those scores were defined as the outcome variable of the QCA method. The confidence interval method was based on the following formula: Percentiles of the original score/(1+ bootstrapped Bias/original score) (35). Two thousand times were selected to improve the accuracy of the value correction during bootstrapping process. MaxDEA Ultra (Version 7.9, Realworld Corp., Beijing, China) was employed to carry out the efficiency calculation.

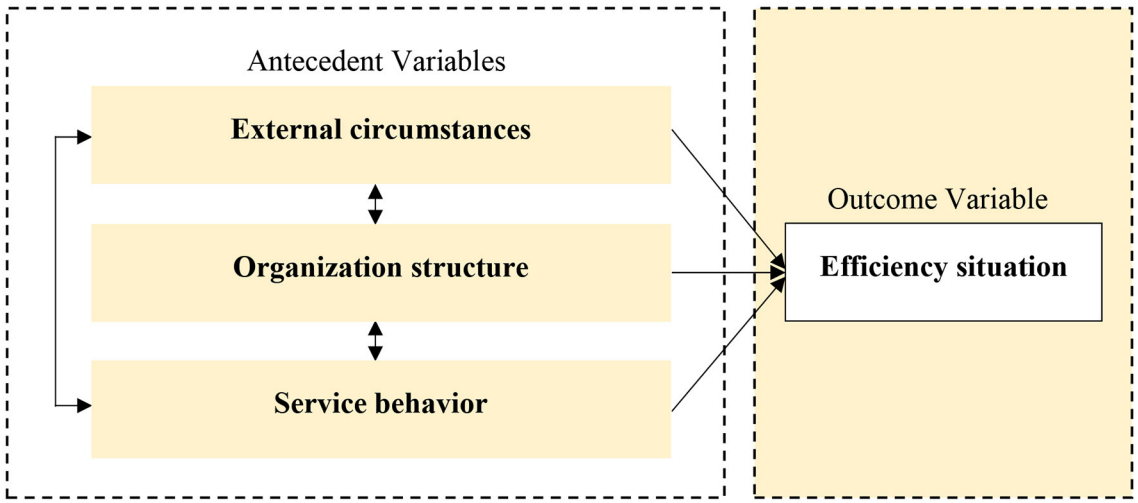

FIGURE 1 | Environment-structure-behavior analytical framework.

Qualitative Comparative Analysis Method

In this study, the fuzzy-set QCA (fs-QCA) method was used to analyze the configurational paths of efficiency advancement in a sample of hospitals. To the best of our knowledge, few studies applied this method to discuss the factors contributing to the efficiency of service delivery in healthcare sectors. As a new approach beyond qualitative and quantitative research, QCA offers a unique perspective in explaining the antecedent conditions that influence the emergence of a given outcome (36). Unlike regression models that examine the net effects of individual variables, this approach was based on the set theory of Boolean algebra. It enables a holistic perspective to explore complex social problems with multiple concurrent outcomes by examining the sufficient and necessary subset of relationships between antecedent conditions and outcomes (37). In dealing with complex causal issues, the QCA approach adheres to various possible paths to achieve the desired outcome, a feature often understood as all roads lead to Rome (38). QCA was divided into three categories depending on the set form: crisp sets, multi-valued sets, and fuzzy sets (36). Unlike the crisp sets' dichotomy, the fuzzy set allows partial membership scores with variable values between 0 and 1. The fuzzy set score represents the degree of a set of different cases, including two qualitative states, namely, full membership and full non-membership (38). Therefore, fuzzy-set QCA is entirely appropriate for discussing the causal relationship between hospital technical efficiency and its antecedent variables.

Moreover, since the method is based on set theory, it is particularly suitable for small and medium-sized samples selected on a case-oriented basis (38). When using this method for analysis, Ragin points out that QCA emphasizes the importance of identifying research questions and selecting appropriate conditions and outcome variables based on theoretical or empirical knowledge (38).

Through the literature review, critical factors affecting hospital efficiency can be divided into three categories: external circumstance, organizational structure, and service behavior, as shown in **Figure 1**. Since the government and public institutions own public hospitals in China, the external environment, such as government subsidies, regional economic development level, and population size, become the key factors affecting the efficiency of public hospitals (5, 9, 39). In terms of hospital organizational structure, ownership type, hospital scale, and human resource structure were often used. In addition, as a healthcare service delivery unit, hospital service behavior also impacts its efficiency, including service capacity, bed utilization status, and patient structure (32, 40).

Therefore, an analytical framework based on Environment-Structure-Behavior (ESB) was constructed in this study and was used in the QCA approach to answering the multiple paths of efficiency states of county hospitals. Fs-QCA (Version 3.1b) software developed by Charles Ragin and Sean Davey was employed to carry out the QCA process.

Variables and Data Source

In this study, 35 county hospitals in Hubei Province of China were selected as cases using a typical sampling method. Each hospital in the sample is the best medical institution in its county in terms of medical service capacity, and all of them meet the standards of Secondary Level A (SLA) general hospital and above as recognized by the National Health Commission, which meets the requirements for Decision Making Unit (DMU) homogeneity in the DEA method. In terms of variable selection, based on the literature review (13, 23), the number of doctors, registered nurses, actual open beds, and medical equipment (purchase price $\geq$ 1 million RMB) were selected as input indicators to reflect the input of human and physical resources in medical institutions. The number of outpatient and emergency visits, surgical operations for inpatient, and discharged patients adjusted by the Case Mix Index (CMI) and CMI were selected as output indicators to reflect the healthcare output of the medical institutions (26, 41). For setting antecedent variables, based on

TABLE 1 | Variables definition.

Indicators	Variables	Definition
Inputs	NoD	Number of doctors
	NoN	Number of nurses
	NoB	Number of actual open beds
	NoME	Number of medical equipment (Purchase price ≥ 1 million RMB)
Outputs	NoOEV	Number of outpatient and emergency visits
	NoSOI	Number of surgical operations for inpatient
	CMI	Case-mix index
	NoDP	Number of discharged patients adjusted by CMI
Antecedents	CCG	County per capita GDP (10 thousand RMB)
	AFA	Annual financial appropriation (1 thousand RMB)
	NoB	Number of actual open beds
	NDR	Nurse doctor ratio
	CMI	Case-mix index
	BUR	Bed utilization ratio

TABLE 2 | Descriptive statistics of variables.

Variables	Mean	Std. Dev.	Min	Max
NoD	234	105	71	569
NoN	413	163	158	913
NoB	851	295	400	2,000
NoME	23	14	2	86
NoOEV	389,214	223,388	124,296	1,178,782
NoSOI	12,141	9,649	1,514	52,256
CMI	0.87	0.09	0.69	1.08
NoDP	33,023	14,796	12,347	89,180
CCG	5.26	3.21	2.15	17.68
AFA	23,677	25,164	1,810	112,431
NDR	1.84	0.30	0.98	2.66
BUR	100.71	11.73	81.66	134.53

the ESB analysis framework, the annual per capita GDP of the county where the hospital is located and the yearly government financial subsidy were selected as proxies for the environmental dimension. The number of actual open beds and nurse-doctor ratio were used as proxy variables for the structural dimension. CMI and bed utilization rate were used as proxy variables for the behavioral dimension. The data in this study were obtained from the Hubei County Healthcare Comprehensive Reform Annual Report for the year 2019. The definitions of input indicators, output indicators, and antecedent indicators are illustrated in **Table 1**. The descriptive statistical analysis of the variables used in this study is shown in **Table 2**.

RESULTS

County Hospital Efficiency Scores

The original efficiency scores of the 35 sample hospitals had a mean of 0.9376, a median of 0.9475, a standard deviation of 0.0729, a maximum value of 1, and a minimum value of 0.7316. After correction of bias, the efficiency values for hospitals showed a skewed distribution with a mean of 0.8994, a median of 0.9195, a standard deviation of 0.0621, a maximum value of 0.9662, and a minimum value of 0.7113. The efficiency scores of the sample hospitals all showed a decline after 2,000 replicate sampling. However, in terms of efficiency score average, they were still higher than the sample county hospitals in the studies by Li et al. (3), Cheng et al. (4), and Liu et al. (5). This difference may stem from the selection method of the sample hospitals. The technical efficiency score distribution of the sample hospitals before and after the correction of efficiency values is shown in **Figure 2**. Bootstrapping Efficiency Score (BES) was used as an outcome variable in the following QCA process.

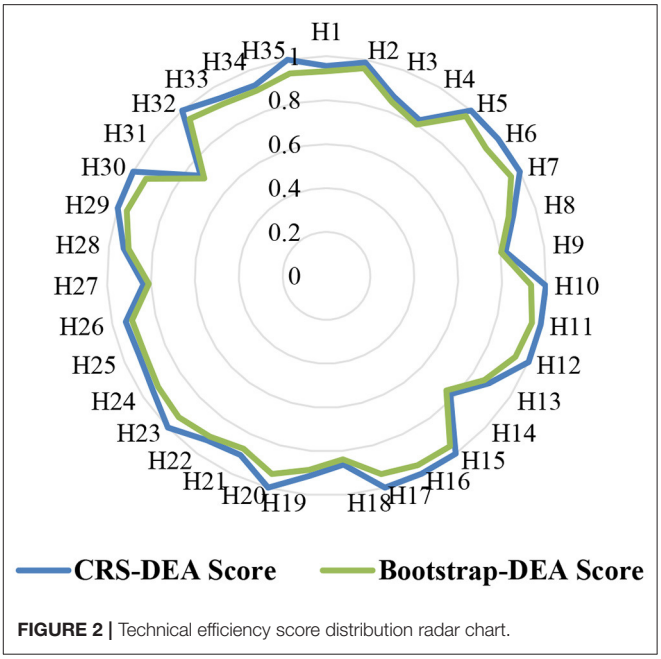

FIGURE 2 | Technical efficiency score distribution radar chart.

Variables Calibration for Fuzzy Sets

Fuzzy sets require converting metrics to sets and then calibrating them for full members, full non-members, and intersections (or maximum fuzzy points) in the set of interest (42). Qualitative anchor points determine the relationship between continuous variable scores and fuzzy set affiliation. Following Tang and Zhang (43, 44), each variable's 75th percentile, 50th percentile, and 25th percentile were considered fully membership, crossover point, and full non-membership. In this study, the antecedent and outcome variables of the case hospital were calibrated based on the calibration procedure in the fs-QCA, and the qualitative anchor points of the variables are shown in **Table 3**.

Necessary Conditions Analysis

The necessity of an outcome means that the condition must exist when the result occurs. The necessary conditions analysis

TABLE 3 | Three qualitative anchors of each variable.

Variables	Full membership	Crossover point	Full non-membership
BES	0.936	0.920	0.872
CCG	6.532	4.300	3.040
AFA	30,114	14,567	7,829
NoB	1,000	800	692
NDR	2.012	1.848	1.664
CMI	0.92	0.86	0.80
BUR	105.188	98.387	93.774

TABLE 4 | Analysis of necessary conditions.

Antecedent variables	High efficiency		Poor efficiency	
	Consistency	Coverage	Consistency	Coverage
CCG	0.4515	0.5117	0.5659	0.5495
∼CCG	0.6026	0.6183	0.4972	0.4371
AFA	0.4806	0.5279	0.5939	0.5589
∼AFA	0.5984	0.6323	0.4983	0.4511
NoB	0.5009	0.5403	0.5426	0.5014
∼NoB	0.5377	0.5784	0.5026	0.4631
NDR	0.5761	0.6313	0.4768	0.4477
∼NDR	0.4960	0.5253	0.6073	0.5510
CMI	0.6446	0.6829	0.4111	0.3732
∼CMI	0.4084	0.4473	0.6507	0.6107
BUR	0.5411	0.5975	0.5052	0.4780
∼BUR	0.5272	0.5543	0.5746	0.5175

of the outcome variable was first explored in the QCA. As we can see in **Table 4**, the consistency of all antecedent conditions was <0.9, which means that none of the antecedent conditions were necessary to achieve high or low levels of efficiency in county hospitals (42, 45, 46).

Standard Analysis

Based on the calibration results, a standard analysis of the causal conditions arising from the results was performed. A data matrix (truth table) containing 2^k rows was constructed, where k is the number of causal conditions in the analysis. Each row of the matrix is associated with a specific combination of attributes and a high number of cases in this condition. At this stage, the minimum solution frequency was set to 1, and a more restrictive consistency threshold for the solutions was chosen to be 0.8 (42, 47). The consistency threshold was set beyond the 0.75 recommended by Ragin (38). **Tables 5**, **6** show the condition configurations to achieve high and poor efficiency in the county hospitals. The tables describe the relevant parameters for each configuration path, such as raw coverage, unique coverage, and overall solution coverage. According to Ragin and Fiss's explanation, the raw coverage is for the proportion of cases that satisfy this configuration, the unique coverage is the proportion of cases that uniquely satisfy this configuration but not any other configuration, and the overall solution coverage explains so the combined coverage of the configurations (38, 42). In addition, according to the parsimonious and intermediate solutions, the core and peripheral causal conditions are established in **Tables 5**, **6**.

Robustness Test

This study followed the method of Schneider and Wagemann (48) and White et al. (49) by changing consistency levels to test the robustness of the QCA results. When the consistency level was 0.85, the solution results were the same as in **Table 5**. when the consistency level was 0.72, the solution results were as shown in **Table 7**, with one additional configuration and no substantial changes in the main findings, except for minor changes in NoB and NDR, which indicated the relative robustness of the results of this study.

DISCUSSION

With the vigorous promotion of county healthcare reform in China, county-level hospitals have played a vital role in the system of tiered medical services with the treatment of major diseases without leaving the county and rehabilitation at the grassroots level. Although the classical regression method can identify the factors affecting the efficiency of county-level hospitals, it still faces difficulties in the specific practice of hospital management because of the complex internal and external circumstances.

This study provides a configuration perspective for understanding the multiple influences on county hospitals in China. The results of QCA indicate that the paths of high efficiency in county hospitals can be divided into three categories, five paths. We named it Structural Optimization (OP), Capability Enhancement (CE), and Government Support (GS), respectively. The consistency of each path is within the acceptable range (>0.8).

The OP type implies that the role of organizational structure optimization dominates this path (C1, C2, C4), illustrating the importance of optimizing the human resources structure in the efficiency improvement process without government support. As shown in **Table 5**, these three configurations are identical in terms of core conditions (NDR*∼AFA) with second-order equivalence. The C1 condition suggests that regardless of the level of economic development of the county where the hospital is located, in the absence of government funding, the hospital can improve efficiency by increasing the NDR to optimize the human resource structure even in the presence of lower NoB, CMI, and BUR. However, if the hospital expands the NoB, it needs to improve CMI and BUR to obtain efficiency gains (C4). Meanwhile, when the hospital is in a county with a good level of economic development and lack of government support, regardless of BUR, the hospital can likewise improve efficiency by increasing the NDR when there is a low NoB and CMI (C2). It is important to note that a high NDR plays a central role in the efficiency improvement process in all three

TABLE 5 | Configuration of conditions for high efficiency.

Configuration	Solution for high efficiency				
	C1	C2	C3	C4	C5
CCG		●	⊗		⊗
AFA	⊗	⊗	⊗	⊗	●
NoB	⊗	⊗	•	•	⊗
NDR	●	●	⊗	●	⊗
CMI	⊗	⊗	●	•	⊗
BUR	⊗			•	●
Consistency	0.9211	0.8943	0.9414	0.9310	0.9131
Raw Coverage	0.1485	0.1257	0.1703	0.1438	0.0558
Unique Coverage	0.0414	0.0159	0.1083	0.0700	0.0287
Overall Solution Consistency	0.9219				
Overall Solution Coverage	0.4203				

Full black circles and crossed-out circles indicate the presence and the absence of causal conditions, respectively. Large circles (● and ⊗) indicate the core conditions, small circles (• and ⊗) indicate the peripheral conditions and the blank cells represent conditions that do not matter for the solution.

TABLE 6 | Configuration of conditions for poor efficiency.

Configuration	Solution for poor efficiency				
	C1	C2	C3	C4	C5
CCG		⊗	●	⊗	●
AFA	⊗	●	●	⊗	●
NoB	⊗	●	●	●	⊗
NDR	⊗		⊗	⊗	•
CMI	⊗	⊗	⊗	⊗	⊗
BUR	⊗	⊗		•	•
Consistency	0.8592	0.7840	0.8969	0.8032	0.9203
Raw Coverage	0.1096	0.1146	0.1239	0.1238	0.0786
Unique Coverage	0.0749	0.0676	0.0762	0.0675	0.0433
Overall Solution Consistency	0.8463				
Overall Solution Coverage	0.4125				

*The meaning of the symbols in this table has the same meaning as in **Table 5**.*

TABLE 7 | Results of robustness test.

Configuration	Solution for high efficiency					
	C1	C2	C3	C4	C5	C6
CCG				•	⊗	⊗
AFA	⊗		⊗	⊗	⊗	●
NoB	•	•	⊗	⊗	●	⊗
NDR		•	●	●	⊗	⊗
CMI	●	●	⊗	⊗	●	⊗
BUR	●	●	⊗			●
Consistency	0.8401	0.8543	0.9211	0.8943	0.9414	0.9131
Raw Coverage	0.2648	0.2091	0.1485	0.1257	0.1703	0.0558
Unique Coverage	0.0456	0.0637	0.0414	0.0159	0.0414	0.0271
Overall Solution Consistency	0.8450					
Overall Solution Coverage	0.5296					

*The meaning of the symbols in this table have the same meaning as in **Table 5**.*

configurations. This was also confirmed in the study of Cheng et al. (4).

In China, inadequate NDR has been a dilemma for hospitals' development (50). In 2020, the nurse-physician ratio in rural areas in China was 1.02, lower than its city counterpart, 1.27 (51). Based on World Health Statistics 2020 released by WHO, the ratio of nurses (including midwifery personnel) to doctors in China was only 1.34, which falls more minor than that in the United States (5.57), Switzerland (4.08), Japan (5.04), and South Korea (3.09) (52). The number of nurses and nursing quality is directly related to public hospitals' operation efficiency (53). For example, when the number of nursing staff is insufficient and patients lack necessary care, the incidence of postoperative complications and mortality of patients after surgery will increase, increasing the hospital's adverse output and leading to low efficiency. Hence, the administrators should pay attention to the risk of nurse shortage in hospital management. In addition, nursing human resource policies and measures need to be enacted by the government health departments to enhance the nursing capacity of medical institutions.

The CE type indicates that in the context of a lack of economic environment and government support, hospitals need to improve their medical service capacity to obtain efficiency gains. The path of C3 shows that in the absence of a favorable external environment and with low NDR, upgrading the hospital's CMI can receive efficiency progress. Increasing the number of beds is an auxiliary condition. CMI is commonly used to measure the overall severity of diseases treated in hospitals and is an essential indicator of the level of hospital service capacity and one of the determinants of hospital efficiency, as demonstrated in the study using the truncated regression approach by Chowdhury and Zelenyuk (41). Currently, China is carrying out Diagnosis-related Group Prospective Payment System (DRG-PPS) reform within the context of public hospitals, so this pathway provides evidence-based recommendations for improving the efficiency of county-level hospitals under DRG payment. Meanwhile, from the functional orientation of county-level hospitals in the three-tier medical and health service system in rural China, the medical service capacity of county hospitals is also an inevitable requirement in its development to achieve that severe diseases without leaving the county in the goal of tiered medical services.

The GS type refers to the fact that when the level of economic development in the county is located is poor but government support is vital, increasing the bed utilization rate can effectively improve efficiency even if there exists lower NoB, NDR, and CMI (C5). The positive effect of bed utilization on technical efficiency was in line with a study in Canada and Iran (41, 54). The number of beds is an essential physical input resource for hospitals, and its usage can significantly affect the operational efficiency of hospitals. This reminds hospital managers that the utilization of bed resources is more important than the number of beds.

In this study, we also analyzed the grouping paths that generate poor efficiency in hospitals, intending to identify the antecedent conditions that lead to inefficiency and prevent hospitals from falling into it. As shown in **Table 6**, the consistency of all four configurations was acceptable, except for the consistency of C2 (0.7840), which did not meet the requirements of Fiss's study regarding consistency (42). Therefore, C2 was excluded from the solution for poor efficiency. By analyzing the four conditions, three categories, namely Insufficient Capacity (IC), Aggressive Expansion (AE), and Poor Decision-making (PD), were classified that leading to inefficiency in county hospitals.

The IC type indicates that low levels of NDR, CMI, and BUR play a core role in hospital inefficiency regardless of the level of economic development of the county in which they are located, while government support shortage and insufficient scale only play a supporting role (C1). This suggests that the hospital's poor human resource structure and misconduct in healthcare delivery play an essential role in the inefficiency type. This path revealed the pivotal role of poor structural and behavioral factors in the inefficient cluster of hospitals. Therefore, to avoid becoming a case in this configuration, structure and behavior indicators of hospital operation need sustained attention.

The AE type contains two configurations (C3, C4). This type elucidates the shortcomings of aggressive scale expansion exposed in service delivery. The path of the C3 shows that a large-scale increase in the number of beds can lead to inefficiency when the level of economic growth and government support in the county is good and when the NDR and CMI of the hospital are low. And C4 shows that a large beds scale increase also leads to inefficiency when the conditions of the level of economic development and government support in the county are lacking in the case of low NDR and CMI of hospitals. A high BUR assists this process. Consistent with the findings of Pirani, these two configurations present the disadvantages associated with the aggressive expansion of bed numbers in hospitals under different external environments (55). The medical cause of health in China is in a phase of rapid development, and the size of public hospitals is expanding at a high rate, as evidenced by a surge in the number of beds. Many studies have examined the appropriate size for the number of beds in Chinese public hospitals, confirming the inefficiencies that result from excessive scale (3, 4). The present type of configuration shows that under the premise of ignoring organizational construction, a rapid increase in the number of beds could lead to inefficiencies.

The PD type refers to the poor management strategy made by hospital managers under an excellent external environment that leads to hospital inefficiency. C5 shows that a low level of CMI became the core condition of inefficiency under the external environmental conditions with a high level of economic development and government support in the county. Meanwhile, high NDR and BUR became supporting conditions. This indicates that hospital managers lacked attention to medical service capability when facing a favorable external environment and did not realize that the level of medical service is the core competitiveness of the hospital. Therefore, neglecting CMI improvement is not advisable in hospital development, and managers need to note it.

CONCLUSION

This study discusses the factors affecting county-level hospital efficiency from configuration. The results show that these factors influence and interact with each other, and the resulting configuration will lead to the efficient state of healthcare institutions. Therefore, the progress of hospital efficiency results from the joint action of multiple factors, not from the change of a single one. Three configuration types illustrated organizational structure factors with high-level NDR as the core condition that plays a crucial role in improving efficiency. Besides, the service capability factor with low-level CMI as the core condition has played a vital role in declining efficiency. Hence, each hospital needs to improve corresponding performance according to its situation and circumstance. Any measures aimed at efficiency promotion should be discussed within the framework of a case-specific analysis.

STRENGTHS AND LIMITATIONS

Previous research has explored critical factors attributed to hospital efficiency of the net effect of independent variables on efficiency values. But we explored multiple causal relationships that lead to an efficiency state from holistic view. However, this study still has some limitations, such as the limited number of antecedent variables and lack of discussion of the efficiency antecedent configuration between natural years. Future research can start with overcoming the limitations of this study, for example, adopting panel data, including hospitals in different provinces, and discussing the effect of different combinations of antecedent variables on efficiency results in more detail. Besides, comparing the QCA results with the regression model would be an interesting direction.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

GY was responsible for the study design, data analysis, and draft writing. GY, JN, YP, and JY were involved in manuscript revision. HT guided and supervised the research. All authors discussed the results, contributed to the article, and approved the submitted version of the manuscript.

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Healthcare Utilization Under a Comprehensive Public Welfare Program: Evidence From Japan

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The public assistance system in Japan provides detailed and comprehensive livelihood support for low-income families with various needs. As one example, and the beneficiaries of the public welfare program in Japan can receive the same medical treatments as those insured of the universal public health insurance without any financial burdens. This system has greatly contributed to maintaining and improving the health of public assistance beneficiaries but may cause excessive healthcare utilization: moral hazard. This study uses a large sample taken from two nationally representative claim data for public assistance and public health insurance patients to estimate the magnitude of moral hazard effect in basic outpatient utilization. The results of the fixed-effect regression analysis utilizing the concept of pseudo panel data analysis and those of propensity score matching show that the average treatment effect of public assistance assignment on healthcare utilization is significantly positive. Specifically, public assistance assignment increases monthly healthcare expenditure by 17.5 to 22.9 percent and the monthly number of doctor visits by 23.1 to 27.8 percent, respectively. In addition, the average treatment effects on the treated are also significantly positive, suggesting that monthly healthcare expenditure significantly decreases by 22.7 to 25.0 percent and the number of visits by 27.6 to 29.7 percent, respectively, when imposing a copayment on public assistance beneficiaries. However, the estimated price elasticity based on these results is very small, approximately −0.02, indicating that the level of copayment rate has little effect on the intensive margin of outpatient healthcare utilization.

Keywords: moral hazard, public assistance, outpatient, health care utilization, fixed-effect model, propensity score matching (PSM), Japan

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INTRODUCTION

In developed Organization for Economic Cooperation and Development (OECD) countries, the public welfare system mainly provides monetary benefits to low-income families, as a minimum livelihood security, and employment assistance for self-reliance. However, because low-income people are generally more susceptible to disease or lack adequate insurance, they postpone or avoid healthcare for economic reasons (1). In these countries, other public welfare systems provide them with healthcare services, and many empirical studies find that such social systems improve their access to healthcare (2–6) and contribute to improving their health and quality of life (7–11). On the contrary, some studies do not necessarily find such effects (12–14), and thus, the research results remain mixed.

The public assistance (PA) system in Japan (*Seikatsu-Hogo Seido*) provides detailed and comprehensive livelihood support to low-income families with various needs, centering on income

security, employment support, healthcare, long-term care, education, childbirth, funeral expenses, and housing. However, the system, which has existed for more than half a century, has several ongoing problems. First, as detailed in the next section, PA beneficiaries can receive the same medical treatments as those insured by the universal public health insurance (UPHI) without any financial burdens, such as insurance premiums, taxes, or copayments. Low-income people have worse health status and more healthcare needs than others, but it has also been pointed out that excessive healthcare utilization without any contribution to health leads to excessive healthcare expenditure, that is, moral hazard (15). In addition, because the share of healthcare costs to total PA expenditure has been the largest soon after the beginning of the system in 1950 (**Figure 1**), the Government Revitalization Unit has suggested that copayments for healthcare costs should be introduced to PA beneficiaries (16). On the contrary, the introduction of copayments may lead to a negative side effect of health deterioration by restraining the beneficiaries from visiting medical institutions. Therefore, it is important to examine how the PA system affects low-income people's healthcare utilization, but currently, there are only a few studies due to data unavailability. Second, because the PA system provides benefits within a lump-sum budget, it is difficult to operate a welfare system that provides comprehensive benefits in a severe and inflexible budget condition, such as that of Japan. In fact, the Japanese government has reduced the levels of livelihood benefits, the core benefit of the PA system, and additional benefits for certain family types, which has significantly influenced beneficiary families' consumption levels (17). Because only a few countries such as Finland, South Korea, Slovakia, and Sweden have a public welfare system providing comprehensive benefits (18), the empirical evidence for policy evaluation is decisively inadequate. Third, a PA system is one of the welfare policies, which also includes healthcare system for low-income population. In this regard, there is a potential concern that public officers in Japan who do not necessarily have medical knowledge may not be able to assess the PA beneficiaries' healthcare utilization correctly even if they attempt to improve the efficiency of healthcare system for the beneficiaries and to control their total healthcare expenditures.

In view of the above, this article uses large-scale individual data taken from the Japanese government's surveys to examine how outpatient healthcare utilization differs among PA beneficiaries and UPHI patients. Although several previous empirical studies have investigated that healthcare utilization in the Japanese PA system, to the best of our knowledge, no studies have focused on the basic outpatient healthcare services for PA beneficiaries. Therefore, the results of this study on how copayment level affects healthcare utilization among low-income people could provide useful policy implications for Japan's future PA system.

In addition, one of the major advantages of focusing on the Japanese PA system is that I can effectively control for some unobserved heterogeneity. Specifically, there is no local institutional heterogeneity in the Japanese PA system, unlike that observed, for example, in the U.S. Medicaid system. In addition, PA patients receive exactly the same medical treatment as public health insurance patients, and physicians, irrespective of their skill and experience, receive the same revenue by providing treatments to both PA and UPHI patients under the uniform national fee schedule. Moreover, there is no need to consider endogeneity between insurance choice and healthcare utilization, as in other countries, because the Japanese UPHI system is both universal and compulsory (19). These circumstances therefore remove common biases, which enable us to obtain consistent treatment effects.

The results from the fixed-effect (FE) estimation using the concept of pseudo panel data analysis and those of using propensity score matching (PSM) show that healthcare utilization by PA beneficiaries with no financial burden is significantly greater than that of those of UPHI patients, ceteris paribus. However, price elasticity is very low, approximately −0.02.

The rest of this paper is organized as follows: The next section presents our policy background and a discussion of our data and statistical models. Section Results provides descriptive statistics of the data, the main empirical results, and our robustness checks. I discuss our results and summarize our limitations in the last section.

MATERIALS AND METHODS

Policy Backgrounds

The current PA system, based on the *Public Assistance Act* of 1950, is one of the oldest welfare programs in postwar Japan. This program provides comprehensive benefits such as employment support, healthcare, long-term care, education, childbirth, funeral expenses, and housing with income security at its core, to applicants who pass a means test administered by their prefectural or municipal government[1] in order to maintain the minimum standards for wholesome and cultured living. All funding comes from taxes, with the central government contributing 75% and each local government 25%. There are some institutional differences in healthcare use between the PA and UPHI systems (**Table 1**). First, UPHI members contribute insurance premiums and taxes in advance, as well as copayments at a medical institution. In principle, PA patients can receive the same medical treatments without these financial burdens. On the contrary, the PA Act imposes access regulations on PA patients, requiring them to visit designated medical institutions with monthly healthcare and medicine vouchers that are issued by their local welfare office. This seems to contrast with the Japanese free access system for UPHI members, but in fact, there is little difference in terms of access, as PA beneficiaries receive their cash benefits and vouchers once a month at their welfare office, and approximately 90 percent of medical institutions accept both PA and UPHI patients. In addition, as medical fees for PA patients are reimbursed on the basis of the UPHI fee system, medical suppliers earn the same profit regardless of the type of patient.

[1]In general, urban inhabitants submit their PA applications to a municipal welfare office, whereas those in towns and villages submit theirs to a prefectural welfare office.

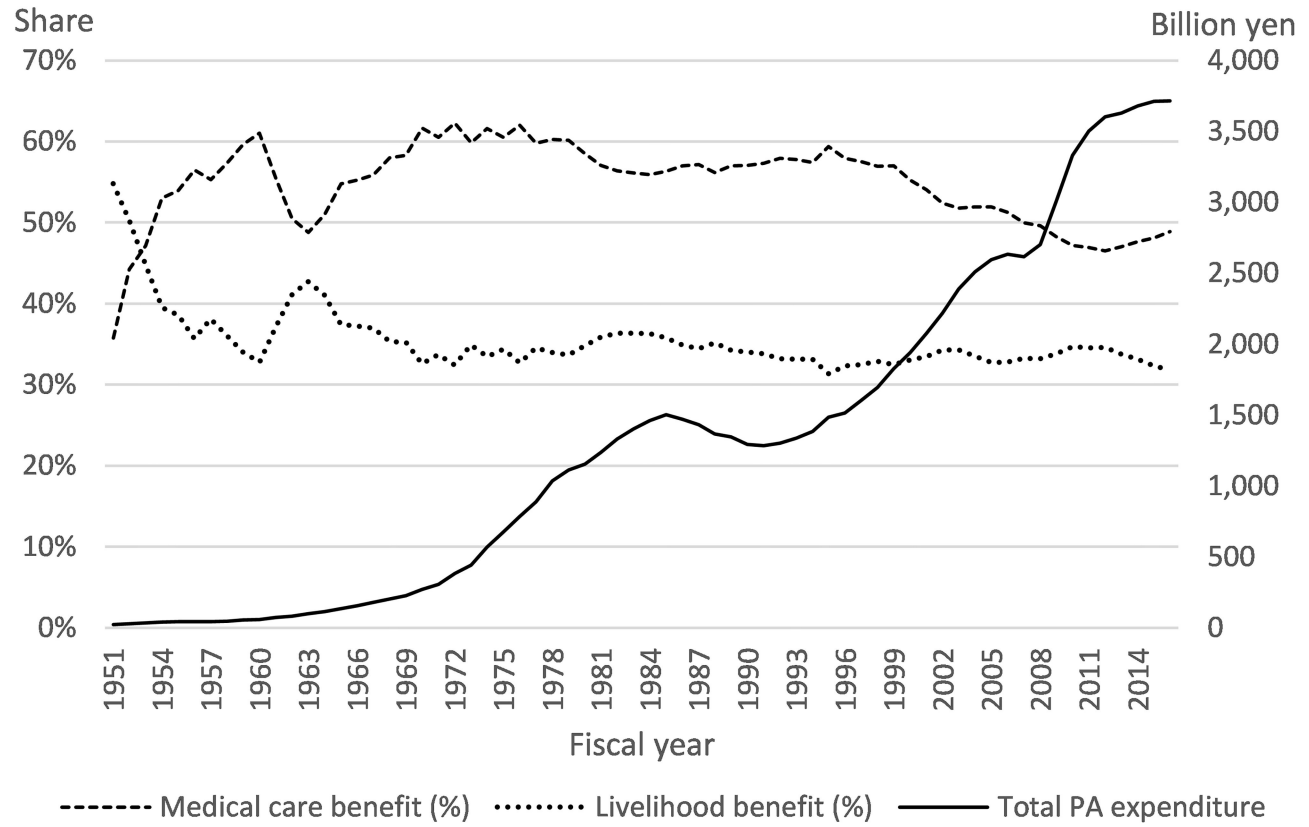

FIGURE 1 | Trends in public assistance expenditures and shares of medical and livelihood benefits. Source from the *Annual Report on Social Security Statistics*, the General Administrative Agency of the Cabinet (1959–2000), and National Institute of Population and Social Security Research (2001–2016).

This means that the risk selection problem is unlikely to occur in Japan.

Some Japanese studies find that this PA system has greatly contributed to maintaining and improving the health of PA beneficiaries. For example, Kumagai (20) uses prefectural data and finds that the PA system has basically contributed to improving the health of PA beneficiaries at the macro-level. In addition, Hayashi (21) uses municipal data and a quantile regression model and finds that local allocation grant subsidies effectively respond to changing healthcare needs in rural areas. However, other studies note that the current PA system for more than half a century has certain flaws and some inefficiencies. Theoretically, exemption from copayment increases healthcare utilization by PA beneficiaries. This income effect is broadly confirmed in aggregated outpatient services (22), hospitalizations (23), public long-term care services (24), and dental services (25). One interpretation is that low-income people generally have a low socioeconomic status (SES), which is strongly correlated with low health conditions and increased healthcare use. However, the absence of any financial burdens may also cause excessive healthcare use, that is, moral hazard (15), resulting in a social loss of excessive healthcare expenses. For example, Fu and Noguchi (24) use individual claim data from long-term care and examine its moral hazard effect; they find that PA beneficiaries have significantly higher costs and days of care than persons with public long-term care insurance. This can be interpreted as the presence of moral hazard, but its effect is very small because the associated price elasticity is only approximately −0.1.

Data

The main data sources in this study are two nationally representative claim records from 2003 to 2007, the *Fact-finding Survey on Medical Assistance* for PA patients and the *Survey of Medical Care Activities in Public Health Insurance* for UPHI patients. These surveys are conducted annually by the Ministry of Health, Labor and Welfare (MHLW) in Japan to obtain basic information for system administration. Both surveys are repeated cross-sectional surveys consisting of randomly selected medical claims (not patient level[2]). This analysis makes use of a number of common items contained in both surveys, specifically, the patient gender, age, prefecture of residence, monthly healthcare expenditure, actual number of visits of medical care, major diseases according to the International

[2]In other words, the subject of this analysis is not patient unit. For example, if a patient visits more than one medical institution in a month, the system will generate medical claims for the number of institutions, and thus the same individual may be counted as a different individual. Unfortunately, due to data limitations, it is impossible to compile such cases into a single individual unit.

TABLE 1 | Institutional differences in healthcare use between the public assistance and universal public health insurance systems in Japan.

	Public assistance system	Public health insurance in 2007
Financial source	Public funds (100%)	Premiums (49.0%), public funds (36.8%), and copayments and others (14.1%)
Copayment rate	0%	10% for those aged 70 and over[(a)], 20% for those aged under 3, and 30% for all other enrollees[(b)].
Patient access control	Visiting designated medical institutions by the *Public Assistance Act* and bringing monthly medical and medicine vouchers issued by the local welfare office.	None (free-access system)
Coverage	As for public health insurance	In-kind (90%) and cash benefit (10%)
Medical supply	Designated medical facilities under the *Public Assistance Act*	Designated medical facilities under the *Health Insurance Act* and the *National Health Insurance Act*.
Medical fee schedule	As for public health insurance	Nationally uniform medical fee schedule
Review of claims	Municipalities or local welfare offices	The Social Insurance Medical Fee Payment Foundation and the Federation of National Health Insurance Organizations.
Population share (in 2007)	1.21%	98.79% (universal health insurance)

[(a)]30% for the persons aged 75 with more than a certain income. [(b)]The high-cost medical treatment system subsidizes patient's copayments if the monthly copayment exceeds a certain level (See section Policy Backgrounds).

Statistical Classification of Diseases (ICD), and type of medical institution (hospital or clinic[3]).

Our sample contains only outpatient claim data for May to control for seasonal effects on utilization, while former claims are available from March to May (latter claims are available for May only). In addition, our sample does not include 50,762 claims that would be subject to the *high-cost medical care benefit* system (*Kogaku Ryoyo-hi Seido*). This system subsidizes patient copayments if the monthly copayment exceeds 267,000 yen (44,000 yen for those covered by the Elderly Health Care System from 1983 to 2008); the copayment rate for healthcare expenses above that amount falls to 1%. However, as such patients are exceptional cases, for example, those with a severe disease or requiring long-term treatment, the level of copayment has little impact on healthcare utilization.

Using claim data entails that I focus on the intensive margin of healthcare utilization. Various empirical health economics studies have shown that copayment level largely influences the extensive margin, choice of a doctor visit, but low-income people are more price elastic or have worse health conditions. In the former case, an increase in copayment rate would cause other negative side effects, such as health deterioration, by restraining PA beneficiaries from visiting medical institutions. There is thus a clear significance in investigating such impacts on the intensive margin of low-income populations' healthcare utilization.

Statistical Model

The empirical equation in this study is specified as follows:

$$\ln Y_{ijt} = \beta_0 + \beta_{PA} PA_{ijt} + \mathbf{x}_{ijt}\beta_x + \mathbf{z}_{jt}\beta_z + \mu_i + \lambda_j + \tau_t + u_{ijt} \quad (1)$$

Y_{ijt} is monthly healthcare utilization, which contains healthcare expenditure adjusted for 2005 prices, and the number of a doctor visit for claim i issued in prefecture j at year t. PA is a dummy variable that equals one if a claim is for a PA beneficiary and zero otherwise. Significantly positive $\hat{\beta}_{PA}$ means that a PA patient uses more healthcare than a UPHI patient.

However, our interpretation of a significantly positive $\hat{\beta}_{PA}$ should be noted. First, this may reflect not only the effect of moral hazard due to the exemption from copayment but also the inherently poor health conditions of a low-income PA beneficiary. This means that simply estimating the value of $\hat{\beta}_{PA}$ as the moral hazard effect may overestimate its scale. To address this issue, I add a fixed effect μ_i to Equation [1] to distinguish these causal effects. In other words, because attributes, such as low SESs and the poor health of low-income people, can be interpreted as individual fixed effects in a panel data model, $\hat{\beta}_{PA}$ can be interpreted as the effect of excessive utilization due to moral hazard by adding a fixed-effect term to the empirical equation. However, because the data used in this study are repeated cross-sectional data, the model cannot strictly consider an individual-level fixed effect. Fortunately, because the surveys are nationally representative random sampling surveys, conducted every year, the average characteristics of the samples are similar from year to year (see **Appendix 1**). Based on these sample characteristics and a concept of pseudo panel data analysis (26), I use the mean of each specific group's healthcare utilization as a proxy for a fixed effect. Specifically, I use the one-year lagged mean healthcare expenses by attributes (PA beneficiary, gender, age, and prefectures), $\overline{\mu}_{it-1}$, as the proxy for the fixed-effect term.

Another problem with interpreting $\hat{\beta}_{PA}$ is an endogenous problem due to institutional PA assignments. As PA assignment is not random but based on the result of a means test by a local government, Suzuki and Zhou (27) and Hayashi (28) find that PA ratios vary among local governments, depending on fiscal status and local socioeconomic circumstances. This means that the estimation results from an equation without local characteristics

[3]Under the Japanese Medical Care Act, a *hospital* is a medical institution with more than 20 beds.

are positively biased because PA_{ijt} and error term u_{ijt} are correlated. To address this problem, Yuda (23) uses instrumental variable (IV) estimation, but these results may not be consistent because this identification relies on the non-linear specification in the first-stage regression. In this analysis, I add several local (prefectural) characteristics, $\mathbf{z}_{jt}$, as confounding factors to Equation [1]. Specifically, these include financial capability index (FCI), one-year lagged PA ratio, physician density, and unemployment rate. FCI is an index that indicates the fiscal condition of local governments. It is the average of the ratio of standard fiscal revenue to standard fiscal need demand over the past 3 years (29), and a higher value indicates greater reserved financial resources. Although local governments, which are the main implementers of the PA system, bear a financial burden of the system, their actual share is less than the statutory share (25 percent) because most of the local burden is subsidized by the local allocation grant (28). Nevertheless, Suzuki and Zhou (27) find that municipalities with financial difficulty are stricter when accepting applications to the PA system and their PA ratios are significantly lower. In the empirical model, I use prefectural FCI and the ratio of municipalities within a prefecture whose FCI is <0.5 because prefectures are common geographical information that is available in the surveys. In addition, the lagged PA ratio is a proxy for a fixed cost of PA administration in each prefecture, which is also related to the above. Physician density (the number of physicians per 100,000 people) is a proxy for local healthcare resources, represents the accessibility of healthcare services, and is considered to have a positive impact on healthcare utilization. However, the financial situation of local governments affects the development of the public healthcare supply system (human production factors, such as the number of doctors and nurses, and physical production factors, such as medical equipment) in a region (27), which ultimately affects the healthcare utilization rate and health status of local residents. Therefore, it may be a confounding factor in the present analysis. Finally, unemployment rate is a proxy for economic fluctuation. PA ratio generally increases during economic downturns, and Suzuki and Zhou (27) find that a local unemployment rate significantly increases the PA ratio. On the contrary, the business cycle has been found to significantly affect population health and healthcare utilization in several developed countries (30, 31). This means that economic fluctuation is a confounding factor on both PA ratio and healthcare utilization.

$\mathbf{x}_{ijt}$ contains the characteristics of patients and suppliers. Patient characteristics are dummy variables of gender (female), 98 age categories, and ICD codes for 119 main diseases. Supplier characteristic is a hospital dummy variable (see footnote 4), which captures differences in the number and quality of medical devices, as well as in the number of medical staff. λ_j is a prefectural fixed effect, which captures the differences in rigor of medical claim reviews (32) and other unobserved heterogeneities among prefectures, and τ_t is yearly fixed effect that captures the effect of biennial medical fee revisions and of comprehensive annual changes in macroeconomic and other socioeconomic circumstances. u_{ijt} is an error term, and I estimate clustering robust standard errors that allow serial correlation of subjects within prefectures (33).

As Equation [1] is compliant with a FE model, $\hat{\beta}_{PA}$ can be interpreted as the average treatment effect (ATE) of zero price on healthcare utilization. However, the estimated ATE may still include potential biases because the dataset does not include household attributes that determine PA eligibility, such as household income and assets, family structure, and working status. Fu and Noguchi (24), facing the same analytic problem, use PSM to balance the observable heterogeneity in PA eligibility. This study follows their strategy to confirm the robustness of our ATE estimation. The ATE estimated by PSM is $ATE = E\left[ATE_{p(X_i)}\right]$, where $ATE_{p(X_i)} = E\left[Y_i|\, MA_i = 1,\ p\,(X_i)\right] - E\left[MA_i = 0,\ p\,(X_i)\right]$ and $p\,(X_i)$ is the estimated propensity score (see **Appendix 2**). The PSM-ATE is the difference between outcomes conditioned on propensity score of treatment and control groups, and it reveals the hypothetical gain from treatment to a randomly selected member of the population when the treatment has universal applicability (34, 35). In addition, comparing this PSM-ATE with $\hat{\beta}_{PA}$ obtained from estimating Equation [1] can show how serious potential bias is. Another great advantage of applying PSM is to facilitate an estimation of the average treatment effect on the treated (ATT), defined as $ATT = E\left[ATE_{p(X_i)}|\, MA_i = 1\right]$. The PSM-ATT can be obtained by matching an observation in the treatment group to that with a similar propensity score in the control group, and it reveals the average gain from treatment for the treated (34, 35). Specifically, the ATT in this paper can be interrupted as the difference between healthcare utilization at zero price and counterfactual utilization at a 10 percent copayment rate. In addition, by employing PSM, I impose a common support condition and apply one-to-one nearest neighborhood matching (1:1 NNM) within a caliper of 0.001 of propensity score. Once a UPHI claim is matched, it is therefore excluded from the sample (i.e., NNM without replacement), but I further apply the 1:1 NNM with replacement and one-to-five (1:5) NNM with replacement for our robustness checks.

RESULTS

Descriptive Statistics

Table 2 presents the descriptive statistics and the results of our mean comparison tests. For PA claims, monthly healthcare expenditure and the number of doctor visits are 31.3 percent (3,357 yen) and 40.4 percent (0.7 visits) higher than those of UPHI, respectively. These trends are consistent with the RAND health insurance experiment (HIE) (7), where a higher copayment rate is associated with lower utilization. In addition, the mean age of PA claims is 1.2 years older, but the difference in the proportion of females is approximately zero. In terms of the distribution of major diseases, compared to UPHI patients, PA persons have more musculoskeletal and connective tissue diseases (4.7 percent points), more endocrine, nutritional, and metabolic diseases (4.0 pp), more cardiovascular diseases (3.1 pp), more digestive diseases (2.7 pp), fewer genitourinary diseases (6.3 pp), fewer mental and behavioral disorders (4.1 pp), and fewer diseases of the skin and subcutaneous tissue (3.4 pp). PA patients visit a hospital 16.1 percent more often, and their lagged

TABLE 2 | Descriptive statistics and mean comparison tests.

Sample	All		PA patients		UPHI patients		Mean difference test	
Variables	**Mean**	**Std.Dvi**	**Mean**	**Std.Dvi**	**Mean**	**Std.Dvi**	**Difference**	**Std.Err**
Dependent variables								
Monthly health care expenditure (thousand yen)	11.243	13.050	14.083	16.707	10.726	12.196	3.357**	(0.034)
Monthly number of doctor visits	1.925	2.176	2.545	3.112	1.812	1.937	0.732**	(0.006)
Individual attributes								
Public assistance (=1)	0.154	0.361	1.000	0.000	0.000	0.000		
Female (=1)	0.587	0.492	0.581	0.493	0.588	0.492	−0.007**	(0.001)
Age	57.757	23.665	58.846	20.041	57.559	24.261	1.286**	(0.044)
Lagged mean MHCE (fixed effect)	16.964	13.737	17.823	18.539	16.808	12.663	1.015**	(0.038)
Main disease‡								
Certain infectious and parasitic diseases (= 1)	0.043	0.203	0.037	0.188	0.044	0.206	−0.008**	(0.000)
Neoplasms (= 1)	0.039	0.194	0.032	0.177	0.040	0.197	−0.008**	(0.000)
Diseases of the blood and blood-forming organs and certain disorders involving the immune mechanism (= 1)	0.003	0.056	0.003	0.051	0.003	0.057	−0.001**	(0.000)
Endocrine, nutritional and metabolic diseases (= 1)	0.077	0.266	0.111	0.314	0.071	0.256	0.040**	(0.001)
Mental and behavioral disorders (= 1)	0.092	0.290	0.058	0.234	0.099	0.298	−0.041**	(0.001)
Diseases of the nervous system (= 1)	0.026	0.160	0.029	0.168	0.026	0.158	0.003**	(0.000)
Diseases of the eye and adnexa (= 1)	0.084	0.278	0.091	0.288	0.083	0.276	0.008**	(0.001)
Diseases of the ear and mastoid process (= 1)	0.015	0.122	0.016	0.126	0.015	0.122	0.001**	(0.000)
Diseases of the circulatory system (= 1)	0.185	0.388	0.211	0.408	0.180	0.384	0.031**	(0.001)
Diseases of the respiratory system (= 1)	0.102	0.303	0.101	0.301	0.103	0.303	−0.002**	(0.001)
Diseases of the digestive system (= 1)	0.052	0.222	0.074	0.263	0.048	0.213	0.027**	(0.001)
Diseases of the skin and subcutaneous tissue (= 1)	0.074	0.262	0.045	0.208	0.080	0.271	−0.034**	(0.000)
Diseases of the musculoskeletal system and connective tissue (= 1)	0.098	0.298	0.138	0.345	0.091	0.288	0.047**	(0.001)
Diseases of the genitourinary system (= 1)	0.081	0.273	0.028	0.165	0.091	0.288	−0.063**	(0.000)
Pregnancy, childbirth and the puerperium (= 1)	0.003	0.053	0.000	0.019	0.003	0.057	−0.003**	(0.000)
Certain conditions originating in the perinatal period (= 1)	0.000	0.017	0.000	0.012	0.000	0.017	0.000**	(0.000)
Congenital malformations, deformations and chromosomal abnormalities (= 1)	0.002	0.043	0.002	0.040	0.002	0.044	0.000**	(0.000)
Symptoms, signs and abnormal clinical and laboratory findings, not Elsewhere classified (=1)	0.013	0.113	0.012	0.108	0.013	0.114	−0.001**	(0.000)
Injury, poisoning and certain other consequences of external causes (= 1)	0.009	0.096	0.012	0.107	0.009	0.094	0.003**	(0.000)
Medical supply								
Hospital (=1)	0.321	0.467	0.457	0.498	0.296	0.457	0.161**	(0.001)
Prefectural macro conditions§								
Prefectural financial capability index[(a)]	0.573	0.263	0.610	0.276	0.566	0.260	0.044**	(0.001)
Low FCI municipality ratio[(a)]	0.437	0.309	0.416	0.324	0.441	0.306	−0.025**	(0.001)
Lagged prefectural PA ratio[(b)]	0.011	0.006	0.014	0.006	0.011	0.006	0.003**	(0.000)
Physician density (per 100,000 persons)[(c)]	207.870	38.321	217.626	37.621	206.094	38.179	11.531**	(0.080)
Unemployment rate (%)[(d)]	4.782	1.131	5.110	1.118	4.723	1.123	0.388**	(0.002)
Observations	1,698,857		261,546		1,437,311			

***represents statistical significance at the 1 percent level.*

‡In the empirical analyses, 119 middle-classified main illnesses according to the ICD-10 are used, and the reference group is the disease described as "symptoms, signs, and abnormal clinical and laboratory findings, not classified elsewhere."

§Source of the prefectural aggregated variables are as follows: [(a)]Annual Statistical Report on Local Government Finance, Ministry of Internal Affairs and Communications, [(b)]Survey on Local Public Finance Conditions, Ministry of Internal Affairs and Communications, [(c)]Survey of Physicians, Dentists and Pharmacists, Ministry of Health, Labor, and Welfare, and [(d)]Labor Force Survey, Statistics Bureau, Ministry of Internal Affairs and Communications.

mean healthcare expenses are 6.0 percent (1,015 yen) higher than those of UPHI.

Main Results

Table 3 presents the estimation results of the effect of PA assignment on healthcare utilization and shows that PA assignment significantly increases Y, regardless of the model. This indicates that PA patients use more healthcare than those of UPHI, ceteris paribus. Models (i) and (ii) are the ATEs by a FE model of Equation [1], indicating that PA assignment significantly increases monthly healthcare expenditure by 17.5 percent ($= \exp\left(\hat{\beta}_{PA}\right) - 1$) and the number of doctor visits by 23.1 to 23.2 percent, respectively. Models (iii) to (viii) are the PSM estimation results, and ATEs and ATTs are quite similar in the matched samples. As explained in **Appendix 3**, all matched samples are more identical than the raw sample, and the mean and median biases of the 1:5 NNM are the smallest. Models (iii) to (v) are ATE results, indicating slightly larger effects on healthcare expenditure (19.1 to 22.9 percent) and a variation in the number of visits (22.0 to 27.8 percent). On the contrary, ATT estimates of Models (vi) to (viii) are larger than ATEs and suggest that monthly healthcare expenditure significantly decreases by 22.7 to 25.0 percent and the number of visits by 27.6 to 29.7 percent, respectively, when imposing a copayment on PA beneficiaries. Because the share of the amount of patients' copayment to total healthcare expenses during the study period is approximately 14 percent (36), price elasticity, based on our ATT estimates, ranges from −0.018 to −0.016, which is approximately one tenth of the gold standard estimate of the RAND HIE of −0.20 (7). These estimates suggest that a zero copayment rate for low-income people would have little moral hazard effect on the intensive margin of their healthcare utilization.

TABLE 3 | Effect of PA assignment on healthcare utilization.

Dependent variable	ln (HCE)	ln (Visits)	*N*
ATE			
(i) FE (with **x**)	0.161**	0.208**	1,698,857
	(0.013)	(0.007)	
(ii) FE (with **x** and **z**)	0.161**	0.209**	1,698,857
	(0.013)	(0.007)	
(iii) PSM (1:1, noreplacement)	0.206**	0.245**	507,163
	(0.002)	(0.002)	
(iv) PSM (1:1, replacement)	0.174**	0.199**	1,698,263
	(0.005)	(0.003)	
(v) PSM (1:5, replacement)	0.183**	0.203**	1,698,263
	(0.004)	(0.002)	
ATT			
(vi) PSM (1:1, noreplacement)	0.206**	0.244**	507,163
	(0.002)	(0.002)	
(vii) PSM (1:1, replacement)	0.223**	0.260**	1,698,263
	(0.005)	(0.003)	
(viii) PSM (1:5, replacement)	0.204**	0.243**	1,698,263
	(0.003)	(0.002)	

*HCE and Visits stand for monthly healthcare expenditure adjusted for 2005 price and the numbers of a doctor visit, respectively. **represents statistical significance at the 1 percent level. Clustering robust standard errors allowing for correlated residuals within prefectures are in parentheses.*

Robustness Checks: Sub-sample Analyses

In this sub-section, I check the robustness of our results by attempting the same analysis using several subsamples and infer what the previous main results reflect.

Different Copayment Rates in the UPHI

In the Japanese UPHI, the copayment rate varies according to the age of the insured. The specific copayment rates during the study period are 10 percent for those aged 70 and over and for bedridden patients aged 65 and over, 20 percent for preschool children, and 30 percent for other insured parties. Figure S1 in **Appendix 4** plots the means of Y by age and shows that these trends change after the ages of 18, 60, and 70. Regarding those aged 18 and under, although the statutory copayment rate ranges from 20 to 30 percent, their actual copayment rate is much lower or close to zero because their parents sustain them and because the prefectural and municipal governments subsidize their copayments (37). In addition, the statutory copayment rate for those aged from 19 to 69 is 30 percent, but for those aged 60 and over, the patterns of healthcare utilization may change; the major retirement age during the study period is 60[4], and retirement increases opportunity costs (38–41). For those persons aged 70 and over, the copayment rate decreases to 10 percent (the Elderly Health Care System; EHCS), which changes their trends in healthcare utilization (42–44). In this subsection, I attempt the same analysis using four age groups to estimate how a difference in copayment rates affects healthcare utilization. In particular, the ATT estimates clearly show that healthcare utilization increases among PA patients when their copayment rate changes from zero to 10 or 30 percent.

Table 4 summarizes the estimation results of ATEs and ATTs and shows that PA assignment significantly increases Y in all models. For those aged 18 and under, there are few differences among any of the methods, and the ATT indicates that the monthly healthcare expenditure and number of visits for PA patients are 4.0 to 6.3 percent and 6.6 to 6.8 percent higher, respectively. Although these estimates are smaller than those of the main results (**Table 3**) and of the other groups, the differences in utilization are not considered a result of moral hazard but of the inherently poor health conditions of low-income PA patients because the actual copayment rates among both groups in this age range are almost zero. On the contrary, I can confirm that the larger the differences in the groups' copayment rates are, the larger the differences in their healthcare utilization. Specifically, Models (iv) and (viii) are the results for EHCS patients, and

[4] *The Survey on Employment Conditions of Elderly Persons*, conducted every four years by the MHLW, reports that 91.1 percent of companies adopted a mandatory retirement age of 60 in 2004 and 85.2 percent in 2008.

TABLE 4 | Effect of PA assignment on healthcare utilization by age groups.

Dependent variable	ln (HCE)				ln (Visits)			
Sample	(i) Under 18	(ii) Aged 19 to 60	(iii) Over 61 (non EHS)	(iv) Over 61 (EHS)	(i) Under 18	(ii) Aged 19 to 60	(iii) Over 61 (non EHS)	(iv) Over 61 (EHS)
Mean difference	0.044**	0.240**	0.191**	0.113**	0.028**	0.261**	0.243**	0.178**
	(0.005)	(0.003)	(0.004)	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)
N	165,129	577,512	309,466	646,750	165,129	577,512	309,466	646,750
ATE								
(i) FE (with **x**)	0.057**	0.182**	0.184**	0.115**	0.047**	0.246**	0.244**	0.168**
	(0.015)	(0.017)	(0.016)	(0.010)	(0.006)	(0.007)	(0.011)	(0.008)
N	165,129	577,512	309,466	646,750	165,129	577,512	309,466	646,750
(ii) FE (with **x** and **z**)	0.057**	0.182**	0.184**	0.115**	0.047**	0.246**	0.244**	0.168**
	(0.015)	(0.017)	(0.016)	(0.010)	(0.006)	(0.007)	(0.011)	(0.008)
N	165,129	577,512	309,466	646,750	165,129	577,512	309,466	646,750
(iii) PSM (1:1, noreplacement)	0.056**	0.223**	0.220**	0.175**	0.065**	0.268**	0.266**	0.204**
	(0.006)	(0.004)	(0.004)	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)
N	38,881	173,690	159,767	126,360	38,881	173,690	159,767	126,360
(iv) PSM (1:1, replacement)	0.059**	0.214**	0.199**	0.118**	0.064**	0.236**	0.244**	0.166**
	(0.017)	(0.009)	(0.008)	(0.008)	(0.014)	(0.006)	(0.005)	(0.006)
N	164,011	575,611	307,369	646,331	164,011	575,611	307,369	646,331
(v) PSM (1:5, replacement)	0.055**	0.215**	0.211**	0.130**	0.062**	0.233**	0.248**	0.170**
	(0.017)	(0.008)	(0.006)	(0.006)	(0.012)	(0.005)	(0.004)	(0.004)
N	164,011	575,611	307,369	646,331	164,011	575,611	307,369	646,331
ATT								
(vi) PSM (1:1, noreplacement)	0.056**	0.222**	0.221**	0.174**	0.064**	0.267**	0.266**	0.203**
	(0.006)	(0.004)	(0.004)	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)
N	38,881	173,690	159,767	126,360	38,881	173,690	159,767	126,360
(vii) PSM (1:1, replacement)	0.040**	0.245**	0.242**	0.208**	0.065**	0.277**	0.291**	0.227**
	(0.012)	(0.007)	(0.010)	(0.008)	(0.008)	(0.004)	(0.006)	(0.005)
N	164,011	575,611	307,369	646,331	164,011	575,611	307,369	646,331
(viii) PSM (1:5, replacement)	0.061**	0.217**	0.222**	0.174**	0.066**	0.265**	0.270**	0.201**
	(0.008)	(0.005)	(0.006)	(0.006)	(0.005)	(0.003)	(0.004)	(0.004)
N	164,011	575,611	307,369	646,331	164,011	575,611	307,369	646,331

*HCE and Visits stand for monthly healthcare expenditure adjusted for 2005 price and the number of a doctor visit, respectively. **represents statistical significance at the 1 percent level. Clustering robust standard errors allowing for correlated residuals within prefectures are in parentheses.*

their ATT estimates indicate that an increase in the copayment rate from zero to 10 percent results in an 18.9 to 23.2 percent decrease in monthly healthcare expenditure and a 22.2 to 25.4 percent decrease in the number of visits. Moreover, the ATT estimates in Models (ii), (iii), (vi), and (vii) indicate that an increase in the copayment rate from zero to 30 percent results in a 24.3 to 27.8 percent decrease in monthly healthcare expenditure and a 30.3 to 33.8 percent decrease in the number of visits. However, because the price elasticities still remain low, ranging from −0.023 to −0.008, the moral hazard effect is very small among all age groups.

Types of Medical Institutions

As mentioned in Section Policy Backgrounds, because the copayment rate for PA beneficiaries is zero and their free access to medical institutions is practically allowed, their preference of medical treatments should be examined to understand their excessive healthcare utilization. For example, some PA beneficiaries may choose a hospital with substantial amounts of large and expensive medical equipment so that they can receive more valuable treatments for free, but other beneficiaries may choose a clinic that is easy to access. On the contrary, in Japan, approximately 75 percent of physicians work for a hospital and earn a fixed salary irrespective of their workloads and outcomes, while the remaining 25 percent work in their own clinic, and their income basically depends on the number of patients. Therefore, doctors in clinics may have a greater financial incentive to overprovide medical services than those in hospitals (45). In this sub-section, I use these two subsamples to examine how the characteristics of medical suppliers affect PA patients' preferences for healthcare utilization.

Table 5 summarizes the estimation results of ATEs and ATTs and shows that PA assignment significantly increases *Y* in all models, but the effect on Y in clinics is larger than in hospitals.

TABLE 5 | Effect of PA assignment on healthcare utilization by types of medical institutions.

Dependent variable	ln (HCE)		ln (Visits)	
Sample	**(i) Clinic**	**(ii) Hospital**	**(i) Clinic**	**(ii) Hospital**
Mean difference	0.284**	0.080**	0.296**	0.162**
	(0.002)	(0.003)	(0.002)	(0.002)
N	1,153,460	545,397	1,153,460	545,397
ATE				
(i) FE (with **x**)	0.220**	0.081**	0.242**	0.165**
	(0.011)	(0.019)	(0.008)	(0.007)
N	1,153,460	545,397	1,153,460	545,397
(ii) FE (with **x** and **z**)	0.220**	0.081**	0.242**	0.164**
	(0.011)	(0.018)	(0.008)	(0.007)
N	1,153,460	545,397	1,153,460	545,397
(iii) PSM (1:1, noreplacement)	0.286**	0.100**	0.281**	0.178**
	(0.003)	(0.004)	(0.002)	(0.002)
N	269,130	231,216	269,130	231,216
(iv) PSM (1:1, replacement)	0.243**	0.077**	0.240**	0.157**
	(0.006)	(0.007)	(0.004)	(0.004)
N	1,151,986	544,872	1,151,986	544,872
(v) PSM (1:5, replacement)	0.246**	0.066**	0.239**	0.155**
	(0.005)	(0.006)	(0.003)	(0.003)
N	1,151,986	544,872	1,151,986	544,872
ATT				
(vi) PSM (1:1, noreplacement)	0.286**	0.099**	0.281**	0.177**
	(0.003)	(0.004)	(0.002)	(0.002)
N	269,130	231,216	269,130	231,216
(vii) PSM (1:1, replacement)	0.303**	0.126**	0.296**	0.182**
	(0.006)	(0.008)	(0.004)	(0.004)
N	1,151,986	544,872	1,151,986	544,872
(viii) PSM (1:5, replacement)	0.291**	0.094**	0.283**	0.174**
	(0.005)	(0.005)	(0.003)	(0.003)
N	1,151,986	544,872	1,151,986	544,872

*HCE and Visits stand for monthly healthcare expenditure adjusted for 2005 price and the number of a doctor visit, respectively. **represents statistical significance at the 1 percent level. Clustering robust standard errors allowing for correlated residuals within prefectures are in parentheses.*
Hsealth Care Utilization under a Comprehensive Public Welfare Program: Evidence from Japan.

Specifically, ATTs on monthly healthcare expenditure in hospitals range from 9.8 to 13.5 percent, but those in clinics range from 33.1 to 35.4 percent. In addition, the ATTs on the number of visits in hospitals range from 19.0 to 19.9 percent, but those in clinics range from 32.4 to 34.4 percent. These results suggest that PA outpatients prefer accessibility to a medical institution to receiving advanced medical services.

DISCUSSION

This study examines the impact of PA assignment on healthcare utilization using large individual datasets of PA and UPHI patients taken from two nationally representative claims data sets of the Japanese government. The results of the regression analysis utilizing a FE model based on the concept of pseudo panel data analysis and those of using PSM show that ceteris paribus, healthcare utilization by PA patients without a financial burden is higher than that of UPHI patients. However, the estimated price elasticity is very small at −0.02, indicating that the level of copayment rate has little effect on healthcare utilization in the intensive margin. Conversely, this result does not indicate an increasingly macro-trend of healthcare expenditure by PA beneficiaries, which implies that moral hazard effects would appear in the extensive margin.

One of the ongoing discussions on policy reform in the Japanese PA system is whether to introduce copayments to PA patients to reduce excessive healthcare expenditure due to the associated moral hazard (16). Because imposing a financial burden would discourage those PA beneficiaries who truly need medical care from visiting a doctor, its introduction is not without political difficulty and social criticism. However, our findings regarding the price inelastic intensive margin in healthcare utilization suggest that imposing a copayment for second and subsequent visits (reexaminations) could not only curb the overall moral hazard effect but also accommodate PA beneficiaries with worse health conditions. In addition, if

policymakers prioritize controlling overall PA expenditure, it would be more effective to impose a regulation on their actual free access, as suggested by our results by the types of medical institution in Section Types of Medical Institutions that PA patients prefer accessibility to a medical institution. For example, a general and family practitioner in a clinic who has the basic clinical skills to deal with all diseases and health problems would be made as a gatekeeper for PA patients. Another would be to replace the current fee-for-service reimbursement system of the UPHI system with that of a DRG/PPS (Diagnosis Related Groups/Prospective Payment System) type that is specific to PA patients.

However, this work has some limitations. First, the increase in healthcare utilization due to the lack of a copayment from PA beneficiaries may be due not only to the inherently poor health conditions of low-income people and the moral hazard effect but also to supplier-induced demand (SID) (46). Specifically, PA patients are less likely to notice additional unnecessary and excessive medical treatment provisions because their actual financial burden is still zero. However, frequent SID provision is quite risky for medical suppliers in the long term because the MHLW can revoke the designation of a healthcare institution or the registration of an insured physician if fraudulent billing of healthcare expenditure is found to be intentional or grossly negligent. In addition, SID has little impact on healthcare expenditure because the costs of medical treatments are reimbursed to a medical institution only after they have been doubly reviewed by the public third-party payer and the insurer (32). In the extant empirical analyses, it is very difficult to identify each effect on inherently poor health, moral hazard, and SID, while the results of Yuda (23) provide useful evidence for an SID effect in the Japanese PA system. Yuda (23) focuses on short-term hospitalization that medical suppliers have broad discretion over healthcare provision and finds that its arc price elasticity is inelastic, only 0.2, which suggests that there is little effect of SID on healthcare expenditure in the Japanese PA system. Second limitation is that our claim data only include the intensive margin in healthcare utilization. There is room for discussion about what policy is most effective for controlling PA healthcare expenditure, depending on the estimates of price elasticity with respect to the extensive margin of healthcare utilization. Third, I do not evaluate how the PA system directly influences PA patients' health and utility or public health in society because our data do not include patient outcomes. For example, RAND HIE reports that low-income people imposed a certain copayment had increased hypertension, poorer vision, worse dental hygiene, and more serious conditions than the other group. It is also important to control for potentially confounding factors of individual heterogeneity (e.g., education, household income and asset, life habits, family structure, disease history, and disease severity) as well as medical supplier characteristics (e.g., number of staff and beds, available medical equipment, and management agency). In particular, the current PSM procedures do not control for economic conditions and attributes of the household that are used in the means test to determine PA eligibility, due to the lack of data. Thus, the estimation results can only reflect price elasticity to certain degree because conditional independence assumption may not be sufficiently satisfied. Hence, further analysis using other comprehensive data, including the above information, may help confirm the findings obtained in this analysis.

DATA AVAILABILITY STATEMENT

The data analyzed in this study is subject to the following licenses/restrictions: the Ministry of Health, Labor and Welfare (MHLW) in Japan for authorization allowed me to use the original survey data for this research under the Statistics Act (No. 53) pursuant to Article 33. To use the original individual data in this study, researchers need to submit their detailed research proposal to the MHLW in advance. Only after the MHLW approves their proposal, the researchers can access the data. Requests to access these datasets should be directed to the Ministry of Health, Labor, and Welfare in Japan, https://www.mhlw.go.jp/stf/toukei/goriyou/chousahyo.html (only Japanese pages exist). In addition, the sources of other prefectural data are listed in the paper.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.895679/full#supplementary-material

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Impact of Economic Freedom and Educational Attainment on Life Expectancy: Evidence From the New EU Member States

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Life expectancy is a significant indicator of public health, life quality, welfare and economic development. Therefore, improvement in life expectancy is among the priority targets of the countries. This paper investigates the effect of economic freedom and educational attainment on life expectancy in the new EU member states, experiencing an institutional, educational, and economic transformation, during the period 2000–2019 by using cointegration and causality tests, because economic freedom and educational attainment can foster the life expectancy through institutional and economic variables such as institutions, governance, sound monetary and fiscal policies, economic growth, innovation, technological development, better living standards and access to superior healthcare services. The causality and cointegration analyses reveal that economic freedom and educational attainment are significant factors underlying life expectancy in the short and long term. However, educational attainment is found to be more effective on life expectancy than economic freedom. The findings have important implications for educational and health policies in analyzed countries. Governments must understand the education–health relationship to be able to develop and promote educational policies that have the potential to improve public health.

Keywords: life expectancy, economic freedom, educational attainment, panel causality analysis, panel cointegration analysis

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INTRODUCTION

Life expectancy is a significant indicator of health status and, implicitly, of the human capital stock of a country. Therefore, any increase in life expectancy reflects improvements not only in the health level of a society, but also in its human development and wellbeing. The globalized world has experienced significant improvements in life expectancy thanks to advances in health care, medical care and living standards (1). The life expectancy at birth has increased up to 73.4 years in 2019 from 66.8 years in 2000 and the healthy life expectancy at birth has also increased to 63.7 in 2019, from 58.3 in 2000 (2). However, life expectancy significantly varies among countries. While the top three countries with the highest life expectancy at birth for both sexes in 2019 were Japan (84.26 years), Switzerland (83.45 years) and, respectively, the Republic of Korea (83.3 years), the last three countries with the lowest life expectancy at birth for both sexes were Lesotho (50.75 years), Central African Republic (53.1 years) and Somalia (56.47 years) (2).

The European Union (EU) members states also experienced the improvements in life expectancy during the 2000–2019 period. Spain had the largest life expectancy at birth with 83.22 years in 2019 and Bulgaria had the lowest life expectancy at birth with 75.07 years in 2019 and the old EU members generally had the higher life expectancy at birth as seen in **Table 1**. However, the evolution of life expectancy between 2000 and 2019 presented in **Table 1** also indicated that the new EU member states such as Estonia, Slovenia, Latvia, Hungary, Slovakia, and Poland had a relatively higher improvements in life expectancy.

The considerable differences in life expectancy have raised the attention of researchers, which started to investigate its determinants. Their results suggest that some social, economic and environmental factors, such as income level, economic growth, education, health care expenditures, number of doctors, nutrition, food availability, urbanization, environmental quality, clean water, sanitation, fertility rate, pharmaceutical consumption or tobacco consumption, could be influence factors of life expectancy (3–9).

TABLE 1 | Evolution of life expectancy at birth in the EU states between 2000 and 2019.

Country	2000 (years)	2019 (years)	Change of life expectancy (years) (life expectancy in 2019—life expectancy in 2000)
Austria	78.17	81.65	3.48
Belgium	77.66	81.42	3.76
Bulgaria	71.61	75.07	3.46
Croatia	74.36	78.64	4.28
Cyprus	78.75	83.14	4.39
Czechia	74.95	79.13	4.18
Denmark	76.93	81.32	4.39
Estonia	70.94	78.88	7.94
Finland	77.6	81.61	4.01
France	78.91	82.48	3.57
Germany	78.09	81.72	3.63
Greece	78.17	81.1	2.93
Hungary	71.34	76.44	5.1
Ireland	76.41	81.84	5.43
Italy	79.36	82.97	3.61
Latvia	70.18	75.38	5.2
Lithuania	72.04	75.99	3.95
Luxembourg	78.24	82.41	4.17
Malta	77.87	81.89	4.02
Netherlands	78.01	81.79	3.78
Poland	73.7	78.27	4.57
Portugal	76.58	81.57	4.99
Romania	71.39	75.57	4.18
Slovakia	73.3	78.23	4.93
Slovenia	76.05	81.31	5.26
Spain	79.08	83.22	4.14
Sweden	79.57	82.4	2.83

Source: World Health Organization (2).

In this study, the effect of economic freedom and educational attainment on life expectancy is analyzed. The countries with higher economic freedom have relatively larger life expectancy than the states with less economic freedom (10, 11). Economic freedom can positively influence economic growth and development, by fostering institutions, governance, legal structure, sound monetary and fiscal policies, financial development, trade liberalization, innovation and competitiveness (12–15). Meanwhile, all of these enhance life expectancy through improvements in healthcare, medical care, better access to nourishment and clean water, and environmental quality (16–18). However, when the economic growth achieved through economic freedom is accompanied by weak environmental regulations, life expectancy is negatively influenced by environmental degradation (19). Meanwhile, lower government size can negatively affect life expectancy by decreasing social expenditures (20). As a consequence, the net influence of economic freedom on life expectancy can differ depending on which factors prevail.

Educational attainment was considered a crucial factor in explaining the differences in life expectancy among countries through access to health-related information, employment of healthcare opportunities, planning horizon and risk perception at the subsequent period (21, 22). In this context, higher educational attainment generally leads to better job opportunities, with higher wages and, in turn, higher wages help individuals to have better living standards and access to superior healthcare services. Educational attainment can also foster life expectancy by raising the efficiency of health production (23). Last, educational attainment may also impact life expectancy by enhancing economic growth, many researchers suggesting that educational attainment is a significant determinant of economic growth (24, 25). Lutz and Kebede (26) investigated the relationship between education proxied by average schooling years of the adults and life expectancy and their results suggest that the education level is a better predictor of life expectancy than the other factors. Furthermore, economic freedom can influence life expectancy via educational attainment, because individuals from countries with higher economic freedom generally give more importance to educational attainment (27).

Both educational attainment and economic freedom are also significant determinants of the socioeconomic development level. Socioeconomic development levels can affect life expectancy through better nourishment and living standards and higher health care access (26). In this context, Preston (28) analyzed the relationship between life expectancy and GDP per capita and the resulting curve, named Preston curve, showed that the persons in richer countries generally had higher life expectancy than those from poor states. When the GDP per capita has low levels, the increases in GDP per capita lead to higher improvements in life expectancy. However, the improvements in life expectancy decrease at higher levels of GDP per capita. Furthermore, Preston (28) attributed the upward shifts of the curve to the advances in medical science and the health care sector.

The related empirical literature has mainly investigated the influence of GDP per capita and various educational indicators on life expectancy, but a few researchers such as Esposto and Zaleski (19, 29–32) have investigated the influence of economic freedom on life expectancy in countries with different characteristics mainly through regression approach. However, these studies have given a common effect of economic freedom on life expectancy for the whole sample and in turn an evaluation about how the influence of economic freedom on life expectancy varies among the countries cannot be made. Therefore, the limited number of studies about the interaction between economic freedom and life expectancy and their research method motivate us to analyze the influence of economic freedom together with educational attainment on life expectancy on a sample of the new EU member states, which have made significant progress in educational attainment and economic freedom thanks to the EU membership negotiations and, subsequently, adhesion by means of cointegration and causality analyses.

The scientific contribution of this article results from two aspects. First, the literature about the nexus between economic freedom and life expectancy has been quite limited. Therefore, this article will enlarge the existing literature, especially in the context in which, to the best of our knowledge, no study has investigated the influence of economic freedom on life expectancy in the case of the New EU member states. Secondly, the very limited literature has analyzed the effect of economic freedom on life expectancy by using the regression method and ignored the country-level differences. This research employed the augmented mean group (AMG) estimator to obtain the long-run effect of economic freedom on life expectancy at the country level. The rest of the article is structured as follows: the literature is summed up in Section 2, the dataset and methods are described in Section 3, empirical applications and discussions are provided in Section 4 and the conclusions are presented in Section 5.

LITERATURE REVIEW

Many studies have empirically investigated the factors aimed to contribute to the improvements in life expectancy, and documented the various social, demographic, economic, environmental and institutional determinants underlying life expectancy as presented in introduction. In this study, the influence of economic freedom together with educational attainment on life expectancy is analyzed taking into account that the literature on the nexus of economic freedom-life expectance has been very limited.

The nexus between economic freedom and life expectancy has been mainly investigated by panel regression analysis in sample of countries with different economic development levels including developed, developing and underdeveloped economies. But however, the studies pointed out that economic freedom raised the life expectancy in all countries. Esposto and Zaleski (29) only checked the relationship between economic freedom and life expectancy varied based on the current life expectancy level and found that economic freedom had higher effect on life expectancy in the countries with a life expectancy under 65. The regression approach gives a common coefficient for all countries and does not let us to see how the effect of economic freedom on life expectancy varies among countries. In this study, the Augmented Mean Group estimator (AMG) was hence preferred to obtain panel and country level cointegration coefficients which indicate the long-term run effect of economic freedom on life expectancy.

In the limited empirical literature about the nexus between economic freedom and life expectancy, Esposto and Zaleski (29) investigated the effect of economic freedom on life expectancy and literacy in 92 countries, with different development levels, by using the regression method. They noticed that economic freedom increased the life expectancy and literacy. Moreover, they argued that the effect of economic freedom on life expectancy was relatively higher in the countries with a life expectancy under 65. On contrary, Gwartney and Lawson (30) suggested that people in the countries with the highest economic freedom had relatively higher life expectancy than the others.

Hassan et al. (31) investigated the relationship between economic freedom and life expectancy in 7 countries during the period 2000–2010 by using the regression method and discovered a positive relationship between economic freedom and life expectancy. Lawson et al. (32), analyzed the interaction among the economic freedom, obesity and life expectancy in 135 countries in 1995 and during the period 2000–2009 with the help of a regression approach. Their findings indicate a positive influence of economic freedom on life expectancy. Last, Sharma (19) analyzed the effect of economic freedom on health indicators in 34 sub-Saharan African economies for the period 2005–2016 via a regression approach and found a positive influence of economic freedom on life expectancy.

The first empirical studies on determinants of life expectancy have generally focused on the validity of Preston curve suggesting the relationship between GDP per capita and life expectancy. However, the influence of educational attainment, a crucial factor for the differences in life expectancy among the countries, on life expectancy has begun to be investigated as of 2000 s. The empirical studies have mainly represented the education by literacy, secondary and tertiary enrollment and education index and employed the regression analysis, cointegration analysis, and cluster analysis and have found that different education indicators have a positive influence on life expectancy in the countries with different development levels (5, 8, 26, 33–42). However, Hazan (43–45) revealed an insignificant influence of educational attainment of life expectancy for some countries.

In the empirical literature about education and life expectancy, Yavari and Mehrnoosh (33) investigated the determinants of life expectancy through regression analysis and discovered that the literacy rate is a significant factor positively influencing life expectancy. Meanwhile, Kabir (34) investigated the social and economic determinants of life expectancy in 91 developing countries through the regression analysis and revealed a significant effect of education on life expectancy in developing countries. Bayati et al. (35) also investigated the socio-economic determinants of life expectancy in 21 countries from the East Mediterranean region during the period

1995–2007 through the regression analysis and found a positive influence of education on life expectancy.

Delavari et al. (5) investigated the social and economic factors impacting life expectancy in Iran during the period 1985–2013 with the help of cointegration and regression analyses. They concluded that GDP per capita, number of doctors, literacy rate, and food availability were positive determinants of life expectancy, but fertility rate had a negative impact on life expectancy. Meanwhile, Hassan et al. (36) analyzed the determinants of life expectancy in 108 developing economies during 2006–2010 by using regression analysis. They noticed that the education index is a significant determinant of life expectancy. Ketenci and Murthy (8) also investigated the determinants of life expectancy in the United States during the period 1960–2012 by using a cointegration test with structural breaks. Educational attainment and real per capita income were the most important factors influencing life expectancy.

Lutz and Kebede (26) investigated the effect of education on life expectancy in a panel of 174 countries over the 1970–2015 period, with the help of the regression analysis, suggesting a positive effect of educational attainment on life expectancy. Moreover, Hamidi et al. (37) examined the interaction between educational attainment and life expectancy in 18 MENA countries over the 1995–2009 period and found a positive effect of educational attainment on life expectancy. Raghupathi and Raghupathi (38) investigated the interaction between education and health in 26 OECD states for the 1995–2015 period and concluded that higher education level positively affected public health and life expectancy. Paramita et al. (39) explored the determinants of life expectancy in 34 provinces of Indonesia via cluster analysis based on structural equation modeling and found a positive effect of average schooling years on life expectancy.

Hendi et al. (40) investigated the relationship between education and mortality in Finland and United States and noticed a positive effect of education level on life expectancy, faster improvements being found at higher levels of education in both countries. Case and Deaton (41) explored the role bachelor's degree (BA) on life expectancy in the United States over the 1990–2018 period and revealed that persons with BA had increased life expectancy and the gap in life expectancy between the ones with BA and the ones with no-BA consistently increased during this period. A recent study was conducted by Siegel et al. (42) regarding the social determinants of remaining life expectancy in Germany, by using data of 2015–2017 period and underlined the education level as a significant determinant of remaining life expectancy.

Some researchers such as Hazan (43–45) have noticed an insignificant effect of educational attainment of life expectancy for some countries. In this context, Hazan (43) examined the interaction between life expectancy at birth and age 5 and schooling in 61 countries during the period 1960–1990 by using correlation analysis and found a positive correlation between schooling and life expectancy at birth, but insignificant interaction between schooling and life expectancy at age 5.

Bilas et al. (44) also investigated the factors influencing the life expectancy in the EU member states via regression analysis and discovered a negative effect of education on life expectancy. Gilligan and Skrepne (45) explored the determinants of life expectancy in 21 Eastern Mediterranean countries during the period 1995–2010. The authors grouped the countries by cluster analysis and then examined the determinants of life expectancy for three clusters. Literacy proved to be a positive determinant of life expectancy only in the countries from the third cluster.

Based on the information obtained from the investigated literature, the research hypotheses of the study

are:

Hypothesis (1): Economic freedom has a significant impact on life expectancy.

Hypothesis (2): Educational attainment has a significant impact on life expectancy.

DATA AND METHOD

The paper analyzes the influence of economic freedom and educational attainment on life expectancy in the new EU Member States during the 2000–2019 period via causality and cointegration tests. In the analyses, life expectancy (LEI) is represented by the life expectancy index, calculated by UNDP (11). The life expectancy index constitutes the health dimension of the human development index and is based on life expectancy at birth. Economic freedom is proxied by the economic freedom index, developed by Fraser Institute (10) and is calculated as a combination of government size, legal system and property rights, reasonable monetary policy, trade freedom and regulation structure [see (10) for more information about the index]. Lastly, educational attainment (EDU) is represented by the education index calculated by UNDP (11). The education index is formed by means of schooling years for individuals with 25 years or more and the expected schooling years of children (11) with school age. The data of life expectancy and education index is taken from the UNDP database and the economic freedom index is taken from the Fraser Institute database. All series are annual and their period is 2000–2019 because the economic freedom index already existed for the 2000–2019 period. The econometric tests are performed by means of Gauss 12.0, EViews 11.0, and Stata 15.0. The logarithmic forms of economic freedom, educational attainment and life expectancy (LNEF, LNEDU, and LNLEI) are utilized in the analyses to eliminate the seasonality.

The influence of economic freedom (EF) and educational attainment (EDU) on life expectancy (LEI) is analyzed using a sample of the new EU member states consisting of Bulgaria, Croatia, Czechia, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia and Slovenia by following the econometric model in equation 1.

$$LEI_{it} = f(EF_{it}, EDU_{it}) \quad (i = 1, 2, \ldots, 11;\ t = 2000,\ 2001, \ldots, 2019) \quad (1)$$

The descriptive characteristics of the variables are depicted in **Table 2**. The mean of life expectancy index, economic freedom index, and education index were 0.8489, 7.4366 and, respectively, 0.8092. Both life expectancy and education were relatively more

TABLE 2 | Descriptive statistics of the dataset.

Characteristics	*N*	Observations	LEI	EF	EDU
Mean	11	220	0.8489	7.4366	0.8092
Median	11	220	0.8480	7.5400	0.8180
Maximum	11	220	0.9430	8.2100	0.9100
Minimum	11	220	0.7650	5.4400	0.65400
Std.Dev.	11	220	0.0389	0.4930	0.0589
Skewness	11	220	0.1147	−1.2033	−0.5691
Kurtosis	11	220	2.4592	4.8481	2.6028

stable in the sample, but economic freedom presented a higher variation among the countries.

The researchers investigating the influence of economic freedom on life expectancy have mainly employed the regression method as seen in literature review and in turn an inference about the relationship between economic freedom and life expectancy at country level cannot be made. In addition to this, presence of heterogeneity and cross-sectional dependence canalize us to select econometric tests which take notice of heterogeneity and cross-sectional dependence. Therefore, Westerlund and Edgerton (46) bootstrap cointegration test, AMG estimator, and Dumitrescu and Hurlin (47) causality test are chosen to investigate the influence of economic freedom and educational attainment on life expectance in short and long term.

In the analysis section, the cross-sectional dependence and heterogeneity are firstly investigated and then, the availability of unit root in three variables is explored. At the next stage, the long-run interaction among economic freedom, educational attainment and life expectancy is investigated by using the Westerlund and Edgerton (46) bootstrap cointegration test taking the availability of heterogeneity and cross-sectional dependence, heteroscedasticity and autocorrelation and produces relatively robust consequences for small samples (46). Furthermore, it prevents the endogeneity problem through fully modified ordinary least squares. The cointegration LM (lagrange multiplier) test statistic grounded on McCoskey and Kao (48) LM test is figured out as follows (46):

$$LM_N^+ = \frac{1}{NT^2}\sum_{i=1}^{N}\sum_{t=1}^{T}\hat{w}_i^{-2}S_{it}^2 \tag{2}$$

The traditional estimators postulate that slope coefficients are constant for all cross-sections, because these estimators enable the constant terms to become different by pooling the individual groups. Therefore, all other coefficients and error variances are constant among cross-sections (49). The second important requirement for a robust estimator is to consider the absence of cross-sectional independence. The first-generation estimators such as mean group estimator of by Pesaran and Smith (50) and pooled mean group estimator by Pesaran et al. (51) take the heterogeneity into consideration, but disregard the presence of cross-sectional dependence, a common characteristic in the highly globalized world. The second-generation AMG estimator by Eberhardt and Bond (52, 53) was utilized to predict the panel and country-level cointegration coefficients in the study due to the subsistence of heterogeneity and cross-sectional dependence. The estimator of AMG takes the availability of common factors and dynamic effects of the three series into consideration and produces efficient consequences, and can be utilized in a condition of endogeneity (52).

The cointegration coefficients are also estimated by CCE-MG (Common Correlated Effects Mean Group) estimator of Pesaran (54) and IFE (Interactive Fixed Effects) estimator of Bai (55) to check the consistency and reliability of estimations by AMG estimator. CCE-MG estimator takes the unobservable common factors into consideration by adding the cross-section averages of dependent and independent variables to the regression. On the other hand, IFE estimator takes notice of heterogeneity, cross-sectional dependency, and multifactor error structure.

Lastly, causal interaction among economic freedom, educational attainment, and life expectancy was analyzed by the causality test of Dumitrescu and Hurlin (47), an improved version of the conventional Granger causality test in a condition of heterogeneity. The causality test (x is a Granger cause y) with stationary x and y variables is defined as following (47):

$$Y_{i,t} = \alpha_i + \sum_{k=1}^{k} Y_i^{(k)} Y_{i,t-k} + \sum_{k=1}^{k} \beta_i^{(k)} X_{i,t-k} + e_{i,t} \tag{3}$$

To sum up, Westerlund and Edgerton (46) bootstrap cointegration test is a second-generation test and takes the cross-sectional dependence unlike the first-generation cointegration tests and it also produces robust consequences under the presence of heteroscedasticity, autocorrelation, and endogeneity problem. On the other hand, AMG estimator calculates both panel and cross-sectional coefficients and also takes the cross-sectional dependence unlike the first-generation estimators. Lastly, Dumitrescu and Hurlin (47) causality test considers the heterogeneity unlike the traditional Granger causality test and can produce relatively more robust findings under the presence of cross-sectional dependence.

RESULTS AND DISCUSSION

In the analysis part of the study, the pre-tests of cross-sectional dependence and heterogeneity among economic freedom, educational attainment and life expectancy are conducted. The cross-sectional dependence indicates that any shock in a

TABLE 3 | Results of cross-sectional dependence and heterogeneity tests.

Test	Test statistic	*P*-value
LM_{adj}	29.347	0.015
LM CD	30.991	0.009
LM	34.265	0.000
$\Delta^{\sim}$	19.453	0.003
$\Delta^{\sim}_{adj.}$	22.705	0.011

TABLE 4 | Results of the CIPS unit root test.

Variables	Level		First differences	
	Constant	Constant + Trend	Constant	Constant + Trend
LNLEI	−1.342	−1.387	−8.335**	−9.012**
LNEF	−1.105	−1.329	−6.667**	−7.375**
LNEDU	−1.411	−1.503	−7.265**	−8.316**

***It is significant at 5% significance level.*

country of the panel affects the other countries of the panel and cross-sectional dependence is widely seen in the highly integrated world (56). In this context, cross-sectional dependence is examined by using tests of $LM_{adj.}$, LM CD, and LM developed by Pesaran et al. (57–59), and the results of those tests are depicted in **Table 3**. The results of the cross-section dependence tests point out the cross-sectional dependence due to a decline in the null hypothesis at 1% as a consequence of the three tests in **Table 3**. For this reason, a unit root test, cointegration and causality tests, which give robust results under the entity of cross-sectional dependence, should be used. The homogeneity test checks whether the slope coefficient in the cointegration equation varies among the cross-sections. Therefore, the specification of homogeneity is important when selecting the causality and cointegration tests and estimator. The availability of homogeneity is explored by the homogeneity tests of Pesaran and Yamagata (60) and the findings of both tests are presented in **Table 3**. The null hypothesis (the entity of homogeneity) is rejected and the entity of heterogeneity is achieved.

The stationarity of the series, in other words the presence of unit root in the series, can lead spurious regression and in turn decrease the reliability of the findings (61). Therefore, the availability of unit root in LNLIE, LNEF and LNEDU is investigated by using the Cross-Sectionally augmented (62) (CIPS) test proposed by Pesaran (63) due to cross-sectional dependence among the three series. The results of the test are presented in **Table 4** and test statistics are compared with the critical values in Pesaran (63). Thus, the null hypothesis indicating the presence of a unit root in the series is accepted for level values of the series, because test statistics are found to be lower than the critical values. However, the null hypothesis (presence of a unit root in the series) is denied for the first differences of the variables, because test statistics are found to be higher than the critical values. In conclusion, test findings indicate that LNLIE, LNEF and LNEDU are I (1).

The long-run interaction between economic freedom, educational attainment, and life expectancy is investigated by using the Westerlund and Edgerton (46) cointegration test due to the presence of heterogeneity and cross-sectional dependency. The cointegration test results are shown in **Table 5**. A significant cointegration relationship between economic freedom, educational attainment and life expectancy is obtained, because null hypothesis of significant cointegration relationship among three variables is accepted considering bootstrap *p*-values.

The cointegration coefficients are calculated by using the AMG estimator, CCE-MG estimator and IFE estimator owing to the presence of cross-sectional dependency, heterogeneity, and robustness. The long run coefficients are presented in **Table 6** and similar findings from three estimators verified the robustness of the AMG estimator, but the magnitude of the impact of economic freedom and education on life expectancy varies depending on the estimators. Both panel and country-level cointegration coefficients by three estimators indicate that economic freedom and educational attainment fostered life expectancy in the long run. The effect of educational attainment on life expectancy at the panel level and country-level is relatively higher when compared to economic freedom. On the other hand, the long-term effect of economic freedom and educational attainment on life expectancy varies among the countries. The positive effect of economic freedom on life expectancy is relatively higher in Hungary, Poland, and Bulgaria, but relatively lower in Czechia, Estonia, and Slovakia. This can be resulted from that Bulgaria made the largest improvement in economic freedom during the study period. Hungary and Poland experienced a similar improvement in economic freedom when compared with the other countries, but relatively larger impact of economic freedom on life expectancy was seen in these two countries. This can be resulted from that the channels which economic freedom affects the life expectancy are more effective in Hungary and Poland. Furthermore, the positive effect of educational attainment on life expectancy is relatively higher in Poland, Hungary, and Lithuania, but relatively lower in Croatia, Czechia, and Slovakia.

The economic freedom is expected to influence the life expectancy through economic growth and development based on country specific characteristics, economic freedom can foster the life expectancy by procuring higher levels of healthcare, medical care, better access to nourishment and clean water, environmental quality, and raising the educational awareness of the individuals if the improvements in economic growth and development are accompanied by economic freedom (27). Otherwise, economic growth with weak institutional quality can negatively influence the life expectancy through higher income and education inequality and lower environmental quality (19). As a result, the net influence of economic freedom on life expectancy can differ based on country specific characteristics. In the related literature, only a few researchers have analyzed the effect of economic freedom on life expectancy in panel datasets with different income levels of countries through the regression method and reached a positive influence of economic freedom on life expectancy (19, 29–32), although a negative impact of economic freedom on life expectancy is also possible theoretically. However, none of the researchers have analyzed

TABLE 5 | Westerlund and Edgerton (46) bootstrap cointegration test.

Constant			Constant + Trend		
Test statistic	**Asymptotic *p*-value**	**Bootstrap *p*-value**	**Test statistic**	**Asymptotic *p*-value**	**Bootstrap *p*-value**
6.385	0.293	0.311	8.210	0.327	0.396

Bootstrap critical values were generated from 10,000 repetitions, and asymptotic probability values were procured from standard normal distribution.

TABLE 6 | Results of cointegration coefficients estimation.

Countries	LNEF			LNEDU		
	AMG	**CCE-MG**	**IFE**	**AMG**	**CCE-MG**	**IFE**
Bulgaria	0.183**	0.159*	0.131*	0.327*	0.302*	0.296*
Croatia	0.148**	0.138*	0.126**	0.214**	0.197*	0.183**
Czechia	0.125**	0.118**	0.112*	0.247*	0.215**	0.198*
Estonia	0.130**	0.124**	0.108**	0.319**	0.280**	0.284**
Hungary	0.211*	0.196*	0.182*	0.401**	0.345*	0.371*
Latvia	0.173**	0.163*	0.142**	0.297*	0.231*	0.193*
Lithuania	0.168**	0.134*	0.115*	0.330**	0.298*	0.270*
Poland	0.192*	0.177*	0.147*	0.417**	0.366**	0.368**
Romania	0.162**	0.141**	0.155**	0.348*	0.322*	0.280*
Slovakia	0.140**	0.120**	0.102*	0.250**	0.228**	0.203**
Slovenia	0.154*	0.134*	0.110*	0.266**	0.213**	0.208**
Panel	0.178**	0.156**	0.125**	0.325**	0.308**	0.256**

***, *It is respectively significant at 1 and 5% significance level.*

TABLE 7 | Results of the Dumitrescu and Hurlin (47) causality test.

Null hypothesis	Test	Test statistics	*P*-value
D(LNEF) ↛ D(LNLIE)	Whnc	8.477	0.000
	Zhnc	9.113	0.000
	Ztild	9.585	0.000
D(LIE) ↛ D(LNEF)	Whnc	2.188	0.273
	Zhnc	2.476	0.314
	Ztild	3.103	0.410
D(LNEDU) ↛ D(LNLIE)	Whnc	6.473	0.000
	Zhnc	6.982	0.000
	Ztild	7.215	0.006
D(LIE) ↛ D(LNEDU)	Whnc	1.863	0.128
	Zhnc	1.945	0.130
	Ztild	2.110	0.138

the country level interaction between economic freedom and life expectancy considering the country specific characteristics. A positive influence of economic freedom on life expectancy in all countries is revealed in line with the empirical studies, but the impact of economic freedom on life expectancy changes in countries due to countries' institutional and educational quality.

Educational attainment has been accepted as a crucial factor in explaining the differences in life expectancy among countries, because education can influence the life expectancy through many diverse channels such as economic growth and development, access to health-related information, employment of healthcare opportunities, planning horizon and risk perception at the subsequent period, raising the efficiency of health production (21–23, 25). The extensive literature about the influence of educational attainment proxied by different education indicators on life expectancy has mainly reached a positive relationship between two variables (5, 8, 26, 33–42). Furthermore, educational attainment together with real GDP per capita have been suggested as the dominant factors for explaining the differences in life expectancy among the countries (8, 21, 23). Our findings were found to be in accord with the related literature.

Lastly, the causality among economic freedom, educational attainment and life expectancy is analyzed by using the Dumitrescu and Hurlin causality test (47). The findings are presented in **Table 7**. The causality analysis reveals a one-way causal effect from educational attainment and economic freedom to life expectancy, but no significant causality from life expectancy to economic freedom and educational attainment is found. The findings indicate that both economic freedom and educational attainment are also significant determinants of life expectancy on the short run, but life expectancy has an insignificant effect on economic freedom and educational attainment.

The causality analysis unveiled that both factors have significant causes of life expectancy in the short term. In other words, the influence of improvements in economic freedom and educational attainment can have a significant influence on life expectancy in the short run. However, a comparative analysis for the findings of causality analysis considering the related literature cannot be made, because the empirical studies have mainly employed the regression approach.

CONCLUSION

Life expectancy is a significant determinant of welfare and public health, the reason for which it represents a priority both for the national governments' policies and for the UN sustainable development goals. Life expectancy has considerably increased in the world, but significantly changed between countries. Therefore, identifying the factors that may influence the differences in life expectancy between countries will contribute to better national and international decisions of the policy-makers.

This article analyzed the effect of economic freedom together with educational attainment on life expectancy in the new EU member states, which passed through a significant economic and institutional transformation process, by using

causality and cointegration tests. The study period was limited with 2000–2019 period thanks to the availability of yearly economic freedom data. The causality and cointegration analyses pointed out a significant effect of economic freedom and educational attainment on life expectancy in line with theoretical considerations and the related empirical literature. However, the effect of educational attainment on life expectancy was higher when compared to economic freedom. The higher effect of educational attainment can be explained through the fact that educational attainment fosters life expectancy through various direct and indirect channels such as innovation, technological development, entrepreneurship, human development, economic growth, and development.

The results of the study clearly indicate that market-oriented economic structures and educational attainment are significant determinants of life expectancy. Furthermore, higher economic growth with insufficient institutional and educational quality can negatively influence the life expectancy. Therefore, economic structures are important for life expectancy, a significant indicator of public health and development level of the countries. On the other hand, educational attainment is revealed to be more effective on life expectancy than economic freedom. Education can help individuals to be better informed and to make competent decisions related to many aspects of their lives, including decisions related to their own health care. There are direct and indirect paths through which education can influence life expectancy. It is well-known that better-educated individuals are more likely to adopt healthier lifestyles therefore incorporating healthy lifestyle education into the school curriculum can be a useful way to achieve behavior change. Also, higher levels of education will increase individuals' opportunities to be better paid and access better health care services and adopt a healthy lifestyle. The health sector alone cannot assure a good level of health for people, all sectors are interconnected therefore adopting and implementing coherent education policies and programmes can be crucial for the long-term development of this sector. For providing the best population health outcomes policymakers have to make decisions based on rigorous data and research evidence. Governments need to make efforts to find proper solutions to improve enrollment and mitigate dropout rates that usually have a negative impact on people's health conditions. Education increases knowledge and information, helps people to be more conscientious about their health status, about health habits that need to be adopted to maintain or improve health conditions, to adopt a positive attitude, generally speaking, to live a healthy lifestyle. Formal learning can be combined with informal learning to promote competencies necessary for each individual to improve their health.

The findings of the study expose how interlinked economic freedom, education and human health can be. Countries can improve their health by increasing educational attainment. Education can create circumstances for better health, on the other hand, poor health is more likely to put educational attainment at risk. Researchers and policy makers have mutual responsibilities for strengthening health. Our findings can increase awareness of the possibility that education can be associated with improved health. Future studies can be conducted to analyze the main or sub-components of economic freedom on life expectancy.

DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. This data can be found here: https://www.fraserinstitute.org/economic-freedom/map? tiongeozone = world&page = map&year = 2019 https://hdr.undp.org/en/content/human-development-index-hdi.

AUTHOR CONTRIBUTIONS

AM, GS, YB, and MG have made significant contribution to design of the article, analysis, writing, and discussion of the article. All authors approved the submitted article.

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BRIEF RESEARCH REPORT
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Research on the Dynamic Feedback Mechanism of Fiscal Policy Regulation Under COVID-19: Evidence From China

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The repeated outbreak of COVID-19 epidemic has brought a heavy blow to the world economy. Fiscal policy is one of the important macro-control measures to pull the economy out of the quagmire, and it is necessary to study the implementation of fiscal policy under the epidemic. Due to the relatively abundant resources of the Chinese government, this study uses China as the research object to study the orientation of fiscal policy under COVID-19 epidemic. We use fiscal policies and a large amount of macroeconomic data to identify fiscal policy and macroeconomic regulation's dynamic mechanism in China. Our findings indicate a dynamic feedback relationship between expenditure-based and revenue-based fiscal policy tools, output gaps, and deficit scales. Before the global economic crisis, fiscal policy can play a good role in adversely regulating the economy, and the difficulty of adjustment after the crisis has increased significantly. During COVID-19 epidemic, the interaction time between variables related to fiscal policy increased, suggesting that the implementation of fiscal policy during the epidemic should be particularly cautious.

Keywords: fiscal policy, dynamic feedback, rule, discretionary, China, COVID-19

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INTRODUCTION

The COVID-19 epidemic has swept the world since the end of 2019, bringing a heavy blow to the economies of various countries (1). In order to deal with the economic downturn caused by the COVID-19 epidemic and prevent secondary disasters caused by the COVID-19 epidemic as much as possible, the government has to rely on the role of macro-control to intervene. It often takes a while for monetary policy to act on the macro economy, and it is difficult to respond to a sudden negative shock like the COVID-19 outbreak in a timely manner. In contrast, the effect of fiscal policy is more immediate. When the economy is severely negatively impacted, studying the dynamic feedback mechanism of fiscal policy on the macroeconomy is conducive to making marginal contributions to research in related fields and conducive to in-depth understanding of fiscal policy regulation. It has important reference value for the formation of a fiscal system that matches the modernization of national governance. Fiscal policy is an essential pillar of national governance, and the level of fiscal governance is related to the country's stability and development. The Chinese government has many resources and has a relatively strong ability to influence economic sectors (2, 3). Therefore, Chinese data is selected as the research object of this

paper to study how fiscal policy is adjusted when the economy suffers a negative blow. However, the problem is that the implementation of fiscal policy is not consistent over a long time. The past handling methods may be seriously divorced from the actual economic situation. Therefore, exploring the implementation preferences of China's fiscal policy should start from a dynamic perspective, while considering many economic variables that may be involved in the process of fiscal policy implementation, so as to make the empirical results fit the actual economy.

This paper constructs a non-linearity reflecting the dynamic and time-varying relationships among fiscal policy tools, output gaps, and fiscal deficits. The model analyzes the dynamic feedback mechanism of fiscal policy and macroeconomics. The main contribution is the practical analysis of the dynamic adjustment mechanism between fiscal policy tools, output gap, and fiscal deficit scale, which can be regarded as an essential supplement to current fiscal policy empirical research. It is of great significance to understand the operational characteristics of the government's fiscal policy during the crisis.

The rest of the paper is organized as follows. The second part is a literature review. The third part introduces the relevant theory of fiscal policy rules and proposes the theoretical framework used in this paper. The third part introduces the empirical analysis method. The fourth part introduces the empirical analysis method. The fifth part is data introduction and selection. The sixth part is the empirical results. The last part is the conclusion.

LITERATURE REVIEW

The research on the effectiveness of fiscal policy has become a key research issue in the field of macro-control in various countries, and it is primarily reflected in the analysis of the policy effectiveness of fiscal rules under a dynamic stochastic general equilibrium system (4, 5). In the discussion on the effectiveness of fiscal policy, the question of the mode of policy operation cannot be avoided, that is, should the government insist on using fiscal policy rules that are pegged to certain macroeconomic variables in the face of a severe negative blow to the economy such as the COVID-19 pandemic, or should the government use discretionary flexibility that adjusts to economic circumstances? On this issue, the debate over policy rules versus discretion has a long history. Keynes, Samuelson and others believed that camera decision-making was more effective, and "Keynesianism" was highly sought after during the Great Depression (6, 7). However, Friedman, Kydland and others took a cautious objection (8–10), arguing that it will lead to problems such as dynamic inconsistency and high welfare costs, which itself will become one of the causes of economic cycles (11–13). From the perspective of the characteristics of macroeconomic regulation, policy rules and discretion have their own advantages and disadvantages (14, 15). Therefore, the expanded policy rules that are partially unified and respond synchronously with changes in other economic variables have been favored by scholars (16–19). The research on how China's finance is regulated has been concentrated in recent years (20–24), the existence and effect of rules have been estimated.

Combing through the literature in the past can reveal that although the research has achieved many meaningful conclusions in many aspects, the orientation of fiscal policy when the economy has suffered a severe negative blow has not been thoroughly explored. This paper focuses on the outbreak of the COVID-19 epidemic, which has caused a huge blow to the economic system, and studies the dynamic characteristics and implementation orientation of China's fiscal policy, aiming to provide experience and reference for other countries' fiscal policy implementation in special times.

THEORETICAL ANALYSIS

The government's expenditure-based and revenue-based policy tools will be adjusted according to the actual government debt scale and the output gap (25, 26).

$$\hat{G}_t^{exp}=\eta_{G^{exp}}\hat{G}_{t-1}^{exp}+\lambda_{G^{exp}y}\hat{y}_{t-1}+\lambda_{G^{exp}b}\hat{D}_{t-1} \quad (1)$$

$$\hat{G}_t^{rev}=\eta_{G^{rev}}\hat{G}_{t-1}^{rev}+\lambda_{G^{rev}y}\hat{y}_{t-1}+\lambda_{G^{rev}b}\hat{D}_{t-1} \quad (2)$$

Simultaneously, considering the lack of data on debt balance in China, fiscal deficits are more effective in restraining government behavior and easier to observe than debt balances (22). Moreover, the discretionary choice has often become the main policy tool of the fiscal sector, which means that fiscal policy is not a completely regular form, so the fiscal policy model is described in detail as:

$$\hat{G}_t^{\exp}=\eta_{G^{\exp}}\hat{G}_{t-1}^{\exp}+\lambda_{G^{\exp}y}\hat{y}_{t-1}+\lambda_{G^{\exp}b}\hat{D}_{t-1}+e_{G^{\exp},t} \quad (3)$$

$$\hat{G}_t^{rev}=\eta_{G^{rev}}\hat{G}_{t-1}^{rev}+\lambda_{G^{rev}y}\hat{y}_{t-1}+\lambda_{G^{rev}b}\hat{D}_{t-1}+e_{G^{rev},t} \quad (4)$$

Among them $\hat{G}_t^{\exp}$ and $\hat{G}_t^{rev}$ are the proxy variables of expenditure and revenue-based fiscal policy tools. $\hat{y}$ and $\hat{D}$ are the output gap and the government deficit's size. $\eta_{G^{\exp}}$, $\eta_{G^{rev}}$ depicts the smoothness of fiscal policy operations. That is, current government expenditures and revenues will be pegged to the previous government to a certain extent. $e_{G^{\exp},t}$, $e_{G^{rev},t}$ respectively represent the unobservable parts of government expenditure and government revenue in fiscal policy tools, reflecting the discretionary degree of fiscal policy tools. $\eta_{G^{\exp}}\hat{G}_{t-1}^{\exp}+\lambda_{G^{\exp}y}\hat{y}_{t-1}+\lambda_{G^{\exp}b}\hat{D}_{t-1}$, $\eta_{G^{rev}}\hat{G}_{t-1}^{rev}+\lambda_{G^{rev}y}\hat{y}_{t-1}+\lambda_{G^{rev}b}\hat{D}_{t-1}$ respectively mean the regulatory changes in fiscal policy instruments.

However, just as the empirical evidence of the non-linear form of Taylor rule, we also believe that the target of fiscal policy in China is not consistent in the long term, and potential targets time-varying. Combined with the theoretical viewpoints above, we further characterize the fiscal policy model as:

$$\hat{G}_t^{\exp}=\eta_{G^{\exp},t}\hat{G}_{t-1}^{\exp}+\lambda_{G^{\exp}y,t}\hat{y}_{t-1}^{*}+\lambda_{G^{\exp}b,t}\hat{D}_{t-1}^{*}+e_{G^{\exp},t} \quad (5)$$

$$\hat{G}_t^{rev}=\eta_{G^{rev},t}\hat{G}_{t-1}^{rev}+\lambda_{G^{rev}y,t}\hat{y}_{t-1}^{*}+\lambda_{G^{rev}b,t}\hat{D}_{t-1}^{*}+e_{G^{rev},t} \quad (6)$$

y^*_{t-1} represents the deviation of output from the potential time-varying production and $\hat{D}_{t-1}^{*}$ represents the fiscal deficit's

deviation from the time-varying fiscal deficit target. There should be a "countercyclical" effect between the output gap and deficit changes and the government's fiscal policy in an ideal state (22, 27). This paper also adds factor enhancement ideas in the empirical research part's fitting process to avoid loss variables distorting the results (28–30), we characterize the fiscal policy model as:

$$\begin{aligned}\hat{G}_t^{\exp} &= \eta_{G^{\exp},t}\hat{G}_{t-1}^{\exp} + \lambda_{G^{\exp}y,t}\hat{y}_{t-1}^{*} + \lambda_{G^{\exp}b,t}\hat{D}_{t-1}^{*} \\ &+ \psi_{G^{\exp},t}F_{i,t-1} + e_{G^{\exp},t} \quad (7)\\ \hat{G}_t^{rev} &= \eta_{G^{rev},t}\hat{G}_{t-1}^{rev} + \lambda_{G^{rev}y,t}\hat{y}_{t-1}^{*} + \lambda_{G^{rev}b,t}\hat{D}_{t-1}^{*} \\ &+ \psi_{G^{rev},t}F_{i,t-1} + e_{G^{rev},t} \quad (8)\end{aligned}$$

$\psi_{G^{\exp},t}$, $\psi_{G^{rev},t}$ is the corresponding coefficient. $F_{i,t} = \left[f_{1,t}, f_{2,t}, \cdots, f_{n,t}\right]'$ is the control variable, $f_{1,t}, f_{2,t}, \cdots f_{n,t}$ is the extracted common factor,the number of common factors is represented by n, and n is selected as 3 in this paper, we have also extracted and analyzed other numbers of common factors, and the results show that the number of factors has no significant impact on the core conclusions of this article. The specific robustness test results are kept for reference. The posterior mean trend of specific common factors will be introduced later. As can be seen from the theoretical analysis in the previous section, the key parameter is the degree of freedom of fiscal policy to respond to targeting $\lambda_{G^{\exp}y,t}$, $\lambda_{G^{\exp}b,t}$, $\lambda_{G^{\exp}y,t}$, $\lambda_{G^{rev}y,t}$, On the one hand, it reflects the relative preference of fiscal authorities to control actual government debt scale and the output gap, and on the other hand, it also reflects the internal feedback mechanism of fiscal policy to the macro economy. From the point of view of the adjustment mechanism, if $\lambda_{G^{\exp}y,t} < 0$, it shows that the change of fiscal expenditure will be accompanied by the reverse change of the output gap, and the macro-economy tends to be stable. On the contrary, it shows that the fiscal expenditure and the output gap change in a forward direction, resulting in greater macroeconomic fluctuations. Similarly if $\lambda_{G^{\exp}b,t} < 0$, it means that the fiscal authorities can effectively control the scale of the fiscal deficit through the application of fiscal rules. Contrary to the expenditure-based fiscal policy rules, in the income-based fiscal policy rule equation, when the adjustment parameters of the output gap and the scale of the fiscal deficit are positive numbers, it means that there is a good automatic stabilizer between the fiscal revenue and the output gap and the size of the fiscal deficit. Revenue-based fiscal policy rules have played a role in counter-cyclical regulation, which is conducive to stabilizing the scale of debt, which in turn is conducive to macroeconomic stability; on the contrary, it shows that the reverse changes in the scale of fiscal debt and tax adjustment have exacerbated the fluctuation of debt scale, which is not conducive to macroeconomic stability.

EMPIRICAL STRATEGY

According to the theoretical analysis, fiscal policy tools are divided into expenditure type and revenue type, the policy targets are divided into output and government debt. Then the following regression equation is preliminarily constructed:

$$X_t = \varphi_t^0 X_{t-1} + \varphi_t^1 Y_{t-1} + \varphi_2^t F_{t-1} + \varphi_t^2 \quad (9)$$

$X_t = \left[\hat{G}_t^{\exp}, \hat{G}_t^{\text{rev}}\right]'$ including expenditure-based and revenue-based fiscal policy tools, $Y_{t-1} = \left[\hat{y}_{t-1}^{*}, \hat{D}_{t-1}^{\star}\right]'$ including fiscal policy pegging to target output and government debt. φ_t^0, φ_t^1 are (2×2) dimension coefficient matrices. F_t refers to the extracted common factor, which is equivalent to the control variable in the equation, φ_t^2 are $(2 \times n)$ dimension coefficient matrices, where n is the number of common factors. $\delta_t = \left[e_{G^{\exp},t}, e_{G^{rev},t}\right]'$ and $\delta_t \sim N(0, \Omega_{2\times 2})$, φ_t^0, φ_t^1, Ω are diagonal arrays. $\varphi_t^0 = \begin{bmatrix}\eta_{G^{\exp},t} & 0\\ 0 & \eta_{G^{rev},t}\end{bmatrix}$, $\varphi_t^1 = \begin{bmatrix}\lambda_{G^{\exp},t} & 0\\ 0 & \lambda_{G^{rev},t}\end{bmatrix}$, $\varphi_t^2 = \begin{bmatrix}\psi_{1G^{\exp},t} & \psi_{2G^{\exp},t} & \cdots & \psi_{nG^{\exp},t}\\ \psi_{1G^{rev},t} & \psi_{2G^{rev},t} & \cdots & \psi_{nG^{rev},t}\end{bmatrix}$. In the model parameter estimation part, refer to Primiceri (31), Negro and Primiceri (32) and Nakajima's (33) method for parameter estimation, split :

$$\delta_t = A^{-1}\Sigma\zeta_t = \begin{bmatrix}1 & 0 & \cdots & 0\\ a_{21} & \ddots & \ddots & \vdots\\ \vdots & \ddots & \ddots & 0\\ a_{k1} & \cdots & a_{k,k-1} & 1\end{bmatrix}^{-1}\begin{bmatrix}\sigma_1 & 0 & \cdots & 0\\ 0 & \ddots & \ddots & \vdots\\ \vdots & \ddots & \ddots & 0\\ 0 & \cdots & 0 & \sigma_k\end{bmatrix}\xi_t \quad (10)$$

Where $\xi_t \sim N(0, I_k)$. Further order $A = tril\left(\alpha_t, k\right)$, $h_t = \left[h_{1t}, \ldots, h_{kt}\right]'$, $h_{jt} = \log\sigma_{jt}^2$, $j = 1, \ldots, k$. After this setting, the model has the form of stochastic volatility, which can verify the discretionary components of different economic periods.

The factor extraction equation is as follows:

$$W_t = \Gamma^F F_t + \Gamma^V V_t + \varepsilon_t \quad (11)$$

W_t is $(N \times 1)$ dimensional information set, as far as possible to cover the macro variables involved in fiscal policy in China. F_t and the unobservable part and the observable part, respectively. Γ^F and Γ^V express the factor loading matrix of dimension and $(N \times M)$ dimension, $N \gg K + M$, $\varepsilon_t \sim N(0, \Omega_t)$.

The tendency of the posterior mean of the extracted common factors has apparent responses during periods of large-scale economic fluctuations in the Chinese economy (for example, during the global economic crisis, the period of the impact of the COVID-19, etc.), indicating that the extracted common factors can represent most of the information contained in the data set. Use the constructed model to deeply analyze the impact response of expenditure-type and revenue-type fiscal policies to various endogenous variables in the fiscal rule equation, and set the impulse response function as follows:

$$IRF_P(\lambda_{jt}, \varpi_{t-1}) = E[P_{t+h}|\lambda_{jt}, \varpi_{t-1}] - E[P_{t+h}|\varpi_{t-1}] \quad (12)$$

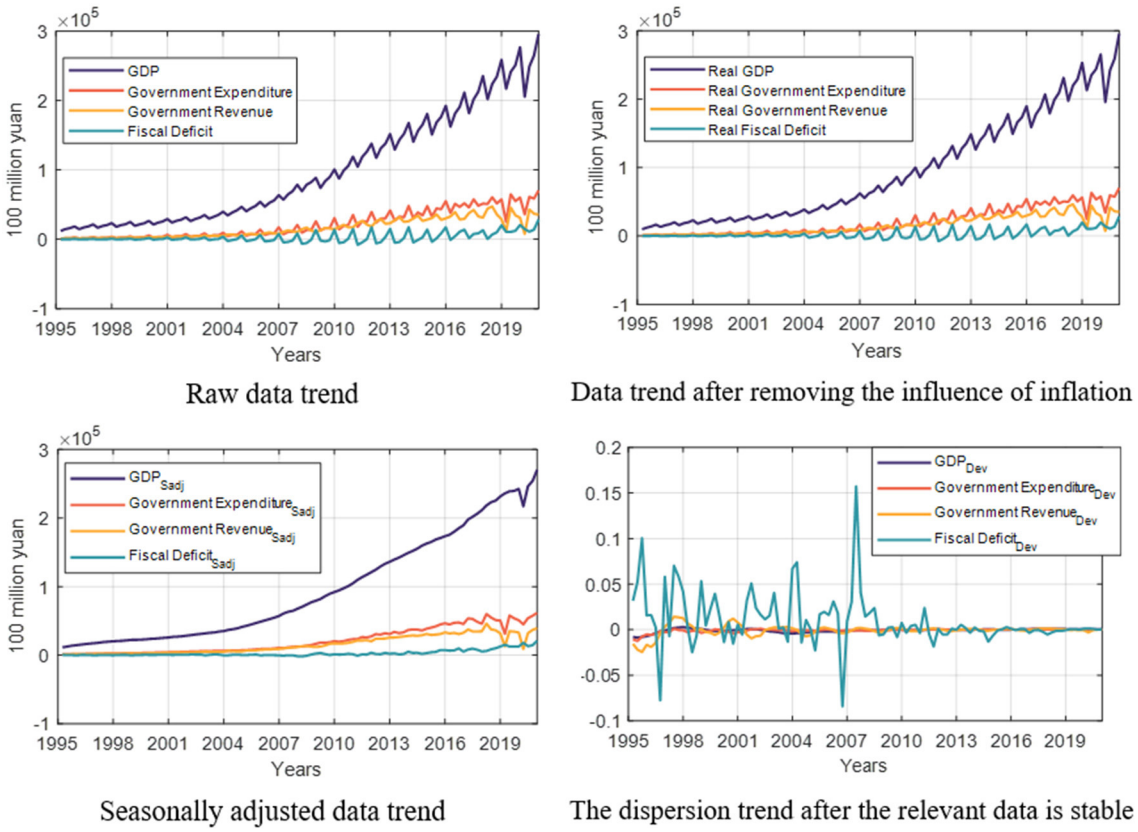

FIGURE 1 | Related data trend description.

Where IRF_P is the impulse response function of the variable P, λ_{jt} is unobservable impulse, ϖ_{t-1} is the historical information set for predicting P, recording all possible impulse response results. h represents the prediction step size and $E[\cdot]$ is the expectation operator.

DATA

In this section, we outline parameter estimation methods and descriptive statistics of related data. The variables involved in the model's central part include economic variables such as output gap, fiscal deficit, government expenditure, government revenue, etc. The selection and description of each data are as follows.

The implicit assumption in this article is that the output gap can be adjusted according to fiscal policy cycles and can include responses from automatic stabilizers' roles. Considering that this article's scope is limited to China, which is a closed economy, the net export value of goods and services is deducted from GDP (22). The nominal GDP is divided by the current quarter's CPI to get the real GDP (34), and X-12 seasonal adjustments are made to data with apparent seasonality. When calculating the output gap, considering that the commonly used HP filter method is too subjective when filtering the noise to obtain the long-term economic variables trend, this article chooses a more objective and rigorous wavelet filter. Obtain potential output (35). The output is divided into two parts: trend component and periodic component. The periodic component is a temporary disturbance and will not cause long-term effects on the output. The long-term trend component can be obtained by suppressing the periodic component through the wavelet filtering method:

$$y_t = y_t^* + \xi_t \tag{13}$$

The trend part obtained through wavelet filtering y_t^* is the potential output and is the output gap. The data processing process of fiscal expenditure and fiscal revenue is consistent with the output gap. The fiscal deficit is the fiscal revenue minus the state fiscal expenditure, and the dispersion $\hat{D}_t^*$ is calculated in the same way as above. The data trend chart is shown in **Figure 1**.

Considering the topic of this paper and the availability of data, a total of 86 economic variables, including China's actual economic activity level, currency level, and price level from the first quarter of 1995 to the fourth quarter of 2020 are selected for analysis. All data are quarterly and come from the wind database. Perform X12 seasonal adjustment on seasonal data and smooth uneven data through logarithmic or differential processing. Due to space limitations, specific data and common factor processing results are omitted in the text, and the processing process is

kept for reference. Extract the unobservable common factors, as shown in **Supplementary Figure 1**.

RESULTS

Figure 2 shows the empirical results, indicating both the expenditure-based and revenue-based fiscal policies are significantly affected by the previous period's policies. The dynamic feedback from output gap on fiscal expenditure ($\varepsilon_y \rightarrow G^{\exp}$) shows that before the global economic crisis, response value was negative and then turned positive. When the output gap is biased to the downside before the crisis begins, that is, the real output of the economy is lower than the potential output, fiscal expenditure increases, the contractionary fiscal deficit will prevent the further decline in real output, and the fiscal expenditure policy can play an effective role in counter-cyclical regulation, which is opposite to the process after the crisis. The feedback from output gap on fiscal revenue ($\varepsilon_y \rightarrow G^{\text{rev}}$) is similar to fiscal expenditure, which shows that during the crisis, the three-dimensional impulse response value fluctuates negatively, and the fiscal revenue policy is difficult to realize counter-cyclical regulation in this period, on the contrary, it will have a pro-cyclical impact on the economy. Such empirical results show that during the economic crisis, both fiscal revenue policy and fiscal expenditure policy are hard to achieve counter-cyclical regulation, so it is necessary to seek more supporting policy measures to promote macroeconomic growth in this special period. The effect of deficit scale on fiscal expenditure ($\varepsilon_D \rightarrow G^{exp}$) is negative during the sample period,

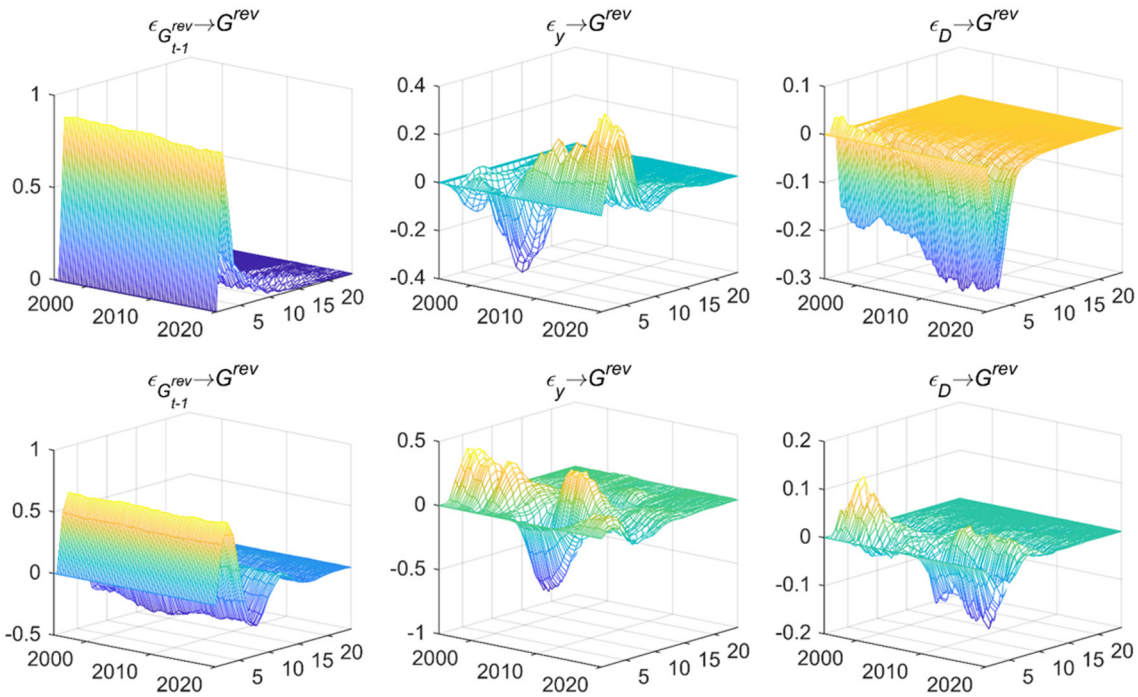

FIGURE 2 | Dynamic feedback on fiscal policy rules. Each subfigure with the title of "$X \rightarrow Y$" demonstrates the response of variable Y to an orthogonalized positive shock of variable X. In other words, X is an impulse variable, and Y is a response variable. One period in the figure denotes one season.

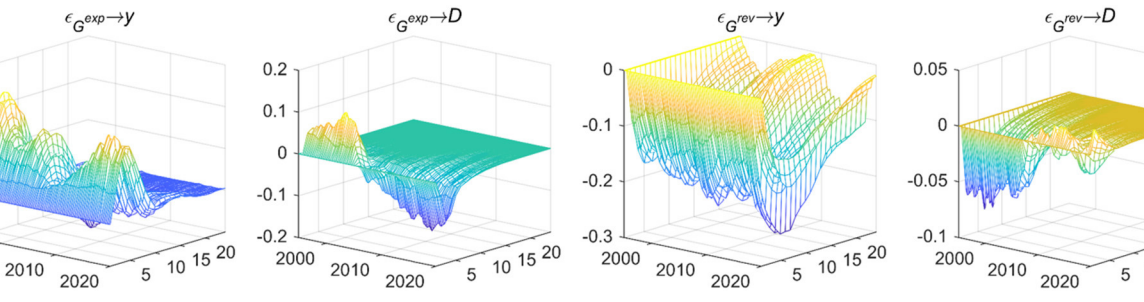

FIGURE 3 | The macroeconomic control effect of fiscal policy. Each subfigure with the title of "$X \rightarrow Y$" demonstrates the response of variable Y to an orthogonalized positive shock of variable X. In other words, X is an impulse variable, and Y is a response variable. One period in the figure denotes one season.

which means the fiscal expenditure policy that focuses on deficit scale can play an effective role in counter-cyclical regulation. And the dynamic feedback from deficit scale on fiscal revenue ($\varepsilon_D \rightarrow G^{rev}$) shows that the impulse response before the global economic crisis is positive and the immediate feedback after the crisis is also positive, however, the lagging response is obviously negative fluctuations, indicating that the complex economic situation will weaken the positive feedback of fiscal revenue policy to regulate and control the deficit scale. The results suggest that both expenditure-based and revenue-based fiscal policies are challenging to play a countercyclical role during the economic crisis. In this particular period, it is necessary to turn to more supportive policy measures to promote macroeconomic growth.

Fiscal expenditure shocks will lead to differential responses to output gaps and fiscal deficits in different periods as shown in **Figure 3**. Expenditure-based and revenue-based fiscal policies both have a time-varying effect on the output gap and the deficit scale. Before the crisis, they can effectively stabilize the output and deficit. However, maintaining the balance of government debt and boosting the economy faced unprecedented trade-offs after the crisis.

The above empirical results show that the external economic environment is an essential factor that affects the dynamic control effect of China's fiscal policy. Negative shocks in the economic system will have an impact on China's fiscal policy dynamic control mechanism. To deeply study the implementation

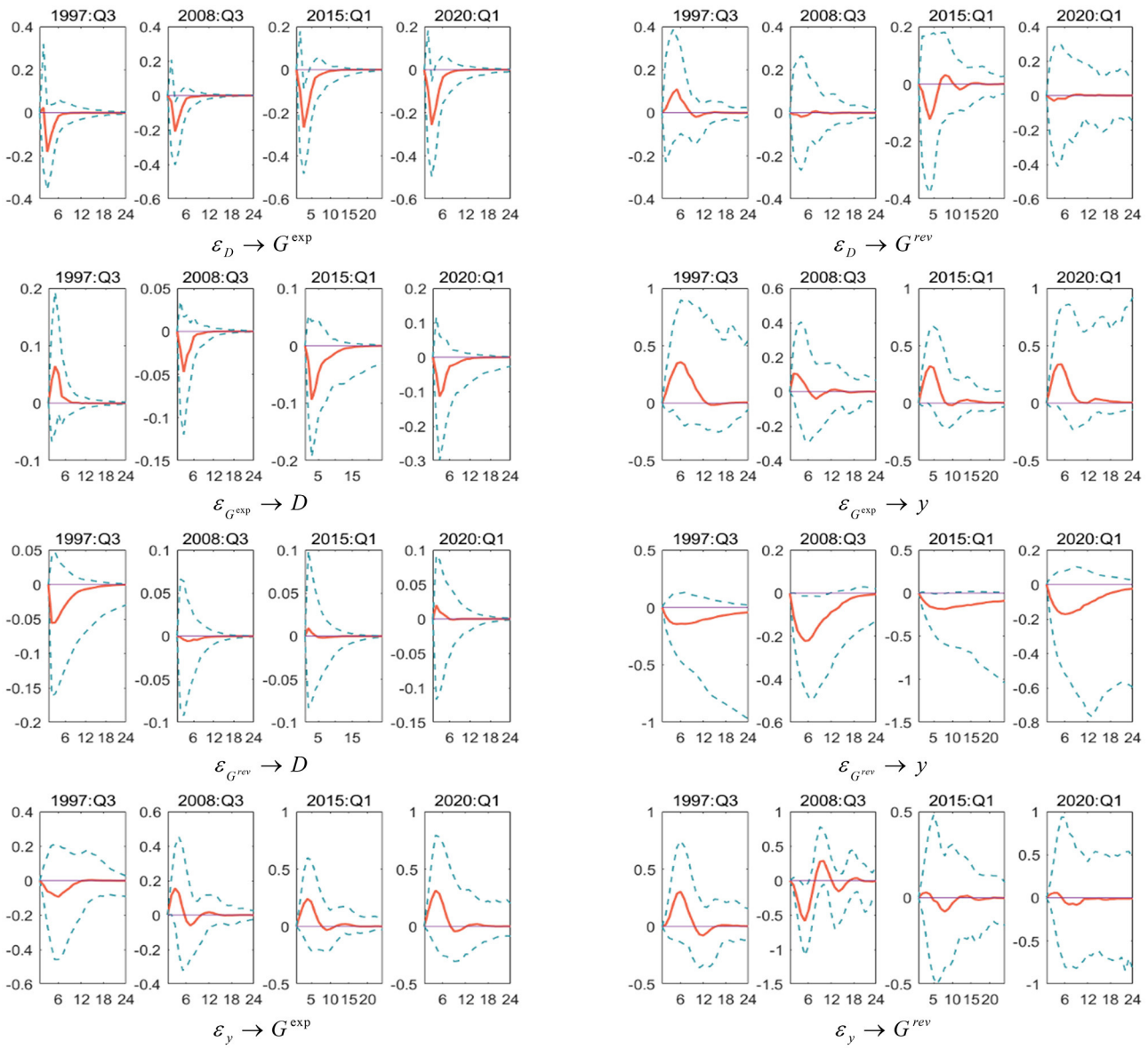

FIGURE 4 | Dynamic feedback trajectory of fiscal policy rules in particular period. Each subfigure with the title of "$X \rightarrow Y$" demonstrates the response of variable Y to an orthogonalized positive shock of variable X. In other words, X is an impulse variable, and Y is a response variable. One period in the figure denotes one season.

characteristics of China's fiscal policy under COVID-19 epidemic, the Southeast Asian financial crisis (1997 Q3) and the global economic crisis (2008 Q3) are selected. China's economy has wholly entered a New Normal (2015 Q1) and the COVID-19's impact (2020 Q1). Several particular time points where the economy has suffered a greater negative impact will be further horizontally compared and analyzed in the sampling interval. Moreover, we observed that fiscal policy has become more discretionary during the COVID-19 outbreak, indicating that when the economy is hit by the COVID-19 pandemic, it tends to flexibly adjust fiscal spending and revenue policies according to the economic situation, which is consistent with the economic fact that China has introduced a series of fiscal support policies in response to the COVID-19 outbreak.

As shown in **Figure 4**, the following important conclusions can be drawn: first, when the economic system is facing negative shocks, the complex and fragile economic environment will increase the difficulty of controlling expenditure-based fiscal policies. Among them, the procyclical feedback between fiscal policy, output gap, and the scale of the deficit after the global economic crisis is rising. Secondly, as the process of fiscal policy control evolves, the interaction time with macroeconomic variables has shortened, indicating that China's fiscal policy control measures are more precise, the dynamic adjustment mechanism does not have a long-term effect even in a particular period. The impulse response results in a special period further confirm the conclusions of the particular test in the text. It is worth noting that the longer period of interaction between fiscal policy variables during COVID-19 epidemic means that the implementation of fiscal policy during COVID-19 epidemic should be particularly cautious, because inappropriate policies are likely to have long-term adverse effects on the economy.

CONCLUSION

The main conclusions obtained in this paper are as follows:

From the empirical results, it can be seen that the time-varying parameter model can better capture the dynamic endogenous relationship between the output gap and the deficit's size during fiscal policy implementation, and there is evident continuity between expenditure-based and revenue-based fiscal policies. The fiscal expenditure policy has failed to show an excellent countercyclical control effect in recent years. Expansion of government fiscal expenditures during the economic downturn can quickly affect, but the government will spend a long time after fiscal expansion to calm economic fluctuations. The revenue-based fiscal policy's immediate regularity is apparent, effectively suppressing the output gap and reducing the deficit's size. It has a timely positive feedback endogenous adjustment effect, but the forward policy's regularity is significantly weakened. The dynamic fiscal policy control mechanism shows that since the global economic crisis, the impact of fiscal policy on the output gap and deficit scale has increased in procyclical effects, indicating that the complex and fragile economic environment has increased the difficulty of fiscal policy control, and the interaction time between fiscal policy variables has become significantly longer during the COVID-19 epidemic. Compared to targeting the deficit's size, fiscal expenditure and fiscal revenue have a more prominent feature of targeting the output gap. Also, due to article length and data availability limitation, the research conclusions still have limitations. In the future, it can be further developed and improved in terms of the mechanism of fiscal policy on macroeconomic regulation and the combination of macro and micro approaches.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

SW: conceptualization, methodology, software, formal analysis, data curation, writing—original draft preparation, and writing—review and editing. BZ, SW, and HG: validation. BZ: investigation, resources, supervision, project administration, and funding acquisition. HG: visualization. All authors contributed to the article and approved the submitted version.

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Tobacco Consumption and Mental Health in the Canary Islands: A Quantitative Analysis

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Although the detrimental health effects of tobacco, there has been scant research into determining comprehensive profiles to characterize individuals with a higher risk of smoking. This paper identifies such profiles and probabilistically quantifies the effects of certain traits on the decision to smoke in the Canary Islands. This characterization is approached from a broad and novel point of view for the region studied, given that the analysis not only studies sociodemographic characteristics, lifestyle and health, but also incorporates mental health. The results show that suffering from some type of psychopathology leads to a higher probability of tobacco consumption. Moreover, just as the promotion of a healthy lifestyle has a direct impact on tobacco consumption, the implementation of public policies that reduce the risks of suffering from a mental illness could also reduce the prevalence of smoking in the region and contribute to the design of more effective prevention strategies.

Keywords: tobacco, mental health, multinomial logit, profiles, prevention

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INTRODUCTION

The tobacco epidemic is one of the world's greatest public health problems, causing more than eight million preventable deaths each year (1). Further exacerbating this problem is that smoking's effects on others are equally harmful, even if tobacco is not used directly. These figures, together with the existing evidence on the devastating health effects of tobacco, make tobacco prevention policies of vital importance and very relevant topic in the academic literature.

Efforts to reduce tobacco consumption are implemented through different national policies and regulatory frameworks. However, given the importance of this public health problem, the World Health Organisation (WHO), at a supranational level, promotes a range of measures. Recently, it presented the "WHO Report on the Global Tobacco Epidemic, 2021. Addressing new and emerging products" (2). This report is based on the Framework Convention on Tobacco Control (3) and the MPOWER strategy (4). It points out that alternative forms of smoking, such as smokeless tobacco or water pipes, also pose a high risk to health, as well as being a strong source of addiction. It also highlights the need for tobacco users to have help in coping with the process of quitting as an effective way to reduce consumption.

The need, therefore, to curb tobacco consumption means public policies aimed at this objective must be as effective as possible. These include legislative regulation to reduce tobacco consumption and regulating its sale, advertising or consumption in public places. If we analyse the effects of these types of laws in Spain, as these are applicable in the region under study (Canary Islands), we should highlight Law 28/2005, 26 December (5) and Law 42/2010, 30 December (6). Although not only in Spain (7, 8), there are many studies that demonstrate the usefulness

of these regulations in terms of prevention (9). In addition, they have not had a negative collateral effect on other aspects, such as economic activity in the hospitality industry (10, 11), despite the total bans on smoking, thus making anti-smoking laws an even more useful instrument. However, although their effectiveness has been demonstrated, they have not been enough to reduce smoking rates, among other things, because the effect of these regulations seems more favorable in individuals from higher social classes (12). Thus, there is a clear need to continue working on regulations, since, in fact, it is this group that consumes the least tobacco (2). In the specific case of the Canary Islands, despite the positive effects generated by the above laws, "further progress must be made jointly in legislative, fiscal and social measures to reduce tobacco consumption" (13), especially as the effects of the laws have been diminishing over the years.

Moreover, according to the literature, prevention policies are also very important, beyond the approval of laws and taxation, especially those based on the specific characteristics that pose the greatest risk of tobacco use. Some studies point to the higher prevalence of tobacco consumption in men, as well as that age, increased income or a higher level of education discourage tobacco consumption (14–16). The prevalence in the case of smokeless tobacco is also higher for men, older, married and belonging to population groups with fewer resources (17). Know these profiles would allow policies to be properly targeted with better results, as the lack of targeting of groups with higher prevalence seems to be one of the main causes for their lack of success (18). However, to date, no studies have been found that, at a significant level of detail, characterize individuals on whom to focus strategies, which is the main line of study of this paper.

This work is confined to the Spanish region of the Canary Islands. This autonomous region, located 1,700 km from the Iberian Peninsula, is made up of eight islands, divided into two provinces. Its GDP per capita in 2021 was equivalent to 75.6% of the national GDP per capita. It is worth mentioning the differences in taxation between the archipelago and the rest of Spain, given that the islands not only have lower value added taxes, which means lower taxation on tobacco consumption, but also that the same tax on tobacco products that is applied throughout Spain is not applicable in the Canary Islands.

Among the total population of the Canary Islands aged 15 years and over, 22.3% use tobacco daily, compared to 22.1% at the national level (19). However, despite not being one of the Spanish regions with the highest proportion of tobacco users, (20) do rank as the region with the highest mortality rate attributed to tobacco use in women.

One characteristic of the archipelago is its status as an outermost region of the European Union, as well as the fact it is a region fragmented into different islands. Logically, this condition affects public health services (21). This means that the non-capital islands are affected by double insularity and are limited in their access to these services. As a result, the necessary support by health services in smoking cessation processes may be reduced. In terms of prevention and characterization of tobacco user profiles, there have been few studies conducted in the region. Among those available, (22) point out that tobacco consumption starts at an earlier age in the Canary Islands than in other regions. Likewise, in a study of adolescents, (23) conclude that some of the factors that explain tobacco consumption are related to the school or high school that individuals attend, supporting the idea proposed by other authors (24–26), where it is argued that the most effective prevention begins in schools. Finally, (27) conclude that the effect of "the group of friends, the consumption of alcoholic beverages and the lack of interest in studies" play an important role in the initiation of tobacco use, an idea that is in line with that expressed by authors such as (28), who emphasize the need to demystify and denormalize tobacco use in social and family settings.

On the other hand, one aspect that, until now, has not been considered in the literature framed in the Canary Islands as an explanatory factor of smoking is mental health. The following paragraphs introduce this idea and provide some of the evidence found on the relationship between smoking and mental health.

Mental health, within this work, is understood as psychological and emotional wellbeing, i.e., it is defined as something broader than the absence of mental disorders diagnosed by a doctor. This definition is in line with the WHO Constitution (29), which defines health as "a state of complete physical, mental and social wellbeing and not merely the absence of disease or infirmity." Given the current importance of mental health, the WHO itself, as well as various states, are developing regulations that serve to protect and preserve the mental health of citizens. Specifically, in 2013, the World Health Assembly of the WHO approved the Mental Health Action Plan 2013–2020 (30), whose overall objective is to "promote mental health, prevent mental disorders, provide care, improve recovery, promote human rights and reduce mortality, morbidity and disability of people with mental disorders" (31).

In this regard, given the importance that mental health has been gaining, especially in recent years, several studies have examined its relationship with different socioeconomic variables (32–34) and with different personal situations, such as unemployment (35, 36) or economic crises (37–39). Regarding the relationship between mental health and tobacco consumption, the results of the work of (40) show that suffering from a mental disorder entails a higher risk of tobacco consumption. Along the same lines, (41) stress the need to implement specific plans aimed at preventing smoking among people with addictions or mental disorders. Zander Neves et al. (42) conducted a study among adolescents that led to the same conclusion, i.e., mental health, in addition to other characteristics such as family context, have a direct implication in the experimentation and use of tobacco among the group analyzed. Similarly, (43) point to the potential relationship between mental state and tobacco use, although they qualify the need to implement policies aimed at reducing the consumption of tobacco products in general, and not only focus on cigarettes.

Consequently, the aim of this work is to identify specific profiles of individuals who are more or less likely to smoke based on socio-demographic, lifestyle and health characteristics, with special attention to mental health. In short, the aim is to propose, in detail, which characteristics have a higher risk of consumption, using the probability associated with each characteristic as a classification factor. To achieve this objective,

this work, in addition to the introduction, has a section dedicated to the data used, after which the methodological tool used, a multinomial logit model, is presented. This is followed by a section with the results of the estimated model, its main implications and conclusions.

MATERIALS AND METHODS

Data

The data come from the 2015 Canary Islands Health Survey, conducted by the Canary Islands Institute of Statistics (44), which is the most recent source of health data available for the Autonomous Region of the Canary Islands. Specifically, the adult questionnaire was used for the population aged 16 and over, and the following variables were considered: socioeconomic variables of the individual, lifestyle habits, such as alcohol consumption or physical activity in their daily routine, and determinants of health status, like self-perceived health status or the presence of chronic diseases. With respect to chronic disease, 30 different diseases are included in the questionnaire. In this work, a dichotomous variable has been defined that indicates the presence of chronic disease and takes the value 1 if the individual has been diagnosed by a doctor with at least one of the chronic diseases included in the questionnaire and 0 otherwise.

In addition, obesity has been considered, as a way of capturing bad eating habits, quantified through the body mass index. Finally, an aspect of interest is the inclusion of the individual's mental health in the analysis to assess its impact on the decision to smoke.

The survey collects an individual's mental health through the GHQ-12 questionnaire that screens for possible current mental disorders (44). According to (45), this questionnaire, whose validity has been demonstrated for the Spanish population, can be used to assess psychological wellbeing and detect non-psychotic psychiatric problems. It is the same questionnaire that has been used in the National Health Survey of Spain for decades to assess mental health. The GHQ-12 is a reliable instrument as a one-dimensional test, it is a general construct of psychological distress that can be used as an initial screening (46). Specifically, it includes 12 items that, as indicated by (47), capture both the individual's psychological wellbeing and social functioning and ability to cope with worries. The questionnaire asks the individual whether during the last 30 days he or she has experienced, on a Likert-type scale, various issues related to mental health: able to concentrate, difficulty falling asleep, playing a useful part, decision-making ability, felt constantly under strain, couldn't overcome difficulties, able to enjoy day-to-day activities, able to face problems, feeling unhappy and depressed, loss of confidence, thinking of self as worthless, feeling reasonably happy. It is therefore an assessment of the individual's subjective mental state. In the Likert-type scale, 0–1–2–3, high scores indicate worse health. From the original scores, they are recoded in a dichotomous way: 0 (responses 1 and 2) and 1 (responses 3 and 4). In this way, the sum of the recoded scores ranges between 0 and 12 points.

To determine the existence or not of a mental disorder based on this questionnaire, various cut-off points have been used in the literature depending on the country [see the works cited by (47)]. In the case of Spain, (48) and (49) use scores above five as a cut-off point as indicators of psychopathology, transforming each item, which has four possible answers, into a dichotomous score. In (47) use as a cut-off point scores above the mean to indicate the presence of mental vulnerability. In the recent work by (50), they also use the GHQ-12, classifying individuals according to the absence of psychopathology (scores below 4), suspected psychopathology (between 5 and 6) and indicative of psychopathology (7–12).

In the present study, several indicators were considered to assess the absence of mental health or the presence of a disorder. Firstly, a score above 3 in the 12 items collected was considered as a cut-off point (51–53). According to this definition, 27.6% of the Canary Island population has mental health problems. Additionally, a second alternative was constructed considering the absence of good mental health to be those individuals whose score was above the mean plus one standard deviation (score above 5), representing 16.2% of the population. Finally, a score above 8 (score above the mean plus two standard deviations) was considered to identify individuals with a mental pathology. With this last, more restrictive criterion, the prevalence of mental health problems in the population is 7.8%.

The consideration of several indicators was motivated by the absence of a single indicator to assess mental health (54), as well as by the possible overestimation of mental health problems that, according to (51), the GHQ-12 produces, as it is a screening instrument that is more sensitive than specific. Taking this into account, mental health defined with the most restrictive criterion was included as an explanatory variable in the estimated model.

From a descriptive point of view, **Table 1** presents the percentage of individuals who, within each explanatory variable, choose each of the smoking categories considered in this study. In relation to gender, the behavior of men and women differs, with men showing a higher proportion of smokers (30.3% of men and 23.3% of women) and ex-smokers (25.0% of men and 12.1% of women), while the majority of women are concentrated in the "never smoked" category (64.6%). The distribution according to age ranges also varies, with the intermediate age groups (26–45 years old and 46–65 years old) having the highest levels of smokers. However, although with differences in magnitude, the educational level categories behave similarly. Among the variables related to the individual's lifestyle, the positive relationship between alcohol consumption and smoking stands out at a descriptive level, since the higher the consumption of alcohol, the higher the concentration of smokers (from 18.3 to 39.1%). In terms of health, the contrast between having or not having a chronic disease does not seem to show a notable difference in the level of smokers; however, the gap within the category of ex-smokers reaches almost 10 percentage points. From the exploratory analysis of the mental health variable, it can be concluded that, among individuals with good mental health, the percentage of non-smokers is higher than among those with a psychopathology (56.7 and 50.9%, respectively), while the difference in the percentage of smokers is even greater, thus showing opposite and differentiated behaviors. It should be noted that, considering only smokers, 10.3% of them have mental health

TABLE 1 | Tobacco use by characteristic and habits (%).

	No smoking	Ex-smoker	Smoker
Gender			
Women	64.6	12.1	23.3
Men	44.7	25.0	30.3
Age			
15–25	68.2	4.7	27.1
26–45	56.2	13.0	30.8
46–65	46.2	20.9	32.9
>65	68.3	21.8	9.9
Family status			
Married-partnered	57.5	21.2	21.3
Level of education			
Non-university studies	55.4	17.4	27.2
University studies	60.0	18.0	22.0
Income level			
Less than €500	48.8	14.3	36.9
500–2,000	57.5	17.5	25.0
More than €2,000	56.4	20.9	22.7
Do you make physical activity part of your daily routine?			
No	60.3	16.5	23.2
Yes	54.0	18.0	27.8
Alcohol consumption			
Never	68.1	13.6	18.3
Occasionally	54.3	17.2	28.5
Usually	33.2	27.7	39.1
Body mass index			
Obesity	58.9	21.6	19.5
Self-perceived health status			
Good	57.9	16.6	25.5
Fair	54.4	19.3	26.3
Bad	47.8	19.7	32.5
Chronic disease			
No	59.7	10.8	29.5
Yes	55.5	18.9	25.6
Mental health			
Not good	50.9	14.6	34.5
Good	56.7	17.7	25.6

problems, while among the individuals in the sample who have never smoked, 7% declare they have some mental health problem.

Methodology

In this paper, a discrete choice model is used to adequately capture the individual decision-making process from among a finite set of alternatives (55). A theoretical justification for these models is based on the Random Utility Theory approach, (56) in which it is assumed that individuals are rational and make decisions to maximize utility. Thus, the probability that an individual *i* chooses alternative *j* can be defined as the probability that this alternative has the highest utility among the set of possible alternatives (57). Utility of individual *i* for alternative *j* (U_{ij}) can be expressed:

$$U_{ij} = V_{ij} + \varepsilon_{ij} \tag{1}$$

Where V_{ij} is the systematic part, a set of explanatory variables (characteristics of the individual and attributes of the alternative), and ε_{ij} is the random part that includes the unobservable or measurable factors. Individual *i* will choose alternative *j*, if and only if:

$$U_{ij} > U_{ik}, \quad \forall \, \mathrm{k} \neq \mathrm{j}$$

Thus, the probability that individual *i* chooses alternative *j*, can be expressed as:

$$P\left(Y_i = j\right) = P\left(U_{ij} > U_{ik}\right) = P\left(\varepsilon_{ik} - \varepsilon_{ij} < V_{ij} - V_{ik}\right) \quad \forall \, \mathrm{k} \neq \mathrm{j}$$

The number of alternatives from which the individual must choose, the ordered or unordered nature of the dependent variable, as well as the distribution assumed for the vector of disturbance terms will determine the model finally specified. In this paper, since more than two unordered alternatives are considered, a multinomial specification is chosen. Furthermore, assuming independent type I (Gumbel) extreme value distributions, the multinomial logit model is obtained where the probabilities of each alternative can be expressed:

$$P\left(Y_i = j\right) = \frac{e^{x_i' \beta_j}}{1 + \sum_{k=1}^{J} e^{x_i' \beta_k}} \quad j = 1, \ldots, J$$

$$P\left(Y_i = 0\right) = \frac{1}{1 + \sum_{k=1}^{J} e^{x_i' \beta_k}} \quad j = 0$$

Where x_i is the vector of explanatory variables, and β is the set of parameters to be estimated.

RESULTS

A multinomial logit model was estimated to explain the decision to use tobacco. The independence of irrelevant alternatives (IIA) was tested through the Hausman specification test (58). The dependent variable of the model is the consumption decision, which consists of three alternatives: no smoking (reference alternative), ex-smoker, smoker. The vector of explanatory variables, which includes individual, lifestyle and health characteristics, is made up of dichotomous variables that take the value 1 if the individual takes the characteristic in question and 0 otherwise. **Table 2** presents the results of the model estimation. The table indicates the reference categories for each of the dichotomous variables considered in the model. However, to quantify the effect of each variable on the probability of each alternative, discrete changes must be obtained, since the parameters are not directly interpretable in magnitude or sign.

Discrete changes are defined as the difference between the probability of each alternative when the individual shows a certain characteristic and when not presenting it. From the discrete changes, calculated for each alternative and for each

TABLE 2 | Estimates of the multinomial logit model.

	Ex-smoker	Smoker
Constant	−3.8940***	−1.3379***
Gender		
Women (ref.)		
Men	0.9961***	0.4766***
Age		
15–25 (ref.)		
26–45	1.0695***	0.5274**
46–65	1.6487***	0.7354***
>65	1.3040***	−0.9016***
Family Status		
Single (ref.)		
Married-partnered	0.02725	−0.5187***
Level of education		
Non-university studies (ref.)		
University studies	−0.0565	−0.4608***
Income level		
Less than €500 (ref.)		
500–2,000	−0.0656	−0.3809**
More than €2,000	0.0777	−0.5226**
Do you make physical activity part of your daily routine?		
No	−0.2289**	−0.1258
Yes (ref.)		
Alcohol consumption		
Never (ref.)		
Occasionally	0.4338***	0.5998***
Usually	1.0863***	1.3798***
Body mass index		
No obesity (ref.)		
Obesity	0.1144	−0.4625***
Self-perceived health status		
Good (ref.)		
Fair	0.2589**	0.2959**
Bad	0.5462**	0.7688***
Chronic disease		
No (ref.)		
Yes	0.6591***	0.2125*
Mental health		
Good (ref.)		
Not good	−0.1390	0.3262*

$N = 3{,}660$ $\chi^2(32) = 744.47$ (0.0000) $R^2_{MCF} = 0.1038$.
Percentage of correct predictions = 60.1%.
*Levels of significance: ***P < 0.01; **P < 0.05; *P < 0.10.*

individual in the sample and then averaged, the effects of the different characteristics on the probability of choosing each alternative can be observed (**Table 3**). Gender differences are confirmed, with men being more likely to smoke than women. The value 0.0369 of the discrete change in smoker alternative indicates that this probability is 3.6 percentage points (pp) higher for men. Individuals aged between 26 and 65 are more likely to smoke than younger individuals. The higher the income level, the lower the individual's probability of smoking compared to individuals with an income of less than €500 that is the reference category (between 6.4 and 8.7 pp lower). If the individual has a university education, his or her probability of smoking is 7.2% lower than if he or she does not have one (see the negative sign of the discrete change for university studies). The educational level was considered as university studies opposed to another because it is the category that presents a differentiated behavior with respect to the rest of the levels. In relation to bad lifestyle habits, not engaging in physical activity in their daily routine decreases the probability of smoking, and alcohol consumption, especially regular consumption, is positively associated with smoking (20.1% more likely to smoke than an individual who does not consume alcohol). With regard to the result for physical activity, it should be noted that this variable refers to habitual routine activity, i.e., physical activity carried out during the normal working day, study or, for example, housework. This definition means that its interpretation has more to do with daily routine than with the intention to do sport, so that the sign it takes could be explained by a sedentary lifestyle. This result could also be explained by the negative effect of a higher level of education and income on the probability of smoking, as these characteristics are usually associated with people who have jobs that tend to be sedentary.

Regarding the obesity variable, the discrete changes indicate that this characteristic discourages consumption, since it increases the probability of not smoking (+4.33 pp) and reduces that of smoking (−7.99 pp). Although, a priori, it might be expected that the accumulation of bad habits would also include a potentially bad diet, given the characteristics of the sample, the result is consistent. In the sample, specifically, the second group with the highest percentage of obese people in descriptive terms is the over-65s, who in turn have the lowest percentage of obese smokers (4% compared with more than 20% in the other groups). The latter could explain the negative sign of the discrete change in this variable, bearing in mind that, in addition, by medical prescription, the over-65s with obesity should stop smoking (a group with more ex-smokers) to avoid extra risk factors in addition to their age and Body Mass Index.

In relation to health, the presence of chronic disease or the presence of fair or poor health have a greater impact on the likelihood of smoking (positive discrete changes). In the case of chronic illness, a higher probability of smoking on a daily basis may be related to the definition of the variable itself. In the survey, from the list of long-term or chronic diseases, some are considered, such as allergies, skin problems, cataracts, chronic constipation or hemorrhoids, which may not necessarily influence the individual to quit smoking.

In terms of mental health, individuals with some psychopathologies are 6.5% more likely to smoke than individuals without these pathologies (reference category). Although several models were estimated considering the mental health variable according to the three indicators mentioned in the description of the data, the best model turned out to be the one that incorporates the most restrictive criterion to determine the presence of psychopathology in individuals.

TABLE 3 | Discrete changes of the multinomial logit model.

	No smoking	Ex-smoker	Smoker
Gender			
Men	−0.1544***	0.1175***	0.0369**
Age			
26–45	−0.1620***	0.1287**	0.0333
46–65	−0.2463***	0.2021***	0.0442
>65	−0.0619	0.2539***	−0.1920***
Family status			
Married-partnered	0.0628***	0.0278**	−0.0906***
Level of education			
University studies	0.0602**	0.0122	−0.0724***
Income level			
500–2,000	0.0552**	0.0092	−0.0644***
More than €2,000	0.0528*	0.0337	−0.0866***
Do you make physical activity part of your daily routine?			
No	0.0360**	−0.0246*	−0.0114
Alcohol consumption			
Occasionally	−0.1131***	0.0303**	0.0829***
Usually	−0.2782***	0.0773***	0.2010***
Body mass index			
Obesity	0.0433**	0.0366**	−0.0799***
Self-perceived health status			
Bad	−0.1476***	0.0340	0.1136***
Fair	−0.0605**	0.0210	0.0395**
Chronic disease			
Yes	−0.0799***	0.0699***	0.1003
Mental health			
Not good	−0.0331	−0.0326	0.0656**

*Levels of significance: ***P < 0.01; **P < 0.05; *P < 0.10.*

TABLE 4 | Predicted probabilities for each alternative by mental health.

	No smoking	Ex-smoker	Smoker
Not good mental health	0.5087	0.1463	0.3449
Good mental health	0.5669	0.1776	0.2556

Table 4 presents the probabilities predicted by the model for individuals in the sample identified with and without some form of mental psychopathology. The probability of smoking for an individual with good mental health is 25.56%, while this probability is 34.49% for an individual who has some mental problem (varies by almost 9 percentage points). These results corroborate the importance of considering mental health as a risk factor when designing tobacco prevention and control policies more effective for this segment of the population and they are in consonance with other studies (59, 60).

Moreover, sub-sample multinomial models were also estimated for different individuals according to their reported mental health, i.e., for individuals with or without psychopathology. However, the results obtained showed worse fits, in terms of comparison with the full-sample models, so this proposal was discarded.

TABLE 5 | Predicted probabilities for each alternative.

	No smoking	Ex-smoker	Smoker
Individual most likely	0.9489	0.6533	0.7888
Individual least likely	0.0609	0.0106	0.0122

We also considered including a variable for affective and personal support as an explanatory factor for the decision to smoke. This would assess the extent to which having greater social support, either from family or friends, may influence an individual's smoking behavior. However, this variable was not significant in the decision to use tobacco.

It is also interesting calculating the probabilities predicted by the model for the profiles of individuals most and least likely to make each smoking decision detected from the discrete changes obtained. **Table 5** shows significant differences for each of the alternatives. For example, an individual with characteristics most likely to smoke have a probability of 78.88%, while the probability of individual least likely is lower than 1.5%. The notable differences highlight the need to take into account the profiles of individuals in the design of effective prevention policies.

CONCLUSIONS

The aim of this work is to identify the profiles of individuals with a higher prevalence of smoking in the Canary Islands. We not only characterize individuals with a higher propensity to smoke, but also for non-smokers or ex-smokers. The analysis carried out, through the estimation of a multinomial logit model, allows us to quantify probabilistically the effects of individuals' socio-economic traits, as well as their life habits and health, both physical and mental, the latter understood as psychological and emotional wellbeing. Precisely, the consideration of the mental health indicator is one of the contributions of the work, not only because of the interest of incorporating mental health as an explanatory variable, a novel aspect in studies of this type, but also because of the difficulty it entails, as there is no consensus in the literature on how to define this indicator. Among the main results found, the positive relationship between greater tobacco consumption and the presence of some mental psychopathology stands out, revealing the importance of implementing policies of promotion and education on not only physical but also mental health care. On the other hand, there could be a multiplier effect on consumption for those individuals of male gender, with intermediate ages, low-income level, non-university studies, who consume alcohol frequently and have a poor health status, since these traits have a positive influence on smoking. In the case of ex-smokers, the traits that generated a greater propensity to smoke are male, over 65 years of age, with a university education, high income level, who consumes alcohol, no psychopathology and poor physical health, both in terms of their self-perceived state of health and the presence of chronic illness or obesity.

However, the profile of the individual most likely to be a non-smoker is that of a young woman, under 26 years of age, with a university education, high income, who does not routinely engage in physical activity (associated with jobs requiring less physical effort), who does not consume alcohol and is in good physical and mental health.

The relevance of characterizing in detail the profile of individuals who use tobacco, but also of non-users, as well as ex-smokers, is key when defining prevention strategies that are not limited to regulation, but also direct the focus of policies toward those individuals who have a higher prevalence of consumption. Likewise, the analysis is particularly interesting for the geographical area chosen, given its status as an outermost region. Therefore, there is an added difficulty in designing prevention control strategies by the health service, as well as the differences in terms of legislation and taxation compared to the rest of the country, as far as tobacco is concerned, and the incidence of the habit in the young population of the Canary Islands. Based on the results found, regardless of the exact quantification of the incidence of each of the characteristics analyzed on the probability of smoking, it seems necessary to direct policies to discourage consumption toward individuals who, based on the profiles found, are more likely to smoke. Specifically, education should be encouraged at an early age, starting in schools, discouraging smoking, so that young people who do not go on to higher education and who may possibly have a lower paid job, requiring greater physical effort, with the consequent impact on their psychological and mental wellbeing, do not take up the habit. It is also concluded that the simultaneous implementation of prevention policies that preserve mental health and promote the reduction of alcohol consumption among the population, while at the same time implementing smoking prevention plans, may make the latter more likely to be successful.

As lines of future research, from a methodological point of view, we intend to explore the consideration of the heterogeneity associated with individuals' decisions through the specification and estimation of mixed models. From the economic point of view, it would be useful to study the criterion for determining individuals according to their state of mental health and to carry out the analysis in successive periods. Finally, it would be valuable to compare the profiles identified with those of other outermost regions in order to detect whether there are similar behavioral patterns. In addition, it is of interest to analyze the differences that, in terms of the study carried out, may occur between the different Autonomous Communities or regions of Spain, including in the analysis characteristics of the analyzed territory.

DATA AVAILABILITY STATEMENT

The data analyzed in this study is subject to the following licenses/restrictions: The anonymized microdata must be requested from the Instituto Canario de Estadística. Requests to access these datasets should be directed to http://www.gobiernodecanarias.org/istac/.

AUTHOR CONTRIBUTIONS

IN-G contributed to conceptualization, investigation, data curation, formal analysis, methodology, validation, writing-original draft, and writing-review and editing. MR-D contributed to conceptualization, investigation, data curation, formal analysis, methodology, validation, writing-original draft, writing-review and editing, and supervision. GG-P contributed to conceptualization, data curation, methodology, writing-original draft, writing-review and editing, and supervision. All authors contributed to the article and approved the submitted version.

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Government Health Expenditure, Economic Growth, and Regional Development Differences—Analysis Based on a Non-parametric Additive Model

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Government health expenditure plays an important role in guaranteeing people's livelihood and in improving the quality of human capital, and it also plays an important role in affecting economic development. In order to characterize the specific trend of government health spending affecting economic growth, and analyze the impact difference in different regions, this paper uses a non-parametric additive model to analyze the impact of government health expenditure on economic development and regional development differences based on three aspects: linear, non-linear and comprehensive effects. From the perspective of linear effects, the results show that the proportion of government health expenditure to GDP nationwide and in the western regions has a positive impact on economic development, while the impact in the eastern and central regions is negative. From the perspective of non-linear effects, in the national and in the eastern, central and western regions, the proportion of government health expenditure to GDP has a significant non-linear impact on economic development. From the perspective of comprehensive effects, the proportion of government health expenditure to GDP has a significant non-linear positive effect on economic development nationwide and in all regions. In addition, the proportion of fixed assets investment to GDP, the proportion of exports to GDP, and the proportion of residents' income to GDP promote non-linear effects to different extents of non-linear promotion, but there are slight differences in different regions. Based on estimation results, the paper recommends that the government further expands the proportion of government health expenditure in GDP, promotes investment in fixed assets, stimulates exports in the eastern region, and continues to implement the western support policy.

Keywords: government health expenditure, economic growth, regional development differences, non-parametric additive model, non-linear effects

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INTRODUCTION

Report on the work of the government (1) pointed out that "Setbacks in economic globalization, challenges to multilateralism, shocks in the international financial market, and especially the China-US economic and trade frictions, had an adverse effect on the production and business operations of some companies and on market expectations. What we faced were severe challenges caused

by the growing pains of economic transformation. An interlacing of old and new issues and a combination of cyclical and structural problems brought changes in what was a generally stable economic performance, some of which caused concern. What we faced was a complicated terrain of increasing dilemmas. We had multiple targets to attain, like ensuring stable growth and preventing risks, multiple tasks to complete, like promoting economic and social development, and multiple relationships to handle, like that between short-term and long-term interests. And the difficulty of making policy choices and moving work forward increased markedly." China's economic development faces a complex and severe external environment, as well as economic challenges due to intertwining contradictions and structural transformation, bringing great difficulties for the steady advancement of China's economy. Therefore, in order to achieve sustained and steady economic growth, we need to begin with all aspects of promoting economic development. Over the years, economic development has always been an important factor influencing national development and social stability. It is the focus of the country and its people, and it is also the focus of many scholars. Regarding existing research at home and abroad, some studies focus on human capital and economic development, such as Xu and Li (2), who studied the relationship between innovative human capital and provincial economies. Zeqiraj et al. (3) found that human capital has a great impact on economic growth. Wang (4) found that human capital in Northeast China plays a decisive role in economic growth. Chen et al. (5) found that human capital has a decreasing impact on the economy in China from east to the west in China. Liu and Xia (6) found that an improvement in the human capital level has a significant role in promoting the quality of economic growth in a province, but has a negative impact on the quality of economic growth in neighboring provinces.

Some studies focus on technological development and economic development. For example, Mensah et al. (7) studied the impact of technological innovation on 28 economies of the Organization for Economic Co-operation and Development (OECD) from 2000 to 2014. Singh et al. (8) studied the relationship between grassroots technological innovation and sustainable development. Ma et al. (9) studied the relationship between urban infrastructure, technological innovation and regional economic development. Wang (10) studied technological innovation in a regional circular economy. Li (11) carried out research on the impact of agricultural technological innovation on agricultural economic development. Song (12) analyzed the relationship between technological innovation and economic growth in Shandong Province.

Although there are many studies on economic development, there are few studies on economic development and government health expenditure, most of which focus on the relationship between medical insurance, personal medical expenditure, and government fiscal expenditure, such as Benoît and Coron (13), who analyzed the financialization of private health insurance in France. Karunaratna et al. (14) studied the effectiveness of compulsory social insurance schemes in regard to the financial burden of patients. Yao et al. (15) analyzed the impact of microhealth insurance on maternity-related costs. Only a few studies have investigated the relationship between health expenditure and economic growth, such as Kumar et al. (16), Zhao et al. (17), Atems (18), Lee et al. (19), Halici-Tülüce et al. (20), Wang and Lee (21), and Wang (22). Regarding the relationship between health expenditure and growth, most studies only analyze only its linear effects, while the increase of government health expenditure can promote the increase of medical and health resources, thereby creating more and better medical conditions for the residents, which can promote the

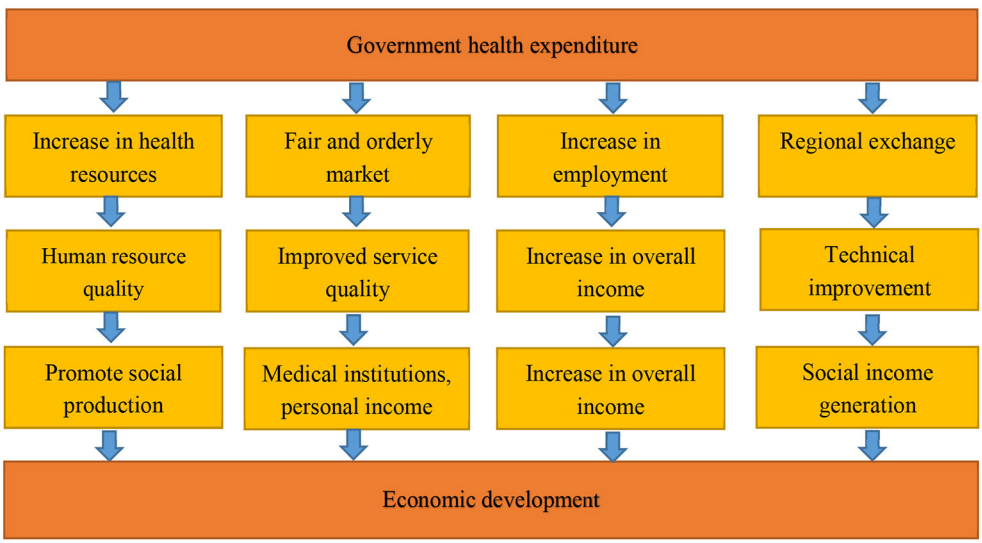

FIGURE 1 | Mechanistic conduction route.

improvement of the health level of human resources and prolong the life expectancy. It can further increase average working hours and socioeconomic benefits. So it may have a non-linear impact. Only a few analyze the non-linear effects, the specific form of influence is not analyzed in detail; thus, its specific trend is still not accurately captured. The study aims to fill in the gaps in extant scholarship.

In 1985, the additive model proposed by Stone (23) does not need to specifically set the relationship between variables. It does not limit the relationship between variables to a specific form, but can automatically fit according to the observed values. It makes the relationship between variables more accurate and specific. The non-parametric additive model incorporates a linear part on the basis of the additive model. It not only can describe the linear relationship between variables, but also can specifically describe the specific non-linear effects between variables. Although the fitting curve of the non-parametric additive model cannot be represented by a function, and the parameter estimates cannot be given, this prediction effect is better than that of the pure parametric model. Therefore, the paper adopts a non-parametric additive model to analyze the impact of government health expenditure on economic development.

As an important expenditure of government finance, government health expenditure is an important factor affecting the development of the health industry of a nation and the health of its people. It also has a non-negligible impact on economic development. How and how much does government health expenditure impact economic development? This study is guided by this important research question. This study conducts a detailed analysis of this issue to meet the following objectives:

The paper not only analyzes the linear relationship between government health expenditure and economic development but also examines the trend of its non-linear influence, clarifying the impact of government health expenditure on economic development.

It uses a non-parametric additive model to further explore the impact of government health expenditure on economic growth, analyzes the differences in the impact of different regions, and supplements and expands the research methods related to this problem.

It combine linear effect analysis, non-linear effect analysis and comprehensive effect analysis with novel angles, supplements and improves the theoretical research related to this problem, and provided theoretical support for macroeconomic regulation and long-term, stable economic development.

Following this introduction, this paper has five parts: the first part presents the theory and the model. The second part describes the selection, use and processing of the indicators and data. The third part tests the applicability of the model. The fourth part conducts a discussion and analysis of the estimation results. The fifth part summarizes the conclusions of the paper and proposes targeted policies.

TABLE 1 | Explanation of the variables.

Variable	Symbol description	Variable interpretation
Per capita GDP	Avegdp	Gross domestic product/total population
The proportion of government health expenditure to GDP	RDhealth	Government health expenditure/gross domestic product
The proportion of fixed assets investment to GDP	RDassets	Total fixed assets investment/gross domestic product
The proportion of exports to GDP	RDexport	Total exports/gross domestic product
The proportion of residents' income to GDP	RDincome	Total resident income/gross domestic product
The level of urbanization	lDurban	Permanent resident population/total population
The proportion of the elderly population	lDold	Elderly population/total population

THEORY AND MODEL

Theoretical Analysis

The government can have different impacts on society through health investment, which then directly or indirectly connects with economic development. In the current social development environment, Tao and Wang (24) analyzed the effect of government health expenditure on economic development based on the following aspects:

The government promotes the development and improvement of the medical and health market by increasing financial and medical investment and medical system reform, thereby creating a fair, orderly and efficient medical and health market, creating a sound medical and health economic system and improving medical institutions and medical care. The quality of personnel services promotes the effective improvement of medical technology and work efficiency, greatly improves the medical quality of hospitals, promotes the economic income of hospitals and medical personnel, and promotes economic efficiency.

Increases in financial and medical investment promote increases in medical and health resources, promote the scale of medical resources, and thus create more and better medical conditions for residents. Such increases can promote the improvement of human resource health and extend life expectancy, and workers can serve society. The increase in the average labor time provided will increase social and economic benefits, and it can promote the improvement of human resources technology and creativity, promote the innovative development of enterprises and industries, and effectively improve the rapid development of the economy.

Financial labor input can promote the employment of the labor force, and it can provide workers with stable and sustained economic income. Furthermore, ensuring the quality of life of workers can appropriately increase the

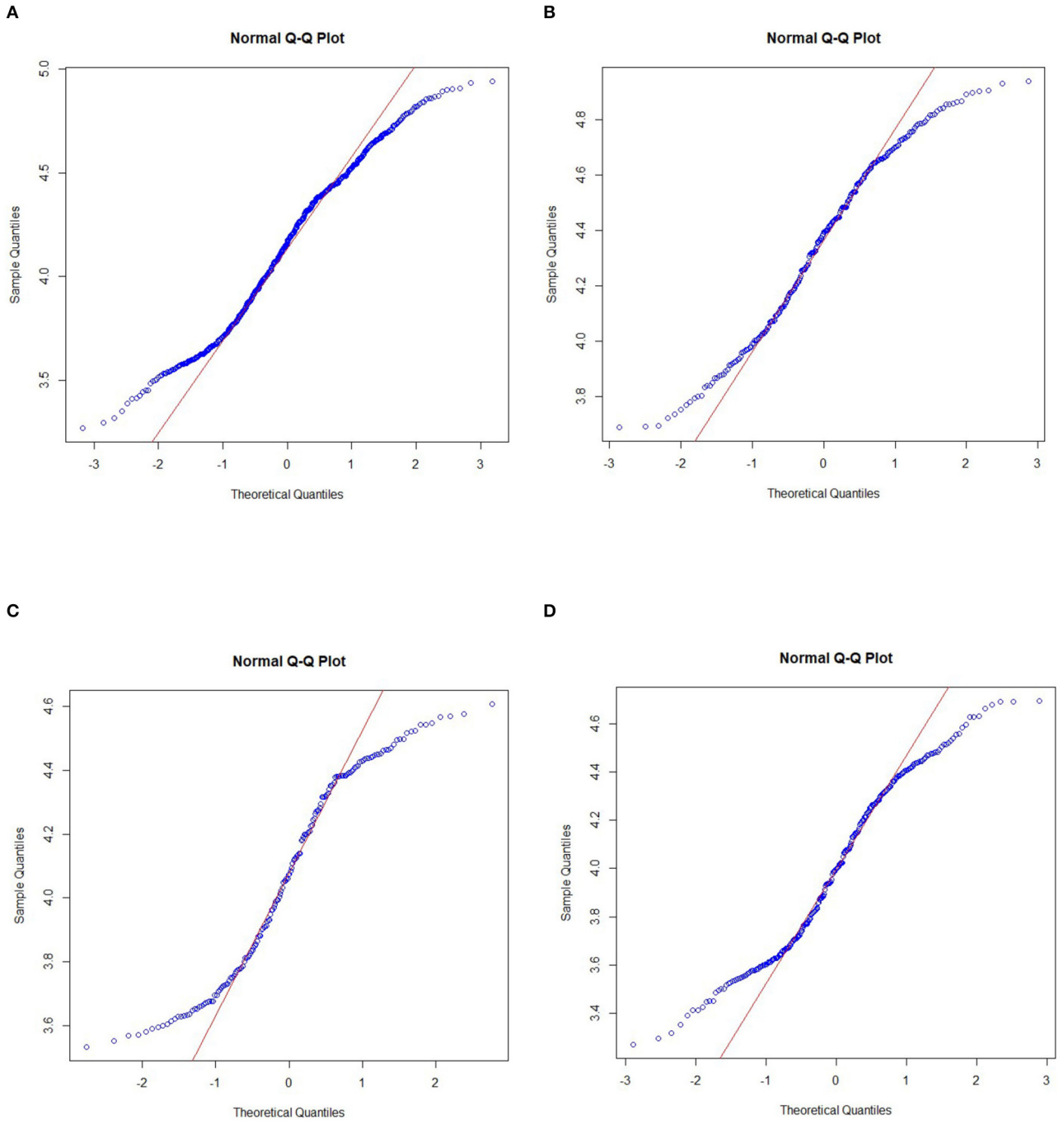

FIGURE 2 | Q–Q plot of the normality test for the whole country and the eastern, central and western regions. **(A)** National Q–Q plot, **(B)** Eastern region Q–Q plot, **(C)** Central region Q–Q plot, and **(D)** Western region Q–Q plot.

disposable income of workers and increase the purchasing power of residents, thereby increasing consumer demand, promoting the development of consumer industries, and stimulating domestic demand, thus effectively promoting economic development.

The government health expenditures in various regions affect each other and thus have an impact on regional economic development (as shown in **Figure 1**).

Government health expenditure directly and indirectly affects economic development through various social connections.

Therefore, government health expenditure will not have a simple linear relationship with economic development, and because of the differences in government health expenditure in different regions, the impacts on different regions will be different.

Model Introduction

Linear models are simple, intuitive, and easy to understand. However, in real life, the role of variables is usually not linear, and linear assumptions may not meet actual needs and may even be contrary to actual conditions. The non-parametric additive model is an extension of the additive model proposed by Stone (23); it is a freely flexible statistical model that detects non-linear effects between variables. The classical linear regression model assumes that the dependent variable y and the independent variables $x_1, x_2, \cdots x_n$ are linear:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n x_n \quad (1)$$

where β_0 is the intercept term, and $\beta_1, \beta_2, \cdots, \beta_n$ are the estimated parameters for each variable.

The generalized additive model is an extension of the linear model:

$$y = s_0 + s_1(x_1) + s_2(x_2) + \cdots + s_n(x_n) \quad (2)$$

where s_0 is the intercept term, and $s(\cdot)$ is the non-parametric function.

It is important to effectively understand the intrinsic relationship between the explanatory variables and the explained variables and to enhance the interpretability and visualization of the model. So we incorporate the linear part on the basis of the additive model to form a new non-parametric additive model:

$$y = \alpha + \sum_{i=1}^{n} \beta_i x_i + \sum_{i=1}^{n} s(x_i) \quad (3)$$

where $\alpha + \sum_{i=1}^{n} \beta_i x_i$ is the linear part of the model, and $\sum_{i=1}^{n} s(x_i)$ is the non-linear part of the model.

TABLE 2 | Normality test statistical results for the nation and the eastern, central, and western regions.

	Nation	Eastern region	Central region	Western region
Skewness	−0.0566	−0.1618	−0.0527	0.0531
Kurtosis	2.0774	1.9793	1.6166	1.8362
W	0.9786	0.9692	0.9328	0.9604
P	1.99×10^{-8}	4.265×10^{-5}	2.621×10^{-7}	1.223×10^{-6}

Based on the above model construction ideas, this article sets the following empirical model:

$$\begin{aligned} avegdp = {} & \alpha + \beta_1 RDhealth + \beta_2 RDassets + \beta_3 RDexport \\ & + \beta_4 RDincome + \beta_5 lDurban + \beta_6 lDold \\ & + s(RDhealth) + s(RDassets) + s(RDexport) \\ & + s(RDincome) + s(lDurban) + s(lDold) + \varepsilon \end{aligned} \quad (4)$$

VARIABLE DESCRIPTION AND DATA PROCESSING

Variable Selection

There are many studies at home and abroad on economic development, but this study mainly focuses on domestic economic development research; thus, it summarizes the status of domestic economic development and the conclusions of existing economic development research because this research focuses on the impact of government health expenditure on economic development. There are many factors influencing the economic growth, while the important factors are capital, labor, exports, income level, urbanization, etc. Fixed asset investment further affects economic growth through the competitive effect, the promotion of technological progress, the adjustment of industrial structure, and the externality, inducement, and orientation of public investment (25). After the population enters old age, its working time decreases, and the social and economic burden increases, which will have a certain inhibitory effect on economic growth (26–28). The increase

TABLE 3 | Correlation coefficient test.

	RDhealth	RDassets	RDexport	RDincome	lDurban	lDold
Worst						
RDhealth	1	0.65	0.33	0.07	0.18	0.15
RDassets	0.65	1	0.37	0.17	0.25	0.17
RDexport	0.33	0.37	1	0.26	0.38	0.18
RDincome	0.07	0.17	0.26	1	0.27	0.18
lDurban	0.18	0.25	0.38	0.27	1	0.32
lDold	0.15	0.17	0.18	0.18	0.32	1
Observed						
RDhealth	1	0.58	0.15	0.04	0.13	0.10
RDassets	0.62	1	0.13	0.14	0.04	0.11
RDexport	0.17	0.24	1	0.18	0.33	0.14
RDincome	0.03	0.04	0.12	1	0.22	0.16
lDurban	0.05	0.15	0.31	0.15	1	0.24
lDold	0.04	0.03	0.12	0.13	0.29	1
Estimate						
RDhealth	1	0.54	0.17	0.04	0.13	0.09
RDassets	0.50	1	0.15	0.10	0.06	0.08
RDexport	0.18	0.14	1	0.14	0.24	0.12
RDincome	0.02	0.10	0.11	1	0.16	0.12
lDurban	0.05	0.19	0.26	0.12	1	0.23
lDold	0.04	0.11	0.10	0.10	0.22	1

in export volume will increase the demand for products and services, drive domestic production, increase employment, improve foreign trade exchanges, and increase market vitality, which is conducive to economic growth (29). Changes or differences in residents' income can be important to the economy (30, 31). Urbanization is conducive to promoting population agglomeration in cities, further generating economies of scale. And market demand will grow rapidly and diversify, which is conducive to promoting specialized division of labor and improving economic efficiency. The education level and health level of the people will be improved, and excellent human resources will be provided for economic development. In addition, over or under-concentration can be very costly in terms of productivity growth (32–34). We choose fixed assets investment to reflect capital, the proportion of the elderly population to reflect labor, the export volume to reflect the export situation, residents' income to reflect the income level, and urbanization to reflect the level of urbanization. Therefore, per capita GDP was selected as the explained variable, and the proportion of government health expenditure to GDP was selected as the main explanatory variable. The proportion of fixed assets investment to GDP, the proportion of exports to GDP, the proportion of residents' income to GDP, the level of urbanization, and the proportion of the elderly population were also estimated as covariates in the model. The specific variables are explained in **Table 1**.

Data Processing

The data for each variable selected by the study mainly come from the China Statistical Yearbook, China Population and Employment Statistics Yearbook, China Financial Yearbook, etc. The data from 31 provinces (municipalities, autonomous regions) during 1996–2017 are selected. For the study sample, the country is divided into three regions: the eastern, central and western regions. The eastern region includes 11 provinces (cities and autonomous regions): Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan. The central region includes 8 provinces (municipalities and autonomous regions): Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, and Hunan. The western region includes 12 provinces (municipalities and autonomous regions): Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang. To eliminate the influence of the price level, the index data are reduced by the index of each variable in 1995. The BP test shows that there is heteroscedasticity. To avoid the influence of heteroscedasticity on the model results, the logarithm of the data for each variable is processed before model estimation.

THE APPLICABILITY TEST

Normality Test

To confirm whether the non-parametric additive model is suitable for analysis, the normality of the explained variable needs to be tested before using the model for regression estimation. Therefore, the normality of per capita GDP is first tested. The Q–Q plot and result statistics of the normality test are shown in **Figure 2** and **Table 2**, respectively.

From the results of the normality test Q–Q plot and the test statistics, per capita GDP does not conform to the normal distribution in the nation or the eastern, central and western regions, showing a distinct skewed distribution. Therefore,

TABLE 4 | Estimation results of linear part.

	Nation		Eastern region		Central region		Western region	
	Coefficients	***P*-value**	**Coefficients**	***P*-value**	**Coefficients**	***P*-value**	**Coefficients**	***P*-value**
RDhealth	0.0177	0.218	−0.0156	0.6	−0.0041	0.62	0.0580	2×10^{-16}
RDassets	0.6162	2×10^{-16}	0.5682	2×10^{-16}	0.6365	2×10^{-16}	0.6592	2×10^{-16}
RDexport	0.2921	2×10^{-16}	0.4281	2×10^{-16}	0.2706	2×10^{-16}	0.2494	2×10^{-16}
RDincome	0.6372	2×10^{-16}	0.5787	2×10^{-16}	0.6424	2×10^{-16}	0.6657	2×10^{-16}
lDurban	0.6537	2×10^{-16}	0.6793	2×10^{-16}	0.6171	2×10^{-16}	0.5437	2×10^{-16}
lDold	0.3391	2×10^{-16}	0.3563	2×10^{-16}	0.3588	2×10^{-16}	0.3298	2×10^{-16}
Intercept	0.3691	2×10^{-16}	0.3654	2×10^{-16}	0.3861	2×10^{-16}	0.3744	2×10^{-16}

TABLE 5 | Estimation results of non-linear part.

	Nation		Eastern region		Central Region		Western region	
	Edf	***P*-value**	**Edf**	***P*-value**	**Edf**	***P*-value**	**Edf**	***P*-value**
RDhealth	6.695	2×10^{-16}	8.357	2×10^{-16}	2.934	2×10^{-16}	2.767	2×10^{-8}
RDassets	2.889	2×10^{-16}	7.977	1.04×10^{-10}	7.499	1.02×10^{-10}	2.650	8.61×10^{-6}
RDexport	7.106	3.36×10^{-14}	5.177	3.71×10^{-9}	1.105	2×10^{-16}	0.940	5.97×10^{-14}
RDincome	8.534	2×10^{-16}	4.772	2×10^{-16}	4.373	2×10^{-16}	8.666	2×10^{-16}
lDurban	8.797	1.31×10^{-13}	7.957	5.42×10^{-4}	5.320	5.71×10^{-10}	8.476	1.48×10^{-8}
lDold	4.006	2×10^{-16}	2.920	1.39×10^{-3}	2.604	9.54×10^{-6}	4.556	7.46×10^{-13}

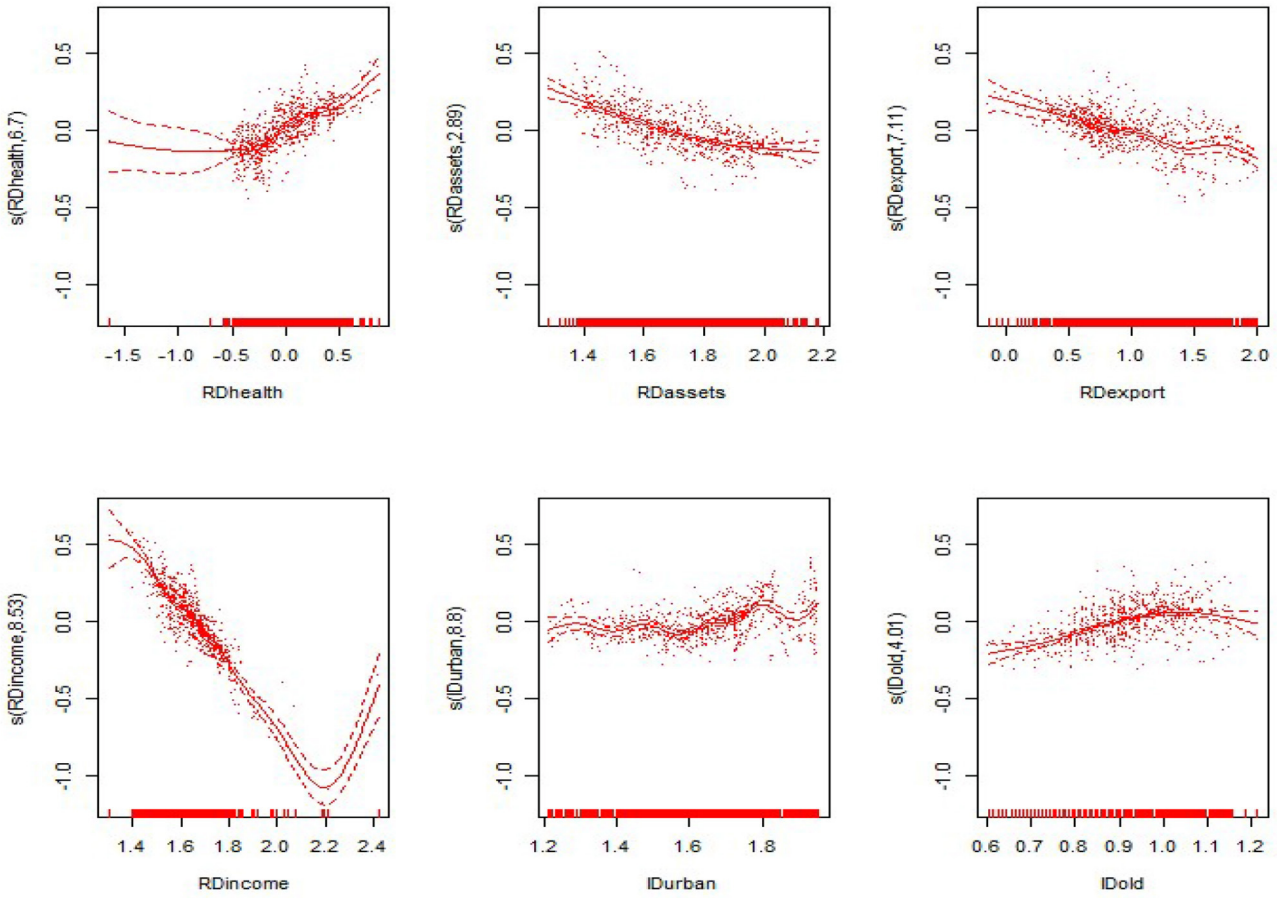

FIGURE 3 | Non-linear effects of the explanatory variables on per capita GDP in the nation.

the distribution conforms to the use of the non-parametric additive model.

Collinearity Test

Before using the model for analysis, in addition to the normality of the explained variables, the collinearity between the explanatory variables needs to be tested. If the model has obvious collinearity problems, the variance and standard error of the regression results will increase, the confidence interval will be expanded, and the model's accuracy will be reduced. Judging whether there is a collinearity problem between explanatory variables generally involves comparing the correlation coefficient R of an explanatory variable with other explanatory variables with a value of 0.5 (or comparing R^2 with 0.25). When the absolute value of the correlation coefficient $R > 0.5$, there is a collinearity problem between the variables. When the absolute value of the correlation coefficient $R < 0.5$, the collinearity problem between the explanatory variables is considered to be low or non-existent and may be ignored. The results of the collinearity test include three indicators: the maximum value (worst), the observed value (observed), and the estimated value (estimate). The estimated results of the three indicators for the collinearity test of each explanatory variable are shown in **Table 3**.

It can be seen from the results of the three indicators that the correlation coefficient between the proportion of fixed assets and the proportion of government health expenditure exceeds 0.5; the other correlation coefficients are all below 0.5, basically passing the test. So non-parametric additive model estimation can be performed.

THE ANALYSIS AND DISCUSSION OF THE EMPIRICAL RESULTS

National and Regional Model Estimation

This part uses the non-parametric additive model to analyze the linear, non-linear and comprehensive effects for the nation and the eastern, central and western regions.

Linear Results

Table 4 shows the results of the linear partial estimation for the nation and the eastern, central and western regions. It can be seen from the table that the proportion of government health

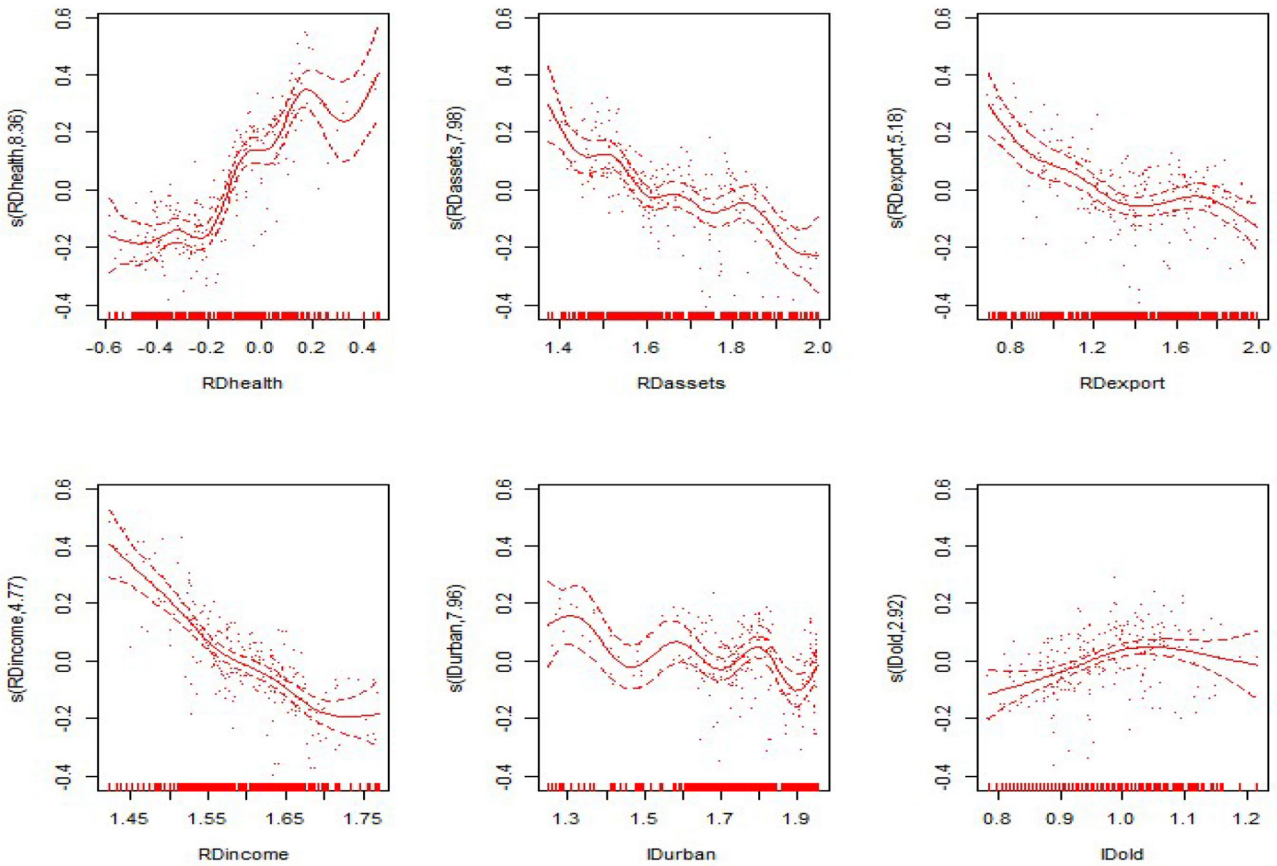

FIGURE 4 | Non-linear effects of the explanatory variables on per capita GDP in the eastern region.

expenditure for the whole country and for the western region has a positive impact on economic development. However, government health expenditure in the eastern and central regions has a negative impact on economic development. The results nationwide and for all regions are not significant. From the linear results, the extent of government health expenditure has different extents of impact on economic development in different regions.

In addition to the proportion of government health expenditure, the proportion of fixed assets investment to GDP, the proportion of exports to GDP, the proportion of residents' income to GDP, the level of urbanization, and the proportion of the elderly population on economic development have a positive impact on the nation and on the eastern, central and western regions. All these results passed the significance test. From the linear estimation results, in addition to the proportion of government health expenditure, other explanatory variables have a significant positive impact on the economic development of each region.

Non-linear Results

From the non-linear estimation results of the model, the model estimates the optimal smoothing degree of each explanatory variable and gives the *F*-value and the *P*-value of each variable (**Table 5** evaluates only the degrees of freedom and the *P*-value). As seen from **Table 5**, the non-linear estimates of the proportion of government health expenditure to GDP, the proportion of fixed assets investment to GDP, the proportion of exports to GDP, the proportion of residents' income to GDP, the level of urbanization, and the proportion of the elderly population were all significant at the 0.1 level. This shows that all explanatory variables have significant non-linear effects on the nation and the eastern, central and western regions. The non-linear effects of various explanatory variables on the economic development of the nation and the eastern, central and western regions are shown in **Figures 3**–**6**. The solid line in the figures represents the non-linear effect of each explanatory variable on economic development, the dotted line represents the 95% confidence interval, and the scatter represents the observed value of the variable.

From the non-linear results of the national model fitting in **Figure 1**, the proportion of government health expenditure has a non-linear influence on economic development. With the gradual increase in government health expenditure, the extent of economic development also gradually increases. The proportion of fixed assets investment also has a non-linear effect, in the form of a convex curve; however, it shows a negative trend with

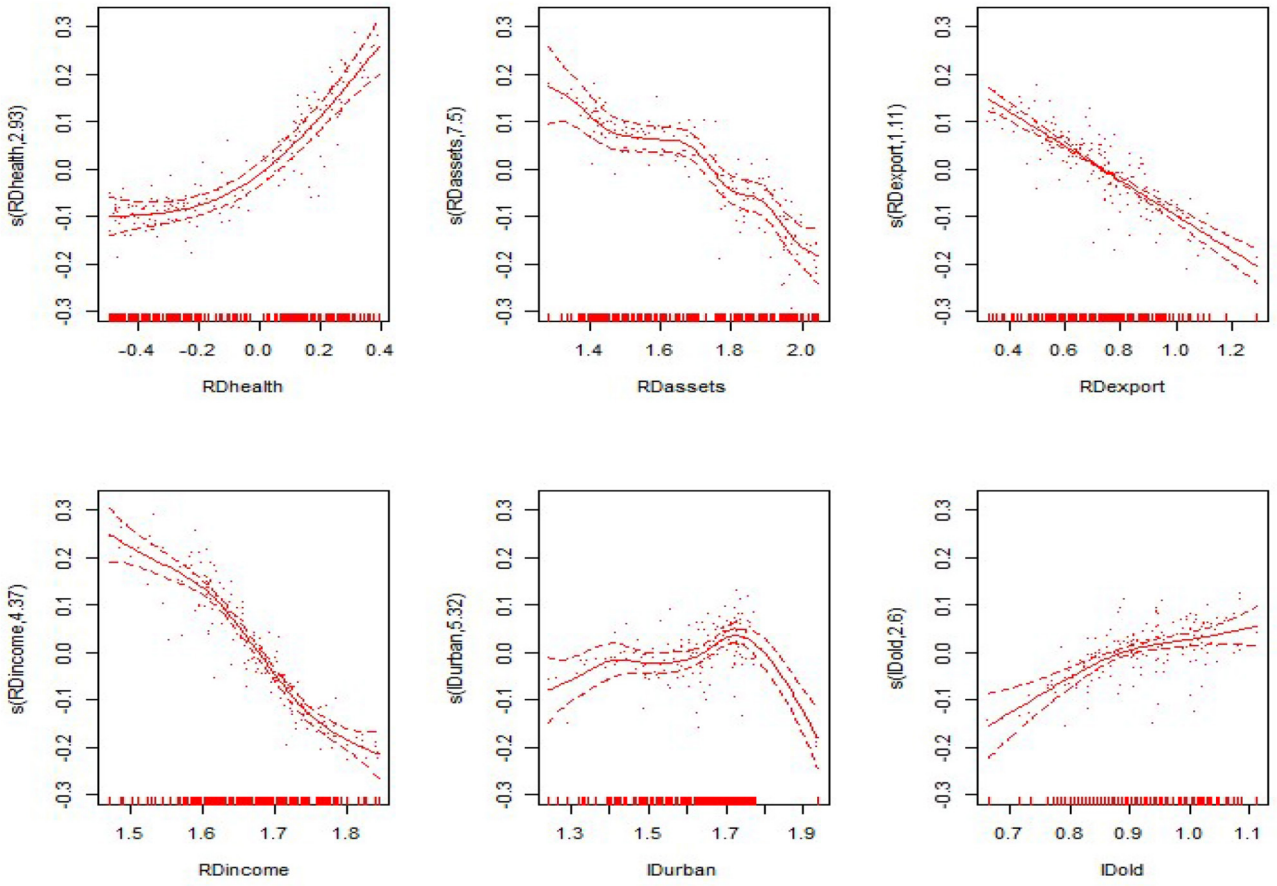

FIGURE 5 | Non-linear effects of the explanatory variables on per capita GDP in the central region.

respect to economic development, and the curve is relatively flat. The trend of the proportion of exports declines, then rises and then declines again; the overall performance shows a negative trend, and the decline is flat. The proportion of residents' income shows a "*V*-shaped" impact on economic development, with the impact on economic development first declining and then rising. The level of urbanization presents a wave-shaped relationship with economic development. The impact of the rising shape has a positive effect on economic development. The impact of the proportion of the elderly population on economic development shows a relatively flat inverted "*U*-shaped" relationship, having a positive impact after a negative impact on economic development.

From the results of the non-linear effects on the eastern, central and western regions in **Figures 4**–**6**, in the eastern region, the impact of the proportion of government health expenditure shows a wavy upward trend with respect to economic development. The impact of the proportion of fixed assets investment on economic development shows a wavy decline. The trend of the export ratio is basically the same as that for the nation. It has the trend of first decreasing, then rising and then decreasing again, and the overall trend is downward. The impact of the proportion of residents' income on economic development shows a convex downward curve. The impact of the level of urbanization on economic development shows a wavy downward trend. The proportion of the elderly population is basically consistent with the trend of the non-linear influence for the nation, presenting a flat inverted "U-shaped" relationship with economic development.

In the central region, the proportion of government health expenditure shows a positive trend with respect to economic development, and the upward trend is faster. The proportion of fixed assets investment shows a rapid wave-shaped downward trend with respect to economic development, showing a nearly linear decline curve with regard to economic development. The impact of the proportion of residents' income on economic development first declines slowly and then declines rapidly. The impact of the level of urbanization on economic development shows an "*M*-shaped," first rising, then falling, then rising after the decline. The proportion of the elderly population showed a rapid rise after the rapid rise in the central region, and the positive impact on economic development was first

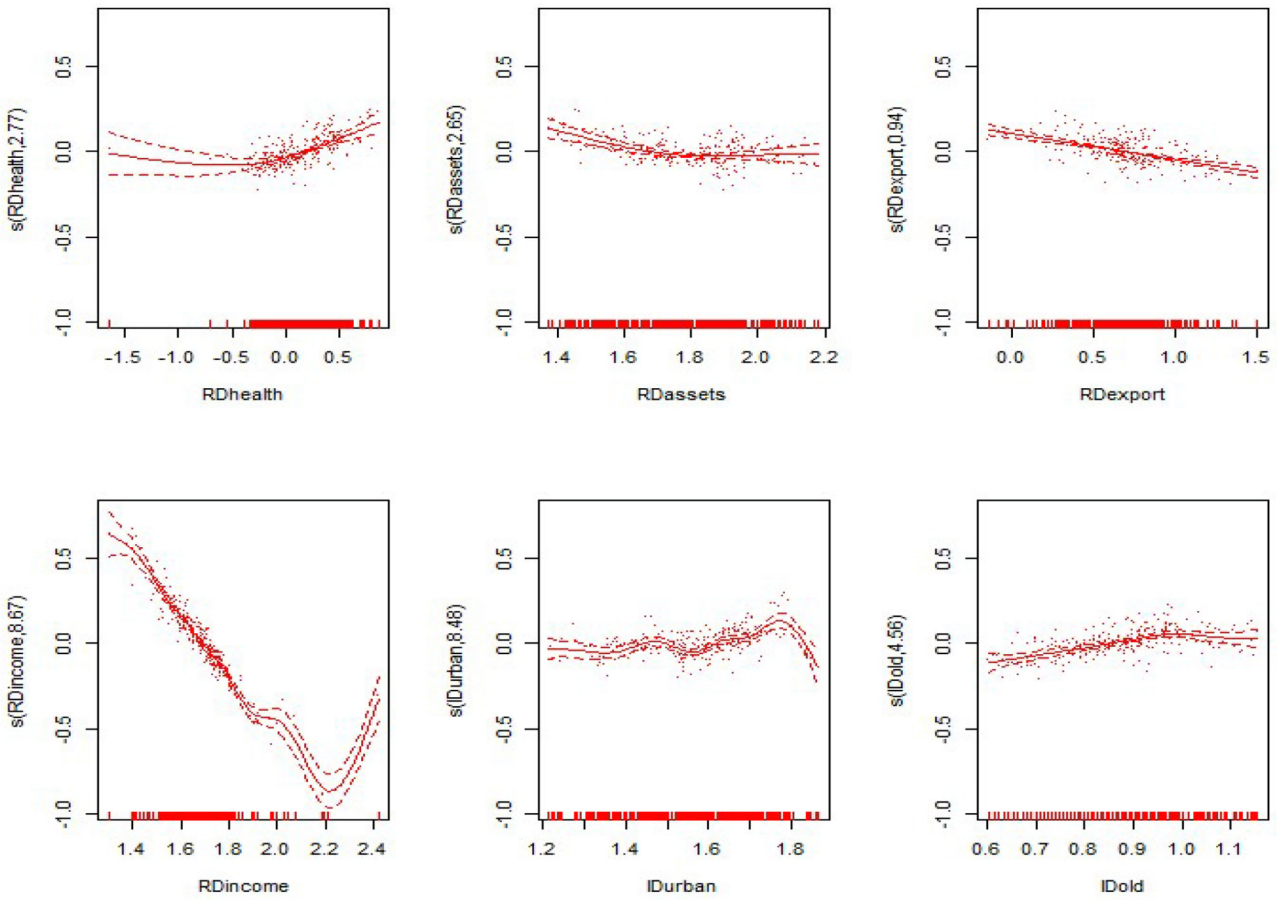

FIGURE 6 | Non-linear effects of the explanatory variables on per capita GDP in the western region.

slowed down. In the western region, the impact of the proportion of government health expenditure on economic development shows a convex upward curve, showing a slow promotion effect on economic development. The impact of the proportion of fixed assets investment on economic development shows a relatively flat "*U*-shaped" trend. The proportion shows a nearly linear downward trend. The impact of the proportion of residents' income on overall economic development shows a "*V*-shaped" pattern. The urbanization level shows a wave-shaped rise in the early stage and a rapid decline in the later stage. The impact of the proportion of the elderly population on economic development is consistent with the eastern region, presenting a flatter inverted "*U*-shaped" trend.

Comprehensive Results

The two subsections above show the linear and non-linear effects of each explanatory variable on economic development, but the final impact of each explanatory variable on economic development requires a comprehensive effect analysis. The following is a summary and discussion of the trends of the comprehensive effects of the explanatory variables on economic development nationwide and in the eastern, central and western regions. The trends are shown in **Figures 7–10**.

Regarding the national comprehensive effects of various variables, the linear effects and non-linear effects of the proportion of government health expenditure positively promote economic development. However, the non-linear impact is significant, the linear effect is not significant, and the comprehensive impact has a significant non-linear impact. With the increasing proportion of government health expenditure, the economic development level shows a convex curve growth trend, indicating that the proportion of government health expenditure has a positive impact on economic development. The proportion of fixed assets investment shows a gradual "convex" curve growth trend, indicating that with the increase in the proportion of fixed assets investment, the level of economic development slowly increases. The proportion of exports shows a wave-shaped upward trend. With the increase in the proportion of exports, the level of economic development generally shows an upward trend. The proportion of residents' income shows a positive "*V*-shaped" effect on the level of economic development, indicating that with the increase in the income level of residents, the level of economic development

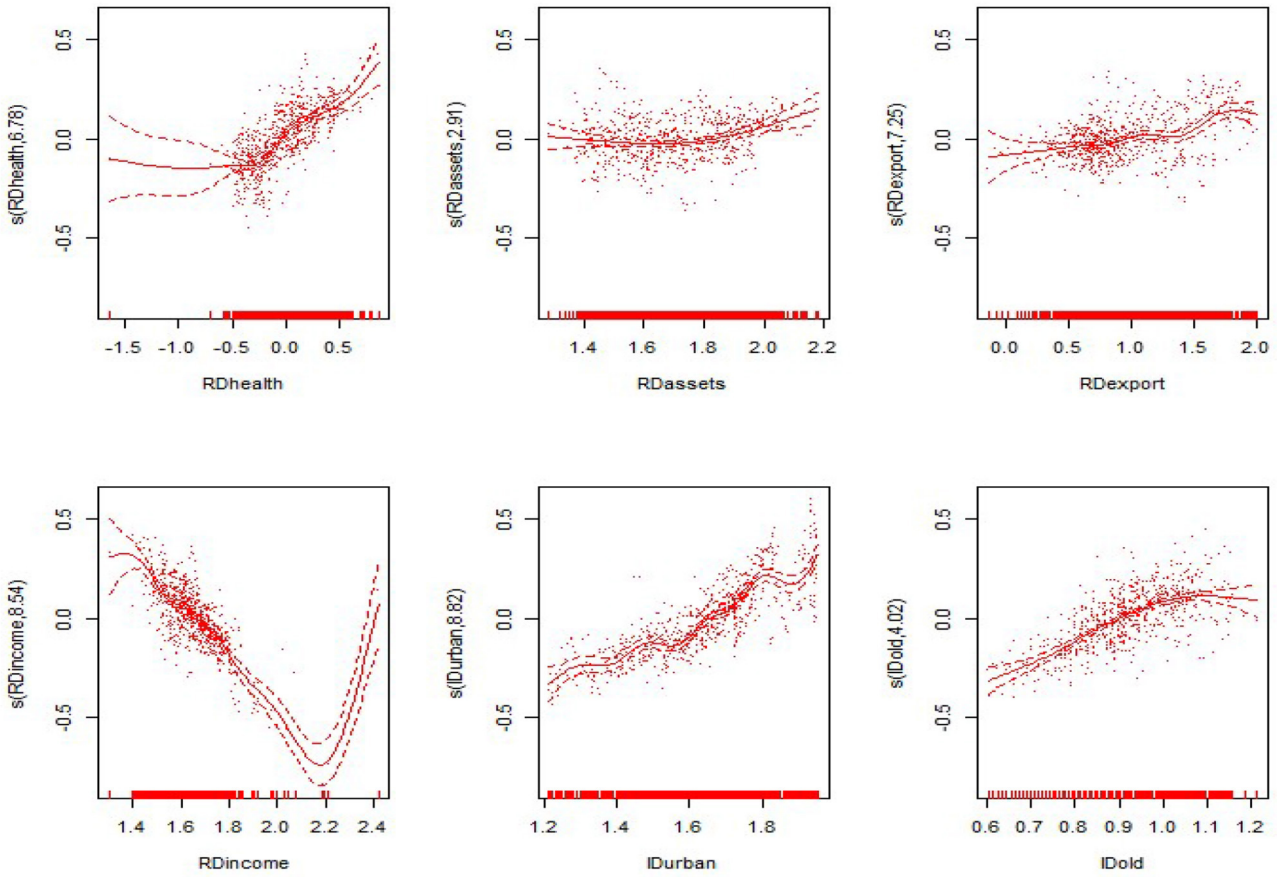

FIGURE 7 | Comprehensive effects of the explanatory variables on per capita GDP in the nation.

shows a downward trend and then an upward trend, according to the current situation of China's economic development. The reason may be that the living standard of early residents is not high. With the increase in income, early residents will use a large amount of income to save, and the consumption level will not be high, which will have a negative impact on economic development. When the income of residents reaches a certain level, it is no longer necessary for them to use more savings for their own protection. They will continuously expand their scope of consumption, increase consumer spending, and begin to play a positive role in promoting economic development. The level of urbanization shows a wavy upward trend with respect to economic development, indicating that the improved urbanization level positively promotes the level of economic development. The proportion of the elderly population shows a flat inverted "*U*-shaped" curve with respect to economic development. With the increase in the proportion of the elderly population, the level of economic development shows a trend of growth and then decline. The reason may be that the increase in the elderly population in the previous period drives the development of the elderly care industry. The effect of industrial development on the economy is higher than the negative impact of the elderly population on the economy. Therefore, the overall impact is positive. As the proportion of the elderly population increases, the economic burden continues to increase, and the impact of the elderly care industry on economic development tends to be saturated. The comprehensive effects of the two show a negative impact on economic development.

Regarding the comprehensive effects in the eastern region, the proportion of government health expenditure has a wavy upward impact on economic development. As the proportion of government health expenditure continues to increase, economic development shows a positive growth trend. The non-linear impact of the proportion of fixed assets investment is negative, while the comprehensive impact is wavy; there is no obvious upward trend. The reason may be that the eastern region's fixed assets investment level is already high; thus, increases in the proportion of fixed assets investment do not exert a significant impact. The proportion of exports increases, and the level of economic development shows a wavy upward trend, indicating that increases in the proportion of exports still have a significant positive effect on economic development in the eastern region. As the proportion of residents' income increases, the level of economic development also shows a *V*-shaped

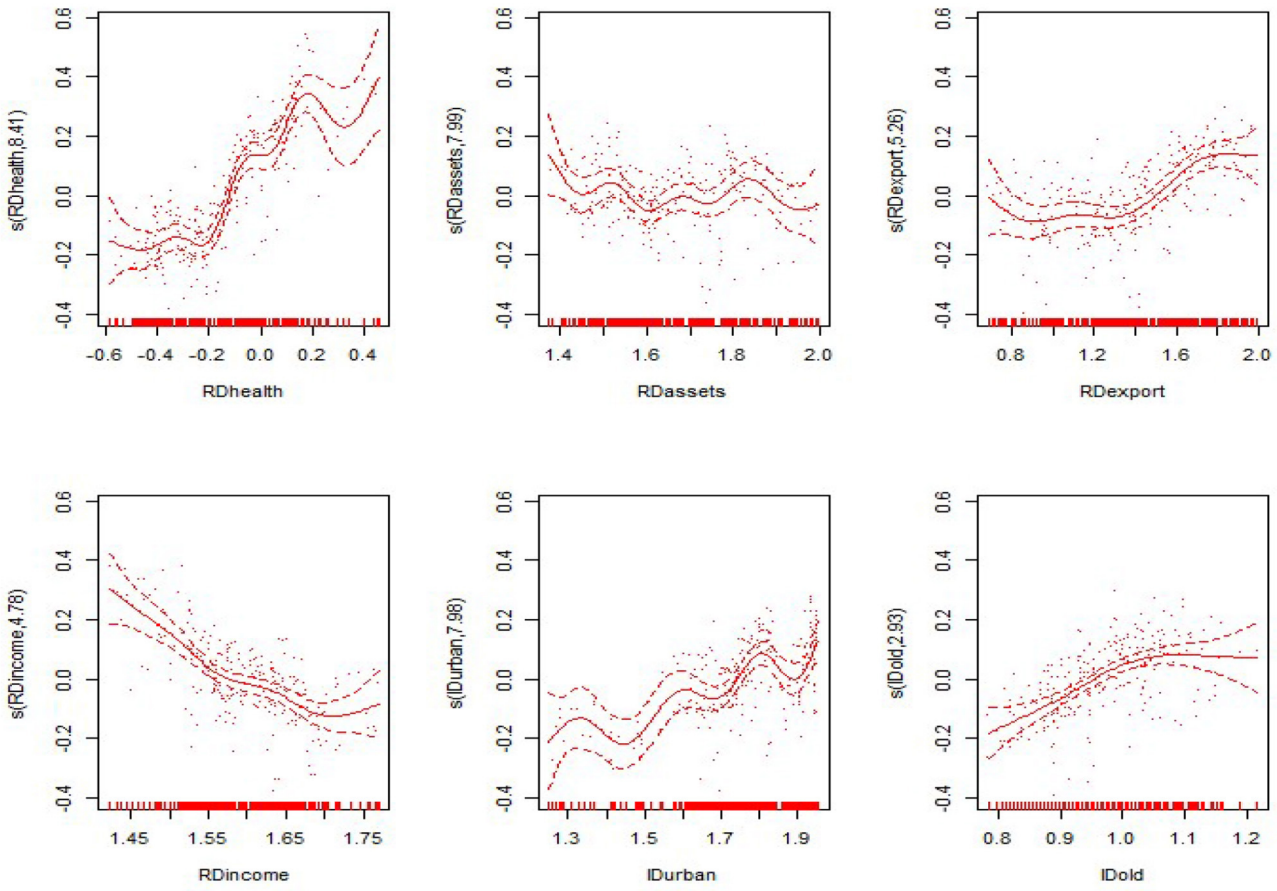

FIGURE 8 | Comprehensive effects of the explanatory variables on per capita GDP in the eastern region.

trend. In the eastern region, residents' income has been heavily invested in wealth management and investment markets. There are no savings, and there is no large amount of consumption. Therefore, the proportion of residents' income in the eastern region will not have a high promotion effect on the economy. The level of urbanization in the eastern region increases, and the level of economic development shows a clear wave-like upward trend, indicating that urbanization has a positive effect on economic development. The proportion of the elderly population is basically consistent with the national trend, and the initial stage has a positive impact on economic development. As the role of industrial promotion has gradually weakened, the burden on the economic development of the elderly population has gradually increased, and this economic development has gradually exerted a negative impact.

Regarding the central and western regions, the proportion of government health expenditure increases, and economic development shows a non-linear growth trend, indicating that the impact of government health expenditure on economic development has significant non-linear effects nationwide and in the eastern, central and western regions. The proportion of fixed assets investment in the central and western regions has a significant non-linear impact that positively drives overall economic development. The proportion of exports in the central and western regions has different effects on economic growth. It has a linear negative impact in the central region. The reason may be that the high quality and service required for exports in the central region cannot be maintained. The promotion capacity needs to be strengthened. Forcing the level of exports to increase will consume a large amount of resources such as manpower, material resources and capital. It will lead to negative economic development. The linear impact of the proportion of exports in the western region is greater than the non-linear impact. It has a linear positive impact in the western region. The reason may be that the western region itself has some naturally suitable export products and provides policy and financial support, creating better export conditions. The proportion of exports will significantly stimulate regional economic development. The impact of the proportion of residents' income is also different in the central and western regions. It has a negative impact in the central region because the economic development level in the central region is still

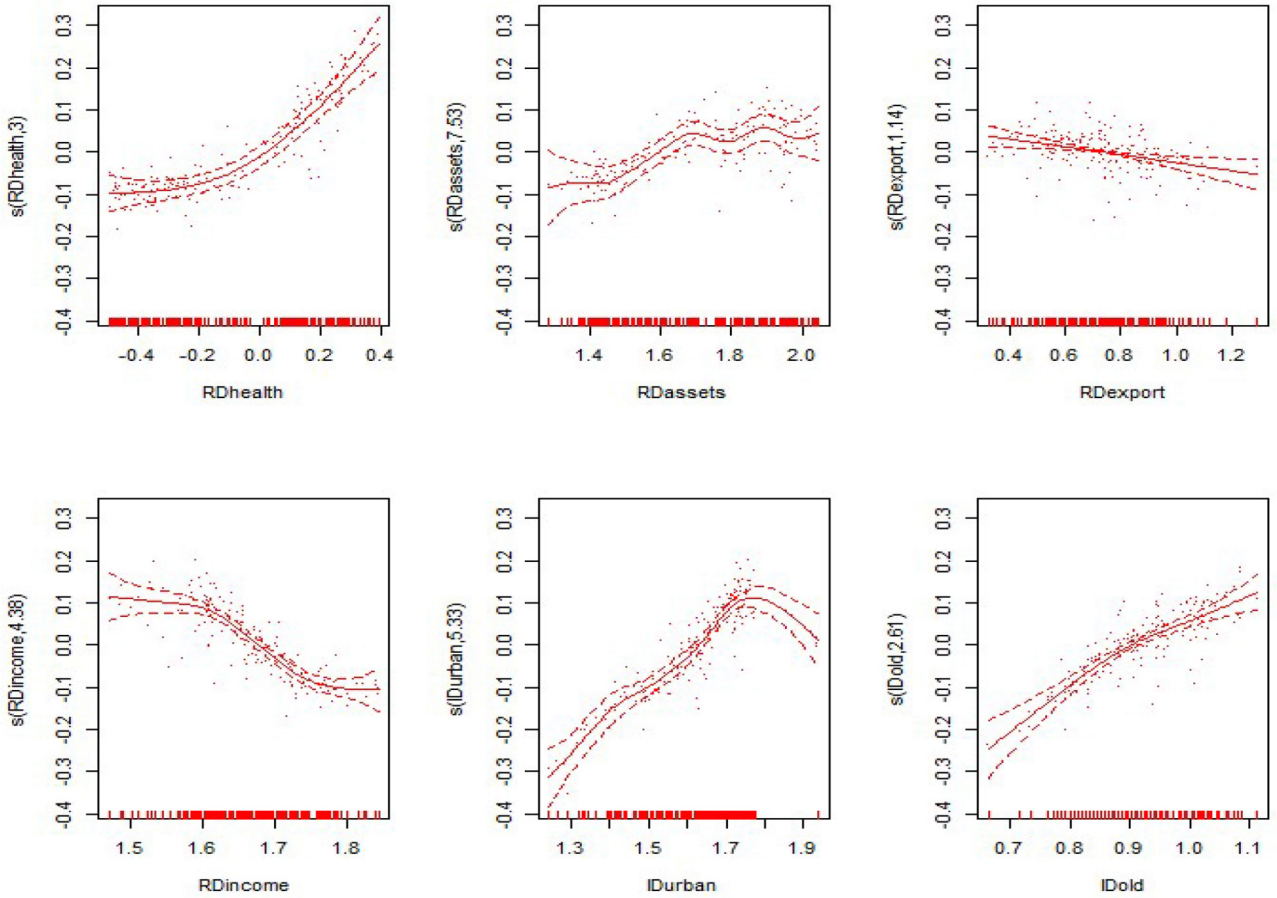

FIGURE 9 | Comprehensive effects of the explanatory variables on per capita GDP in the central region.

not very high overall and has not yet reached the standard of living for free consumption. Therefore, the income of most residents enters savings and cannot contribute to economic growth. In the western region, the impact of the proportion of residents' income is basically consistent with the national trend, and the overall trend is "*V*-shaped." The trends of urbanization in the central and western regions are consistent. With the improvement of the urbanization level, the level of economic development first rises and then declines. With the strengthening of urbanization in the early stage, urban industrial agglomeration has accelerated industrial development, improved labor and capital agglomeration, and effectively promoted rapid economic development. High urbanization will also result in a series of problems such as environmental pollution, ecological damage, and space congestion, which will have a negative impact on economic development. The proportion of the elderly population in the nation and in the eastern, central and western regions has the same impact on economic development, first growing and then falling.

Based on the above results, the proportion of government health expenditure does not have purely linear effects on economic development. Instead, it has a combination of linear and non-linear effects. It is necessary to analyze its comprehensive effects. Regardless of whether a region or the nation as a whole is being analyzed, the proportion of government health expenditure have a non-linear positive impact on economic development. Similarly, the proportion of fixed assets investment, the proportion of exports, the proportion of residents' income, the level of urbanization, and the proportion of the elderly population have a non-linear effect on economic development. However, according to the actual situation of different regions, the impact is different.

Model Check

To prove the model effect, the paper tests the relationship between the fitted values and the response values. Plots of the response values vs. the fitted values for the nation and the eastern, central and western regions are shown in **Figure 11**.

It can be seen from **Figure 11** that there is a clear linear relationship between the fitted values and the response

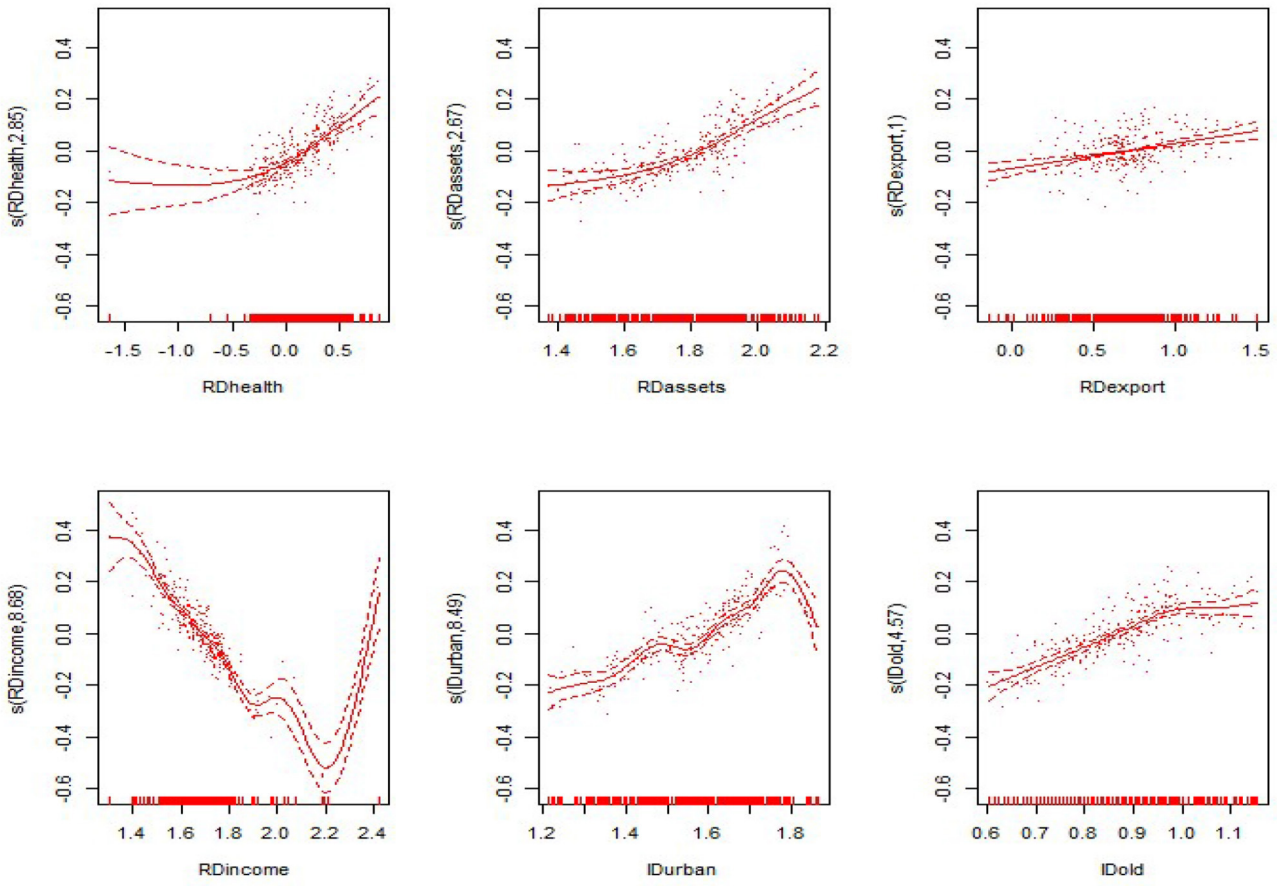

FIGURE 10 | Comprehensive effects of the explanatory variables on per capita GDP in the western region.

values in the four plots, indicating that the model has a good fitting effect and that the estimation results have high credibility.

To further test the fitting effect of the model, the residual sum of squares of the non-parametric additive model is compared with the ordinary linear model, as shown in **Table 6**. It can be seen from **Table 6** that the residual sum of squares of the non-parametric additive model is significantly smaller than that of the ordinary linear model, indicating that the model is more accurate than the estimation results of the ordinary linear model.

Based on the above test, it can be seen that the non-parametric additive model can analyze the linear relationship and the non-linear relationship between the variables separately. Thus, the influence mechanism between the variables is clearer and has a more superior estimation effect. Therefore, the model is used to analyze the effects of government health expenditure on economic development and is more scientific and accurate.

Endogenous Test

To deal with the endogeneity problem, the paper tests the endogeneity by 2sls. The results are shown in **Table 7**.

It can be seen from **Table 7** that the effects of the estimated results in each region is basically the same as the previous results. Under identification test and Hansen *J*-test indicate that the over-identification test is past. And Cragg-Donald Wald *F* statistic test shows that the weak instrumental variable test is significantly passed. So the test result is valid.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

This study attempts to analyze the linear, non-linear and comprehensive effects of government health expenditure on the economic development of the nation and the eastern, central and western regions of the nation by using a non-parametric additive model. The results show the following: (a) based on the different geographic entities analyzed, i.e., the nation and the eastern, central and western regions, the linear impact of the proportion of government health expenditure on economic development is positive nationwide and in the western region,

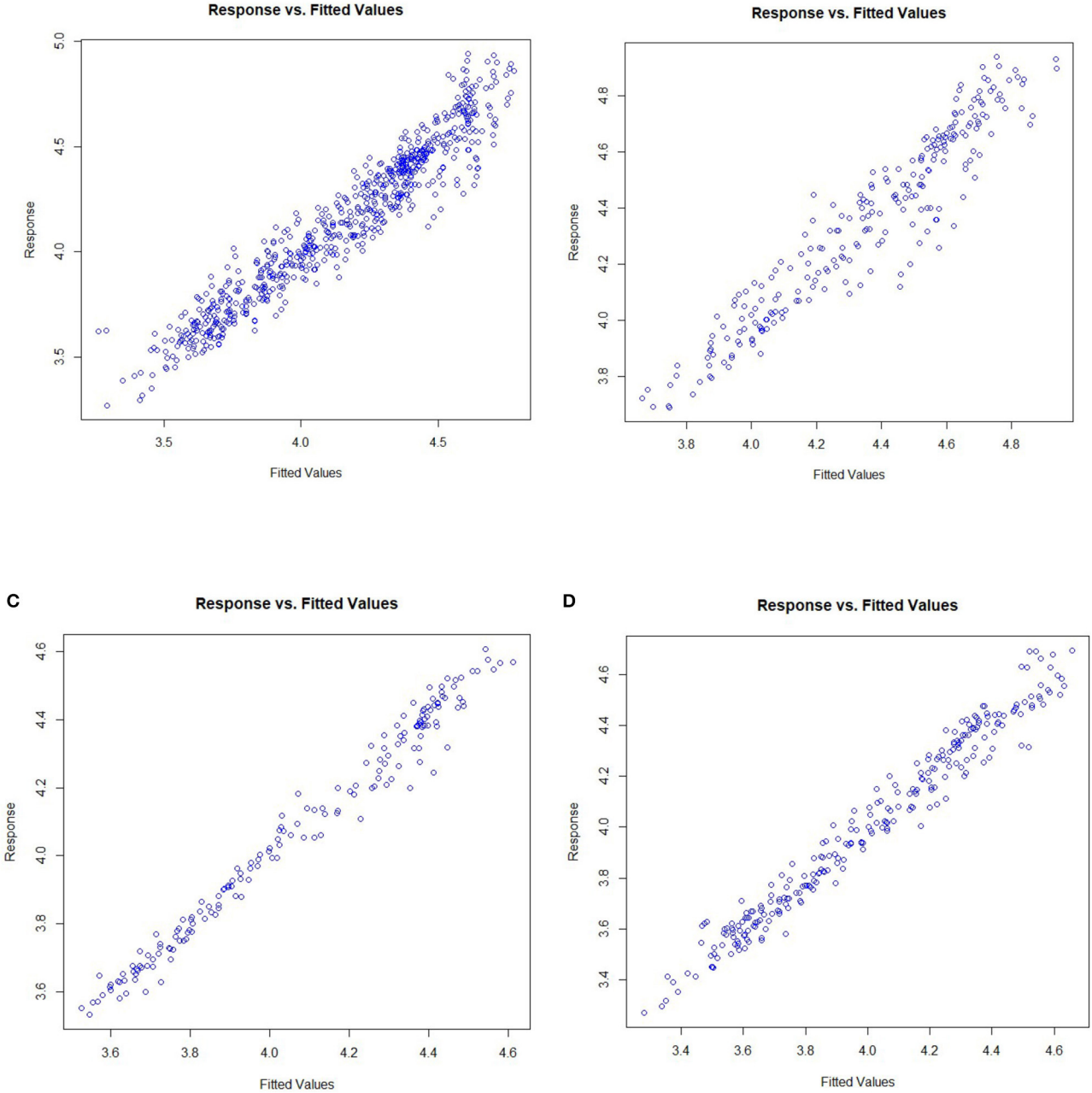

FIGURE 11 | Plots of the response values vs. the fitted values for the nation and the eastern, central, and western regions. **(A)** Nation, **(B)** Eastern region, **(C)** Central region, and **(D)** Western region.

negative in the eastern and central regions, and significant only in the western region. The proportion of government health expenditure has a significant non-linear impact on economic development nationwide and in the eastern, central and western regions. The comprehensive effect of combining its linear and non-linear effects shows significant non-linear positive effect nationwide and in all regions. (b) The impacts of the proportion of fixed assets investment, the proportion of exports, the proportion of residents' income, the level of urbanization, and the proportion of the elderly population on economic development are significantly positive nationwide and in the eastern, central and western regions. In addition, their non-linear influences in different regions vary depending on regional differences. Regarding the comprehensive impact of different variables on

economic development, the proportion of fixed assets investment has a positive non-linear effect nationwide and in all regions; the proportion of exports has a positive non-linear effect nationwide and in the eastern region. However, in the central and western regions, it has a nearly linear negative impact. The proportion of residents' income has a positive "*V*-shaped" effect nationwide and in the western region, and it has a non-linear negative impact in the eastern and central regions. The urbanization level shows a non-linear positive impact nationwide and in the eastern region. The trend in the central and western regions shows first growth and then decline. The proportion of the elderly population in the nation and in the eastern, central and western regions shows a first rapidly positive and then a flat positive impact on economic development. (c) The non-parametric additive model does not perform a simple analysis of the influence between variables. However, it can analyze the linear influence and the non-linear influence separately, which can help us more clearly understand the conduction path between variables. Compared with ordinary linear regression, it is more scientific and accurate.

Recommendations

Currently, the challenge of economic growth is being faced both internationally and domestically. Economic growth has slowed down. Some countries have even begun to experience negative growth. China's economy has also begun to undergo structural transformation from the initial "extensive" rapid growth, and it is necessary to maintain steady economic development. It is necessary to adjust the various factors that promote the stable development of the economy in a scientific and rational way. Based on the conclusions of this research, the following policy implications can be obtained:

First, whether for the whole country or for different regions, the government should promote the further development of the economy by increasing the proportion of government health expenditure to GDP. By increasing government health investment, the government can increase investment in medical and health resources and improve the quality of medical and health personnel. To improve the service level of medical institutions and medical personnel, the government should promote the improvement of the health of human capital and provide high-quality human resource reserves for China's economic development.

Second, we must promote social and business investment in fixed assets, promote product exports, promote innovation and entrepreneurship to create more jobs for the society, continuously increase residents' income, promote urbanization, and create a good development environment for the rise of the elderly care industry and related industries, which should then be promoted. In addition, we must create jobs for the elderly population and reduce the personal and national economic burden of the elderly population after retirement.

Third, the economic development of the eastern, central and western regions can be increased by increasing investment in fixed assets. In addition, for the eastern region, relevant policies can be introduced to stimulate exports and expand urbanization by government. For the central region, exports should not be pursued excessively. The level of urbanization should be expanded, and the income level of residents should be appropriately raised to develop the economy. However, in the process of promoting urbanization, the complex impact of urbanization must also be taken into account. For the western region, government should continue to adhere to the western support plan, and the problem of slow economic development should be solved by promoting exports and increasing residents' income.

TABLE 6 | Residual sum of squares between the non-parametric additive model and the ordinary linear model.

	Non-parametric additive model	Ordinary linear model
Nation	7.0816	11.1637
Eastern region	2.3643	4.5140
Central region	0.3247	0.7395
Western region	1.0386	2.6146

TABLE 7 | Endogenous test results.

	Nation		Eastern region		Central region		Western region	
	Coefficients	*P*-value	Coefficients	*P*-value	Coefficients	*P*-value	Coefficients	*P*-value
RDhealth	0.4627	0.000	0.9251	0.000	0.4308	0.000	0.2557	0.000
RDassets	0.0168	0.802	−0.1921	0.027	0.1990	0.054	0.5935	0.000
RDexport	0.1154	0.000	0.2320	0.000	0.1048	0.000	0.0103	0.688
RDincome	0.1363	0.000	−1.2982	0.000	0.9498	0.000	0.8995	0.000
lDurban	0.8952	0.000	0.3975	0.000	0.6118	0.000	0.7991	0.000
lDold	0.8972	0.000	0.7316	0.000	0.7823	0.000	0.6715	0.000
intercept	3.6006	0.000	5.1672	0.000	3.7294	0.000	2.5803	0.000
Underidentification test	140.749	0.000	71.004	0.000	28.965	0.000	61.809	0.000
Cragg-Donald Wald F statistic	1,134.247	640.218	251.662	146.368				
Hansen J statistic	0.549	0.4588	0.014	0.9065	3.694	0.0546	2.889	0.0892

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

YW and CT contributed to conception and design of the study. QX organized the database. YW performed the statistical analysis and wrote the first draft of the manuscript. CT and QX wrote sections of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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Obamacare: A bibliometric perspective

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Obamacare is the colloquial name given to the Affordable Care Act (ACA) signed into law by President Obama in the USA, which ultimately aims to provide universal access to health care services for US citizens. The aim of this paper is to provide an overview of the political-legal, economic, social, management (or administrative), and medical (or health) repercussions of this law, using a bibliometric methodology as a basis. In addition, the main contributors to research on ACA issues have been identified in terms of authors, organizations, journals, and countries. The downward trend in scientific production on this law has been noted, and it has been concluded that a balance has not yet been reached between the coexistence of private and public health care that guarantees broad social coverage without economic or other types of barriers. The law requires political consensus to be implemented in a definitive and global manner for the whole of the United States.

KEYWORDS

Obamacare, Affordable Care Act, strategic diagram, PEST analysis, SciMAT

Introduction

The Affordable Care Act (ACA) signed into law by President Obama in the USA, often referred to as Obamacare, aims to provide universal access to healthcare services for US citizens. At the time of its enactment in 2010, the vast majority of the health care system was privately owned and there were 48 million uninsured non-elderly persons (1).

Previously, several initiatives had been made, including the Social Security Act of 1935, enacted by Franklin D. Roosevelt. This law established a pension system for those over 65 years of age, although in the following years it also covered the family members of workers who died prematurely, and the disabled (2). It is also worth mentioning the reform signed into law by Lyndon B. Johnson in 1965, which consisted of the creation of the two major public health services in the USA: Medicare and Medicaid. These programs were created in order to provide coverage to people with fewer resources and those who were in a state of social vulnerability. Specifically, Medicare was designed essentially for people over 65 years of age, although it also included certain vulnerable populations, which mainly covered people with limited resources (3).

From its conception to the present day, the ACA has sparked a great debate in society, obviously mainly in the USA, but also in other countries. It is undeniable that this debate is often influenced by certain interest groups that promote it, since they may have political, economic, or other interests. This study aims, as far as possible, to give an objective view of the ACA. For this reason, high-quality scientific publications will be used as a basis for the study. However, there is a large number of such publications available on this subject. In order to achieve the greatest possible objectivity given such a large amount of information, in this study we have opted to use bibliometric techniques. Although the concept of bibliometrics itself can be understood differently (4), there is a certain consensus in defining it as the use of quantitative techniques (mathematics and statistics) on the documents published on a certain subject. Thus, one advantage of bibliometric indicators is that they make it possible to measure not only the purely quantitative aspects of the subject under investigation but also its qualitative nature (5). The success of this study will be largely based on the prior documentation of the area to be investigated, since without such an understanding of the area it would be impossible to interpret the results obtained by the bibliometric analysis, which, furthermore, requires considerable refinement and a qualitative evaluation in order to obtain the definitive results.

The main objective of this study is, therefore, to provide a cross-sectional view of the implications of the ACA from its enactment in March 2010 to the present day, by comparing how it may have progressed during this period. The PEST analysis (political, economic, social, and technological) is useful for outlining the strategic environment of a region or subject matter (6). By adapting this type of analysis, this paper aims to study the political (also including related legal aspects), economic, social, management (or administrative) and medical (concerning health) aspects related to the implementation of the law, therefore, it aims to make a PESMM analysis of Obamacare. All of which in accordance with the perspective of the various high-quality scientific publications that have been published on ACA. Evidence of this type of PEST analysis using bibliographic sources is available here (6). The secondary aims of this paper fall within those typical of bibliometric analyses. As such, we also want to identify the main researchers interested in ACA in terms of countries, organizations, journals, and authors.

The rest of this paper is structured as follows. In Section Related work, a study of related research has been carried out, since other authors have conducted cross-sectional studies on the ACA, highlighting the differences between them and our proposal. Section Research methodology presents the research methodology followed. Section ACA analysis from a bibliometric perspective presents and analyzes the results of the application of this methodology in order to achieve the proposed objectives. Finally, conclusions and proposed future work are discussed.

Related work

A search for systematic literature review (LR) or bibliometric studies (BS) related to the ACA was carried out, obtaining a current overview of these papers by restricting the search to papers published from 2020 onwards, using both Clarivate and Google Scholar. After performing the corresponding searches and studying the results obtained, the related papers have been summarized in Table 1.

As can be seen, there are several review papers related to the ACA, but many of them are specific to certain aspects of the law, and those that are more general are not analyzed using bibliometric techniques. Based on the searches carried out, we can conclude that this paper is original and that nothing similar exists in the literature.

Research methodology

In this section we will explain the research methodology followed in this study and the results of which will be shown in the following section.

Bibliometric mapping is an important field within bibliometrics. Its objective is to show the structural and dynamic aspects of scientific research to enable further interpretation. In this paper we will follow the methodology shown in Figure 1, which is inspired by Cobo (44) and Galán et al. (45). The advantage of this methodology is that there are tools that allow us to carry out most of its stages, and in this study we mainly use the following tools: SciMAT (5), VOSviewer (46), and Microsoft Excel.

Each stage is described in more detail below.

Setting the objectives of the analysis

This study aims to achieve the following specific objectives: to extract and analyze the different issues that have been involved in different aspects of the ACA: political, social, health, economic and management or administration, to further study the political and social aspects involved in the ACA, to study how these issues have evolved from the period of implementation of the ACA to the present-day, to identify the main researchers interested in the ACA in terms of countries, organizations, journals and authors, and to study the trend of scientific production concerning the ACA.

Data collection

To carry out this study we required high-quality scientific literature published on the ACA. There are several bibliographic database options (45): Clarivate, Scopus, Google Scholar, etc.

TABLE 1 Related work.

References	Description	Type
Xu et al. (7)	Impact of ACA on colorectal cancer outcomes.	LR
Matkin and Ring (8)	Impact of the ACA on academic medical centers.	LR
Song et al. (9)	Impact of the ACA on dental health	LR
Chernew et al. (10)	The evolution of the ACA in payment systems	LR
Lee et al. (11)	Impact on women's coverage, utilization, affordability, and health after the ACA: A review of the literature.	LR
Zhao et al. (12)	Analysis of access to care across the cancer control continuum in the ACA over the past decade.	LR
Neiman et al. (13)	Impact of ACA on surgical patients.	LR
Glied et al. (14)	Study of the financial barriers of the ACA	LR
Peikes et al. (15)	Effects of the ACA on primary health care	LR
Ercia et al. (16)	Analysis of ACA in patient enrollment strategies	LR
Norris et al. (17)	Impact of ACA on the utilization of cost-sharing elimination of preventive care services.	LR
Soni et al. (18)	How ACA insurance expansion has affected health outcomes.	LR
Kamstra et al. (19)	Analysis of how the ACA fell short for a vulnerable population in Hawaii	LR
Kates et al. (20)	ACA coverage of HIV treatment and prevention funding in the USA.	LR
Nathan et al. (21)	Evaluation of the benefits of the expansion of Medicaid for oncology patients.	LR
Moss et al. (22)	Analysis of cancer care with the ACA Medicaid expansion.	LR
Hilts et al. (23)	Impact of hospital partnerships on population health.	LR
Fiedler (24)	Legislative history of the ACA	LR
Buntin and Graves (25)	Study of the evolution of health care spending since the approval of the ACA.	LR
Corlette et al. (26)	The effect of the ACA on the individual insurance market	LR
Adigun et al. (27)	Impact of the ACA on the health care of immigrants in the United States	LR
Rozier (28)	Community benefit assessment of not-for-profit hospitals in the U.S.	LR
Himmelstein and Woolhandler (29)	Analysis of medical care with the ACA	LR
Bossick et al. (30)	Impact of state legislation on reproductive health in the United States.	LR
Layton et al. (31)	Impact of ACA on long-term care.	LR
Lindley et al. (32)	Analysis of children's palliative care in the United States since 2010.	LR
Minas et al. (33)	Analysis of health disparities in oncology treatment in the ACA.	LR
Morgan et al. (34)	Study of preventing readmissions due to trauma in ICUs	LR
Marye (35)	Study of the relationship between insurance type and emergency department use for children with asthma in the United States during the ACA.	LR
Titus and Kataoka-Yahiro (36)	Analysis of barriers to health care access in Hispanics with type 2 diabetes in the ACA.	LR
Watkins et al. (37)	Analysis of the customized preventive services of the ACA	LR
Zavala et al. (38)	ACA disparities in cancer health in ethnic minorities.	LR
Hong et al. (39)	Impact of the hospital value-based purchasing program on Medicare.	LR
Clark et al. (40)	Analysis of the prevalence of health insurance among gender minorities.	LR
Steinberg et al. (41)	Racial differences in outcomes after receiving advanced heart failure therapies in the ACA	LR
Manchikanti et al. (42)	Comparative analysis before and after 2009 in patients undergoing vertebral augmentation treatment with Medicare.	LR
Ermer et al. (43)	Impact of Medicaid expansion for cancer care.	LR
Current work	Impact of the ACA at a cross-sectional level: political-legal, social, economic, medical and management.	BS

In this paper, we have used Clarivate as many authors consider it to be a higher quality source, although there are fewer papers available. This is not a problem in this case, as a preliminary study has identified several thousand articles on ACA.

The time period chosen for the study will be up to 2021, not including the current year, 2022, in order for the work to be reproducible. Specifically, the chosen dates are 01/01/2008 to 12/31/2021.

In the Clarivate advanced query option, the following expression has been used on the Clarivate Web of Science Core Collection:

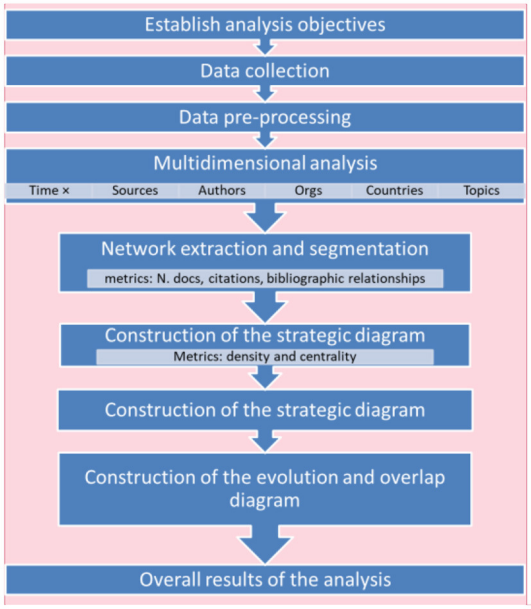

FIGURE 1
Steps used in the research methodology.

TS = ("obamacare" or "obama-care" or "obama care" or "Affordable Care Act")

The TS field implies searching for publications on ACA (including different forms of spelling and informal terms) in the title, abstract and/or keywords. The query was carried out in April 2022, obtaining a total of 6,369 documents.

Data pre-processing

The documents obtained were exported from Clarivate to seven files since only up to 1,000 documents can be exported at a time. Once this was done, they were included in SciMAT since this tool has several functionalities for data preprocessing. To increase the quality of the data, the keywords have been normalized by merging them in their plural and singular forms, words have also been merged with their corresponding synonyms, and several keywords that refer to the same concept have been identified by using the Levenshtein distance in SciMAT.

Multidimensional analysis

To obtain an overall view of the subject under analysis, we are going to perform the analysis from different points of view or dimensions. Table 2 explains each of these dimensions and includes the types of quantitative analysis we are going to perform on them, which are typical of the tools we are using in this paper (SciMAT and VOSviewer).

TABLE 2 Dimensions of analysis, meaning, and type of analysis available for them.

Dimension	Description	Type of analysis
Sources	Journals, conference proceedings...	Citations
Authors	Author and co-authors	Co-authorships
Organizations	Authors' affiliations and funding organizations	Co-authorships
Countries	Authors' countries	Co-authorships
Topics	Keywords	Co-occurrences

According to the type of analysis, we use the following bibliographic relationships that will allow us to quantitatively relate various bibliographic elements, thus allowing us to construct the corresponding networks (45); co-authorship, the relationship of the articles is determined according to the number of co-authorships; citation, the relationship of the articles is determined according to the number of times they cite each other; co-occurrence, the relationship of keywords is determined according to the number of documents in which they appear together. For this purpose, the equivalence index is often used.

Network extraction and segmentation

After this construction, a process of segmentation or grouping of the elements that are considered similar is usually performed. Therefore, nodes that are considered to be close enough to each other and sufficiently separated from the other groups are grouped together. An example of a thematic network can be seen in Figure 2.

Construction of the strategic diagram

This type of diagram is particularly interesting in the analysis of co-occurrences as it allows the importance of each of the topics that have emerged in the analysis to be outlined. It is based on two measures (5):

- **Centrality** measures the degree of interaction of a network with other networks. This value can be understood as a measure of the importance of an element in the development of the entire analyzed field of research.

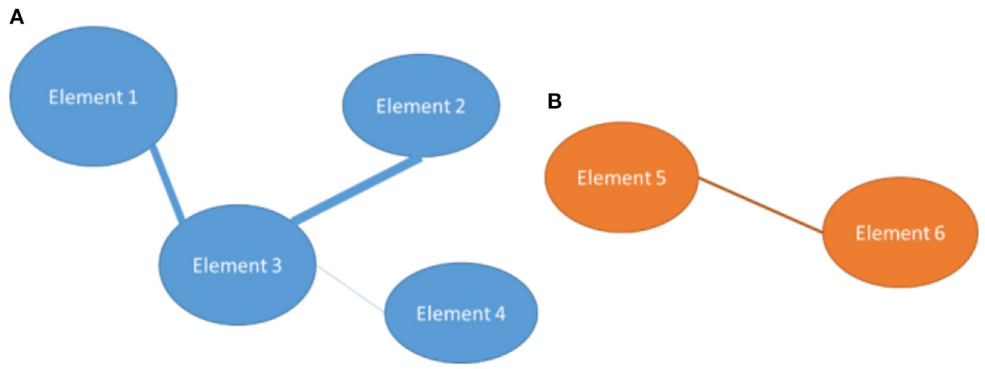

FIGURE 2
Thematic network where the different elements (dimensions) and segmentation of the network are linked using a different color for groups, group **(A)** and group **(B)**.

- **Density** is the internal strength of the network or element in question. This value can be considered to be a measure of the degree of the development of the topic.

The strategic diagram makes it possible to classify the topics that were identified in the bibliometric study into four categories, as shown in Figure 3.

Construction of the evolution and overlap diagram

The topic divisions have been divided by periods, and afterwards, the evolution and overlap diagram of the corresponding items is obtained, which shows the evolution of the topics and the overlapping of these detected topics (which is an indicator of their stability) in successive periods of time. An example of both diagrams is shown below in Figure 3.

Visualization and interpretation of results

Based on the results obtained for each dimension, mainly the graphs already mentioned in the previous points, the researcher must interpret and, in many cases, fine-tune the results based on the selection of the various parameters that the tools have, until they understand what is happening in that particular analysis.

Overall results of the analysis

Although this methodology is largely based on quantitative techniques, the researcher, based on the different global results obtained for each dimension (subject, authors, countries, etc.), has to interpret them globally and try to meet the objectives set out in the first stage.

ACA analysis from a bibliometric perspective

In this section we will explain the results of applying the previously mentioned research methodology to the topic analysis. To do so, we will begin by analyzing the different topics related to the ACA that were identified in the bibliometric analysis and we will try to look at them from the different PESMM perspectives mentioned above. In this analysis, an analysis of the temporal evolution of these issues must be carried out, since the application of the law has evolved with the different changes of government, judicial resolutions, etc. Subsequently, we will analyze the different sources (journals, conference proceedings, etc.) where we have found studies related to the ACA. We will then analyze the contributions made to this area by the most important authors, countries and organizations. Finally, we will extract the overall results of the analysis and extract the fundamental factors of the intended PESMM analysis.

Topic analysis

As mentioned above, this type of analysis is essential in order to meet the main objectives of this study. As such, we will analyze the keywords of the articles obtained in three different ways: those specified by the authors themselves; those specified by the Clarivate for each article; and the additional keywords extracted from the title of the article and the abstract. It is important to remember that for this type of analysis we will use the co-occurrences of these keywords among the different articles, as

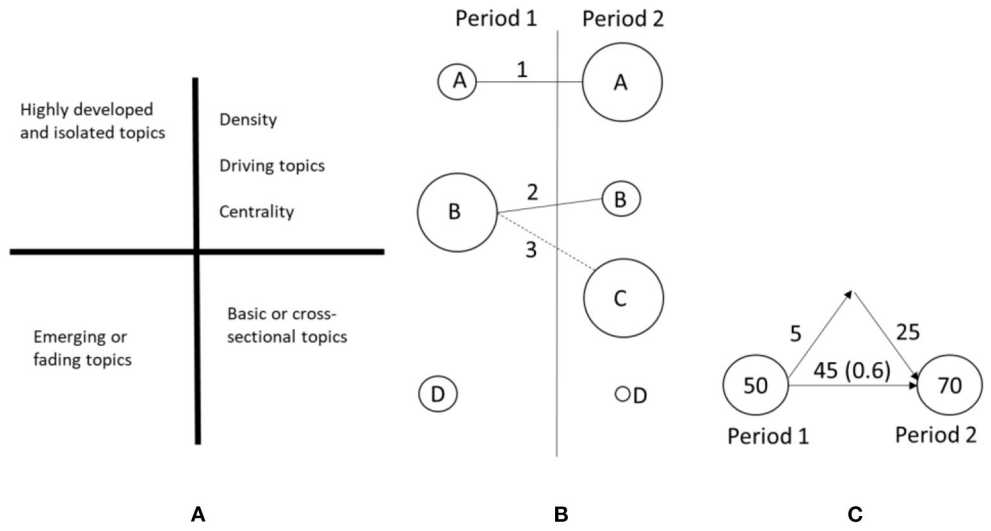

FIGURE 3
Strategic diagram **(A)**, examples of an evolution diagram **(B)**, and overlap diagram **(C)**.

mentioned in Section Research methodology. In other words, one keyword will be related to another according to the number of documents in which both appear together.

We will divide the period of analysis in two, since the ACA itself has undergone several variations from its conception to its attempted implementation, motivated among other factors by the complexity of the implementation itself, judicial vicissitudes... but above all, one such determining factor has been the different changes in the U.S. governments:

- **Until 2017**: would be the stage of growth in scientific interest in this subject, including work prior to the law itself and the implementation period under the Obama administration. Obviously, this administration has been a great promoter of this law, so its development during this period is quite noticeable.
- **2017–2022**: is the post-Obama stage, which included that of President Trump and later Biden. This stage was also influenced by the pandemic caused by Covid-19. The political changes after the 2016 elections brought about reforms to the law that generated uncertainty, although after Biden's arrival to power the law now seems to be more entrenched.

For the analyses shown below, the SciMAT tool will be used primarily for the construction of the strategic and evolution/overlap diagrams (explained in Section Research methodology). Note that prior to the construction of these diagrams, the keywords have been preprocessed by grouping synonymous terms (although written differently) as explained in Section Data pre-processing.

Period of analysis "until 2017"

Figure 4 shows the strategic diagram for the first analysis period "until 2017." This diagram was initially constructed with SciMAT and was enhanced with the typology of each quadrant in order to determine the importance of the topics. In addition, each of the topics has been qualitatively typified into five major areas or topic categories, each of which is related to the ACA:

- POLITICAL: this includes topics dominated by the political and legal aspects of the health law reform implemented by the ACA.
- ECONOMIC: issues related to the economic aspects of the ACA are included in this category.
- SOCIAL: the social impact of the ACA is unquestionable and this category includes issues related mainly to the social aspect of the law.
- MANAGEMENT: this includes issues related to the management and administration involved in the implementation of such a complex law that has such a significant impact.
- MEDICAL: the health of citizens was of course the primary objective of the law and studies with medical implications of the law would fall into this category.

Political

In this category we have included the following topics:

- *AFFORDABLE-CARE-ACT* (Supplementary Figure 10). This is the most important (it is a driving topic) and extensive thematic network of the period, bringing together works of various kinds related to the ACA

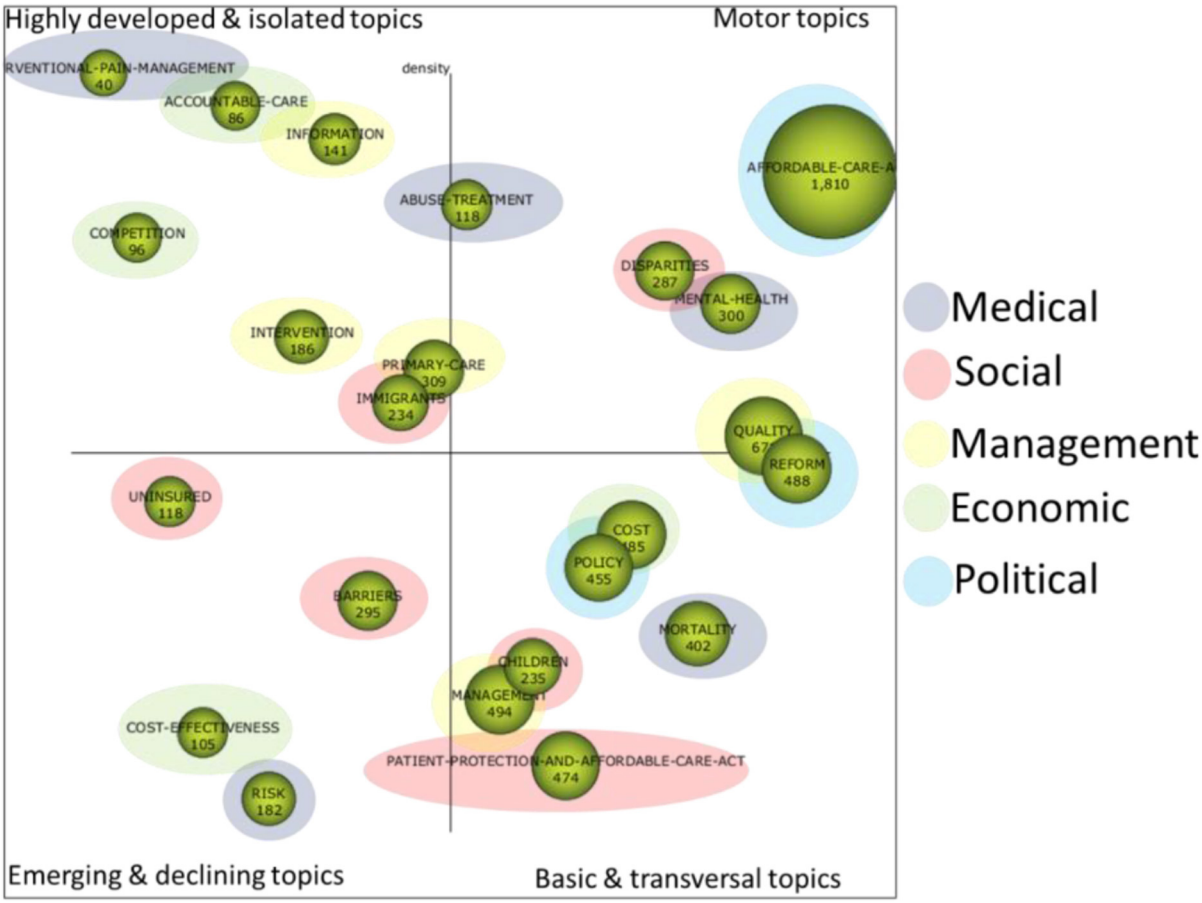

FIGURE 4
Strategic diagram analysis period "until 2017".

law itself. A significant work included here is President Obama's own analysis in an initial paper on the Obama-Biden reform (47) and a later paper on the implementation of the reform and the steps to be taken next (48). Studies on MEDICAID are also included, which is a government-run health coverage offered to people with limited income. The extension or expansion of this type of coverage is one of the main objectives of the ACA, and thus we can find works that deal with this expansion in low-income adults (49).

- *REFORM* (Supplementary Figure 11). This is a basic and cross-sectional issue that essentially includes political and legal aspects related to the law reform, which has involved important studies (50–53). The changes in insurance coverage brought about by the law would also be included here, with a number of studies, such as (54). There are also interesting studies that consider whether the law reform will lead to structural or circumstantial changes, such as the one in (55), which is closely related to the hypothesis set out in this paper.
- *POLICY* (Supplementary Figure 12). This is also a basic and cross-sectional topic that essentially includes aspects of studies that are more closely related to politics in this period (56–59). Studies on public opinion are also included in this topic (60).

Social

In this category we have included the topics explained in more detail below:

- *IMMIGRANTS* (Supplementary Figure 13). Undoubtedly, this is one of the groups that is most affected by the ACA. We can find studies on undocumented immigrants (61), Hispanics (62), the abolition of immigration-related barriers to health care (63), etc.
- *DISPARITIES* (Supplementary Figure 14). In this topic we can find papers related to disparities based on ethnicity, particularly in the case of African Americans (64), gender (22), rural areas (65), etc.

- *UNINSURED* (Supplementary Figure 15). The uninsured are a serious problem addressed by the ACA. As examples we have the following studies (66, 67).
- *BARRIERS* (Supplementary Figure 16). Studies would include other types of barriers to health access such as language, educational level, teenagers' access to contraceptives (68), etc.
- *CHILDREN* (Supplementary Figure 17). Here we find interesting studies on health management in children (69) and school cooperation (70).
- *PATIENT-PROTECTION-AND-AFFORDABLE-CARE-ACT* (Supplementary Figure 18). This last social issue deals with various topics related to the protection of patients' health, such as a healthy diet (71), access to accurate health information on the Internet (72), tele-assistance (73), etc.

Economics

In this category we have classified the following topics:

- *COMPETITION*. An interesting topic to analyze in terms of the ACA is the impact that the law has had on the health care market (74), antitrust policies (75), etc.
- *ACCOUNTABLE-CARE*. This topic is closely related to the issues of equipping staff in organizations made possible by the law (76).
- *COST-EFFECTIVENESS*. Addresses economic efficiency in the health care industry (74).
- *COST*. Similar to the previous topic, it focuses on the changes in the costs implied by the law, such as the elimination of certain shared costs (77).

Management

In this category we have classified the following topics:

- *QUALITY*. The issue of quality associated with the health care system is a critical topic that has been addressed, for example, by (78).
- *PRIMARY-CARE*. Primary health care is key for health care management, in this regard we can find several studies, such as (79).
- *INTERVENTION*. An important aspect of management is the reduction of readmissions (80), treating the mental health of caregivers (81), etc.
- *INFORMATION*. Communication is a key part of health management, with regard to both the ACA itself and the health issues included in it, such as proper nutrition, in which we highlight studies related to fast food (82), medication (83), etc.
- *MANAGEMENT*. This topic covers the management process itself in relation to various aspects of the ACA, highlighting the work of (84) on the transition to reform brought about by the ACA.

Medical

In this category we have included all topics related to ACA and various medical matters:

- *INTERVENTIONAL-PAIN-MANAGEMENT*. This topic deals with pain management and pain treatment processes including treatments for chronically ill patients, e.g., pain management and pain management processes (85).
- *MORTALITY*. These are studies that deal with mortality related to diseases such as cancer (86), cardiovascular diseases (87), etc.
- *RISK*. Health risk management is an important topic that includes preventive treatment of patients (88).
- *ABUSE-TREATEMENT*. Drug abuse is a challenge for the ACA with important work such as (89).
- *MENTAL-HEALH*. Psychiatric disorders, behavioral disorders, depression, etc. are included here with various studies such as (90), which deals with access to this type of care according to sociodemographic profiles. An interesting study is (91), which deals specifically with the relevance of ACA in improving citizens' mental health.

Analysis period "2018–2021"

The extended strategic diagram for this period can be found in Figure 5. We can make the same observations about its construction as we have made for the previous period (see Figure 4). It should be noted that in this period we have only been able to classify one thematic group in the area of economics. It is not that there are no studies that include economic aspects related to the ACA, but rather that they are not connected closely enough for the analysis to group them together. Therefore, certain economic aspects are less prevalent in the other areas in the current period.

Each of these categories is explained in more detail below.

Politics

In this category we have included the topics explained in more detail below:

- *AFFORDABLE-CARE-ACT* (Supplementary Figure 19). This thematic group has the same meaning as the one studied in the previous period and, similarly to the previous period, in the current period it is also the most important in terms of the number of documents and their importance, qualifying as a driving topic in the strategic diagram. Debate continues over what the near-term future of the reform (92) and the expansion of health coverage will be since the arrival of the Biden administration (93).
- *HEALTH-POLICY* (Supplementary Figure 20). This is a basic, cross-sectional topic that addresses issues such as

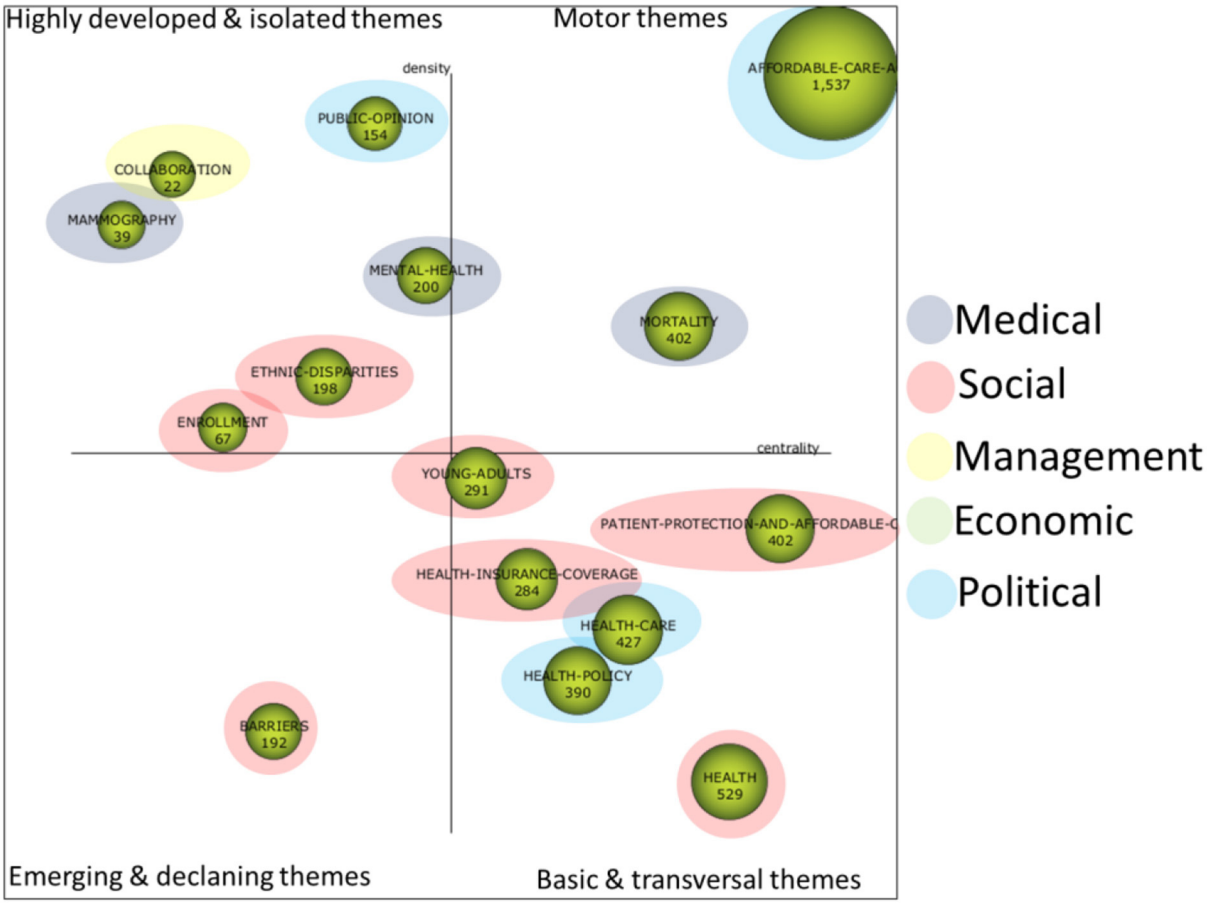

FIGURE 5
Strategic diagram analysis period "2018–2021".

better health brought about by the reform (94), community needs with respect to hospitals (95), equality in terms of health (96), etc.

- *HEALTH-CARE* (Supplementary Figure 21). This network includes issues such as Americans' own understanding of the welfare state (97) and the specific challenges that lie ahead for the welfare reform.
- *PUBLIC-OPINION* (Supplementary Figure 22). The law itself still has an uncertain future, and in this regard public opinion has become particularly important during this period, as the public's view will undoubtedly dictate the future of what will happen with the ACA. We found several studies in this regard (98), some of them conducted in the era of Donald Trump (99).

Social

The following is an explanation of the topics included in this category during this period:

- *ETHNIC-DISPARITIES* (Supplementary Figure 23). This includes studies related to the disparity in the health care system in relation to migrants (100), Hispanics (101), etc.
- *YOUNG-ADULTS* (Supplementary Figure 24). There are several studies that deal specifically with young people and adults (102, 103).
- *HEALTH-INSURANCE-COVERAGE* (Supplementary Figure 25). As was seen in the first period of analysis, the impact of the ACA on insurance coverage is an important topic of analysis. In the current period, we have found studies focused on retirees (104, 105), etc.
- *BARRIERS* (Supplementary Figure 26). Again, as in the previous period, this group of topics is focused on the study of barriers to the expansion of medical care (106), disparities in access for the disabled (107), etc.
- *PATIENT-PROTECTION-AND-AFFORDABLE-CARE-ACT* (Supplementary Figure 27). This group of topics is also found in the previous period. It includes papers on

the health of the uninsured (108), financing treatment of cancer patients (109), effects of the law on the management of chronically ill patients (11), etc.

- *HEALTH* (Supplementary Figure 28). This topic includes analyses of people with limited income (110), and the treatment of those addicted to certain substances (111), etc.

Economics

In this category we have classified the following topics:

- *ENROLLMENT* (Supplementary Figure 29). In this period, which includes the Trump era, there are several studies that deal with the issues related to the recruitment of policyholders in the ACA plan (112, 113).

Management

In this category we include a single topic:

- *COLLABORATION*. It includes collaborations between organizations to manage health (114, 115), including not-for-profit hospitals (28).

Medical

It includes various medical topics related to the ACA:

- *MORTALITY*. The subject of mortality was also included in the previous period; some papers on this subject can be found in (116). It also includes studies related to Covid-19 (117).
- *MENTAL-HEALTH*. This is another topic that was also found in the previous period. Some studies that could be cited in this regard are (118, 119).
- *MAMMOGRAPHY*. In this period this medical test has become very important due to its global advancement in the health system as a preventive method, some working examples are (120, 121).

Topic development from the period "until 2017" to "2018–2021"

The following evolution diagrams have been made in order to study this development (Figure 6). This diagram shows the topics that have remained relevant from one period to the next (*AFFORDABLE-CARE-ACT, BARRIERS*, *DISPARITIES*, *MORTALITY*, and *MENTAL-HEALTH*…) and which have already been discussed in the previous points. Several of the topics from the first period have been dropped, especially those related to the economic aspects of the ACA, such as *COMPETITION*, *COST*, *COST-EFECTIVENESS*, etc.

In the last period, some new topics have appeared, such as *MAMOGRAPHY*, *ENROLLMENT*, *COLLABORATION* which may imply a specialization of studies in a law that has become more widely implemented. In the overlap diagram (see Supplementary Figure 30) we can quantitatively see how 21% of the topics have remained the same from one period to the next and how the second period showed a drop in the number of topics covered.

Source analysis

We will first study how publications on the subject have evolved over time. Figure 7 shows this evolution both in terms of publications and citations. An initial conclusion is that the topic has been of growing interest in the scientific community up until 2017, which was the last year of the Obama administration. This fact is evidenced by the number of publications. If we look at the quotations, we can also see a shift in the cycle that occurs in that same year, where the quotations stop growing exponentially and finally end up decreasing from 2020 onwards. As this change in trend occurred in 2017, it is ruled out that the decline in publications and general interest in ACA is due to the effects of the pandemic caused by COVID-19.

If we want to get an idea of the type of studies being carried out on the subject, it is interesting to look at the areas in which the different publications have been produced. We can observe these areas in (Supplementary Figure 31). As we can see, the areas related to health policies are the most predominant, but areas such as medicine, economics, society and law are also important.

Supplementary Figure 32 shows the typology of the publications analyzed, in which scientific articles clearly stand out, followed by editorials and conference abstracts. It is also worth mentioning that 35 review books related to the subject have been found.

Author analysis

The most important authors in terms of the number of publications are shown in (Supplementary Figure 33). As can be seen, Professor Ben Sommers of Harvard University and a specialist in Economic Policy and Health is by far the most named with 87 publications related to the ACA. He is a major author with a 54-h-index (i.e., he has 54 publications with at least 54 citations) and with more than 11,000 citations at the time of this paper, according to Google Scholar, and whose main research interests are health policies for vulnerable populations, the uninsured, and the social security system. He has received numerous awards for his research, including *Outstanding Dissertation Award*, the *Alice Hersh New Investigator Award*, the 2015 *Article-of-the-Year Award* and the 2017 *Health Services Research Impact Award* from *Academy Health*, a preeminent national association of health policy researchers, according to its website.

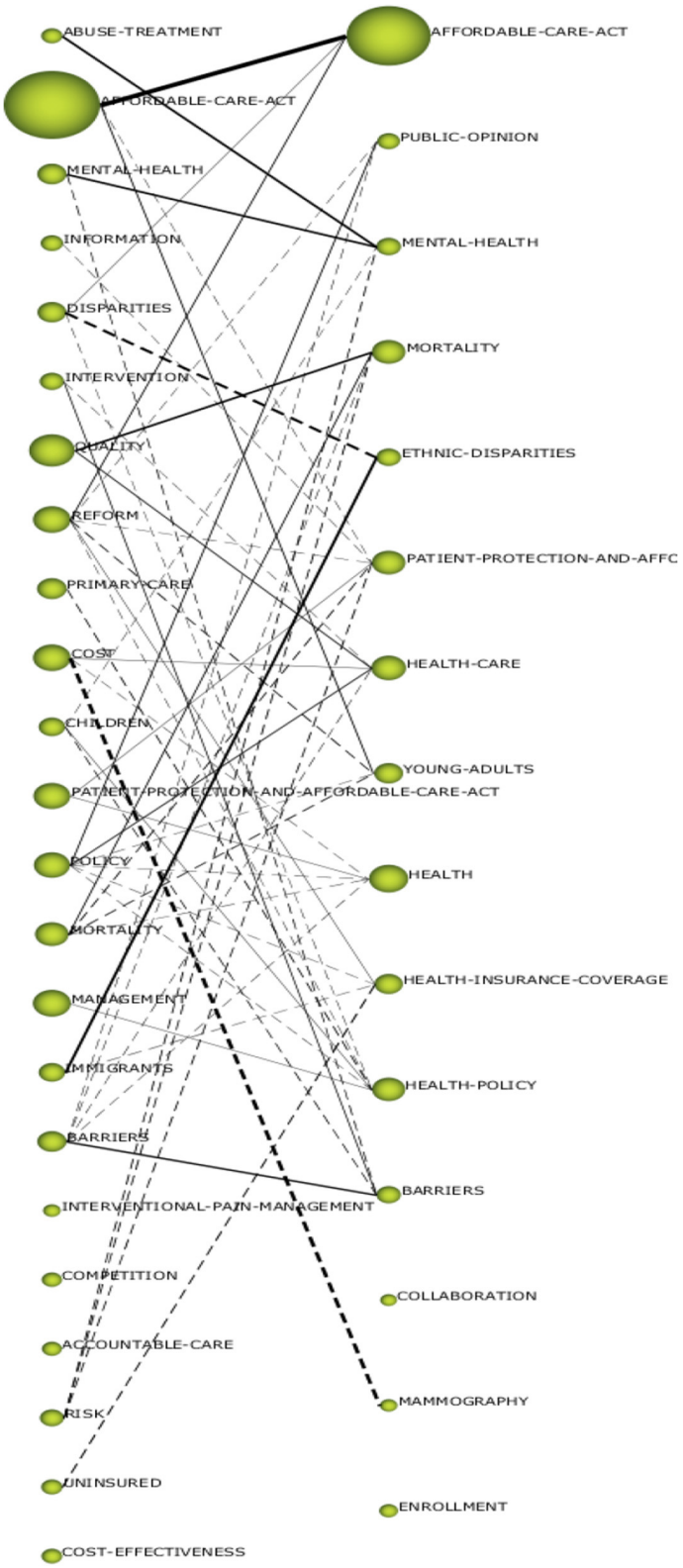

FIGURE 6
Evolution diagram from the period "Until 2017" to the period "2018–2021".

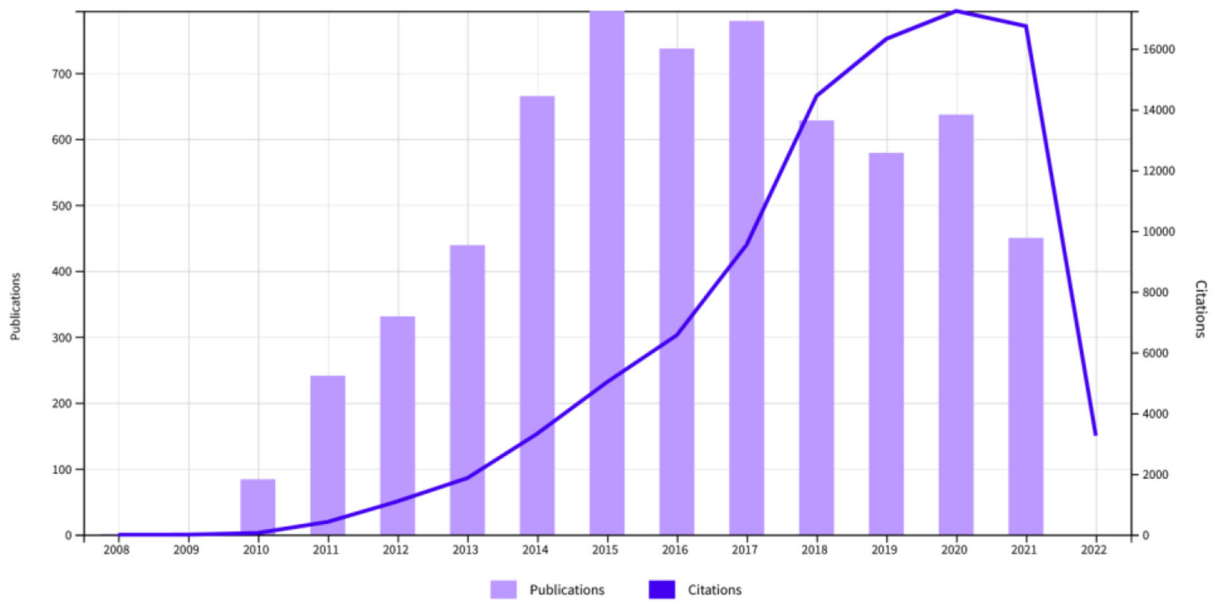

FIGURE 7
Changes in the number of publications and citations on the subject.

Figure 7 shows the relationship of publications and the link between authors determined by the number of papers they co-signed.

Country analysis

The country analysis shows that the USA has taken the lead in this area, as can be seen in Figure 8. The ACA has also sparked some interest in the United Kingdom, Canada, Germany, and China.

Likewise, we can build a network of co-authorships according to countries, as we did previously for the authors. This network is shown in (Supplementary Figure 35). Countries with the highest number of publications on the analyzed topic, which again corroborates the importance of the United States in this type of study, which is only natural since it is a law that is specific to this country.

Analysis of organizations

As this is a topic of great interest in the USA, there is an extremely high number of public and private universities and research centers in the USA that have publications on this subject. Among the most important organizations in ACA research are Harvard University, the University of California system, which is composed of several universities in California, the University of Michigan, and the University of Pennsylvania, as shown in Figure 8.

If we build a network of co-authorships between organizations to give us an idea of the collaboration between them, we will observe that there are many instances of collaboration between the different institutions in the USA when it comes to analyzing the ACA. This network is shown in Supplementary Figure 37. Organization analysis by author.

We can also conclude from this network that organizations belonging to the same system are obviously more likely to collaborate with each other in a more active way.

Overall results of the PESMM analysis of the ACA

The results of the analysis will be presented in this section, in particular in terms of the topics that have been identified. As mentioned above, we have focused on five major topic areas of the ACA: Political, Economic, Social, Management, and Medical. Therefore, we will highlight the most significant factors of this PESMM analysis based on the bibliometric analysis carried out for each of the areas involved. In this case, no distinction will be made between periods, although we will try to use, as far as possible, the findings of authors from the last period in order to make them more up-to-date. This PESMM analysis is shown schematically in Figure 9.

The most important factors in each area are explained below:

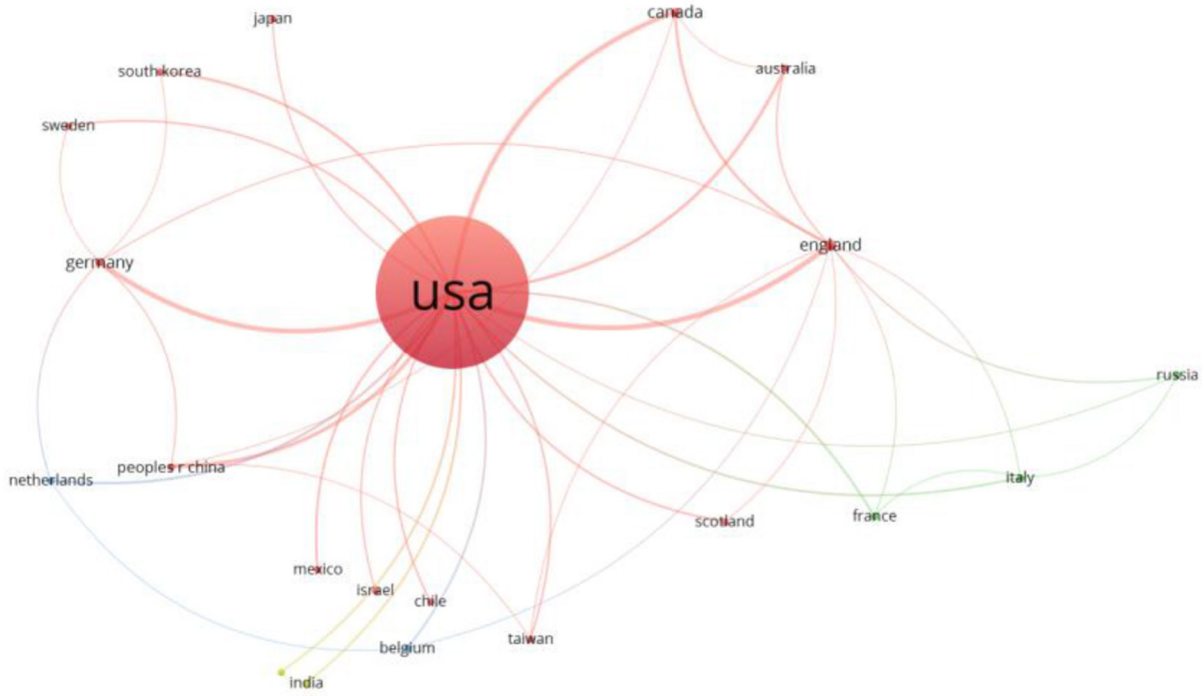

FIGURE 8
Co-authorship network of the most important countries in the subject analyzed.

- **Political**. Political stability is a critical factor in the ultimate success of ACA implementation. As mentioned in Section Topic analysis, the change of administration has caused changes in the course of the law and the uncertainty surrounding it, although it now seems to be entrenched thanks to Biden's rise to power. Therefore, it is evident that there is a need for political consensus between Republicans and Democrats on the fundamental aspects of the ACA to avoid jeopardizing it in the future. One of the things the Democrats should do to achieve this is to stop the media hoarding of Obamacare, which even goes by the name of the president who initiated it (Obamacare). Republicans, in turn, must understand that in the twenty-first century quality universal health care is a social need, especially in the wake of the Covid-19 health crisis. It is important to take into account the federal implementation of the law, especially in the development of Medicaid (which insures the most vulnerable classes). In 2017, nearly 20 states opted not to apply it (122), which is a significant problem for the ACA. There have also been federal barriers to implementing the law because although the law covers women's needs (including contraceptive measures and abortion), the states' own federal laws in many cases impede its application. In the last period analyzed, an issue related to public opinion arose, and of course, public awareness of the culture of free, quality universal health care is a fundamental factor for ensuring its continued existence in the future.
- **Economic**. The ACA has meant that the healthcare co-payment and co-insurance formulas have become popular and coexist on a regular basis. The ACA has incorporated formulas for a number of provisions of value-based or pay-for-performance benefit schemes. According to some authors, it is not clear that this promotes equity of care and there is a risk that resources could be diverted from hospitals and physicians serving disadvantaged populations (122). Non-profit hospitals in the USA must demonstrate the benefits they provide to the community in order to be granted tax exemption. This assessment is therefore very important (123). Public administrations encourage investment in health care that benefits the population, and there is also a demand for public-private partnerships (124). However, in addition to overall health spending, it is also important to consider spending per citizen.
- **Social**. In spite of the ACA, there are financial barriers to health care. Hefty costs in the form of co-payments, co-insurance, etc. hinder access to health care and often lead to financial hardship for citizens or even financial ruin (122). Barriers also exist in the disease coverage itself, with many citizens being underinsured in this regard (14). Although

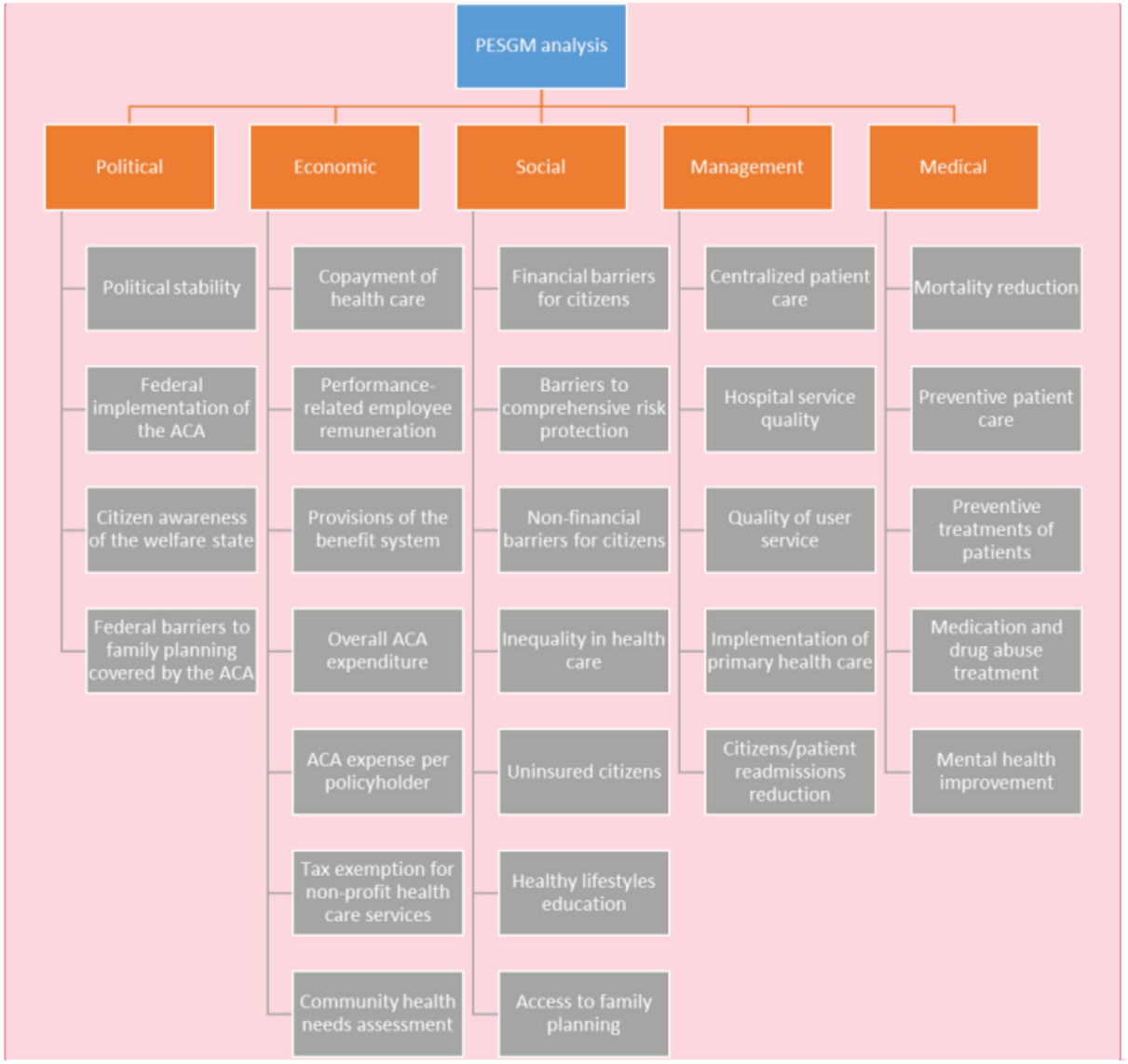

FIGURE 9
PESMM analysis of the ACA.

the ACA already reduced the number of uninsured citizens in 2017 (122), the most economically disadvantaged groups, which often coincide with African Americans, Hispanics, immigrants, undocumented migrants, etc. are often very vulnerable in this regard. Another important aspect is educating the population about a healthy lifestyle in areas such as nutrition, sports, etc. The law has improved access to contraception by making coverage mandatory for insured women (122), although as discussed above, there are federal barriers to such services.

- **Management**. The law has encouraged proactive health management through primary health care, centralized patient care and collaboration between health organizations. This should undoubtedly have an impact on the quality of these services and should improve management by avoiding readmissions and general inefficiencies.
- **Medical**. The reduction of mortality, pain treatment, preventive health care (promoting gynecological and urological check-ups, mammograms, etc.), treatment of drug and medication abuse, improvements in mental health, etc. are the objectives of the implementation of the ACA, and although there is still a long way to go, there are already a number of studies that point to improvements in these areas.

Conclusion and future work

The reform brought about by the ACA is the most important reform that has been undertaken in the USA in recent times, with great repercussions at a political-legal, economic, social, management (or administrative), and medical (or health) level. In this paper we have tried to consider the impact of this law in all these areas from an objective point of view, as far as possible, thanks to the bibliometric methodology used. It has been noted that the law requires political consensus to be implemented in a definitive and global manner throughout the United States. A balance is yet to be struck between the coexistence of private and public health care to ensure broad social coverage without economic or other types of barriers. At a management level, we have also observed that considerable room for improvement exists in factors such as centralized patient management, which also undoubtedly has repercussions on efficiency and, therefore, economic factors. Several medical studies have shown the positive impact of ACA on various treatments and the prevention of diseases. From a more global point of view, it could be said that the ACA is causing a change of mentality in the USA, especially after COVID-19, which has highlighted the need for free and universal health care for the entire population.

In a more purely bibliometric aspect, the main contributors to ACA research have been identified in terms of authors, organizations, journals and countries. In addition, we have noted a downward trend in the scientific contribution to this law.

It should not be forgotten that since 2020 the world has been experiencing a health crisis caused by COVID-19, which has affected the very implementation and vision of the law. We believe that it is still too early to analyze the impact this may have had; therefore, this work could be updated in the near future. In this regard, the methodology used in this work is regarded positively, since it reflects several of many authors' partial assessments from a broader and supposedly objective point of view.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found at: Scopus Google Scholar Web of Science.

Author contributions

AC-A, JG, and RC contributed to conception and design of the study. RC organized the study. All authors contributed to manuscript revision, read, and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.979064/full#supplementary-material

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Regional well-being inequalities arising from healthcare expenditure public policies in Spain

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Well-being inequalities arising from different healthcare expenditure public policies is currently a hot topic at a national scale, but especially so at a sub-national level because the inequalities in question are among citizens of the same country. Spain is an optimal study area to carry out research on this topic because it is considered to have one of the best health systems in the world, it is one of the top-ranking countries in terms of life expectancy rates (the indicators we use for well-being), and it has a decentralized public health system with significantly different regional healthcare expenditure public policies. Given that the factors involved in the complex direct, indirect, and second-order relationships between well-being and health spending are latent in nature, and that there are more hypotheses than certainties regarding these relationships, we propose a partial least squares structural equation modeling specification to test the research hypotheses and to estimate the corresponding impacts. These constructs are proxied by a set of 26 indicators, for which annual values at a regional scale were used for the period 2005–2018. From the estimation of this model, it can be concluded that mortality, expenditure and resources are the factors that have the greatest impact on well-being. In addition, a cluster analysis of the indicators for the constructs included in this research reveals the existence of three clearly differentiated groups of autonomous communities: the northern part of the country plus Extremadura (characterized by the lowest well-being and the highest mortality rates), Madrid (with the best results in well-being and mortality, the lowest public health expenditure per inhabitant and percentage of pharmaceutical spending, and the highest percentage in specialty care services and medical staff spending), and the rest of the country (south-eastern regions, with similar well-being values to those of the first group but with less health expenditure). Finally, a principal component analysis reveals that "healthiness" and "basic spending" are the optimal factors for mapping well-being and health spending in Spain.

KEYWORDS

Spanish health system, life expectancy, well-being inequalities, healthcare expenditure public policies, partial least squares structural equation modeling, cluster analysis, principal component analysis

Introduction

A key question when approaching research on health spending is what modern societies are primarily seeking to achieve with such spending. In the earliest literature on the topic, a variety of answers can be found, including wellness, well-being, psychological well-being, flourishing, mental health, quality of life, life satisfaction, and hedonic well-being (1–6).

The selection of the optimal "response variable" is an intellectual challenge and remains a hot topic, with contributions from multiple, widely differing scientific disciplines (7–12). In this research, we initially selected the concepts of wellness and well-being as the "response variable," because they are two overarching concepts, which incorporate practically all the individual or partial responses (dimensions) cited in the literature. However, choosing one of them is an extremely difficult task.

Wellness, as defined for the first time in Dunn (13), refers to a special state of individual health which sees man as consisting of body, spirit and mind, and which depends on his environment. Three years after the pioneering concept put forward by Dunn, the World Health Organization (WHO) defined health in terms of wellness as "physical, mental, and social well-being" (14). Therefore, wellness is a global concept, and while physical and mental health contribute to it, they are not the only contributors. In the literature on the topic, after the WHO definition of wellness, the social, occupational, spiritual, intellectual and emotional dimensions are also cited as drivers for wellness (15). Hattie et al. (16) consider the creative self, coping self, social self and the essential self as the wellness dimensions that complement the physical self-dimension. Ardell (17), Myers et al. (18), Stoewen (19) are other interesting papers contributing to this debate. There is even some literature suggesting that wellness is a concept that is much more closely linked to happiness than to health [the pioneer in this line is Saracci (20)]. However, there is a consensus in the wellness literature that the core dimensions are physical and mental (21–24).

As for well-being, as expected, there is no consensus on a simple definition of the concept. However, as stated in CDC (25) and the literature cited therein, there is general agreement on the following aspects: well-being includes the presence of positive emotions and moods (e.g., contentment, happiness), the absence of negative emotions (e.g., depression, anxiety), satisfaction with life, fulfillment, and positive functioning. Therefore, well-being can to an extent be identified with judging life positively and feeling good. Obviously, from a public health perspective, physical (and recently mental) well-being is seen as critical to overall well-being. However, this is not the only aspect of well-being. Overall well-being also includes socio-economic well-being, development and activity, emotional well-being, psychological well-being, life satisfaction, domain specific satisfaction and engaging activities and work [see CDC (25) and the references therein].

In this research, we focus on well-being rather than on wellness. There are three reasons for this decision:

(i) As stated on Dr. Brandt's blog (26), wellness and well-being are like siblings: related, but different. Both are intimately linked to good health, and the two go hand-in-hand but are different. Wellness is a set of habits and behaviors, while well-being is a state of mind. In other words, wellness is a practice that can lead to greater well-being. It could be said that wellness is an important element of overall well-being, and that well-being is a more inclusive concept than wellness.

(ii) In some branches of the literature, wellness is often identified with individuals and well-being with groups of individuals.

(iii) In post COVID pandemic times, well-being is even more essential than ever. We have been reminded how important health and well-being are from all angles, including the economic one. As noted in Gonzalez-Natal et al. (27), well-being has now become a multistakeholder, multisectoral and multidimensional concept and people's expectations change very quickly. Specifically, the multidimensional aspect of the current concept of well-being is one of the reasons for the evolution from wellness to well-being. Therefore, it is no surprise that governments are implementing programs focused on the well-being of their citizens.

Having decided that well-being is the optimal response variable, the focus moves to how to measure well-being. From the above paragraphs, it can be easily deduced that well-being is a subjective concept. Accordingly, self-evaluations are typically used to measure it at an individual level, although objective indicators such as household income, neighborhood crime rate, etc., are also frequently used (28–30). None of them yield a complete assessment of well-being because this concept is in essence multidimensional, requiring a multimethod assessment approach. According to Alexandrova (31), at least three approaches to the concept of well-being can be distinguished: hedonic balance, life satisfaction and a version of Aristotle's idea of eudaimonia. The more than 4,000 papers per year that are currently published in Web of Science indexed journals on well-being-related topics can be framed within these approaches. The literature is also abundant on current ways of well-being measurement. By way of example, Ong et al. (32) review 240 studies published between 2005 and 2019.

However, our focus is on well-being at an aggregate scale; in other words, we are interested in community well-being (specifically Spanish well-being). Community well-being is a relatively new concept in the literature on the topic and is closely related to public health. It is not the sum of individual well-beings; it has its own entity. What is more, community well-being is necessary for individual well-being [see Kim et al. (33), and the references therein for details and discussion on this topic]. Having said that, as at the individual scale, and borrowing

the words of Barrington-Leigh (34), there is a key question to be answered: Can a single number or index capture society's well-being well-enough to guide all policy decisions? This is an undeniably seductive idea that points to multidimensional indexes. However, given that multidimensional indexes are not free from subjectivism or measurement errors, a second question that needs answering is: Can a single variable (not an index but only a register) meet the above goal? Most of the recent literature points to life expectancy because it rests on a number of key dimensions related to health, housing and environment conditions, food quality, and other aspects of human life (17).

The second decision to take when approaching research on the relationship between healthcare expenditure policies and well-being at a sub-national level is the country that is the focus of the research. Obviously, the ideal would be to analyze the above relationship in all countries with a decentralized health system; however, such a task goes beyond the scope of this article and constitutes a statistical challenge from the point of view of the massive database needed to feed the statistical strategies implemented to obtain the associated estimates.

In light of the above limitation, we focus our research on Spain. At a national scale, the Spanish Public Health System is considered one of the best public health systems in the world from several perspectives: completeness, efficiency, care universalization, accessibility, primary care, quality of specialized care, spatial location, and decentralization in the management of health resources, among others. As a result, in 2020 (latest data available) Spain, together with Switzerland, had the highest life expectancy at birth in Europe (83.9 years) and was sixth in the world after Hong Kong, Japan, Macau, Switzerland and Singapore (35). This position, together with the fact that Spain also has one of the lowest mortality rates from preventable and treatable causes, suggests that public health and healthcare interventions are effective in preventing premature mortality.

The second reason for focusing our research on Spain is that, in 1986, responsibility for healthcare was decentralized from the central government to the autonomous communities, which allows us to study inter-regional disparities. Consequently, despite the existence of an Inter-territorial Council of the National Health System, whose main responsibility is to ensure equal access to health services throughout the national territory (36), it could be said that in Spain there are 17 different (regional) health systems, each with its own spending policy. Some of them claim to be the best regional public health system in the country, with the best—or one of the best—public health systems in the world. As an example, the president of the region of Madrid recently claimed that the region held first position in the ranking of Spanish regional public health systems, citing the fact that the top three positions in the Hospital Excellence Index 2021 were taken by hospitals of the region of Madrid. Therefore, the following questions arise: What about the disparity in the inter-regional healthcare systems? Does it correspond to a disparity in regional public health expenditure? In other words, is there a direct relationship between public health expenditure policies and well-being? Are there differentiated clusters of areas according to well-being indicators?

The COVID pandemic could be considered a good stress test for the national (or sub-national) public health systems' effectiveness and efficiency when facing extreme situations. Spain was one of the countries most affected by the pandemic in terms of deaths per million inhabitants. It ranks 13th in the world and 5th in Europe (37). Sachs et al. (38) developed an overall index of epidemic control for 33 OECD countries (all of them except Chile, Colombia, Mexico and Iceland), by combining the data on COVID-19 mortality rates, effective reproduction rates, and epidemic control efficiency. Spain was the worst performing country, being strongly penalized for its poor efficiency in the control of the pandemic from the perspective of reductions in daily contacts. Accordingly, we do not consider pandemic-based data as an indicator for the performance of the Spanish public health system, because its performance at that time has more to do with the political management of the pandemic and with Spain being one of the world's major travel hubs than with the performance of the public (and private) health system. There is no doubt that Spain demonstrated a low level of control, not only in airports but also of transmission across the country.

The National Health System in Spain was created in 1908 and has changed over the years. Initially, it was a centralized system, that is, it depended on the Spanish national government. However, with the Spanish Constitution of 1978, which designed the "State of Autonomies," a process of decentralization began that has resulted in a transfer of responsibilities, including responsibility for health care, to the autonomous governments (39, 40). This has been a lengthy process and has occurred unevenly among the different regions. There are different reasons for decentralizing a country's healthcare system, such as the pursuit of public efficiency. However, the real reason behind the Spanish situation is territorial identity. In fact, the process had begun and made substantial progress even before the establishment of general (health-related) criteria on the functioning of the health system and the distribution of responsibilities to the autonomous communities, which occurred with the introduction of General Health Law 14/1986.

The so-called historical autonomous communities (Cataluña, País Vasco and Galicia), as well as the assimilated autonomous communities (Andalucía, Navarra, Comunidad Valenciana and Islas Canarias) assumed responsibility for the legislative development and management of healthcare from the beginning, in the period 1980–1999. However, in the period 2000–2007, the remaining 10 autonomous communities (Aragón, Castilla-León, Islas Baleares, Castilla-La Mancha, Extremadura, Asturias, Cantabria, Murcia, La Rioja and Madrid), known as the common regime communities, only assumed responsibility for healthcare management. It was not

until the period after 2007 that, through the reform of their Statutes, they were placed on an equal level with the historical autonomous communities and acquired the capacity to legislate.

Law 21/2001, of December 27, which created the new regional financing model and introduced fiscal co-responsibility, was crucial in this process. This meant the end of designated health financing. Thus, universal healthcare in Spain, instituted in 1989, is financed through taxes (that is, health financing was integrated into the general autonomous financial system without distinction from other responsibilities). In addition, the central government, through the general state budget, transfers funds to the autonomous communities, using population as a criterion for distribution, adjusted for the population over 65 years of age and insularity. Consequently, the economic resources of each autonomous community depend on the proportion of the transfers received from the central government and on the taxes assigned to the autonomous communities. Therefore, different allocated resources generate different degrees of regional financial sufficiency, which will affect particular spending policies. Indeed, the political decentralization recognized by the Spanish Constitution entails its own financial and legislative capacity, which gives rise to an inevitable regional diversity (41).

The Spanish healthcare system covers all healthcare except dental care and optical items. Medications are not free of charge, except for those dispensed during hospital admissions, or those needed for the treatment of occupational diseases. This is intended to prevent substance abuse and self-medication. However, pensioners pay a symbolic price, with a maximum of 18 euros per month. The rest of the population pays a higher or lower percentage, depending on their income level (50% for those with incomes below 22,000 euros per year, 60% for incomes between 22,000 and 100,000 euros per year, and coverage of only 18 euros for higher income levels).

In brief, Spain is considered to have one of the best, if not the best, public health systems in the world, and although it is decentralized, the autonomous communities must guarantee the universality of benefits. However, they are free to choose the method of managing the resources to achieve not only the aforementioned objective of universality but also the preservation of health and promotion of well-being, thus reducing the mortality risk (42, 43). Initially, it could be thought that decentralization favors well-being because decision-makers are closer to citizens and assumed to better understand their preferences and needs.

Summarizing, in light of the above considerations, this research has a double objective. The first is to test the research hypothesis that posits potential complex relationships between well-being and the constructs that are assumed to influence it (especially those related to public health spending), and also to estimate these direct and indirect impacts. The second is the clustering of the Spanish autonomous communities according to their indicators for well-being and the aforementioned constructs, thereby visualizing the intra-country well-being disparities due to regional public health spending policies.

The first objective is addressed by applying partial least squares structural equation modeling (PLS-SEM). This statistical method enables the simultaneous analysis of relationships between observable and latent variables and between latent variables. As such, it can deal with complex causal relationships that traditional linear regression models cannot (44). For the second objective, we used agglomerative hierarchical cluster analysis (AHCA). In addition, principal component analysis (PCA) was used to reduce the dimensionality of the problem and obtain a regional efficiency map for well-being, that is, a graphical representation of the differences between regions in terms of the two principal components that jointly capture the largest percentage of the variance in the indicators for the constructs used in this research.

The relationship between public health expenditure and well-being has not been extensively studied, despite its great importance for socio-economic agents and citizens in general, from a myriad of perspectives (health, economic, fiscal, psychological, sociological…). There is some scientific research using life expectancy as a proxy for well-being in Europe, Australia, Malaysia, sub-Saharan Africa, and Bangladesh. The results obtained are not conclusive: whereas in Eastern Europe (45), Australia (46), Malaysia (47) and sub-Saharan Africa (48) a significant relationship has been found, in Bangladesh (49) and the European Union (50) such a relationship does not exist or is marginal. The methodologies used in the above research are diverse, but traditional (data envelopment analysis, multivariate logistic regression, multivariate logistic regression, multiple linear regression with panel data and fixed effects, etc.). As far as we know, PLS-SEM has not been applied in this type of research involving complex direct, indirect, and second-order relationships between observable and latent variables in scientific research on well-being and healthcare expenditure public policies with the focus on Spain. In addition, this study is the first to explore intra-country differences in well-being arising from the different public expenditure policies implemented by the Spanish autonomous communities; this is the first time that these autonomous communities have been clustered according to the indicators for the constructs involved in the relationship between public health expenditure and well-being.

Therefore, this research contributes to filling an important gap in the literature on such a critical topic, especially in Spain, a benchmark country at the top of life expectancy rankings, which is recognized as having one of the best health public systems in the world. A secondary contribution is of a methodological nature: we successfully import PLS-SEM from other disciplines where it is widely used (marketing, tourism, hospitality management, etc.) to the vital area of healthcare.

After this introductory section, Section 2 states the hypotheses to be tested. Section 3 briefly describes the database and the statistical methodology, and Section 4

presents the results obtained. Section 5 discusses those results and concludes.

Research hypotheses

The methodological approach used to study the direct and indirect relationships between public health spending and well-being, as well as other secondary relationships, strongly depends on both the theoretical framework underpinning the topic and on the situation and state of the art in the study area. Therefore, in this section we focus on those matters and formulate the research hypotheses accordingly.

We decided to use life expectancy at birth as a proxy variable for well-being. Fortunately, as outlined in the introductory section, Spain leads the European ranking, jointly with Switzerland, and has one of the highest life expectancy values in the world (especially for women).

Spain has an aging problem (25), which is set to worsen in the near future. According to the 2020–2070 population projections from the Spanish Statistical Office, in 2035 the population aged 65 and over will account for 26.5% of the total population (51). Obviously, population aging implies the need for more health services; in addition, when life expectancy is very high, as is the case in Spain, new health services are required in order to tackle the new (and usually chronic) pathologies typical of very elderly people (52).

Accordingly, it is no surprise that, despite the high quality public health systems the Spanish citizens enjoy, they are continuously demanding more and more, and better and better, health services. This translates into an increase in the public health spending targeted at augmenting resources, with the assumption that the more resources the higher the life expectancy. In fact, some studies claim that the 2008 crisis[1] triggered a decline in health budgets in many European countries (53, 54) and that Spain was no exception in 2011. Compared to 2010, the budgets of the regions decreased by an average of 4.11%. In 2012, the health budget was cut by 14% (55) and 12% in 2013, albeit unevenly between regions (56). This research line claims that these reductions in public health spending may have been the cause of the poor outcome in the current health crisis caused by the SARS-CoV-2 virus (57). In contrast, there is another approach to this question that does not find a relationship between higher public health spending and better results (58–60). From this perspective, the focus should not be on the amount of expenditure but on its proper use, that is, the resources in which it is invested and the degree of use of those resources. For the researchers taking this line, health spending must be allocated to direct investment in, for example, technological medical equipment or improving facilities such as hospital beds, operating rooms, or day hospital places, among others. Note that the total budget can be used for current expenditure or investment. For nomenclature purposes, the total health budget for a given period, to be spent in that period, will be referred to as "expenditure" (or "spending"). The expenditure realized in previous years is the main driver of what we term "resources": primary care medical staff, medical personnel in specialized care, hospital beds, operating theaters, day hospital places, technological equipment (for example, nuclear magnetic resonance or computed axial tomography equipment). Thus, current resources depend not only on current spending, but mainly on expenditure in previous periods. And, depending on its allocation, a given amount of spending may generate more or less resources for the present and the future.

The aging of the population and rising technological costs, combined with limited healthcare budgets, have put the spotlight on the sustainability of healthcare systems. Present needs must be met without threatening the possibility of meeting future needs. In this way, it will be possible to steadily reduce mortality and morbidity rates and achieve greater well-being (61). Numerous empirical studies in the literature reveal how higher healthcare spending leads to lower mortality rates. For example, local studies in India (62) or sub-Saharan Africa (63) have shown that spending reduces infant mortality. Similarly, Owusu et al., analyzing the period 2000–2015 in 177 countries, showed that expenditure led to a reduction in maternal and infant mortality (64). In this vein, a 2012–2014 study of 1,558 patients at Mount Sinai Medical Center and Icahn School of Medicine at Mount Sinai in New York City concluded that the higher the expenditure the lower the in-hospital mortality (65). Another noteworthy study, carried out by Ades et al. on 27 European Union countries, evidenced a decrease in cancer mortality related to an increase in spending (66). Therefore, we expect to find the same relationship in Spain.

Healthcare expenditure is affected by the cost of increasingly advanced technology and by the price of services, but fundamentally by the level of use of the system; for example, by the propensity to hospitalize or the induced demand (56). Therefore, strategies to reduce hospital stays, increase outpatient surgeries or even eliminate preoperative tests for those patients without a history of risk are some of the proposals made by researchers in this regard (56, 67). However, physicians should not be prevented by the system from prescribing expensive diagnostic tests or treatments, as long as they are necessary for the patient's health. In this regard, the European Federation of Internal Medicine and the American Council of Internal Medicine developed the Charter of Professionalism, which calls for medical personnel to strive for an efficient and rational use

1 In fact, not only the 2008 crisis. It is worth noting that the economic legacy left by President Zapatero enormously aggravated the effects of the crisis and was an important burden for the country. The enormous public debt and public deficit led the European Commission to force President Zapatero to cut welfare spending by 15 billion euros. Obviously, this poor economic legacy strongly conditioned the spending policy in the following years.

of healthcare resources, while always providing the patient with quality and safe care (68). Optimal use of resources will help to ensure a quality healthcare system (69).

On the other hand, it could be said a priori that the non-use of the health system brings health complications and can even cause death. The whole world has witnessed this phenomenon during the pandemic that started in China at the end of 2019. Health systems were severely affected: scheduled surgeries had to be canceled (70, 71); consultation with medical specialists became a challenge (72); online medical consultations rather than face-to-face were highly recommended (if not compulsory) (73); and preventive procedures for different diseases, including dangerous ones such as cancer, for example, were practically eliminated (74, 75). The latter was particularly detrimental for citizens because a delay in diagnosing diseases notably increases the risk of mortality and morbidity (75, 76). Similarly, the empirical evidence shows that neither the training of health professionals nor investment in technology are a priority for governments during periods of crisis (54, 77).

Previous studies found that countries with higher gross domestic product (GDP) had better life expectancy rates (78). That is not only due to the health system's adequate or inadequate performance but is also explained by social and economic factors such as poverty (79) or lifestyle (type of diet; sedentary lifestyle vs. physical activity; smoking, etc.) (80). In recent decades, well-being gains stem from income growth that has brought about profound transformations in living conditions (81). For this reason, we incorporate GDP as a control variable, a global indicator that reflects the added value produced by a country.

Based on the above discussion, we formulate the following research hypotheses:

Hypothesis 1 (H1): *Expenditure positively influences Resources.*
Hypothesis 2 (H2): *Expenditure negatively influences Mortality.*
Hypothesis 3 (H3): *Resources positively influence Use.*
Hypothesis 4 (H4): *Resources positively influence Well-being.*
Hypothesis 5 (H5): *Resources negatively influence Mortality.*
Hypothesis 6 (H6): *Use positively influences Well-being.*
Hypothesis 7 (H7): *Use negatively influences Mortality.*
Hypothesis 8 (H8): *Use positively influences Safety*
Hypothesis 9 (H9): *Safety negatively influences Well-being.*
Hypothesis 10 (H10): *Mortality negatively influences Well-being*
Hypothesis 11 (H11): *GDP positively influences Well-being.*
Hypothesis 12 (H12): *Safety and Mortality mediate the relationship between Use and Well-being.*
Hypothesis 13 (H13): *Mortality and Use mediate the relationship between Resources and Well-being.*
Hypothesis 14 (H14): *Resources and Use mediate the relationship between Expenditure and Mortality.*
Hypothesis 15 (H15): *Use mediates the relationship between Resources and Mortality.*

Data and methodology

Sample and data collection

The data used in this article, basically the key indicators of the Spanish Health System (SHS), were taken from the SHS statistical site. Obviously, this set of indicators follows the guidelines of the European Core Health Indicators (ECHI) (originally called European Community Health Indicators) developed by the European Commission to provide comparable information on European healthcare systems, and it also reflects the OECD and WHO approaches (82, 83).

In terms of spatial coverage, the statistical site of the SHS provides the annual average value of the key indicators not only at national level but also at a regional scale, that is, for the 17 autonomous communities and the two autonomous cities that make up Spain. However, these two autonomous cities have not been included in the analysis because the data on health expenditure were not available for them. In terms of temporal coverage, the period under study is 2005 to 2018, the year just before the COVID pandemic. The statistical site of the SHS provides statistical information dating back to 1990; however, it is only since 2005 that it has provided data for all the indicators we use in our PLS-SEM.

Accordingly, our database is composed of 17 (spatial dimension) x 14 (time dimension) x 26 (number of indicators, see subsection 3.2) values. That is a total of 6,188 observations. The sample size is a core factor when implementing PLS-SEM[2] because an insufficient sample size could mean core effects or relationships existing in the population are not revealed (the well-known probability of type II error in a testing procedure with fixed significance level or probability of type I error). G*Power statistical software (v. 3.1.9.6) (84) can be used to determine the statistical power (or its complementary, the probability of type II error) for different model configurations and values of the linear coefficient of determination and significance level.

In our case, the number of observations per indicator (238) is large enough to consistently perform a PLS-SEM-based analysis: significance level of 0.01; mean effect of 0.15; statistical power of 0.95; minimum linear coefficient of determination (R2) in the model of 0.10. The minima suggested for the more exacting

2 The complexity of the model has little effect on the sample size requirements because the PLS-SEM algorithm does not compute all the relationships existing in the model at the same time but instead estimates partial ordinary least squares regressions.

TABLE 1 Constructs and description of indicators.

Construct	Indicator	Description
Well-being	WE1	Life expectancy at birth
(mode A)	WE2	Life expectancy at age 65
Mortality	MO1	The age-adjusted death rate from cancer per 100,000 population
(mode B)	MO2	The age-adjusted death rate from cerebrovascular disease per 100,000 population
	MO3	The age-adjusted mortality rate for diabetes mellitus per 100,000 population
Expenditure	EX1	Public health expenditure managed by the autonomous communities, per inhabitant
(mode B)	EX2	Percentage of spending on specialty care services
	EX3	Percentage of public health expenditure on staff remuneration for the training of residents
	EX4	Percentage of pharmaceutical spending
Resources	RE1	Medical personnel in specialized care per 1,000 inhabitants
(mode B)	RE2	Primary care medical staff per 1,000 people assigned
	RE3	Hospital beds per 1,000 inhabitants
	RE4	Operating theaters per 100,000 inhabitants
	RE5	Day hospital places per 1,000 inhabitants
	RE6	Operating computed axial tomography (CT) equipment per 100,000 inhabitants
	RE7	Nuclear magnetic resonance (NMR) equipment per 100,000 inhabitants
Use	US1	Yearly hospital admissions per 1,000 inhabitants
(mode B)	US2	Average length of stay in hospital (in days)
	US3	Outpatient surgery percentage
	US4	Surgical intervention rate per 1,000 inhabitants/year
	US5	CT usage rate per 1,000 inhabitants/year
	US6	NMR usage rate per 1,000 inhabitants/year
Safety	SA1	Overall in-hospital mortality per 100 hospital discharges
(mode B)	SA2	In-hospital mortality post-surgery per 100 surgical discharges
	SA3	Rate of suspected adverse drug reactions
Economic driver	ED1	Gross domestic product per capita

recent methods by Kock and Hadaya (85) —the inverse square root method and the gamma-exponential methods— are also exceeded when increasing the significance level to 0.05 and reducing the statistical power to 0.8.

Variables

The variables under study are not directly observable, so they constitute what is known as constructs, composites, or latent variables. These constructs are measured (or proxied) through indicators or manifest variables used as statistical inputs to analyze their complex relationships (86). Table 1 lists and describes the six constructs (*Well-being*, *Mortality*, *Expenditure*, *Resources*, *Use* and *Safety*) and a control variable (*Economic driver*) used in this study, as well as their corresponding 26 indicators and the control variable GDP.

Well-being was measured through life expectancy at birth (WE1) and life expectancy at age 65 (WE2). It is worth noting that Well-being is the only construct measured reflectively (mode A) because the indicators for it are competitive and represent manifestations of the construct; in other words, the causal relationship goes from the construct to the indicators and a change in the construct will immediately impact all its indicators, which translates into a strong correlation among the indicators. The other five constructs were considered as formative constructs, that is, they were measured in a formative mode (mode B), as their indicators are assumed to represent specific dimensions of the construct; accordingly, the causal relationship goes from the indicators to the construct and the indicators should not be strongly correlated (87).

Mortality rates per 100,000 population from cancer (MO1), cerebrovascular disease (MO2) and diabetes mellitus (MO3) are among the 15 leading causes of death in 2018 in Spain, accounting for 34% of the total number of deaths. Therefore, they can be considered as reliable measures of the *Mortality* construct, which is a leading referent for geographical comparisons (88).

As for the third construct, *Expenditure*, it was measured by four indicators: Public health expenditure per capita (EX1), and the percentage of spending on specialized medical care (EX2), remuneration of resident doctors in training (EX3) and medicines (EX4). It is worth noting that the Spanish Constitution of 1978 establishes that the public authorities

guarantee citizens will be provided with a public Social Security System, which covers the protection of health and health services. It also makes it possible for the autonomous communities to assume responsibility in the field of health (in fact, the 17 Spanish autonomous communities have done so). In this sense, the General Health Law of 1986 establishes the political decentralization of health so that health expenditure and its distribution is different throughout the Spanish territory. This is why one of the key objectives of this study is to test for well-being disparities within the country due to the diverse public health spending policies.

The amount of current and past expenditure determines the current volume of health resources of the SHS in each geographical area, which is assumed to be an important determinant of people's well-being. *Resources* were measured with the following indicators: Number of specialty doctors (RE1), number of primary care doctors (RE2), number of hospital beds (RE3), number of operating theaters (RE4), number of day hospital places (RE5), and computer axial tomography (CT) (RE6) and nuclear magnetic resonance (NMR) (RE7) equipment.

The level of use of these resources is also considered in the literature on the topic as a driver of the population's well-being. *Use* was measured through the number of hospital admissions (US1), the average hospital stay (US2), the percentage of outpatient surgery (US3), the number of surgical interventions (US4), as well as the use of CT (US5) and NMR (US6) equipment.

The last construct considered is *Safety*, which was measured through three indicators: in-hospital mortality (SA1), mortality after surgery (SA2) and adverse medication reaction (SA3).

In addition, we include in the model a control variable, *Economic driver,* representative of the economic level of the Spanish autonomous communities, considering that a prosperous financial situation should favor well-being. It was proxied by a single indicator: GDP per capita.

Methodology

Three different methods have been applied to test the relationship between health expenditure and population well-being.

First, the proposed model is analyzed by applying PLS-SEM (89) with the statistical software SmartPLS (v. 3.3.2.) (90). The algorithm used is the traditional PLS, i.e., composite-based (91), and path-weighting scheme (92) with a maximum number of iterations of 300 (93). PLS-SEM uses the non-parametric technique of bootstrapping with replacement to test the significance of the regression coefficients (94–96). In the first step, the measurement model, i.e., the relationships between the constructs and their indicators, is assessed. For reflective constructs, the reliability of the indicators, the reliability of the construct, and its convergent and discriminant validity are tested. For formative constructs, however, the multicollinearity between the various indicators and the significance and relevance of each indicator is analyzed. In the second step, the relationships between the constructs, known as structural modeling, are examined, which requires testing for the absence of collinearity between the latent variables as well as the magnitude, sign and significance of their connections (97).

Figure 1 shows the proposed model, which includes the constructs, indicators and research hypotheses mentioned previously.

Second, AHCA is implemented to classify the autonomous communities into groups (clusters). The territories are gradually grouped into categories that include homogeneous elements according to the variables considered and that differ from the rest of the clusters. The criterion used to establish the classification was Ward's method, which minimizes the squared Euclidean distance. In this way, the set of variables considered in the study produces a small number of regional clusters (98–100). The results of this analysis are presented, as usual, in a dendrogram.

Third, by performing a PCA, the set of variables in the study was reduced to only two dimensions, in order to provide a graphical representation that visually shows the differences between autonomous communities stemming from the inputs considered (101–103).

For those not familiar with clustering and PCA, see Bezdek (104, 105), respectively. Both statistical techniques were implemented with the software IBM SPSS Statistics 27.0 (106).

Results

Descriptive analysis

Table 2 reports the main descriptive statistics of the indicators or manifest variables considered in the study. In addition, Appendix 1 lists their means at a regional scale. It is worth noting the disparities between the autonomous communities regardless of the indicator. However, there is an unquestionable fact: Madrid is the autonomous community that registers the best values in all the indicators for well-being and mortality along with the lowest public health expenditure per inhabitant.

Going into some detail, but without intending to be exhaustive, Madrid clearly leads the way in Well-being as measured by life expectancy related indicators, WE1 and WE2; it is followed by Navarra and Castilla y León; Andalucía, Canarias and Extremadura, are the Spanish regions with the lowest life expectancy, both at birth and at 65 years of age.

Regarding Mortality indicators, again Madrid registers the best values in all of them. In MO1 it is accompanied by Castilla-La Mancha and Murcia, in MO2 by Asturias, and in MO3 by

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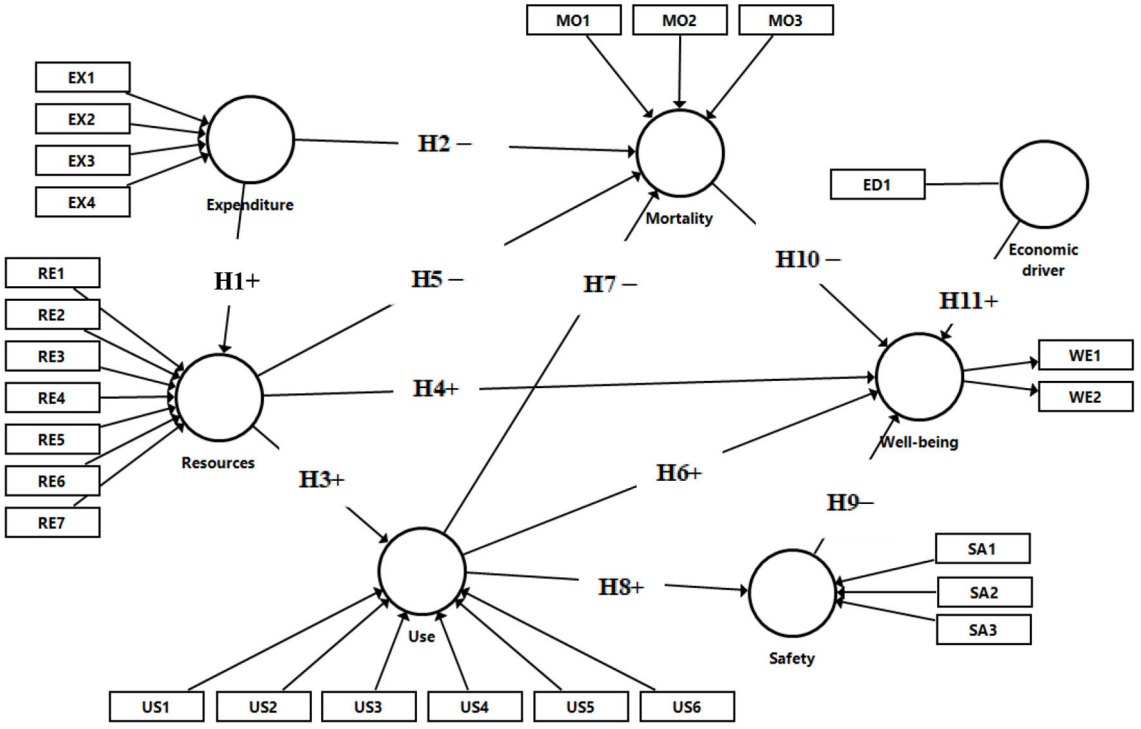

FIGURE 1
Research model.

Cantabria and Galicia. País Vasco, Comunidad Valenciana and Galicia have the worst MO1 values; Andalucía, Murcia and Extremadura show the lowest values for MO2 and Canarias almost triples the national mean in MO3. As for Expenditure, interestingly, Madrid, together with Andalucía, is the Spanish region with the lowest EX1 (just over 1,200 euros per inhabitant), although there is a relevant difference between these two regions: Madrid is at the top of the Well-being ranking whereas Andalucía is at the bottom. País Vasco, Navarra, Extremadura and Asturias, in this order, are the regions with highest EX1 (more than 1,500 euro/inhabitant). It is worth noting that the public health expenditure per inhabitant managed by País Vasco is 26.3%, higher than that managed by Madrid. However, Well-being indicators in Madrid are clearly better than in País Vasco. EX2 and EX3 are led by Madrid, in the first case accompanied by Asturias and in the second by Cantabria.

On the contrary, Madrid, together with Baleares, is the region with the lowest percentage of pharmaceutical spending. Castilla-La Mancha and Castilla y León show the lowest EX2 values, País Vasco and Baleares register the lowest EX3 values, and Galicia and Comunidad Valenciana have the highest percentage of pharmacy spending. In brief, Madrid has the best Well-being results along with the lowest public health expenditure per inhabitant. Note that Madrid has the highest control over pharmaceutical spending, while showing the highest values in the country both in percentage of spending on specialty care services and on staff remuneration for residents training.

As for Resources, in general, Andalucía, Baleares and Canarias show the lowest values, whereas Aragón, Asturias, Cataluña and Extremadura are at the top of the ranking in at least two indicators. Importantly, Madrid is generally among the Spanish regions with the lowest values in Resources indicators (especially in RE2 and RE6); however, it is at the top of the ranking, together with La Rioja, in RE7 (nuclear magnetic resonance equipment per 100,000 inhabitants).

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TABLE 2 Descriptive statistics.

Construct	Indicator	Mean	Std.	Min.	Max.
Well-being	WE1	82.457	1.241	78.880	85.430
	WE2	20.909	0.920	17.980	23.140
Mortality	MO1	150.192	10.834	118.330	178.560
	MO2	32.184	8.902	15.950	69.700
	MO3	11.289	5.841	2.590	42.200
Expenditure	EX1	1,412.224	164.689	1,022.620	1,876.750
	EX2	59.111	4.861	43.540	70.950
	EX3	3.284	0.922	1.260	5.870
	EX4	18.440	3.005	12.040	28.020
Resources	RE1	1.700	0.219	1.234	2.246
	RE2	0.778	0.105	0.590	1.110
	RE3	2.493	0.460	1.650	3.697
	RE4	6.465	1.015	4.300	9.037
	RE5	0.278	0.128	0.080	0.709
	RE6	1.141	0.258	0.640	1.875
	RE7	0.566	0.223	0.120	1.029
Use	US1	91.980	15.588	55.549	129.986
	US2	7.184	0.796	5.700	9.980
	US3	40.877	8.110	17.260	58.180
	US4	69.997	14.704	36.804	118.193
	US5	73.019	17.184	21.639	118.950
	US6	28.897	14.735	6.018	81.146
Safety	SA1	4.365	0.662	2.980	5.920
	SA2	1.648	0.285	0.930	2.370
	SA3	452.028	387.987	10.000	2,076.360
Economic driver	ED1	22.913	4.582	14.194	35.041

Number of observations per indicator: 238.

Regarding the Use of such resources, País Vasco, La Rioja and Asturias, in this order, are at the top of the ranking for US1, with Madrid at the bottom of the ranking. Canarias and Galicia are the Spanish regions with highest US2 values, whereas Cataluña and Comunidad Valenciana occupy the two last positions. La Rioja is the autonomous community with the largest outpatient surgery percentage (US3) and Navarra and Canarias the two regions with the lowest percentage. Cataluña and País Vasco have the highest values in US4, whereas Canarias exhibits the lowest value (the surgical intervention rate per 1,000 inhabitants/year is less than half that of Cataluña and País Vasco). As for usage of equipment, Galicia and Asturias lead the ranking in CT usage, while Madrid and Comunidad Valenciana are in the top two positions for NMR. At the other extreme, Baleares and Canarias, and País Vasco and Canarias, are in the last two positions of the rankings for CT and NMR, respectively.

Finally, as for Safety, the ranking of SA1 is led by Baleares and Cataluña, with Galicia and Asturias in the last two positions. Navarra has the best (lowest) SA2 ratio, and Galicia and Cantabria the worst ones. Navarra, Asturias and Aragon, in this order, have the highest rate of suspected adverse medication reactions (SA3), almost five times that of Castilla-La Mancha, which has the lowest rate.

Regarding the control variable GDP per capita, the ranking is led by Madrid, followed by País Vasco and Navarra. The bottom three positions are occupied, in this order, by Castilla-La Mancha, Andalucía, and last of all, Extremadura.

In brief, as mentioned previously, there are important disparities among the Spanish autonomous communities regardless of the indicator. Nevertheless, there seem to be important political (the sign of the government, when this sign has been the same for a long time; this is the case of Madrid, Andalucía and Extremadura), geographical (in the case of Canarias) and historical-political (in the case of País Vasco and Navarra) latent reasons behind such disparities.

Partial least squares structural equation modeling

Figure 2 shows both the inner and outer estimation results for the PLS-SEM specification we propose to test the research hypotheses listed in Section 2.

Measurement model

Table 3 reports the results on the validity of Well-being, the only latent variable considered in reflective mode (mode A). The construct is acceptable since all indicator loads are >0.707 (Panel A) (107). Moreover, the construct reliability is verified, given that Cronbach's Alpha, Dijkstra-Henseler's Rho and Composite Reliability are >0.7 (91, 108). The average variance extracted (AVE) exceeds 0.5, supporting the convergent validity (109). Specifically, Well-being explains, on average, 98.8% of the variance in its two indicators. Finally, the Fornell-Larcker criterion supports the discriminant validity (110) since 0.994 (marked in bold on the diagonal), which is the square root of the AVE, is greater than the correlation of Well-being with the rest of the latent variables (values located on the same horizontal line). Likewise, the heterotrait-monotrait ratio (HTMT) (111), 0.526, indicates that Well-being is a discriminant construct since this value is <0.85.

Table 4 includes the data corresponding to the assessment of the structural measurement model of the constructs estimated in formative mode (mode B). As can be seen, there are no multicollinearity problems (VIF<5), and all indicators were kept in the model since those whose weights were not significant did exhibit significant loads (97, 112).

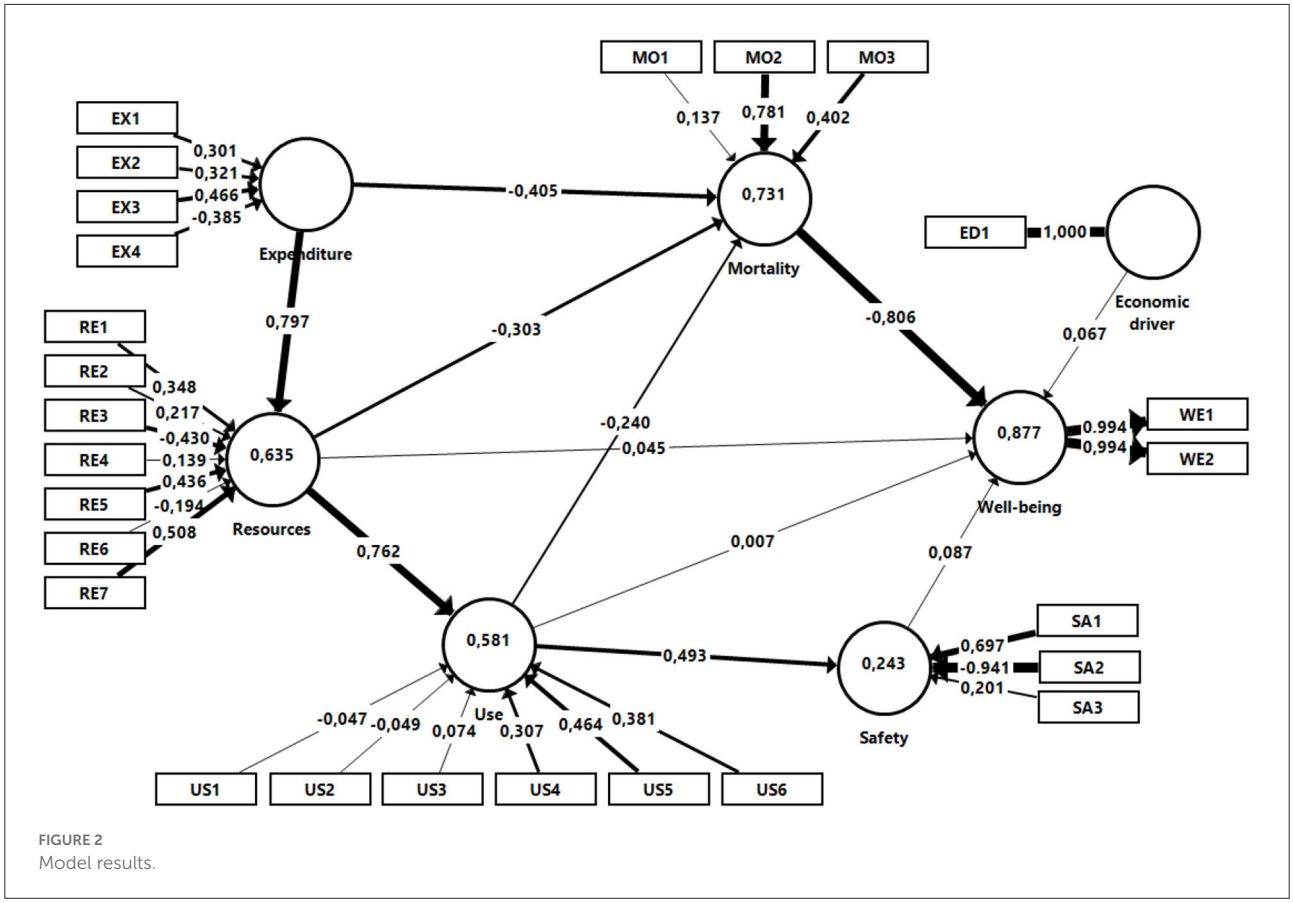

FIGURE 2
Model results.

Structural model

Table 5 shows the main results of the structural model estimation, with the signs of the coefficients assigned according to the relationships posited in the research hypotheses formulated in Section 2. The assessment was performed through one-tailed bootstrapping with 10,000 replications (113, 114). No collinearity problems were found.

Panel A reveals that Expenditure significantly influences both Resources and Mortality, the former positively and the latter negatively ($p = 0.000$ in both), which supports[3] hypotheses H1 and H2.

Likewise, Resources positively and significantly influences Use, and negatively and significantly influences Mortality ($p = 0.000$ in both cases); however, its relationship with Well-being is not significant ($p = 0.143$). Consequently, the empirical evidence from the PLS-SEM model estimated supports hypotheses H3 and H5, but not H4.

Use proved to have significant relationships with Mortality and Safety ($p = 0.000$ in both cases), but not with Well-being. The relationship with Mortality is negative, whereas with Safety it is positive. Therefore, H7 and H8 were validated, but not H6.

Furthermore, Safety exerts a small (path coefficient of 0.087) although significant ($p = 0.013$) influence on Well-being, but with a different sign than expected, which leads us to reject H9.

Finally, Mortality negatively, and strongly, influences Well-being (the path coefficient is −0.806, with an associated p-value of 0.000), which validates H10. With respect to the control variable, Economic driver, a positive weak but significant relationship with Well-being is found, thus verifying H11.

Panel B shows that the total effects of some constructs on others are all significant. Therefore, considering that the direct effect of Use on Well-being is not significant, but the total effect is, it can be concluded that the mediation by Safety and Mortality of the relationship between Use and Well-being is a *full mediation*, verifying H12. Similarly, given that the direct effect of Resources on Well-being is not significant, but the total effect is, we can conclude that the mediation by Mortality and Use of the relationship between Resources and Well-being is again a *full mediation*, thus validating H13.

Finally, since the direct and total impacts of Expenditure on Mortality turned out to be significant, there is a *partial mediation* by the variables Resources and Use of the relationship between Expenditure and Mortality, supporting H14. Similarly, the variable Use *partially*

3 We use the terms "support" and "validation" in the sense of "no rejection".

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TABLE 3 Outer model evaluation. Reflective construct-mode A (well-being).

Indicator	Load (λ)	*p*-value	CI 2.5%	CI 97.5%
Panel A. Outer loads				
WE1	0.994**	0.000	0.992	0.995
WE2	0.994**	0.000	0.992	0.995

	Value	*p*-value	CI 2.5%	CI 97.5%
Panel B. Construct reliability and average variance extracted				
Cronbach's Alpha	0.988**	0.000	0.984	0.991
Dijkstra–Henseler's Rho	0.988**	0.000	0.985	0.991
Composite reliability	0.994**	0.000	0.992	0.995
AVE	0.988**	0.000	0.985	0.991

	ED	EX	MO	RE	SA	US	WE
Panel C. Discriminant validity (Fornell-Larcker criterion)							
Expenditure (EX)	n.a.						
Mortality (MO)	−0.511	n.a.					
Resources (RE)	0.343	0.797	n.a.				
Safety (SA)	0.292	0.495	−0.558	n.a.			
Use (US)	0.295	0.570	−0.702	0.762	n.a.		
Well-being (WE)	0.523	0.740	−0.931	0.774	0.585	0.671	**0.994**

	Value	Mean	CI 2.5%	CI 97.5%
Panel D. discriminant validity (HTMT criterion)				
WE→ ED	0.526	0.525	0.433	0.607

Two-tailed test. *Significant at 5% significance level; **Significant at 1% significance level. The significance of the loads and their 95% confidence interval were calculated by a bootstrapping procedure with 10,000 replications.

mediates the relationship between Resources and Mortality, supporting H15.

Panel C shows the model's explanatory power through the R^2 coefficient and reports the decomposition of the variance explained by the preceding constructs. The antecedent variables for Well-being explain 87.7% of the variance in Well-being under a linear relationship, with Mortality being the most influential construct. Considering that more than 70% of the variance in Mortality is explained by Expenditure and Resources and, to a lesser extent, by Use, it can be concluded that Well-being is strongly determined by these variables. Indeed, this statement can be corroborated in light of the total effects of each construct on Well-being: −0.807 for Mortality, 0.706 for Expenditure, 0.476 Resources and 0.244 Use. However, as outlined previously, Safety and Economic driver show small total effects on Well-being (0.087 and 0.067, respectively). Given the R^2 values, it can be concluded that the model demonstrates a high explanatory power (112, 115). Finally, the Stone-Geisser test-statistic, with a value of 0.8594, indicates a high in-sample predictive power of the final reflective dependent construct (116).

Agglomerative hierarchical cluster analysis

Having estimated the total effects of the formative constructs and the control variable on the reflective composite, we address the second objective of this research: implementing an AHCA (Ward method) to classify the Spanish autonomous communities into groups according to the indicators of the constructs considered in this research. More specifically, in light of the results of the estimation of our PLS-SEM specification (see Figure 2), which indicates that Mortality, Expenditure and Resources are the factors that have the greatest impact on Well-being, the cluster analysis has been performed using as inputs only the indicators for the abovementioned constructs. Figure 3 depicts the resulting dendrogram. Figure 4 depicts the regional clusters on the map of Spain. Finally, the mean values of the abovementioned indicators for each cluster are shown in Appendix 2.

As can be seen in Figures 3, 4, three clusters can be clearly distinguished. Cluster 1 (in blue) is composed of Baleares, Canarias, Comunidad Valenciana, Murcia, Castilla-La

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TABLE 4 Assessment of the measurement model. Formative constructs-mode B.

	VIF	Weight	*p*-value	CI 2.5%	CI 97.5%	Load
Mortality						
MO1	1.341	0.137**	0.000	0.078	0.196	0.598**
MO2	1.303	0.781**	0.000	0.719	0.837	0.900**
MO3	1.049	0.402**	0.000	0.318	0.486	0.535**
Expenditure						
EX1	1.263	0.301**	0.000	0.178	0.419	0.445**
EX2	2.199	0.321**	0.000	0.178	0.445	0.807**
EX3	1.302	0.466**	0.000	0.358	0.561	0.649**
EX4	2.145	−0.385**	0.000	−0.503	−0.276	−0.791**
Resources						
RE1	2.045	0.348**	0.000	0.242	0.453	0.708**
RE2	1.367	0.217**	0.000	0.130	0.300	0.204**
RE3	1.541	−0.430**	0.000	−0.532	−0.322	0.113^{ns}
RE4	3.317	0.139^{ns}	0.062	−0.004	0.287	0.644**
RE5	1.737	0.436**	0.000	0.337	0.537	0.768**
RE6	2.413	−0.194**	0.001	−0.303	−0.083	0.468**
RE7	2.113	0.508**	0.000	0.372	0.636	0.835**
Use						
US1	2.237	-0.047^{ns}	0.645	−0.244	0.157	0.470**
US2	1.944	-0.049^{ns}	0.604	−0.239	0.135	−0.398**
US3	1.694	0.074^{ns}	0.350	−0.084	0.223	0.475**
US4	2.984	0.307**	0.004	0.088	0.508	0.691**
US5	3.026	0.464**	0.000	0.270	0.672	0.899**
US6	2.946	0.381**	0.000	0.167	0.579	0.887**
Safety						
SA1	1.564	0.697**	0.000	0.465	0.874	0.333**
SA2	1.542	−0.941**	0.000	−1.065	−0.755	−0.681**
SA3	1.339	0.201*	0.037	0.017	0.377	0.632**

Two-tailed test. *Significant at 5% significance level; **Significant at 1% significance level. The significance of the weights and their 95% confidence intervals, as well as the significance of the loads, were calculated by a bootstrapping procedure with 10,000 replications. ns, not significant.

Mancha and Andalucía. Shown in red is cluster 2, which comprises Aragón, La Rioja, Castilla y León, Navarra, Asturias, País Vasco, Cataluña, Cantabria, Galicia, and Extremadura. Finally, in green is cluster 3, consisting only of Madrid, which displays atypical behavior that does not fit with the rest of the country's regions.

To check that the clusters were indeed well-constructed, an ANOVA was performed in which the means of each group were used together with that of Economic driver. The goodness of fit for this ANOVA model ($F = 5.237$ and p-value $= 0.020$) supports the results obtained from the dendrogram shown in Figure 3.

As shown in Appendix 2, the first cluster (Baleares, Canarias, Comunidad Valenciana, Murcia, Castilla-La Mancha and Andalucía) is characterized by the lowest Well-being and the highest Mortality rates. The indicators for Expenditure in this group generally lie between those of groups 2 and 3.

Group 2 has similar Well-being values to those of group 1, although the Mortality rates are the highest of the country. The Expenditure indicators show values between those of groups 1 and 3, except for E3, whose mean is close to that of group 1.

Madrid, the only member of group 3, shows the best results in Well-being and Mortality along with the lowest public health expenditure per inhabitant and percentage of pharmaceutical spending, and the highest percentage in specialty care services and medical staff spending.

There are no notable differences between the three groups in the indicators for Resources.

Principal component analysis

Finally, a PCA was applied to the variables used in the previous stage to reduce the indicators to only two independent

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TABLE 5 Assessment of the structural model. Direct and Total effects.

	Path	*p*-value	CI 5%	CI 95%
Panel A. Direct effects				
ED→ WE	0.067**	0.005	0.024	0.109
EX→ MO	−0.405**	0.000	−0.501	−0.302
EX→ RE	0.797**	0.000	0.762	0.835
MO→ WE	−0.806**	0.000	−0.879	−0.733
RE→ MO	−0.303**	0.000	−0.428	−0.190
RE→ US	0.762**	0.000	0.729	0.806
RE→ WE	0.045^{ns}	0.143	−0.022	0.118
SA→ WE	0.087*	0.013	0.029	0.141
US→ MO	−0.240**	0.000	−0.308	−0.167
US→ SA	0.493**	0.000	0.414	0.582
US→ WE	0.007^{ns}	0.419	−0.052	0.065
	Effect	***t***	**CI 5%**	**CI 95%**
Panel B. Total effects				
ED→ WE	0.067**	0.005	0.024	0.109
EX→ MO	−0.793**	0.000	−0.831	−0.758
EX→ RE	0.797**	0.000	0.762	0.835
EX→ SA	0.299**	0.000	0.249	0.367
EX→ US	0.607**	0.000	0.568	0.661
EX→ WE	0.706**	0.000	0.668	0.748
MO→ WE	−0.807**	0.000	−0.879	−0.733
RE→ MO	−0.486**	0.000	−0.588	−0.393
RE→ SA	0.376**	0.000	0.312	0.456
RE→ US	0.762**	0.000	0.729	0.806
RE→ WE	0.476**	0.000	0.389	0.572
SA→ WE	0.087*	0.013	0.288	0.142
US→ MO	−0.240**	0.000	−0.308	−0.167
US→ SA	0.493**	0.000	0.414	0.582
US→ WE	0.244**	0.000	0.162	0.320

Dependent variable	R^2	**Antecedent variables**	**Path coefficients**	**Correlations**	**Explained variance**
Panel C. Decomposition of the explained variance					
Well-being	0.877	Economic driver	0.067	0.523	0.035
		Mortality	−0.806	−0.931	0.751
		Resources	0.046	0.774	0.035
		Safety	0.0878	0.585	0.051
		Use	0.007	0.671	0.005
Mortality	0.731	Expenditure	−0.405	−0.784	0.318
		Resources	−0.303	−0.809	0.245
		Use	−0.240	−0.702	0.168
Resources	0.635	Expenditure	0.797	0.797	0.635
Safety	0.243	Use	0.493	0.493	0.243
Use	0.581	Resources	0.762	0.762	0.581

One–tailed test. *Significant at 5% significance level; **Significant at 1% significance level. Both the significance of the path and effect coefficients, as well as their 95% confidence intervals were calculated by a bootstrapping procedure with 10,000 replications.

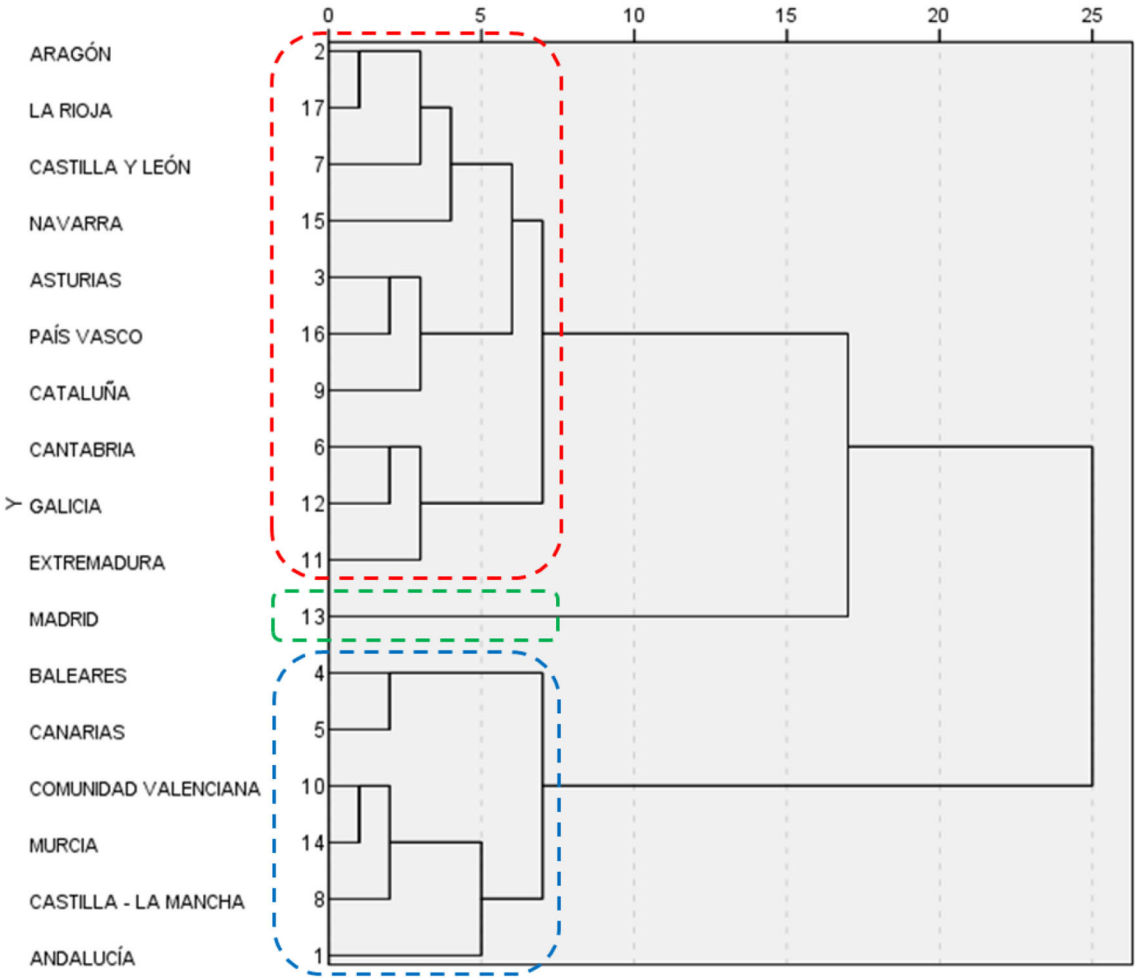

FIGURE 3
Dendrogram.

principal components and subsequently produce a graphic representation of the autonomous communities according to these two factors. After performing the Bartlett test of sphericity, yielding a *p*-value of 0.000, the principal components were computed, so that the first two account for 57.65% of the variance in the 16 indicators for Well-being, Mortality, Expenditure and Resources. This percentage can be considered high enough to proxy the Well-being/Healthcare reality of the Spanish autonomous communities through a two-factor map.

Figure 5 depicts a graphical representation of the three previous clusters as a function of the first two principal components. Table 6 shows the factor loadings matrix.

According to the entries of the factor loadings matrix, the first principal component (factor 1) is associated with lower mortality, higher life expectancy, higher percentage of spending on specialist physicians and, consequently, more specialist physicians, more places in day hospitals and more NMR equipment. By contrast, factor 2 is associated with more healthcare spending, a higher percentage of spending on pharmacy, more primary care physicians and more CT equipment. However, the loadings of the number of hospital beds and operating theaters are similar for both factors. Considering these results, factor 1 can be identified with "healthiness" and factor 2 can be interpreted as "basic spending".

It can be observed that the results obtained confirm those of the cluster analysis: the autonomous communities of the blue cluster register less basic spending and are less healthy. Conversely, the communities included in the red cluster register more basic spending and, in return, they are healthier. An interesting exception is Madrid, which has the lowest basic spending, but at the same time is the healthiest region in the country.

FIGURE 4
Spanish map of clusters.

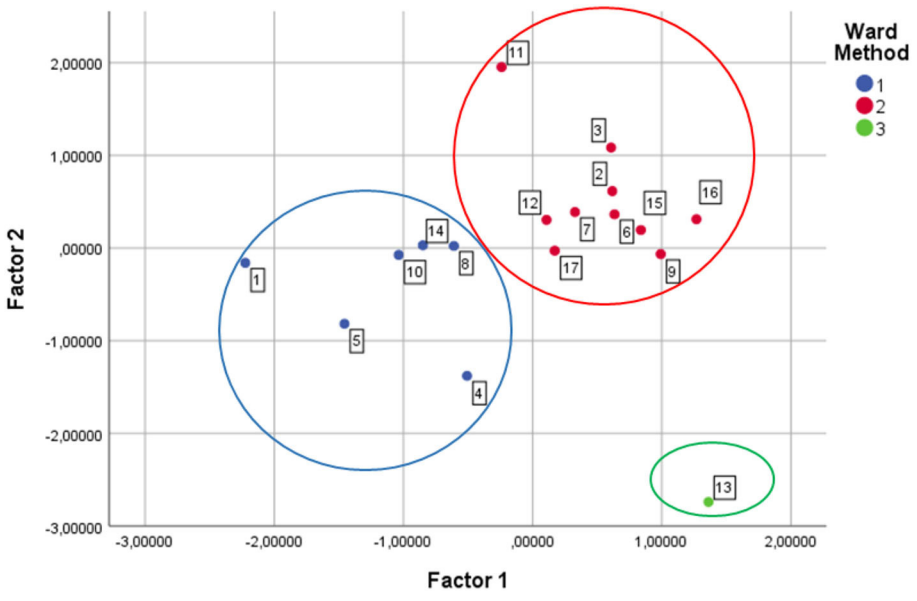

FIGURE 5
Factors chart.

Discussion and conclusions

The topic of well-being inequalities arising from different healthcare expenditure public policies is a very interesting topic at a national scale, but is especially worthy of study at a sub-national level. Accordingly, we focused our research on Spain, the reasons being that (i) it is among the top countries in life expectancy rankings; (ii) it is considered to have one of the best public health systems in the world; and (iii) it has a decentralized public health system at the scale

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TABLE 6 Factor loadings matrix.

Variable	Factor 1	Factor 2
RE1	0.856	0.222
RE2	0.159	0.597
RE3	0.527	0.594
RE4	0.616	0.599
RE5	0.564	0.158
RE6	0.232	0.757
RE7	0.848	0.067
EX1	0.386	0.676
EX2	0.489	−0.596
EX3	0.290	−0.403
EX4	−0.555	0.350
WE1	0.791	−0.447
WE2	0.802	−0.461
MO1	−0.012	0.744
MO2	−0.619	0.426
MO3	−0.628	0.089

Extraction method: principal component analysis.

of the autonomous community. There is an additional reason: according to a celebrated study by Foreman et al. (117) based on 79 drivers for health as well as on trends in health, in Spain life expectancy at birth will reach 85.8 years in 2040, one of the highest in the world.

What is behind such a high life expectancy? The commonly proposed reasons that can be found in the literature on the topic are the absence of armed and social conflicts, the sharp decline in deaths from traffic accidents, the diet, the climatological and environmental conditions, the policies that have made it possible to improve the lifestyle of the population, the significant reduction in the infant mortality rate and, especially, the notable improvements in the medical treatments and the quality of care in the universal public health system. Therefore, in one way or another, the different aspects of healthcare expenditure public policies are behind life expectancy and, as explained below, behind well-being[4].

As outlined in the introductory section, when approaching research on health spending, a key question is what modern societies are primarily seeking to achieve with such spending. There is a myriad of possible answers as to this overall objective; selecting one is an intellectual challenge and remains a pending task. In this research, we initially considered wellness and well-being, before eventually selecting well-being because (i) it could be said that wellness is an important element of overall (multidimensional) well-being, and that well-being is a more inclusive concept than wellness; (ii) wellness is often identified with individuals and well-being with groups of individuals; (iii) governments are currently implementing programs focused on the well-being of citizens.

Given the non-observability of the variables involved in the complex relationship between well-being and health spending (there are more hypotheses than certainties regarding this relationship), we have addressed the impacts of health spending-related constructs on well-being in the framework of a PLS-SEM specification. To proxy the abovementioned constructs, we used a set of 26 indicators. In addition, regional GDP per capita was used as a control variable.

The estimation of the PLS-SEM specification we propose yields some interesting results. From the estimates corresponding to the inner part of the model, it can be concluded that Mortality is the construct that most influences, negatively, Well-being (the path coefficient is −0.806), which validates H10. Safety also exerts a small though significant influence on Well-being, but with a different sign than expected. The control variable, Economic driver, has a weak positive relationship with Well-being. The other formative constructs have no significant influence on Well-being. Other interesting results obtained from the estimation of the model are the influence of Expenditure on both Resources and Mortality, the positive impact of Resources on Use and its negative effect on Mortality, and the significant relationship of Use with Mortality and Safety. As for second-order relationships, the analyses of direct and total effects lead us to conclude that Safety and Mortality *fully mediate* the relationship between Use and Well-being, that Mortality and Use *fully mediate* the relationship between Resources and Well-being, while the variables Resources and Use *partially mediate* the relationship between Expenditure and Mortality; similarly, Use *partially mediates* the relationship between Resources and Mortality.

Summarizing, in light of the results from the estimation of the proposed PLS-SEM specification, only the fourth, sixth and ninth research hypothesis were rejected, whereas the other twelve were supported. It is important to note that the link between quality and quantity of health funding is far from being a direct relationship, since the way in which the budget is managed plays a crucial role. Spending more does not mean spending better. Therefore, a particular allocation of resources may not be the best way to achieve better well-being, which could explain the rejection of H4, despite the fact that the total effects indicate that Resources have a positive and significant influence on Well-being. In addition, preventive medicine and social awareness policies, such as flu vaccine drives or accident-prevention campaigns, should be considered. Accordingly, there might be a link between well-being and corporate governance that would explain the failure to support H6, whereas Use directly and positively influences well-being. Furthermore, considering that Safety indicators would increase with Use, and that Use has a positive overall effect on Well-being, the positive sign of the relationship

4 Certain socio-economic factors are also popular in some research (GDP, economic inequalities, density of social and family networks...).

between Safety and Well-being would make sense, explaining the rejection of H9.

As for the estimates relating indicators with formative constructs in the outer part of our PLS-SEM specification, it is worth highlighting that all of them have a similarly moderate impact on Expenditure (the percentage of pharmaceutical spending in a negative sense). There is a logical explanation for the positive and significantly influence of spending on medical resident training. It is understood that having more trained professionals will enable more efficient patient care. As expected, investments in human capital have effects on social well-being (81). As for the negative sign for pharmaceutical spending, some members of the population are not willing to consume pharmaceuticals, preferring to opt for alternative medicine or treatments when possible. The propensity to take medication is significantly lower in those under 65 years of age than in older people (118). People feel uncomfortable taking medication because it interrupts their regular routine and behavior. For example, a previous study revealed that non-adherence to the consumption of medicines was explained by factors such as warnings against drinking alcohol with medication, people's inability to remember the exact time of intake or its impact on their sex life (119).

Regarding the construct Resources, the indicators that had a positive impact on it were, in this order, NMR equipment per 100,000 inhabitants, day hospital places per 1,000 inhabitants and medical personnel in specialized care per 1,000 inhabitants; and to a lesser extent, primary care medical staff per 1,000 people assigned. On the contrary, the number of hospital beds per 1,000 inhabitants, and to a lesser extent, CT equipment per 100,000 inhabitants, show a negative effect on the construct. There are a number of possible explanations for the sign of the aforementioned impacts: it is worth noting that, in Spain, NMR has a better reputation than CT because it does not produce radiation; in addition, it is more user friendly for patients. When circumstances allow it, patients prefer to continue their recovery process at home, which explains the negative impact of the number of hospital beds and the positive effect of day hospital places. These relationships are consistent with previous research (120).

In the case of the degree of Use, only three of the six indicators were significant: first of all, the CT usage rate per 1,000 inhabitants/year; in second place, the NMR usage rate per 1,000 inhabitants/year; and finally, the surgical intervention rate per 1,000 inhabitants/year, all of which exert a positive influence.

As for Mortality, it is explained by three indicators, one of which is the most influential of the entire model in a positive sense. We are referring to the age-adjusted death rate from cerebrovascular disease per 100,000 population. The strong positive relationship of this indicator with the construct is not trivial, given that, according to the 2014 WHO Report (121), cardiovascular diseases are responsible for 37% of deaths of people under 70 years of age. The age-adjusted mortality rate for diabetes mellitus per 100,000 population has a moderate positive influence on Mortality, whereas the positive effect of the age-adjusted death rate from cancer per 100,000 inhabitants is very low. The importance of early prevention in these diseases is crucial to limiting their mortality rate. In addition, diabetes brings with it other diseases; consequently, comprehensive care of patients is essential to maintain their well-being and quality of life (122).

Finally, Safety is explained by three indicators. In-hospital mortality after surgery per 100 surgical discharges is the indicator that has the greatest (negative) impact on Safety; in fact, its coefficient is close to −1. The overall in-hospital mortality per 100 hospital discharges has a strong positive effect on the construct, whereas the impact of the rate of suspected adverse medication reactions is both positive and moderate.

As for the results of the regional clustering analysis, which obviously correspond to those from the descriptive analysis (Table 2), three clusters can be clearly distinguished. Cluster 1 is composed of Baleares, Canarias, Comunidad Valenciana, Murcia, Castilla-La Mancha and Andalucía. It is characterized by the lowest Well-being and the highest Mortality rates. The indicators for Expenditure in this group generally lie between those of groups 2 and 3. Cluster 2 includes Aragón, La Rioja, Castilla y León, Navarra, Asturias, País Vasco, Cataluña, Cantabria, Galicia, and Extremadura, and it has similar Well-being values to those of cluster 1; however, it also exhibits the highest Mortality rates of the country. The spending indicators show values between those of clusters 1 and 3, except for the percentage of public health expenditure on staff remuneration for training residents, whose mean is close to that of cluster 1. Cluster 3 is a single-region cluster including only Madrid, which displays atypical behavior that does not fit in with the rest of the country's regions. Madrid shows clearly superior results in Well-being and Mortality, with the lowest public health expenditure per inhabitant and percentage of pharmaceutical spending, and the highest percentage in specialty care services and medical staff spending. Interestingly, there are no noticeable differences between the three groups in the indicators for Resources.

The Community of Madrid is the region that spends the least and ranks at the top for Well-being. This performance could be attributed to Madrid having a younger population than the rest of the regions, which would imply that they are less dependent on the health system. However, this is not the case: Madrid is in fourth position for average age by autonomous community ordered from lowest to highest, with the communities with the youngest population being the Region of Murcia, Baleares and Andalucía (123). There are a number of possible reasons for this successful result: First, that the right party, which can be said from an economic perspective to be a liberal party, has governed the Community for almost three decades. Second, that the Community of Madrid exhibits the highest population density of the country, approximately 800

inhabitants per km^2 (124). In other areas of the country the population is more dispersed than in Madrid, and it is necessary to invest in hospitals distributed among many low-density population centers; this is the case with Castilla-La Mancha, Castilla y León, and Extremadura, where the population density is 25 inhabitants per km^2 (124). That said, it should be noted that although in recent decades the regional governments of Madrid have made a firm commitment to a large hospital network, Madrid is not the Spanish region with the largest number of hospitals. Cataluña with 69, Andalucía with 50, and Comunidad Valenciana with 39 all have more public hospitals than Madrid (with 35, some of which enjoy global recognition for their quality). Cataluña and Andalucía also have more private hospitals than Madrid (150 and 62, respectively, whereas Madrid has 48). Similar comments can be made about the number of hospital beds. Third, Madrid, Andalucía, Cataluña and Comunidad Valenciana, in this order, are the regions with the largest endowment of high-tech equipment, although in the case of Cataluña 61% of this equipment is in private centers. The other two Spanish regions following Cataluña in the percentage of high-tech equipment located in private hospitals are Baleares (54%) and Canarias (46%). Fourth, Madrid is, after two of the smallest regions of Spain, Asturias and La Rioja, the region with the shortest waiting time for patients to be attended in consultations, and the region with the lowest rate of patients waiting per surgery per 1,000 inhabitants. Fifth, Madrid (36.6%), together with Cataluña (31.8%) and Baleares (29.5%), is one of the Spanish regions with the highest health insurance capillarity, which might allow for lower public spending while at the same time maintaining the quality of the health system (125). Data for reasons two and three were taken from Acta Sanitaria (126). UNESPA (127) is the source for data cited in reasons four and five.

However, despite the statistical information provided above, Well-being in Cataluña, and especially in Andalucía, Comunidad Valenciana and Baleares, is noticeably lower than in Madrid. These results suggest that the "Madrid model" should be explored by the rest of the Spanish autonomous communities, especially those that have a very large population and/or are densely populated.

Finally, coming back to the non-clustering-related results, it can be also concluded that the higher the per capita health expenditure, the higher the percentage of spending allocated to specialized medical personnel and the training of doctors, and the lower the pharmaceutical spending. Given the significant positive influence of Expenditure on Well-being, this translates into an increase in the Well-being of the population. Likewise, when the number of physicians, both in primary and specialized care, the number of places in day hospitals and NMR equipment increases, the life expectancy of the population also rises. Additionally, the number of surgical interventions and the use of CT and NMR equipment contribute to an increase in Well-being. Therefore, according to this research, medical personnel and advanced diagnostic equipment, as well as the freedom for doctors to resort to surgical interventions without budgetary restrictions, are core resources of the healthcare system.

The results revealed in this study are of great importance for public policymakers. As is well-known, there is a current of opinion in Spain, independent of people's political alignment, which calls for the centralization of health services. The main reason giving rise to this current of feeling is that many citizens have to travel dozens of kilometers to go to hospital when in fact their nearest hospital is in the neighboring autonomous community. In addition, more and more citizens are aware of the differences in the costs and services of the different regional health systems. Some autonomous communities are recognized as having some of the best hospitals in Europe (and in some cases the world, as in Madrid) and, unfortunately, others are known for their long waiting lists. Political battles over the size and way of managing the health budget must be based on scientific research rather than on slogans or simple opinions, both regionally and nationally. More taxes, supposedly allocated to the health system, does not necessarily imply greater Well-being. It depends on how the resources are used and where the funds are spent. On many occasions, the inappropriate management of health spending means extra expenditure does not result in a proportional increase in citizens' Well-being and life satisfaction. This is the lesson we have learned from this research, especially from the Community of Madrid. This is an important lesson for Spain's left-wing and extreme left political parties; a lesson that should encourage them to abandon the mantra that more spending necessarily implies greater Well-being. The amount of spending is a necessary but not sufficient condition for Well-being. The Spanish autonomous communities must study the modus operandi of the Madrid health system, because the Community of Madrid is, by far, the leader of the Well-being ranking while spending relatively little compared to the rest of the regions.

As for the limitations of this research, they include two that are worth mentioning. The first one is the assumption that patients in each autonomous community are treated by the health services of the community in which they reside. However, given the inevitable mobility of the population throughout the country, there are many interactions between regional health systems. For example, if a citizen from any region of the country has a problem that requires very specialized care, he or she is transferred to the big cities, especially Madrid. In this way, the largest cities provide healthcare not only to their own population, but also to patients from other regions. The same applies in tourist areas, where non-residents are treated. It was not possible to account for this fact in this study, which is a limitation of our research that could give rise to a future research line.

The second limitation is framed within the relationship between life expectancy and Well-being. A long life expectancy means living many years, which is not the same as living many good quality years. This is an important aspect to consider, especially in the case of women. As is well-known, there are

physiological aspects underlying the difference in longevity between men and women. Female hormones protect against mortality after the end of reproductive age but are also a factor in the development of problems in the bones, muscles, and joints. Therefore, deflating female life expectancy using some quality-of-life index related to the aforementioned aspects can yield a more realistic relationship between life expectancy and Well-being. Finding a way to overcome this limitation represents another future challenge for researchers on this topic.

We would like to emphasize that the data used in this research correspond to the usual health situation of the country, as they do not include the years of the pandemic. They therefore do not reflect expenditure patterns or ways of dealing with times of crisis in each region. However, an interesting line of future research would be to compare the pre- and post- pandemic health situation in terms of (i) testing the research hypotheses (which posit the potential complex relationships between Well-being and the constructs that are assumed to influence it, especially those related to public health spending), as well as of the estimation of such direct and indirect impacts; and (ii) the clustering of the Spanish autonomous communities according to their indicators for Well-being and the aforementioned constructs, so that the intra-country Well-being disparities due to regional public health spending policies can be visualized. This would allow us to estimate the legacy of the pandemic for the Spanish health system.

Finally, from a methodological point of view, another interesting research line is the development and estimation of the spatial and spatio-temporal versions of our PLS-SEM specification to consider the spatial or spatio-temporal dependencies existing in the healthcare and health spending databases. If such dependencies do in fact exist but are not accounted for, the estimates will not be accurate and their variances will be underestimated, which in turn implies an overestimation of the confidence levels and an underestimation of p-values, leading to incorrect rejections of the research hypothesis.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: http://inclasns.msssi.es.

Author contributions

MCVM: conceptualization and software. MCVM and J-MM: methodology and formal analysis. MCVM, MG, and J-MM: writing—original draft. MG: data curation. J-MM: writing—review and editing. All authors contributed to the article and approved the final manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.953827/full#supplementary-material

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Efficiency measurement and spatial spillover effect of provincial health systems in China: Based on the two-stage network DEA model

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The effectiveness of a health care system is an important factor for improving people's health and quality of life. The purpose of this research is to analyze the efficiency and spatial spillover effects of provincial health systems in China using panel data from 2009 to 2020. We employ the two-stage network DEA model to evaluate their efficiencies and use a spatial econometric model for empirical estimation. The results suggest that the overall efficiency, resource allocation efficiency, and service operation efficiency of health systems in different regions of China generally have fluctuating upward trends, with large differences in efficiency among the various regions. Further analysis reveals that the efficiency of China's health system has a significant spatial spillover effect. The level of economic development, fiscal decentralization and old-age dependency ratio are important factors affecting the health system efficiency. Our findings help to identify the efficiency and internal operating mechanisms of China's health system at different stages, and are expected to contribute to policymakers' efforts to build a high-quality health service system.

KEYWORDS

health system, two-stage network DEA model, resource allocation efficiency, service operation efficiency, spatial spillover effect

Introduction

As it relates to people's health, public health is an important area for improving people's quality of life and promoting economic development. Insufficient or inefficient spending on public health reduces the health of citizens, which in turn slows down the process of economic development (1). The outbreak of the COVID-19 pandemic has had a great impact on the public health system of countries, seriously threatening the lives of many people (2). Therefore, in the context of COVID-19 ravaging the world, how to effectively improve health system efficiency and protect people's health has become a major issue that needs to be solved urgently.

Since the reform of its medical and health system in 2009, China has been committed to improving its national public health system and continuously helping to better the health and physical quality of the people. The 18th National Congress of the Communist Party of China released the Healthy China 2030 Plan, which explicitly calls for building a sound medical security system and enhancing the quality of health services, thereby meeting the public's demand for health. In terms of public health expenditure, China's fiscal expenditure on medical and health rose from 399.419 billion yuan in 2009 to 1921.619 billion yuan in 2020, accounting for 7.82% of the government's public budget expenditure from 5.23%. Clearly, the central government attaches great importance to basic medical and health services and continues to improve the quantity and quality of public health supplies. However, the situation of health care in China is not optimistic. As the disease spectrum changes and population aging intensifies, China's total health resources remain inadequate. The problems of difficult medical treatment and high cost for patients have not been solved, and the imbalance of health resource allocation among regions is severe. Moreover, the outbreak of the COVID-19 pandemic has posed a serious challenge to the supply capacity of its health system. It is foreseeable that the China government will focus on increasing the supply of health resources and improving health system efficiency in the long run.

Health system efficiency is an important indicator of how well a health system is functioning (3). Although a comprehensive estimation of such efficiency is a complex task (4), it can effectively measure the allocation of health resources and the level of residents' health output. Currently, most studies use parametric and non-parametric methods to evaluate health system efficiency. Among them, non-parametric methods are represented by Data Envelopment Analysis (DEA) (3, 5), and parametric methods are mainly represented by Stochastic Frontier Analysis (SFA) (6, 7). Some scholars have combined the two to study health care efficiency (8), but SFA may lead to biased measurements due to its dependence on the functional form and the distribution of random errors (9). In addition, most studies apply DEA to assess health system efficiency by considering the health system as a "black box," but fail to focus on the internal operating patterns and variability characteristics of the health system. Although a few studies in the literature have used a two-stage DEA model to estimate health expenditure efficiency, the whole production process and the two sub-stages are regarded as independent of each other, which does not reflect the connection between different stages and the overall process. Therefore, this paper adopts the two-stage network DEA model to measure health system efficiency in China from 2009 to 2020 and reveals the operation status of health systems in different regions at different stages. We look to answer the following questions. What are the differences in health system efficiency among the regions in China and the reasons for them? Are there spatial spillover effects in health system efficiency across regions? What should be done to improve the efficiency of China's health system?

The main contributions of this study are summarized as follows. First, we divide a health system into resource allocation stage and service operation stage and adopt the two-stage network DEA model to measure health system efficiency, so as to reveal the differential characteristics of the system's different stages. Second, this paper provides an in-depth analysis of the evolutionary trends of efficiency at different stages of the health system, while visualizing health system efficiency by combining relevant contents of geography, and then comprehensively examines the spatial evolutionary characteristics of health system efficiency in China. Third, most studies in the literature only focus on the efficiency changes and influencing factors of a local health system, but lack any analysis of the impacts of inter-regional health systems, and so they do not reveal these systems' spillover effects and influence mechanisms. Therefore, this paper further analyzes the spatial spillover effect of health system efficiency and extensively explores the influencing factors of health system efficiency and their spatial spillover effects in terms of economic development, fiscal decentralization, population structure, and education level, so as to provide a useful addition to the existing literature.

The remaining contents of this paper are arranged as follows. The Literature Review section mainly reviews the relevant literature. The Methods section introduces the research methods, variable measurements and data. The Empirical Analysis section discusses the empirical results. The Conclusion and Policy Recommendations section summarizes the research conclusions and puts forward relevant policy recommendations.

Literature review

Health system efficiency

Scholars have conducted a large number of studies in the field of health. Especially after the COVID-19 pandemic, health system efficiency has become a greater focus of scholars and policy makers.

The existing research on health system efficiency mainly focuses on the application and measurement of health system efficiency. The non-parametric method based on data envelopment analysis has become the mainstream and is the most commonly used efficiency evaluation technology in the health field. In 1983, Nunamaker (10) first applied DEA method to the research in the field of medical and health care. Subsequently, Banker et al. (11) also used this method to evaluate the multivariate input-output efficiency of American teaching hospitals. Since then, the number of studies using DEA model to measure different types of medical and health institutions has been increasing, and the research objects include primary medical and health institutions, hospitals, professional public

health institutions, and public health systems. For example, Tsai and Molinero (12) estimated and analyzed the efficiency of 27 NHS institutions in the UK based on the non-parametric DEA method. Kontodimopoulos et al. (13) evaluated the operation efficiency of 17 small-scale hospitals in rural Greece. Novignon (14) applied DEA model to investigate the efficiency of health expenditure in sub-Saharan Africa and found that the efficiency of local health expenditure was low.

With the deepening of research, the deficiencies of the traditional DEA model have become increasingly prominent. Many studies have improved and optimized the traditional DEA model and gradually applied it to various fields of economy and society. On this basis, the measurement of health system efficiency has been further expanded, gradually evolving from the application of the traditional DEA model to the use of a more efficient and comprehensive DEA model. It mainly includes Super-SBM model (15, 16), Bootstrap DEA model (17, 18), Dynamic Network DEA model (19). Some studies also adopt the Malmquist productivity index to decompose healthcare efficiency (15, 20). Meanwhile, a three-stage DEA model is employed in the empirical analysis (21, 22). Moreover, more and more scholars are no longer limited to using the DEA model alone, they tend to combine the DEA model with other models to evaluate the health system efficiency. For example, Rouyendegh et al. (23) combined the fuzzy analytic hierarchy process with DEA to quantify the data and construct a DEA-FAHP model.

In recent years, people's health has been greatly threatened by the increasingly serious pollution problem, which poses a challenge to the operation of the health system. Therefore, scholars have begun to attach importance to the evaluation of health expenditure efficiency in combination with environment and public health (24), so as to more comprehensively investigate the real situation of health system efficiency. Some studies put energy consumption, environmental pollution and public health in the same framework, and analyzed the efficiency values at different stages by constructing a dynamic network DEA model (25–27). These studies divide the whole model into production stage and health treatment stage. The output of the production stage mainly includes pollutants, which are regarded as the input of the health treatment stage, and the output of the health treatment stage involves indicators related to residents' health such as disease incidence. For example, Chen et al. (25) integrated pollution, energy, public health, and social media, adopted a modified Undesirable Dynamic Network model to analyze the efficiency of different stages, and discovered that the production stage of cities in China is more efficient than the health treatment stage, and that the disparity in sanitation expenditures among the cities is large and inefficient.

After the outbreak of COVID-19 pandemic, scholars have increased relevant research in the field of health care, mainly concerning the operational efficiency of health institutions (28), health expenditure efficiency (2, 29) and government public health management efficiency (30, 31). For example, Kamel and Mousa (28) used the DEA model to measure the operational efficiency of 26 isolation hospitals in Egypt during the COVID-19 pandemic and identified important drivers affecting their efficiency. Martínez-Córdoba et al. (31) calculated the efficiency of government public health resource management in the context of the COVID-19 pandemic.

In addition, the influencing factors of health efficiency have also been widely concerned. Previous studies have mainly analyzed the influencing factors of health system efficiency from many aspects, including economic conditions, government level, social and environmental factors. From the perspective of economic status, most scholars' studies have shown that economic status is an important factor affecting the health system efficiency (32, 33). At the government level, official corruption and policy formulation have a significant impact on the health spending efficiency (14, 34–36). In terms of social and environmental factors, health system efficiency is also constrained by demographics, ethnic characteristics, and environmental performance (34, 37). In recent years, an increasing number of studies have focused on the impact of institutional factors on health systems efficiency, especially the effect of fiscal decentralization (38, 39). For example, Zhou (39) proposed that fiscal decentralization reduces the efficiency of health spending in China by distorting government spending decisions and is a major factor affecting the functioning of the health system.

Spatial spillover effects

In recent years, there has been an increasing focus on the interactions between economic agents and the correlation between things, which requires explicit consideration of spatial factors. LeSage and Pace (40) regarded the spatial spillover effect as one of the core contents of spatial econometric model estimation, and believed that the spatial spillover effect was a measure of the impact of a variable change in a single region on other regions. On this basis, the research on spatial spillover effect has developed rapidly, and the focus of the research has evolved from focusing on macro-economic growth issues to micro-environmental welfare.

On the one hand, the spatial spillover effect is applied to the study of economic growth. Previous literatures mostly focus on the spillover effects of economic growth from the perspective of specific industries, involving the fields of transportation infrastructure and tourism (41–43). For example, Hu and Liu (41) used a spatial econometric model to examine the existence of positive externalities of transportation and its spillover effects on economic growth in adjacent regions. Tong et al. (42) argued that the spillover effect of road infrastructure on agricultural output in neighboring states varies with the spatial weight matrix used in the model. Ma et al. (43) pointed out that the economic growth effect produced by tourism development has

the characteristics of spatial spillover. In recent years, some studies have also conducted in-depth analysis of the spillover effects of economic growth from different perspectives (44, 45).

On the other hand, the spatial spillover effect is employed to the research of environmental pollution. With the increasingly serious global environmental pollution problem, scholars have begun to explore the characteristics of pollution problems from different angles. In this context, the spatial spillover effect has been widely used in the study of pollution emissions (46), and scholars are committed to finding the key to solving the environmental pollution problem from the perspective of spatial correlation, including urbanization (47), environmental regulation (48, 49), and financial development (50, 51). For example, Li et al. (47) explored the spatial spillover effects of industrialization and urbanization on the discharge of seven pollutants in the Huang-huai-hai region of China based on the spatial Durbin model. Feng et al. (48) emphasized the spatial spillover effect of environmental regulation on PM2.5 concentration, and identified the influencing factors of pollution spillover, such as industrial structure and population density. Zhong and Li (50) explored the relationship between financial development and green total factor productivity and its spatial spillover effects. Khezri et al. (51) discussed the direct and spillover effects of financial development on CO2 emissions, confirming the importance of the influence of neighboring countries on their own CO_2 emissions. In addition, there are also some literatures that incorporate both economic growth and environmental issues into the research framework, and analyze the spatial spillover effects of green economic growth.

Methods

Two-stage network DEA model

Data Envelopment Analysis (DEA) can deal with the problem of multiple inputs and multiple outputs. As such, it has been continuously expanded and improved in the development process and has been widely used to evaluate the relative efficiency of decision-making units. Traditional DEA is an important method for evaluating efficiency. The existing literature applies the model to analyze problems in different areas of the economy and society, and provides many useful insights. These studies mainly involve the evaluation of the efficiency of financial institutions. Sufian and Kamarudin (52) measured the profit efficiency of individual banks operating in Bangladesh by using the Slack-Based DEA, and the findings provided empirical evidence on the level of profit efficiency in the country's banking sector. Aghimien et al. (53) employed the DEA to assess the technical efficiency, scale efficiency and pure technical efficiency of Gulf Cooperation Council banks. Kamarudin et al. (54) used the Slack Based DEA model to calculate the profit efficiency of 31 commercial banks operating in Bangladesh from 2004 to 2011 and investigated the determinants of bank profit efficiency. Hussain et al. (55) evaluated the level of bank revenue efficiency based on the Non-parametric DEA method. In addition, a large number of studies have also used traditional DEA model to assess energy efficiency and environmental performance (56–59).

However, traditional DEA models treat the decision-making unit as a "black box" and fail to pay attention to the internal structure of the system, which may lead to misleading results (60, 61). In contrast, the two-stage network DEA model is an extension of the traditional DEA model, and its advantages are mainly reflected as follows. On the one hand, it analyzes the organizational structure contained in the decision-making unit (60). By dividing the decision-making unit into different production processes, and using input elements, output elements and intermediate variables to closely link the different production processes of the decision-making unit, so as to reflect the logical relationship of input and output in different stages. On the other hand, the two-stage network DEA model helps to improve the accuracy of measurement results and specifically analyze the sources of system inefficiencies, thereby obtaining richer information (62). Through the analysis of the sub-stage and the overall stage, the operation of the complex production system can be effectively identified and the efficiency of each sub-process can be evaluated, and then reveal the ineffective source of the system and the different characteristics of different stages.

Two-stage DEA assumes that the entire production system is composed of two sub-stages. Stage 1 uses initial input X to produce intermediate output Z, and stage 2 uses intermediate output Z to produce final output Y. In order to calculate the expected production frontier in the entire system, the output of stage 1 is required to be exactly the expected input of stage 2.

Assuming that there are n decision making units (DMU), each DMU has m input terms and s output terms. X_{ij} is the i^{th} input of the j^{th} DMU, expressed as $X_j = (x_{1j}, x_{2j},..., x_{mj})^{\text{T}}$; Y_{rj} is the r^{th} output of the j^{th} DMU, expressed as $Y_j = (y_{1j}, y_{2j},..., y_{sj})^{\text{T}}$; Z_{pj} is the p^{th} intermediate output of the j^{th} DMU, expressed as $Z_j = (z_{1j}, z_{2j},..., z_{qj})^{\text{T}}$. Under the premise of constant returns to scale, the formula for measuring the efficiency of the k^{th} DMU is as follows:

$$\begin{aligned} &E_k = \max \sum_{r=1}^{s} u_r Y_{rk} \Big/ \sum_{i=1}^{m} v_i X_{ik} \\ &s.t. \sum_{r=1}^{s} u_r Y_{rj} \Big/ \sum_{i=1}^{m} v_i X_{ij} \le 1,\ j = 1, 2, ..., n \\ &u_r, v_i \ge \varepsilon,\ r = 1, 2, ..., s;\ i = 1, 2, ..., m \end{aligned} \tag{1}$$

among which, the efficiency of stage 1 is:

$$\begin{aligned} &E_k^1 = \max \sum_{p=1}^{q} w_p Z_{pk} \Big/ \sum_{i=1}^{m} v_i X_{ik} \\ &s.t. \sum_{p=1}^{q} w_p Z_{pj} \Big/ \sum_{i=1}^{m} v_i X_{ij} \le 1,\ j = 1, 2, ...n \\ &w_p, v_i \ge \varepsilon,\ p = 1, 2, ...q;\ i = 1, 2, ...m \end{aligned} \tag{2}$$

And the efficiency of stage 2 is:

$$\begin{aligned} E_k^2 = & \max \sum_{r=1}^{s} u_r Y_{rk} \Big/ \sum_{p=1}^{q} w_p Z_{pk} \\ s.t. & \sum_{r=1}^{s} u_r Y_{rj} \Big/ \sum_{p=1}^{q} w_p Z_{pj} \le 1, j = 1, 2, ..., n \\ & u_r, w_p \ge \varepsilon,\ r = 1, 2, ..., s;\ p = 1, 2, ..., q \end{aligned} \tag{3}$$

Here, ε is a small non-Archimedean number; $\boldsymbol{v} = (v_1, v_2, \ldots, v_m)^{\mathrm{T}}$ is the coefficient vector of input X; $\boldsymbol{u} = (u_1, u_2, \ldots, u_s)^{\mathrm{T}}$ is the coefficient vector of final output Y; and $\boldsymbol{w} = (w_1, w_2, \ldots, w_q)^{\mathrm{T}}$ is the coefficient vector of intermediate output Z. $E_k = 1$ indicates that DEA is valid, and $E_k < 1$ indicates that DEA is invalid.

By solving Equations (1), (2), and (3), the overall efficiency E_k, stage 1 efficiency E_k^1, and stage 2 efficiency E_k^2 can be obtained, respectively. However, the efficiency of this traditional two-stage DEA measure is performed independently and cannot link the different stages and the overall process. Drawing on the research of Kao and Hwang (60), this study integrates the traditional two-stage DEA model and converts it into a linear equivalent model as follows:

$$\begin{aligned} & E_k = \max \sum_{r=1}^{s} u_r Y_{rk} \\ & s.t. \sum_{i=1}^{m} v_i X_{ik} = 1, \\ & \sum_{r=1}^{s} u_r Y_{rj} - \sum_{i=1}^{m} v_i X_{ij} \le 0,\ j = 1, 2, ..., n \\ & \sum_{p=1}^{q} w_p Z_{pj} - \sum_{i=1}^{m} v_i X_{ij} \le 0,\ j = 1, 2, ..., n \\ & \sum_{r=1}^{s} u_r Y_{rj} - \sum_{p=1}^{q} w_p Z_{pj} \le 0,\ j = 1, 2, ..., n \\ & u_r,\ v_i,\ w_p \ge \varepsilon,\ r = 1, 2, ..., s;\ i = 1, 2, ..., m;\ p = 1, 2, ..., q \end{aligned} \tag{4}$$

At this time, $E_k = E_k^1 \times E_k^2$. However, the optimal solution obtained from Equation (4) may not be unique, and decomposition of the overall efficiency value is not guaranteed to be unique. Therefore, Kao and Hwang (60) proposed to find a set of multiplied subsets that generate the maximum efficiency value while still solving for the overall efficiency value according to Equation (4). Details are as follows:

$$\begin{aligned} & E_k^1 = \max \sum_{p=1}^{q} w_p Z_{pk} \\ & s.t. \sum_{i=1}^{m} v_i X_{ik} = 1 \\ & \sum_{r=1}^{s} u_r Y_{rk} - E_k \sum_{i=1}^{m} v_i X_{ik} = 0 \\ & \sum_{r=1}^{s} u_r Y_{rj} - \sum_{i=1}^{m} v_i X_{ij} \le 0,\ j = 1, 2, ..., n \\ & \sum_{p=1}^{q} w_p Z_{pj} - \sum_{i=1}^{m} v_i X_{ij} \le 0,\ j = 1, 2, ..., n \\ & \sum_{r=1}^{s} u_r Y_{rj} - \sum_{p=1}^{q} w_p Z_{pj} \le 0,\ j = 1, 2, ..., n \\ & u_r, v_i, w_p \ge \varepsilon, r = 1, 2, ..., s;\ i = 1, 2, ..., m;\ p = 1, 2, ..., q \end{aligned} \tag{5}$$

The efficiency value of stage 1 can be solved by Equation (5), and the efficiency value of stage 2 can be obtained by $E_k^2 = E_k / E_k^1$. Similarly, the maximum efficiency of stage 2 can be solved first, and then the efficiency of stage 1 can be calculated.

Spatial autocorrelation

Spatial autocorrelation is an index used to measure the degree of spatial agglomeration of an attribute in a region. It is mainly divided into global spatial autocorrelation and local spatial autocorrelation. Global spatial autocorrelation mainly examines the spatial correlation degree of an attribute in the whole area, which is usually tested by Moran's I index. The calculation formula is as follows:

$$\text{Moran's } I = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} W_{ij}(x_i - \bar{x})(x_j - \bar{x})}{S^2 \sum_{i=1}^{n} \sum_{j=1}^{n} W_{ij}} \tag{6}$$

$$S^2 = \frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n}$$

where n denotes the total number of units in the study; W_{ij} denotes the spatial weight matrix; x_i and x_j respectively, denote the observed values in spatial units i and j; and $\bar{x}$ denotes the mean of all spatial units. The value range of Moran's I index is $[-1, 1]$. When the value is >0, it indicates positive spatial correlation; when it is <0, it indicates negative spatial correlation; when it is equal to 0, it indicates random distribution in space (i.e., no correlation).

Spatial econometric model

Compared with traditional linear regression models, spatial econometric models can effectively address the issues of complex spatial dependence and spatial correlation (63). At present, common spatial econometric models mainly include spatial lag model (SLM), spatial error model (SEM), and spatial Durbin model (SDM). Among them, SDM considers the spatial dependence of independent and dependent variables at the same time, so that the estimation results are not affected by the degree of spatial dependence of omitted variables. It is an optimization of the first two models and has a wider application (64). Therefore, this study adopts the spatial Durbin model to analyze the influencing factors of health system efficiency in China. The specific form of the model is as follows.

$$Y = \alpha + \rho WY + \beta X + \eta WX + \mu + \nu + \varepsilon \tag{7}$$

where Y denotes health system efficiency; ρ denotes the spatial autoregressive coefficient; W denotes the spatial weight matrix; X denotes the factors that affect health system efficiency; β denotes the regression coefficients of influencing factors; η denotes the coefficients of spatial lag items in influencing factors;

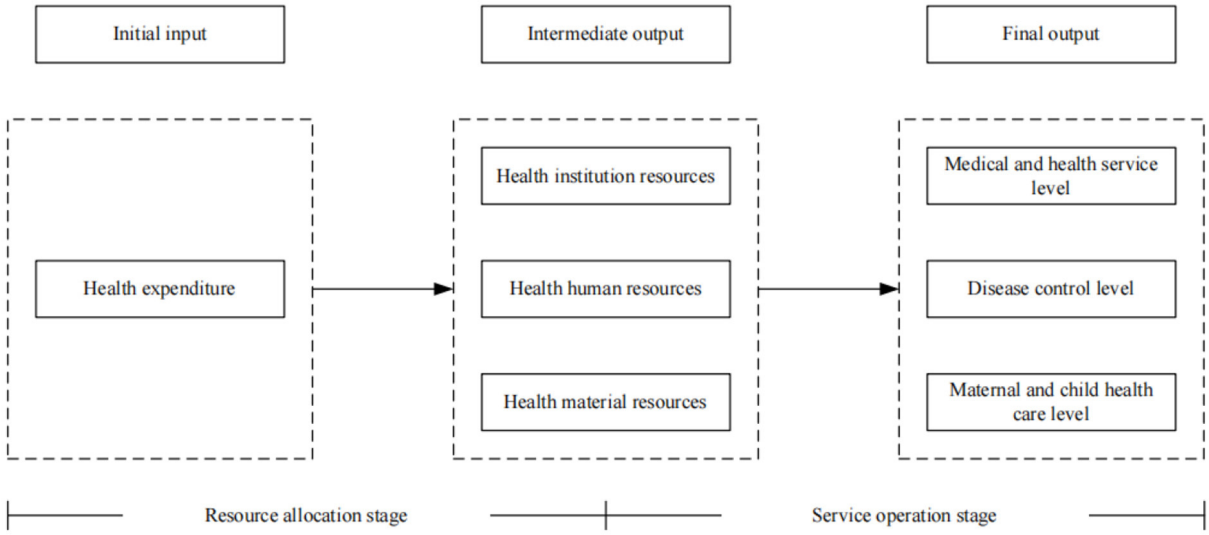

FIGURE 1
The production process of a health system.

μ and ν denote individual fixed effects and time fixed effects, respectively; and ε denotes the stochastic error.

Variable selection and data source

Input-output indicators

According to the characteristics of the operations of the medical and health system, the health production process of the health system is regarded as a multi-stage value transfer process (65). Health financing is the source of the health system. It forms available health resources by investing in health funds, which in turn determines the utilization of health services and the health level of residents (66). Guo et al. (65) believed that the whole process of the health system from initial resource input to final goal realization actually includes two stages: resource allocation and service operation. Among them, the resource allocation stage refers to the process of producing a certain quantity and quality of health resources by investing health funds. The service operation stage refers to the process in which existing health resources serve patients and produce certain social benefits. Therefore, referring to the research of Guo et al. (65), we divide the health production process of the health system into two stages: resource allocation and service operation, as shown in Figure 1. We name the efficiency value measured in the resource allocation stage as resource allocation efficiency, that is - the first stage efficiency. At the same time, the efficiency value measured in the service operation stage is named service operation efficiency, that is - the second-stage efficiency.

At present, most studies regard the input-output process of the health system as a "black box" when evaluating health efficiency, and fail to consider the intermediate production process and the different characteristics of each stage. Therefore, in the selection of input indicators, human, financial and material resources are all regarded as input indicators of health efficiency. However, for the medical and health system, there is a sequential relationship between financial resources, material resources and human resources. Health expenditures are largely used for the construction of health infrastructure, including the establishment of health institutions, the purchase of equipment, and the introduction of health technicians (67). Therefore, in the resource allocation stage, we refer to the research of Zhou (39) to choose health expenditure as the only input indicator, and use the per capita medical and health expenditure to measure it. Health institution resources, health human resources, and health material resources are selected as output indicators, and the output indicators are measured by the number of medical and health institutions per thousand population, health technicians per thousand population, and beds in health institutions per thousand population, respectively.

In the service operation stage, the purpose of health resources investment is to improve the level of medical services and residents' health (66). Therefore, we regard the output of health resources in the previous stage as the input index of this stage, and select the level of medical and health services and residents' health as the final health output index. From the perspective of medical and health services, the service items of medical institutions focus on diagnosis and treatment services and inpatient services (68). Therefore, the level of medical and health services is measured by the number of diagnoses and treatments and hospital bed utilization rate (39, 68). From the perspective of residents' health output, Yu et al. (9) pointed out

TABLE 1 Input-output indicators of health system efficiency.

Category	Dimension	Specific indicators
Initial investment	Health expenditure	Per capita medical and health expenditure (*I1*)
Intermediate output	Health institution resources	Number of health care institutions per thousand population (*M1*)
	Health human resources	Health technicians per thousand population (*M2*)
	Health material resources	Number of beds in health institutions per thousand population (*M3*)
Final output	Medical and health service level	Number of diagnoses and treatments (*F1*)
		Hospital bed utilization rate (*F2*)
	Disease control level	Incidence of class A and B notifiable infectious diseases (*F3*)
	Maternal and child health care level	Maternal mortality (*F4*)
		Perinatal mortality (*F5*)

that the health output of residents can be measured from the aspects of disease control and maternal and child health care. Therefore, we select the incidences of class A and B notifiable infectious diseases to measure the level of disease control, and select the maternal mortality and perinatal mortality to measure the level of maternal and child health care. This is because the incidence of infectious diseases, maternal mortality and perinatal mortality describe the health output status of residents from different perspectives, and panel data are easy to obtain (9). Since the incidence of infectious diseases, maternal mortality, and perinatal mortality are negative indicators, we carried out positive processing of these three indicators, that is - taking the reciprocal. The specific input-output indicators system involved in health system efficiency appears in Table 1.

Influencing factors

Existing studies have pointed out that the health system efficiency is affected by many factors such as economic conditions, institutional conditions, demographic characteristics and social environment (39, 68). On this basis, combined with the review and summary of the existing literature, we analyze the influencing factors of the health system efficiency from the aspects of economic status, institutional factors, population structure and education level. From the perspective of economic status, a country's economic environment directly determines the input intensity of its health resources, and then affects the supply capacity and quality of medical and health services (69). Commonly used measurement indicators include economic development level and urbanization rate. The level of economic development is the main factor restricting the supply of basic medical and health resources in a region, which reflects the economic strength and the level of people's welfare in a region (15). Therefore, it must be added to the model. We use per capita GDP of each region to assess economic development level (*pgdp*). Urbanization plays an important role in medical expenditure, provision of public goods and facilities, and utilization of health services (39, 70, 71). Liang (72) believed that the urbanization rate reflects the public health level of a region. Therefore, this study uses the proportion of urban population to the total population of each region at the end of the year to measure urbanization rate (*urban*).

From the perspective of institutional factors, China's fiscal decentralization system enables local governments to have greater power to allocate resources, which further reflects the ability of local governments in providing public services. Most scholars emphasized that the fiscal decentralization system affects the decision-making of local governments in the provision of health services, which in turn affects the health care efficiency (73, 74). Therefore, we incorporate fiscal decentralization (*fiscal*) into the analysis model, and use the proportion of local government per capita fiscal expenditure to central government per capita fiscal expenditure to measure it. From the perspective of population structure, changes in population structure are also a key factor affecting the effect of health care expenditures (71, 75). At present, the aging phenomenon of China's population is gradually becoming prominent, which undoubtedly has a certain effect on the operation efficiency of the health system. In this study, we use the old-age dependency ratio (*depend*) to characterize the changes in the population structure, and select the dependency ratio of the elderly population in each region to express it. From the perspective of education level, many studies have confirmed the close relationship between education level and health care efficiency (9, 73), which means that education level needs to be included in the regression model. We use the illiteracy rate (*edu*) as a proxy for education level, and choose the proportion of illiterate population to the population aged 15 and above in each region for evaluation. A lower proportion of illiterate population means a higher level of education.

Data sources

In view of data availability, we choose panel data of 31 provinces in China from 2009 to 2020 (excluding Hong Kong, Macao and Taiwan). The data of all indicators are obtained from China Statistical Yearbook, China Health Statistical Yearbook, China Population and Employment Statistics Yearbook, and statistical yearbooks of various provinces.

TABLE 2 Descriptive statistics of input-output indicators.

Variable	Obs	Mean	Std. Dev.	Min	Max
I1	372	911.9729	520.6888	199.8247	3944.5350
M1	372	0.7528	0.3270	0.2018	2.1767
M2	372	5.8895	1.5395	2.7355	12.6152
M3	372	4.9666	1.1944	2.6047	7.9894
F1	372	23650.07	18615.05	959.00	89200.00
F2	372	83.7796	7.7772	48.3000	100.2000
F3	372	0.0046	0.0017	0.0015	0.0124
F4	372	0.0975	0.1003	0.0043	0.9091
F5	372	1.9618	0.8470	0.4160	5.5556

TABLE 3 Descriptive statistics of regression variables.

Variable	Obs	Mean	Std. Dev.	Min	Max
efficiency	372	0.5775	0.1735	0.1478	1.0000
pgdp	372	45846.53	24188.58	10971.00	128207.00
fiscal	372	7.0400	3.8179	2.6793	24.3355
urban	372	0.5673	0.1370	0.2230	0.8960
edu	372	6.1046	6.1594	0.8900	41.1800
depend	372	13.9660	3.6932	6.7100	25.4800

To sum up, Tables 2, 3 report the descriptive statistical analysis results of input-output indicators and regression variables, respectively.

Empirical analysis

Evolution of temporal and spatial pattern of health system efficiency in China

Measurement results of health system efficiency in China

According to the above research methods, we obtain the efficiency values of the two-stage health system for each province in different years. In order to compare and analyze health system efficiency between different provinces, this study calculates the average health system efficiency of 31 provinces in China from 2009 to 2020 and reports the results in Table 4. In terms of overall efficiency, the level of health systems in most provinces in China is relatively low. For example, the average overall efficiency of health systems in Beijing, Inner Mongolia, Hainan, Guizhou, Tibet, Qinghai and other provinces is <0.5. Most of these provinces are located in the western region, and the backward level of economic development is the main reason for the low overall efficiency of the health system in the western region. On the contrary, although Beijing and Shanghai are located in the developed eastern region, the overall efficiency of their health systems is lower, only 0.3210 and 0.5255, respectively. This is because Beijing and Shanghai have a high level of economic development and rich medical resources, which have a strong siphon effect on the labor force and medical demanders, resulting in an overload of the medical system, thus reducing the efficiency of the regional health system. Most studies have confirmed this view (39, 65, 76). In comparison, the overall efficiency of the health system in the eastern and central regions is relatively high, with Shandong, Henan, Jiangsu, and Hebei having the highest overall efficiency. The reason may be that the geographical distance between Shandong and Hebei and regions with rich medical resources is relatively short, medical patients tend to transfer to adjacent developed areas to obtain better medical resources, and the net output of medical patients helps reduce the burden of regional health system, so as to alleviate the dilemma of shortage of health resources (39).

From the perspective of the resource allocation stage, the resource allocation efficiency of the national health system is 0.6840, which still has a lot of room for improvement. Among them, Shandong, Liaoning, Shanxi, Hunan, Heilongjiang and Zhejiang have higher resource allocation efficiency of their health systems, all of which are >0.8, indicating that the health resources in these areas have been effectively allocated, and the medical and health expenditures have achieved a reasonable output level.

From the perspective of the service operation stage, the service operation efficiency of the national health system is high, and the efficiency value reaches 0.84. It can be seen that the service operation of China's health system is relatively good. The empirical results of Yu et al. (77) also showed that the overall efficiency of China's medical and health service system was relatively high from 2010 to 2017, and it was found that after excluding the influence of the environment and random error factors, the overall efficiency of China's medical service system was mostly in the stage of increasing scale. It can be seen that the conclusion of this paper is consistent with the relevant literature. Among them, the efficiency values of Shanghai, Jiangsu, Guangdong, and Jiangxi are all 1, reaching the optimal production frontier. This indicates that the service quality of the health system in these areas is high and the scale effect of health output can be achieved.

Evolution trend of health system efficiency in China

According to the economic development level and geographical location of different regions, we divided the samples into eastern, central and western regions. The eastern region includes Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong and Hainan. These provinces and cities are mainly located along the coast and are the most developed regions in China. The central region includes Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan,

TABLE 4 Average efficiency of health system at different stages in each province.

Province	Overall efficiency	Resource allocation	Service operation	Province	Overall efficiency	Resource allocation	Service operation
Beijing	0.3210	0.5617	0.5686	Hubei	0.6724	0.7711	0.8710
Tianjin	0.5076	0.5672	0.8930	Hunan	0.7170	0.8483	0.8453
Hebei	0.7510	0.7815	0.9585	Guangdong	0.7168	0.7168	1.0000
Shanxi	0.5693	0.8644	0.6610	Guangxi	0.6162	0.6805	0.9059
Inner Mongolia	0.4041	0.6399	0.6327	Hainan	0.4132	0.5136	0.8063
Liaoning	0.6924	0.9590	0.7175	Chongqing	0.5482	0.6448	0.8503
Jilin	0.5808	0.7216	0.7942	Sichuan	0.6869	0.7527	0.9156
Heilongjiang	0.6738	0.8418	0.7953	Guizhou	0.4957	0.5894	0.8449
Shanghai	0.5255	0.5255	1.0000	Yunnan	0.5450	0.5854	0.9347
Jiangsu	0.7844	0.7844	1.0000	Tibet	0.1902	0.2571	0.7463
Zhejiang	0.6756	0.8204	0.8230	Shaanxi	0.5327	0.7826	0.6814
Anhui	0.6218	0.6234	0.9977	Gansu	0.5192	0.6101	0.8524
Fujian	0.5919	0.6755	0.8758	Qinghai	0.2638	0.3972	0.6643
Jiangxi	0.6196	0.6196	1.0000	Ningxia	0.4305	0.5727	0.7532
Shandong	0.9546	0.9803	0.9738	Xinjiang	0.4882	0.7179	0.6838
Henan	0.7939	0.7963	0.9968	Mean	0.5775	0.6840	0.8401

Hubei and Hunan. And the western region includes Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang, which are the least developed regions. We draw the trend chart of their overall efficiency of health systems, as shown in Figure 2. As can be seen, the overall efficiency of the national health system exhibits a fluctuating upward trend, rising from 0.5020 in 2009 to 0.6239 in 2020. There are divergent views in the existing literature on trends in health system efficiency. Some scholars believe that the efficiency of China's health system shows a slight downward trend (78, 79). A few studies believe that the efficiency of China's health system has an irregular evolution trend. For example, Zhou (39) emphasized that the overall efficiency of the Chinese government's health spending from 2008 to 2018 was almost an "Ω"-shaped fluctuation trend. However, the opinions of Yu et al. (9) are consistent with the conclusions of this study. We all believe that the overall efficiency of China's health system has shown a fluctuating upward trend after 2009.

As can be seen from Figure 2, the overall efficiency of the health system increased significantly from 2009 to 2014, which mainly relates to the reform of China's medical and health system in 2009. Local governments continue to improve the quantity and quality of the supply of health resources, standardize the order of drug circulation, and constantly improve the operating mechanism of health institutions, thereby promoting the rapid improvement of health level (9). From 2014 to 2015, the overall efficiency of the health system declined briefly, which may be due to the large investment of health resources in the few years before and the rapid improvement of service quality of large-scale health institutions, resulting in an influx of a large number of health technicians and patients into large-scale health institutions. This not only leads to the continuous loss of talents in grassroots health institutions, but also fails to make effective use of grassroots medical resources, thus reducing the operation efficiency of the health system (65). However, the overall efficiency of the health system recovered steadily from 2016 to 2020, as local governments began to pay attention to improving the benefit compensation mechanism, which in turn helps to improve the performance of the health system.

In terms of sub-regions, the overall efficiency of the health system in the eastern, central, and western regions shows an upward trend, and there are great differences in the efficiency of the health system among them. The overall efficiency of the health system in the eastern and central regions is higher than the national average, while that in the western region is lower than the national average. There is no consensus among scholars on the overall efficiency of health systems in different regions. Most studies have confirmed that the health system efficiency in the eastern region is the highest, and its health system operation is better than that in the central and western regions (77, 80). However, a few scholars believe that the health system efficiency in the eastern region is much lower than that in the central and western regions (79). Although existing studies hold different views on the changing trends and overall levels of health system efficiency in different regions of China, they all agree that there are significant regional differences in China's health system efficiency (77, 81, 82), which is the same conclusion as this paper.

According to the two-stage measurement results, we further analyze the change trend of health system efficiency in

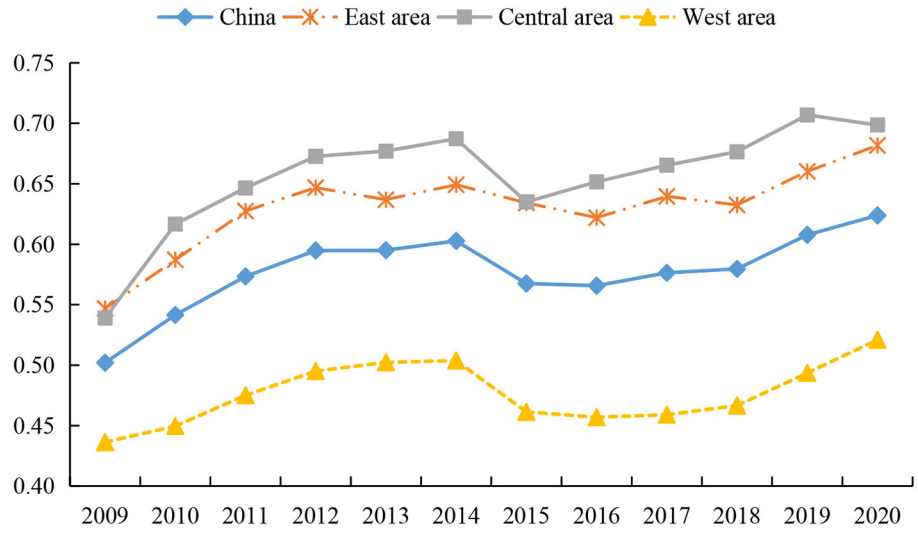

FIGURE 2
Trends of overall health system efficiency in different regions from 2009 to 2020.

the resource allocation stage and service operation stage, as presented in Figures 3, 4. Figure 3 depicts the changing characteristics of resource allocation efficiency of health systems in different regions of China. First, the resource allocation efficiency of health systems in different regions shows a fluctuating and slowly rising trend, which is similar to the conclusions of most studies (76, 79). Among them, the efficiency of health systems in all regions increased significantly from 2009 to 2014, decreased from 2014 to 2015, and then showed a slow upward trend. The reason for this phenomenon is similar to the change of overall efficiency. However, we find that the declining point in the eastern region occurred in 2012. This is due to the fact that there are many large health institutions in the eastern region, and the large investment in health resources in the early stage makes the maintenance cost of medical equipment rise faster, and so the time point of weak growth in resource allocation efficiency appears earlier.

Second, the rankings of the resource allocation efficiency of the health system do not change during the investigation period, that is - the efficiency value of the central region is the highest, followed by the eastern region, and the western region is the lowest. Scholars have different views on the allocation of health resources in different regions. Most studies examine the allocation efficiency of health resources by measuring the health expenditure efficiency, and draw inconsistent conclusions. Some studies emphasize that the improvement efficiency of health resources in the eastern region is the highest (79), while some studies believe that due to the siphon effect, the resource allocation efficiency of the developed eastern region is lower than that of the central and western regions (65). However, we found that most of the studies confirmed that the health resource allocation in the central region is better, and some studies pointed out that the health resource allocation efficiency in the central region is the highest (65, 81, 83), which is similar to the viewpoint of this paper. The explanation of the conclusions of this study can be summarized as follows. The main reason is that the eastern region attracts a large number of floating population due to its high level of economic development and obvious regional advantages, which make the total demand for medical and health care constantly increase. In order to meet the medical needs of a large population, health institutions in the eastern region continue to increase medical equipment and beds. However, due to the lack of supporting management mechanism, a large number of health expenses is only used to maintain the daily operations of health institutions, leading to low efficiency of health technology and a low level of resource allocation (65). The resource allocation efficiency of health systems in the western region is at a low level, which may be restricted by factors such as economic development and geographical location. The input of health cost in the western region is small, but the cost of health resource acquisition and transportation is high, and so high output levels cannot be achieved. Moreover, it is difficult for the backward western regions to attract high-quality health technicians, thereby reducing the allocation efficiency of health resources.

Figure 4 shows the changing characteristics of service operation efficiency of the health systems in different regions of China. First, during the whole investigation period the eastern and central regions showed a fluctuating upward trend, while the western region showed a fluctuating downward trend first and then a rising trend. We see that the service operation efficiency of the health system in various regions increased rapidly from 2011 to 2012. This is explained by the fact that the reform of the medical system in 2009 led to a continuous increase in the input

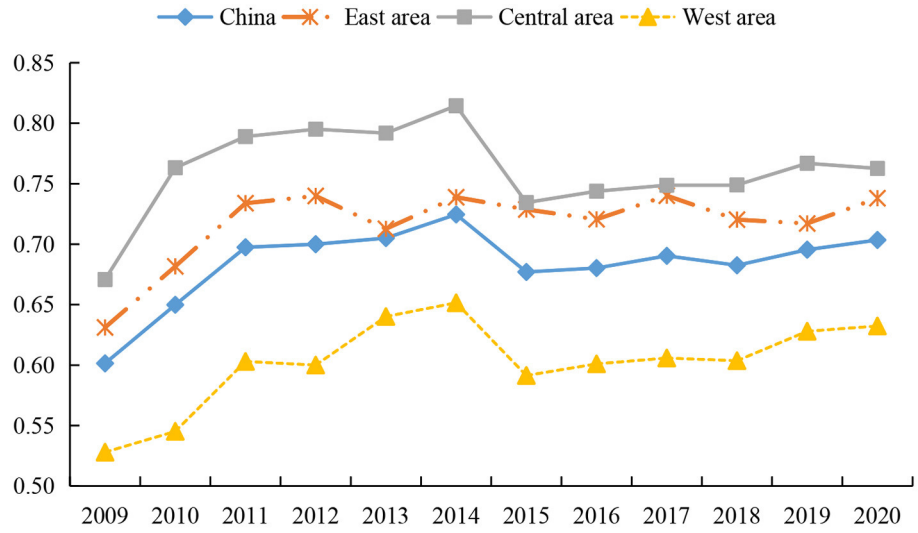

FIGURE 3
Trends of resource allocation efficiency of health systems in different regions from 2009 to 2020.

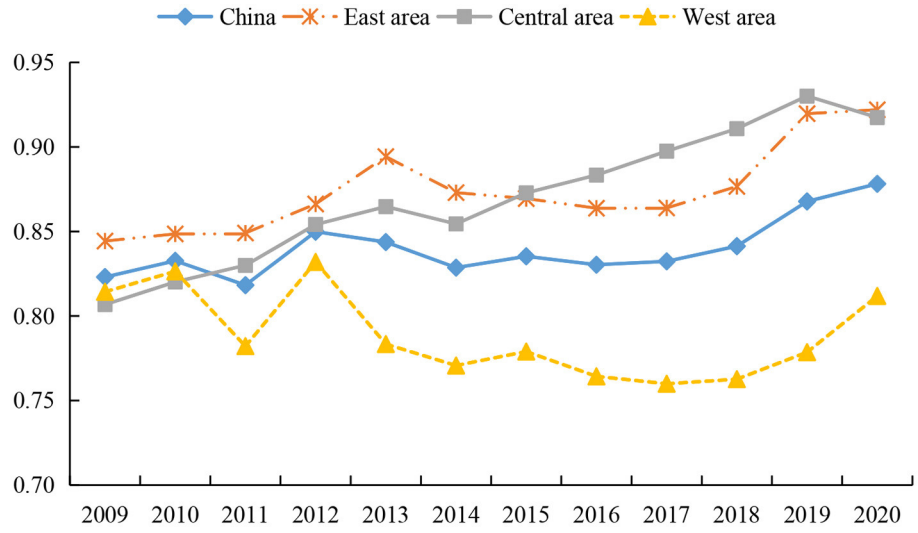

FIGURE 4
Trends of service operation efficiency of health systems in different regions from 2009 to 2020.

of health resources, while the lag of health output has made the service operation effect in some regions only manifest itself after 2011.

Second, there is little difference between the efficiency values of the eastern region and the central region, while the efficiency values of the western region are at the lowest level, with values of 0.8742, 0.8702 and 0.7888, respectively. For the comparison between the efficiency of the central and western regions, there are differences in the relevant studies. Some scholars believe that during the operation stage of health services, the efficiency of the central region has been lower than that of the eastern and western regions over the years, showing the phenomenon of "central collapse" (65, 68). However, the conclusion about the highest efficiency of health services in the eastern region is consistent with the views of most studies (65, 68, 79). This is because the eastern region not only has advanced medical equipment and high-quality health technicians, but also residents in the region have high health awareness, which makes the service operation efficiency of the health system hit a high level. However, due to fierce market competition in the eastern

region, it also causes greater work pressure and work intensity. This situation increases the possibility of residents' illness, brings challenges to the medical service system (39), and reduces the operation efficiency of the health system to a certain extent. Affected by the shortage of financial funds, the western region has insufficient investment in high-quality medical equipment and health technicians, which restrict the improvement of service operation efficiency (82). In addition, a large number of people in the western region flows to economically developed areas, making the existing medical equipment underutilized and a large number of health resources idle and thus reducing the service efficiency of the health system.

Temporal and spatial pattern of health system efficiency in China

We further use ArcGIS software to analyze the temporal and spatial pattern of health system efficiency in China. Based on the data of two time points in 2009 and 2020, this study employs the natural fracture method to divide health system efficiency into five types, low efficiency, lower efficiency, medium efficiency, higher efficiency, and high efficiency, so as to explore the spatial evolution characteristics of the health system efficiency in China. Figure 5 displays the spatial evolution characteristics of overall efficiency of the health system in different provinces of China. Accordingly, the regions with low overall efficiency in 2009 include Tibet, Qinghai, Inner Mongolia, Jilin and Beijing, and the regions with high overall efficiency are only distributed in Shandong. In 2020, the regions with low overall efficiency are only distributed in Tibet, and the regions with high overall efficiency are mainly concentrated in eastern regions such as Shandong, Zhejiang, Jiangsu, Hebei, and Liaoning. Compared with 2009, the proportion of regions with medium and above efficiency level has increased significantly, from 48% in 2009 to 74% in 2020. Among them, the areas with high overall efficiency increased significantly, while the areas with low overall efficiency decreased.

Figure 6 depicts the spatial evolution characteristics of resource allocation efficiency of health systems in different provinces of China. It can be seen from the figure that the regions with low resource allocation efficiency in 2009 include Tibet and Qinghai. The regions with high resource allocation efficiency are only distributed in Shandong, and the regions with higher resource allocation efficiency are concentrated in seven regions, which include Jiangsu, Guangdong, Hebei, Hubei, and Hunan. In 2020, Tibet, Qinghai, and Hainan are regions with low resource allocation efficiency, Shandong, Liaoning, Jilin and Shaanxi are regions with high resource allocation efficiency, and those with higher resource allocation efficiency include nine regions, such as Jiangsu, Zhejiang, Tianjin, Hebei, and Hunan. Compared with 2009, the number of regions with high resource allocation efficiency and higher resource allocation efficiency has increased, while the number of regions with low resource allocation efficiency has hardly changed.

Figure 7 presents the spatial evolution characteristics of service operation efficiency of health systems in different provinces of China. According to Figure 7, the regions with low service operation efficiency are concentrated in Xinjiang, Shanxi, Jilin, and Beijing, and the regions with high service operation efficiency are mainly distributed in 11 regions, such as Shanghai, Guangdong, Fujian, Anhui, and Jiangsu. In 2020, Tibet, Qinghai, Inner Mongolia, Shanxi, and Shaanxi are regions with low service operation efficiency, and ten regions with high service operation efficiency are mainly distributed in Shanghai, Guangdong, Zhejiang, Hebei, and Henan. Compared with 2009, the number of areas with high service operation efficiency and areas with low service operation efficiency changed little. Moreover, the regions with high service operation efficiency are gradually concentrated from a relatively discrete distribution to the eastern region.

Analysis of spatial spillover effects of health system efficiency in China

Spatial autocorrelation test

The spatial correlation of health system efficiency needs to be examined prior to spatial econometric model analysis. Based on the spatial adjacency weight matrix, this research adopts GeaDa software to calculate the global Moran's I index from 2009 to 2020, and the results are in Table 5. As can be seen from the table, the Moran's I index of health system efficiency in all years except 2018 passed the 5% significance test, which indicates that the efficiency of provincial health systems in China has significant spatial correlation. From 2009 to 2015, the global Moran's I index decreased from 0.3943 to 0.2063, indicating that the spatial correlation of health system efficiency tended to weaken. The global Moran's I index fluctuates in the range of 0.1598–0.2227 from 2015 to 2020, and the spatial impact of health system efficiency still persists. In general, the efficiency of China's health system exhibits spatial dependence, that is - the level of health systems in one region affects the level of health systems in adjacent regions through spatial spillover effects.

Test and identification of spatial econometric models

Due to the significant spatial correlation of health system efficiency, the traditional least squares regression will lead to biased estimation results. Therefore, this study introduces a spatial econometric model to analyze the influencing factors of health system efficiency. Before model estimation, the spatial econometric model needs to be identified and tested. The results appear in Table 6. Generally, the LM test method is used to determine whether SEM or SLM should be selected. Table 6 reports that both LM-spatial error and Robust LM-spatial error pass the significance test at the 1% statistical level, LM-spatial

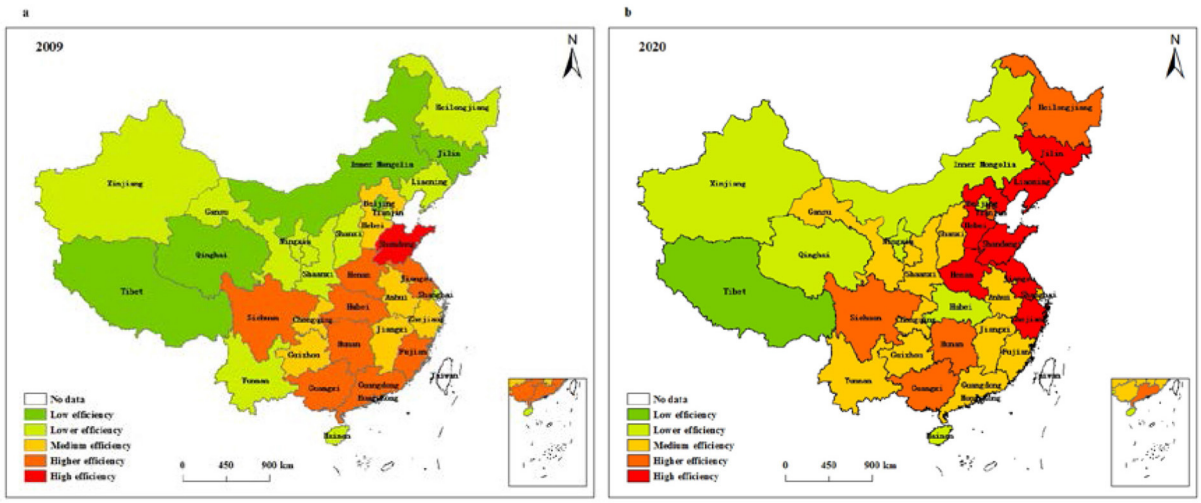

FIGURE 5
Spatial pattern of overall health system efficiency in **(a)** 2009 and **(b)** 2020.

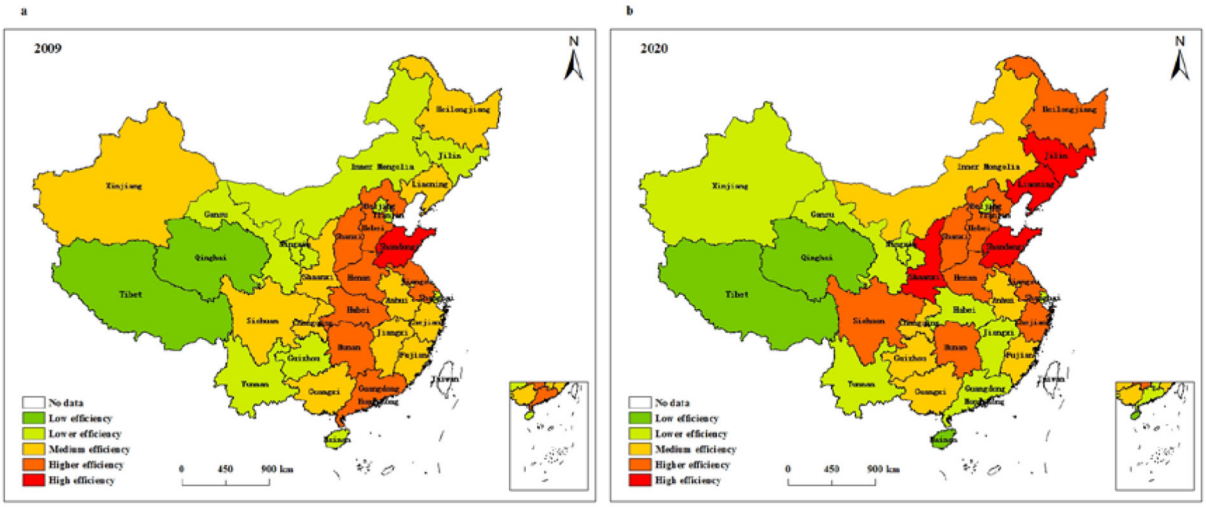

FIGURE 6
Spatial pattern of resource allocation efficiency of health systems in **(a)** 2009 and **(b)** 2020.

lag is also significant at the 1% statistical level, and Robust LM-spatial lag passes the 10% significance test, indicating that both models of SEM and SLM can be used for empirical test. However, the LM test method does not take into account the applicability of SDM, and so it is necessary to employ the LR test and the Wald test to judge whether SDM will be simplified to SEM or SLM. Table 6 presents that both LR-spatial error and LR-spatial lag reject the null hypothesis at the 1% statistical level, and both Wald-spatial error and Wald-spatial lag also reject the null hypothesis at the 1% statistical level. The results show that SDM cannot be simplified into SEM and SLM. In addition, according to the results of the Hausman test, the index is 48.45 and passes the significance test at the 1% statistical level, which means that the research model should use fixed effects. Therefore, we choose the fixed-effect SDM to empirically investigate the spatial spillover effect of health system efficiency.

Spatial spillover effects and decomposition results

On the basis of the above analysis, we apply Stata software to conduct a regression test on the factors influencing health system efficiency in 31 provinces in China from 2009 to 2020. The estimated results are in Table 7. As can be seen from the table, the

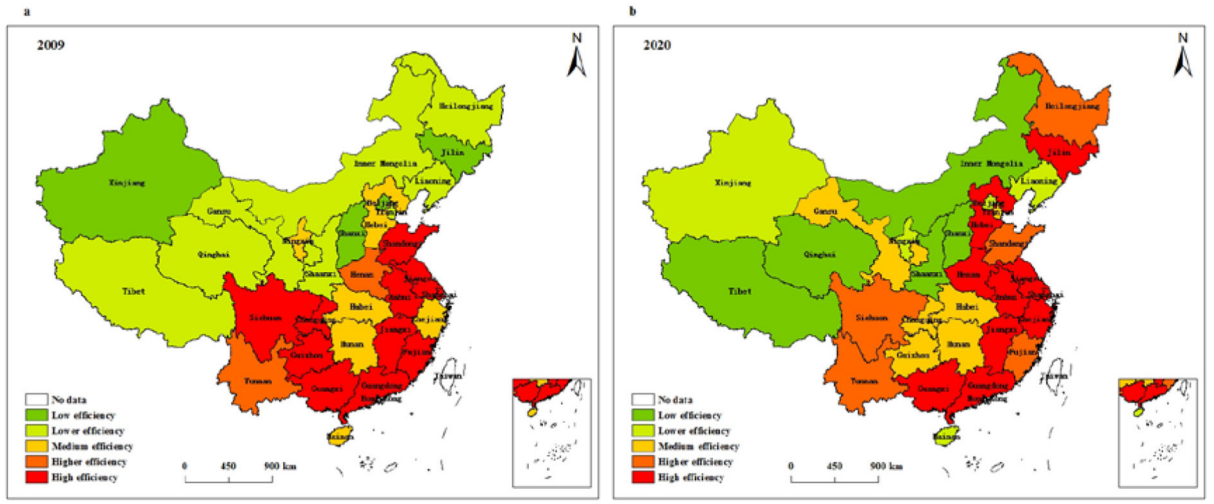

FIGURE 7
Spatial pattern of service operation efficiency of health systems in **(a)** 2009 and **(b)** 2020.

TABLE 5 Global Moran's *I* index of health system efficiency in China from 2009 to 2020.

Year	Moran's *I*	*Z*-value	*P*-value	Year	Moran's *I*	*Z*-value	*P*-value
2009	0.3943	3.5778	0.001	2015	0.2063	2.0840	0.026
2010	0.3867	3.5776	0.001	2016	0.2202	2.1932	0.019
2011	0.3126	2.9584	0.002	2017	0.1925	1.9580	0.031
2012	0.2570	2.5132	0.014	2018	0.1598	1.6975	0.057
2013	0.2281	2.2875	0.019	2019	0.1788	1.8455	0.043
2014	0.2224	2.2300	0.018	2020	0.2227	2.1422	0.020

TABLE 6 The results of identification tests of spatial econometric models.

Content	Method	Statistics	*P*-value
Test of SEM and SLM	LM-spatial error	47.67	<0.001
	Robust LM-spatial error	31.87	<0.001
	LM-spatial lag	18.54	<0.001
	Robust LM-spatial lag	2.74	0.098
Simplified test for SDM	LR-spatial error	23.82	<0.001
	Wald-spatial error	24.40	<0.001
	LR-spatial lag	24.16	<0.001
	Wald-spatial lag	25.09	<0.001
Hausman		48.45	<0.001

level of economic development, fiscal decentralization, and old-age dependency ratio all pass the significance test at the 1% level. The level of economic development and fiscal decentralization system have a significantly negative impact on health system efficiency, and there exists a significantly positive relationship between old-age dependency ratio and health system efficiency. Since SDM considers the influence of related variables in adjacent areas, the coefficients of the spatial lag terms do not fully explain the actual effects of the variables. Systematic bias will occur if we use the coefficients only to analyze the spillover effect of the variables (40). Therefore, we further decompose the research model into direct effect, indirect effect, and total effect, which can reduce estimation bias to some extent and improve the accuracy of model estimation. The results are in Table 8.

As far as the direct effects are concerned, the regression coefficient of the level of economic development is significantly negative at the 1% level, meaning that its improvement has a negative impact on local health system efficiency. As for the relationship between the economic development level and the health system efficiency, there are different views in the existing literature. Some studies have pointed out that economic development improves the income level of residents and the supply of health resources, which in turn has a positive effect on the health system efficiency (15, 81, 84). However, some studies believe that the high growth of the regional economy has inhibited the improvement of the health system efficiency (39). The research in this paper confirms the latter viewpoint

TABLE 7 Regression results of the spatial Durbin model.

Variable	Spatial Dubin model				
	Coefficient	Standard error	z	[95% confidence interval]	
ln*pgdp*	−0.6591***	0.1849	−3.56	−1.0216	−0.2967
ln*fiscal*	−0.3021***	0.0964	−3.14	−0.4910	−0.1132
ln*urban*	−0.1810	0.1740	−1.04	−0.5220	0.1600
ln*edu*	−0.0374	0.0414	−0.90	−0.1185	0.0437
ln*depend*	0.2649***	0.0720	3.68	0.1237	0.4061
W*ln*pgdp*	1.2023***	0.3293	3.65	0.5570	1.8476
W*ln*fiscal*	−0.5274***	0.1843	−2.86	−0.8887	−0.1661
W*ln*urban*	−0.3109	0.3596	−0.86	−1.0158	0.3939
W*ln*edu*	−0.1084	0.0949	−1.14	−0.2944	0.0776
W*ln*depend*	0.3732**	0.1449	2.58	0.0893	0.6572
sigma2_e	0.0097***	0.0007	13.55	0.0083	0.0111
Individual effect	Control				
Time effect	Control				
Observations	372				
Log-likelihood	333.7146				

again. This may be due to the siphoning effect of higher levels of economic development on the labor force (85). A large amount of labor force flows from economically backward regions to developed regions, resulting in excessive population density and an overload of the health system in economically developed regions, which in turn inhibits the service efficiency of these health systems.

The regression coefficient of fiscal decentralization is significantly negative at the 1% level, which confirms that a fiscal decentralization system reduces health system efficiency in the region. Although some studies suggest that fiscal decentralization can improve the health system efficiency by making the government's health spending policy more flexible (78), most studies affirm the negative impact of fiscal decentralization on the health system efficiency (39, 81, 82). Possible explanations for this result are as follows. On the one hand, a fiscal decentralization system enables local governments to have greater power over resource allocation (86). Under the motivation of "promotion tournament," local governments are more inclined to invest funds in infrastructure construction while ignoring the improvement of people's livelihood in order to pursue high GDP growth (39). The inefficiency of a local health system is mainly caused by the lack of attention and investment of the local government in the health sector (87). On the other hand, the long-term tax-sharing system widens the financial gap between regions, restricts the supply capacity of the health system in the regions with backward financial resources, and then reduces the operation efficiency of the health system (88).

The regression coefficient of the old-age dependency ratio is significantly positive at the 1% level as well. This result is different from the general conclusion. Existing studies generally believe that the aging population aggravates the shortage of health resources, which seriously hinders the improvement of health system efficiency (15, 84). However, the reasons for the conclusion of this study can be summarized as follows. This may be due to the fact that China is still in the early stage of population aging, and the negative effect of the increase in the proportion of old-age dependency on the health system efficiency has not yet arisen (39). In the early stage of population aging, due to the deterioration of the physical functions of the elderly population, the total demand for public medical resources gradually increases, which promotes the improvement of medical resource supply and service capacity in the region to a certain extent. As the aging of the population becomes increasingly prominent, local governments start to pay attention to investment in elderly services, especially in medical and health care (89), thus helping to improve the service efficiency of the health system.

The level of urbanization has a negative effect on health system efficiency, but the result is not significant. By comparing other studies, it is found that some studies emphasize that urbanization means higher residents' income, better infrastructure and medical services, which is conducive to improving residents' medical treatment level and driving the improvement of health efficiency (9, 81). However, with the acceleration of China's urbanization process, the negative effect of urbanization on the health system efficiency has become increasingly prominent (78, 90). We believe that the reason for

TABLE 8 Direct, indirect, and total effects of the spatial Durbin model.

Variable	Direct effect	Indirect effect	Total effect
ln*pgdp*	−0.7022*** (−3.68)	1.1840*** (4.10)	0.4818 (1.49)
ln*fiscal*	−0.2856*** (−3.17)	−0.4215** (-2.58)	−0.7072*** (−4.05)
ln*urban*	−0.1785 (−1.02)	−0.2546 (−0.78)	−0.4331 (−1.19)
ln*edu*	−0.0289 (−0.73)	−0.0923 (−1.16)	−0.1212 (−1.39)
ln*depend*	0.2505*** (3.60)	0.3039** (2.42)	0.5544*** (4.02)

its negative effect is related to the siphon effect of the labor force, which is similar to the mechanism of economic development level. The illiteracy rate has a negative impact on health system efficiency, but the regression results are also insignificant. The reason for the negative correlation can be explained as the improvement of education level helps to improve the professional quality of health technicians and also enhances the health consciousness of residents, thus contributing to the improvement of the service efficiency of the health system.

The regression results of indirect effects suggest that the coefficient of economic development level is significantly positive, indicating that the improvement of economic development level in an adjacent region will promote the improvement of local health system efficiency. Possible explanations for this result are as follows. On the one hand, the developed economic level of adjacent areas drives the rapid development of the local economy and the improvement of people's livelihood through technological spillovers and trade exchanges, which are conducive to improving the supply capacity of local health resources. On the other hand, adjacent areas with a higher economic level may promote labor force migration to the local area, resulting in the aggregation and increase of human capital and thereby helping to improve the service efficiency of the local health system. Moreover, the cross-regional mobility of labor forces will also promote the full utilization of local medical resources. The regression coefficient of fiscal decentralization is significantly negative at the 5% statistical level, which shows that the degree of fiscal decentralization in an adjacent region inhibits the improvement of local health system efficiency. This is mainly due to the fact that the higher the degree of fiscal decentralization is in an adjacent region, the more likely the adjacent governments is to promote economic development by distorting fiscal supply decisions. The existence of competition between regions makes local governments follow the practice of an adjacent region, that is - an increase in investment in infrastructure construction at the expense of financial resources in health care and other livelihood areas leads to a serious shortage of service supply in the local health system and ultimately reduces the operating efficiency of local health system.

The regression coefficient of the old-age dependency ratio is significantly positive at the 5% statistical level, which suggests that an increase of the old-age dependency ratio in an adjacent region promotes the efficiency of the local health system. The reason may be that large numbers of elderly people in adjacent areas have increasing demand for public medical resources, which will prompt some elderly people in adjacent areas to turn to local health institutions for medical treatment, thereby driving local health resources to be fully utilized. The level of urbanization fails to pass the significance test, indicating that the impact of urbanization on health system efficiency does not have a spatial spillover effect. There is also no spatial spillover effect between illiteracy rate and health system efficiency, which may be due to the investment in educational resources in adjacent areas being independent of each other, the total migration of high-quality talents from adjacent areas to the local area is small, and the service efficiency of the local health system has not been greatly improved.

Conclusion and policy recommendations

Based on panel data of 31 provinces in China from 2009 to 2020, this research adopts the two-stage network DEA model to provide a comprehensive measurement of health system efficiency. On this basis, the spatial econometric model is used to deeply explore the influencing factors and spatial spillover characteristics of health system efficiency throughout China.

The findings in this paper mainly include the following aspects. First, the overall efficiency of China's health system is low, which is mainly caused by the low efficiency of resource allocation. Specifically, health system services are operating relatively well, while resource allocation still has room for improvement. Second, there are differences in the evolution of trends in health system efficiency. The overall efficiency of China's health system show a fluctuating upward trend, with large differences between different regions. From the perspective of the resource allocation stage, the resource allocation efficiency of health systems in different regions fluctuates and rises slowly. Among them, the central region has the highest efficiency value, followed by the eastern region, and the western region has the lowest efficiency value. From the perspective of service operation efficiency, the eastern and central regions shows a fluctuating upward trend, while the western region shows a fluctuating downward trend first and then rising trend. Among them, the efficiency value of the eastern region is similar to that of the central region, and the efficiency value of the western region is at the lowest level. Finally, the improvement of economic development level and fiscal decentralization significantly reduces health system efficiency, and an increase of the old-age dependency ratio promotes the development of the health system. In terms of spatial spillover effects, the improvement of economic development level and old-age dependency ratio in adjacent regions can help the efficiency of

the local health system, while an increase in the degree of fiscal decentralization in adjacent regions hinders the improvement of the efficiency of the local health system. There is no spatial spillover effect of urbanization and illiteracy rate on health system efficiency.

Based on the above discussion, we put forward the following policy recommendation.

First, the government should pay attention to regional disparities in health system efficiency and allocate medical resources rationally. On the one hand, the investment scale of health resources should be adjusted according to the economic strength and resource endowment of different regions. Specifically, the eastern region should implement refined health resource management and improve the medical management system to avoid wasting resources due to redundant inputs. The government should also strengthen policy support to the medical system in the western region and continue to increase financial investment. On the other hand, cooperation among health institutions in different regions can be enhanced to improve the regional imbalance of China's health system. Especially in the post-epidemic era, the government should establish a joint prevention and control mechanism for major risks and improve information sharing and health resource deployment capabilities between regions, so as to achieve precise and effective prevention and control of epidemics. An important way to improve efficiency is to establish the mechanism of supporting health resources in backward areas, such as the sharing of health resources and the construction of medical alliances.

Second, to improve the technical level and management capacity of the input elements of health resources, it is suggested that health institutions carry out business training, special training, and domestic and foreign training programs to improve the professional skills of health technicians. At the same time, health institutions need to introduce advanced medical equipment and management models to promote the rapid improvement of the service efficiency of the health system. In addition, local governments should encourage technological innovation in the medical field and increase investment in medical technique research and development, so as to continuously improve the health status of patients.

Third, local governments need to strengthen and improve the economic and institutional environments that affect the efficiency of health systems. In terms of the economic development environment, local governments should guide high-quality resources in developed areas to gather in backward areas and continuously improve the economic development and health service system of backward areas, so as to reduce the burden on the health system in developed areas. In the aspect of institutional environment construction, the government must focus on constraining investment preferences in production and construction and increase the proportion of public service provision in government assessment, especially in the assessment of health system quality. Moreover, the government should adhere to the matching of powers and expenditure responsibilities, so as to avoid excessive sinking of expenditure responsibilities. In terms of helping the elderly population, the government needs to formulate health service policies related to this growing population and increase the supply of health service facilities for the elderly. In the education field, governments must emphasize the health education of residents and strengthen the popularization of health knowledge, which can then promote the improvement of health system efficiency.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

Author contributions

Conceptualization, writing—original draft preparation, and visualization: YY and LZ. Methodology, software, and resources: YY. Validation and data curation: LZ, YY, and WZ. Formal analysis: XZ. Investigation: MY. Writing—review and editing: WZ and YY. Supervision, project administration, and funding acquisition: WZ. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Village doctors' dilemma in China: A systematic evaluation of job burnout and turnover intention

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Background: Village doctors (VDs) in China undertook arduous primary healthcare missions. However, they received little attention in comparison to doctors in urban public secondary and tertiary hospitals. There is an urgent need to explore the overall situation of turnover intention and job burnout among VDs to evaluate and adjust current health manpower policy.

Methods: In this study, seven databases like PubMed, EMBASE, Web of Science (WOS), WanFang, China Science and Technology Journal Database (VIP), Chinese BioMedical Literature Database (CBM), and China National Knowledge Infrastructure (CNKI) were systematically searched, relevant experts were consulted, and empirical research on job burnout and turnover intention among VDs in international publications was evaluated. Therefore, we evaluated the prevalence of job burnout among VDs in general, across all dimensions and different severity levels, as well as the scores of each category. For turnover intention, we assessed the prevalence of different groups and their overall situation and also identified significant contributors.

Results: In this study, we integrated 20 research evidences on job burnout and turnover intention among 23,284 VDs from almost all provinces in China, and the prevalence of turnover intention among VDs in China was as high as 44.1% [95% confidence interval (CI): 34.1–54.2], which was two to four times that of primary health workers in high-income countries, but not much different from some developing countries. Simultaneously, VDs with the highest risk of turnover intention were men [odds ratio (OR): 1.22 (1.05–1.43)], those with a monthly income below USD 163.4 [OR: 0.88 (0.78–0.98)], those with a high educational level [OR: 0.88 (0.78–0.98)], and those <40 years old [OR: 1.27 (1.16–1.40)]. Similarly, the detection rate of job burnout toward them was 59.8% (95% CI: 38.7–79.1) with the MBI-GS score being 44.44 (95% CI: 37.02–51.86) in a total of 90, while the detection rate of job burnout in moderate and above almost reached 20%. The most significant contributor that affects job burnout was low personal accomplishment (LPA), and the detection rate for moderate and higher severity was 65.2% (95% CI: 58.7–71.7).

Conclusion: Attention should be paid to the high turnover intention and severe job burnout of primary health workers in rural areas of developing countries, and targeted measures should be taken to improve the situation. Health policymakers should increase financial subsidies for VDs, set a reasonable workload, improve various health policies such as pension insurance for VDs, and encourage "targeted training" for medical students to enrich and expand their team.

Systematic review registration: https://www.crd.york.ac.uk/PROSPERO/, identifier: CRD42021289139.

KEYWORDS

turnover intention, job burnout, village doctors, China, systematic review, meta-analysis

Introduction

Village doctors (VDs), who are affectionately known as "gatekeepers" of rural health service systems, refer to personnel who have obtained the qualification certificate of VDs and work in village clinics, and are also the main guardians of farmers' health and provide basic public health services, including mainly the establishment of rural health archives, health education, prevention and control of infectious diseases, healthcare for the elderly, the management of chronic diseases, etc. (1, 2). In the mid-1950s, VDs were called as "barefoot doctors," because they did not have good experience in the professional medical system and were mostly recruited from ordinary villages, and their main workplace was the village clinic funded and operated by the government. However, they were not included in government employees and only in temporary workers who faced dismissal at any time and were at the bottom of China's rural health system (3–5). Nevertheless, the World Health Organization (WHO) still regarded the barefoot doctor system as a successful example of healthcare provision in developing countries that addressed medical resource shortages *via* political mobilization by the government (3). In 1985, the Ministry of Health stopped using the term barefoot doctors; those who passed a government assessment qualified as "VDs" (3, 6). Since then, VDs have undertaken more and more basic healthcare missions gradually and have drawn increasing attention from the academic community, particularly in relation to their training and career development. Researchers have recently started to focus on problems like relatively low pay, job burnout, disparity in human resources, social security, turnover intention, and the limited service capacity of VDs (1, 7). According to the statistical results of the China National Health Commission (8), in 2020, the number of diagnoses and treatments in village clinics reached 1.43 billion, accounting for 18.48% of the total medical service in China. On average, the annual number of diagnoses and treatments in each village clinic was 2,349. VDs play an irreplaceable role in ensuring and improving the health of rural residents as the most basic and extensive medical service providers in rural areas (2).

However, since 1980s, with the collapse of the rural collective economic system in China, former VDs needed to pay for the operation of village clinics. In this case, the privatization of user-paid medical and healthcare system and services led directly to a sharp decline in funding for rural medical and healthcare (9). Consequently, due to the lack of official funding, the medical technology level and service quality of village clinics have lagged behind in recent years. More seriously, the health system reform schedule also excluded VDs from the government project all the time before the New Rural Cooperative Medical System (NRCMS), which was initiated by Chinese Government in 2003, resulted not only in the low satisfaction of rural residents with medical services but also in the high turnover rate of VDs themselves (10). Simultaneously, the government also announced "Deepening the Reform of the Medical and Healthcare System" in 2009. Nevertheless, the shortage of personnel has hindered reforms in the rural healthcare system (6) and this situation has so far increasingly deteriorated. The number of VDs in China significantly decreased from 1.61 million in 2011 to 741,000 in 2020, while their daily average number of diagnoses and treatments increased from 6.7 to 7.6 during the same period [raw data source: the official website of the China National Health Commission (http://www.nhc.gov.cn/)], indicating that the burden of VDs was not reduced but that a significant loss of personnel occurred.

Job burnout refers to a series of psychological and physiological reactions caused by the pressure of the interpersonal relationship and work itself. It is characterized by three dimensions: emotional exhaustion (EE), depersonalization (DE), and low personal accomplishment (LPA) (6), and is affected by work, individual, and organizational and social factors (11, 12). Turnover intention refers to the thought that an individual has to resign from his current job and look for another job (13). In the classical turnover theory, turnover intention is usually regarded as an important cognitive process

before turnover behavior. It is the most effective antecedent variable to predict turnover behavior (14, 15). The higher the turnover intention, the greater the probability that an individual will engage in turnover behavior.

In recent years, the increasing trend in job burnout among VDs in China can also be reflected in a lack of enthusiasm and willingness to provide high-level services (16). The primary cause of this phenomenon has been blamed on healthcare system reforms, integrated management, low income, heavy workload, and other determinants, which indirectly hinder health promotion and increase the tendency of VDs to leave (16–18). However, as this group is at the bottom of the rural health system, limited attention has been paid to them. Currently, there are only a few studies on job burnout and turnover intention among VDs in specific areas or in a small range. In contrast, in China, doctors in large hospitals, such as urban secondary or tertiary public ones, not only have much higher social status and welfare benefits than VDs (19–21) but also have drawn much attention in academia, with respect to the evaluation of the current situation or influencing factors of turnover or job burnout toward them (14, 19, 22–24). VDs are also important and need the same attention, but with regard to the studies of two most important factors affecting turnover behavior and work efficiency, namely job burnout and turnover intention, the corresponding original survey was insufficient compared with their colleagues in urban public hospital. Moreover, no scholar has comprehensively evaluated the current dilemma of VDs in China from the perspective of a systematic review. Consequently, our team has undertaken this mission and attempted to close this gap through a systematic evaluation of the current status and potential significant contributors of turnover intention and burnout among VDs in China.

Collectively, this paper aimed to answer the following two key questions:

(i) What is the current situation of job burnout and turnover intention among VDs in China?
(ii) What are the significant contributors that affect job burnout and turnover intention in this special group?

Methodology

A meta-based analysis was applied in this study. Compared with traditional literature review or emerging bibliometric analysis (considering that these types of analyses mostly focused on the knowledge map), both systematic review and meta-analysis had a relatively broad horizon of current hotspots and could quantitatively reflect the research status in the field (25–27). This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis Protocols guidelines (28) and registered with the International Prospective Register of Systematic Reviews (PROSPERO, registration number: CRD42021289139).

Search strategy

We searched cross-sectional studies on job satisfaction, turnover intention, and job burnout among Chinese VDs that had been published in electronic databases like China National Knowledge Infrastructure (CNKI), WanFang, China Science and Technology Journal Database (VIP), Chinese BioMedical Literature Database (CBM), PubMed, Embase, and Web of Science (WOS). At the same time, experts in the field of social medicine were consulted to achieve supplements and obtain the relevant literature. After pre-screening and consulting expert advice in the field of social medicine and epidemiology, the amount of literature published before 2011 was not only very small, but also the quality of literature could not be guaranteed, so it was not representative. Consequently, the retrieval time limit is set from 01 January 2011 to 01 January 2022. A search strategy was based on a combination of: "rural doctor," "rural physician," "VD," "village physician," "turnover intention," "burnout," etc. Specific literature retrieval strategies of each database can be found in Supplementary Appendix A.

Study eligibility

Eligible studies were publications that reported the prevalence or questionnaire score and determinants related to turnover intention or burnout among VDs in China. Eligibility criteria included the following: (1) types of studies: original cross-sectional studies (those presenting non-original data, such as reviews, editorials, opinion papers, or letters to the editor, were excluded); (2) types of participants: Chinese VDs; (3) the outcome of burnout measures: Professional Maslach Burnout Inventory (MBI) series job burnout measurement table should be used as a measurement tool. MBI is the most widely used job burnout measurement tool in the world. In empirical research publications related to job burnout, more than 90% of papers and research reports use the MBI scale as a measurement tool (29–31). Simultaneously, the prevalence or score of burnout and the status of all dimensions were reported in this study. According to the provisions of the MBI series questionnaire, the status should include the low, medium, and high level or the dimensions included EE, DE, and low personal compliance. (4) The outcome of the turnover intention measures: the prevalence of turnover intention and related factors should be reported. (5) The studies whose necessary data information was incomplete or missing, or the repeated published ones, should be excluded.

Data extraction

Firstly, the title information of the relevant literature was retrieved through a retrieval strategy, and Endnote *X9* software was used for literature management. After the duplication process, two reviewers read the title and abstract for preliminary screening according to the inclusion and exclusion criteria, and then further examined the full text to judge the qualification. Disagreements about inclusion criterion were resolved by a third reviewer. For the final selection of qualified literature, two parallel groups independently extracted the research data and made records, including the first author, survey time, survey area, sampling method, turnover intention, burnout, etc.

Quality assessment

Two reviewers (YC and YS) independently evaluated the risk of bias (ROB) included in this study and cross-checked the results. When the two reviewers had different opinions, the third reviewer (YY) could decide through discussion. The quality of the cross-sectional studies was evaluated by using the 11 items of the observational study quality evaluation standard recommended by US healthcare quality and research institutions (32). The total score was 11 points, and all included studies were grouped based on their scores, which were categorized as good (8–11), moderate (4–7), and poor (0–3). The ROB of the original study was made by reference to quality results.

Data synthesis and statistical analysis

The primary outcome of this review was the prevalence or score of turnover intention and job burnout among different groups. Prevalence was estimated as the total number of positive cases (i.e., the turnover intention or burnout cases) divided by the total number of participants. For the evaluation of turnover intention, overall consolidation was defined as the evaluation of prevalence, and there was no report of overall turnover intention in the form of a score (33). Simultaneously, significant contributors to the association between factors and turnover intention among VDs were measured as an odds ratio (OR), which was the secondary outcome of this study. Each factor would be analyzed using a meta-combination, the required related variables that were reported in the questionnaire to be the same in diverse included researches, which meant that it was feasible to merge the factor into two groups. In addition, at least three studies related to each factor had to be included in the meta-analysis. However, for job burnout, the prevalence and score would be reported at the same time. Because MBI series questionnaires have been uniformly adopted, the scoring standards are relatively consistent, so the scores reported can be directly combined. Meanwhile, we would conduct a subgroup analysis based on three dimensional characteristics of job burnout, namely, DE, EE, and LPA, and evaluated the main determinants to explore which one would contribute the most to the outcome.

The *meta*-package in *R* software (version 4.0.3, Auckland University, USA) was mainly used for data analysis, and the main outcome was assessed *via* a single-arm analysis. For prevalence or proportion, firstly, the normality test was conducted. If the data did not conform to the normality, they would be transformed by logarithm, logit, or double antisinusoidal transformation. For the evaluation of scores of job burnout or the prevalence of turnover intention, we used the inverse variance weighting method for pooling, and the significance of the pooled OR and its 95% confidence interval (CI) were determined using the *Z*-test when a meta-analysis was conducted.

The Cochrane *Q*-test and I^2 value were used to test whether there was heterogeneity among all studies (34). According to the Meta-analysis of Observational Studies in the Epidemiology guideline (35), if $p > 0.10$ and $I^2 \leq 50\%$, it was indicated that there was no statistical heterogeneity among the research results, and the fixed effects model was applied to analyze the results; if $p \leq 0.1$ and $I^2 > 50\%$, the random-effects model was used for meta-analysis. Publication bias was evaluated using Egger's test. Sensitivity analysis was performed by grouping or excluding low-quality studies if necessary. If quantitative synthesis and a meta-analysis were not feasible, a narrative approach and descriptive statistics were used.

Results

Study and sample characteristics

A total of 1,117 literature studies were obtained from various databases and references recommended by experts. Using Endnote *X9* software, 516 duplicate literature studies were eliminated, and by reading titles and abstracts 226 irrelevant literature studies were eliminated. Subsequently, the type of review studies, documents with inconsistent research objects, and incomplete data information were excluded by reading the full text. Finally, a total of 20 literature studies were included for qualitative and quantitative analyses (see Figure 1 for a detailed process).

In the analysis of turnover intention, we included 13 original studies (2, 36–46), including 17,346 VDs. A characteristic of 13 included studies of turnover intention among Chinese VDs is shown in Tables 1, 2. Of these, seven studies were conducted in eastern China (2, 37, 38, 42, 44–46), six in central provinces (36, 38–40, 43, 47) and one in the western region (38). And, these studies were conducted in all 21 provinces of China between 2012 and 2020. A total of seven studies (36–39, 41, 43, 47) used a dichotomous question to measure turnover intention (Do

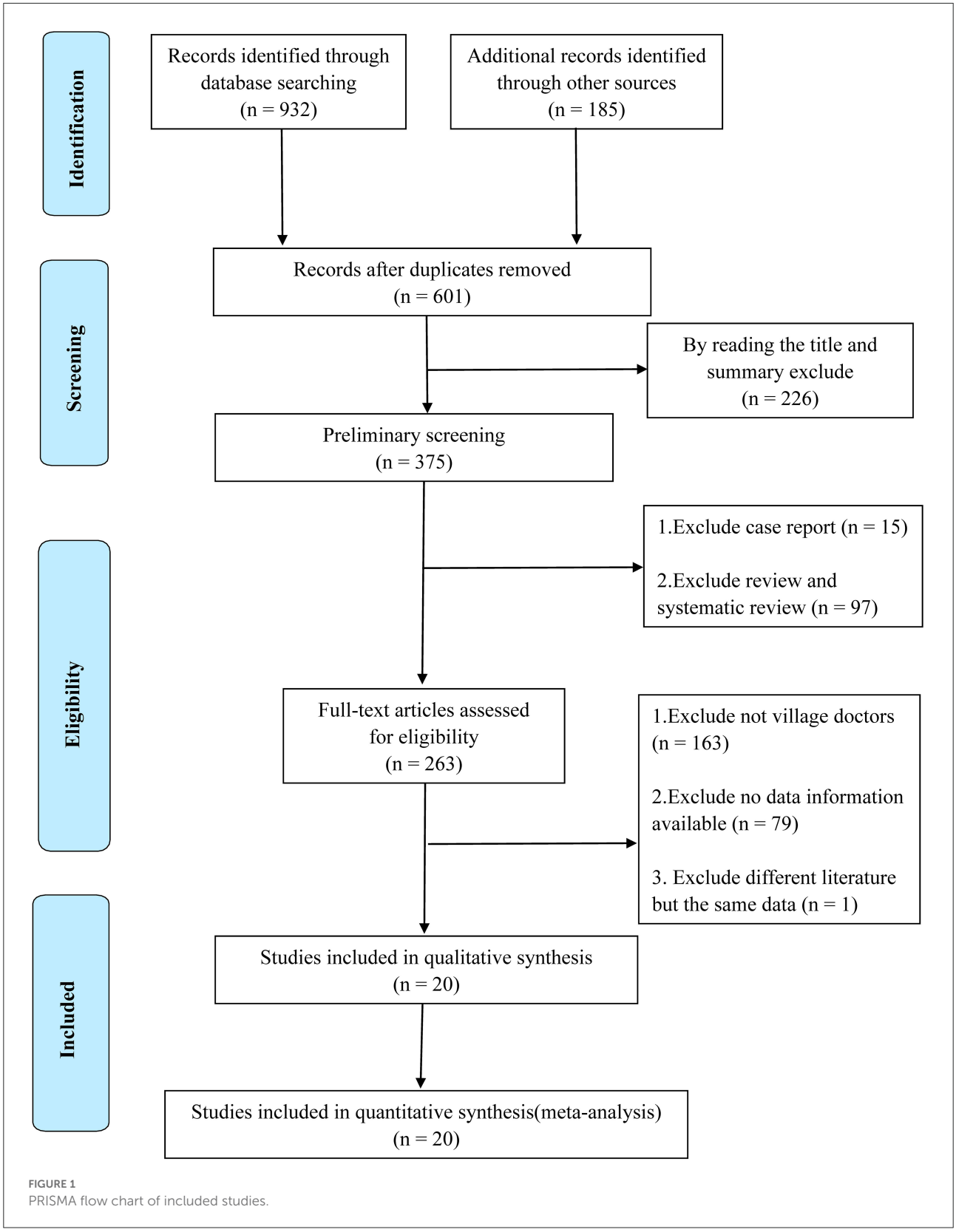

FIGURE 1
PRISMA flow chart of included studies.

TABLE 1 A characteristic of 20 included studies of burnout and turnover intention among Chinese village doctors (VDs).

Study ID	First author	Publication year	Survey area	Investigation period	Sampling method
1	Xu Zhou (48)	2021	Shandong Province	2020.05	Multi stage random sampling
2	Siyu Chen (49)	2019	Shandong Province	2018.01∼2018.03	Convenience sampling
3	Ye Wu (50)	2019	Jilin Province	2017.11∼2018.01	Multi stage stratified cluster sampling
4	Yun Sun (47)	2017	Anhui Province	2015.09∼2017.03	Convenience sampling
5	Li Du (53)	2015	Guizhou Province	*NA*	*NA*
6	Bingjie Shen (36)	2018	Central China	2016.11∼2017.04	Census
7	Xinyi Zhao (2)	2021	Various regions of China	*NA*	Convenience sampling
8	Xuewen Zhang (17)	2021	Shandong Province	2019.05∼2019.06	Stratified cluster random sampling
9	Xiaodong Yao (51)	2021	Shanxi Province	2019.07∼2019.09	Multi stage cluster sampling
10	Jialin Wang (37)	2021	Shandong Province	2020.05	Multi stage random sampling
11	Zhiyuan Li (38)	2021	6 provinces in China	2013∼2017	Stratified cluster sampling
12	Hao Li (39)	2020	Shanxi Province	*NA*	Multi stage stratified random sampling
13	Haiming Xie (40)	2015	Hebei Province	2013.11	Stratified cluster sampling
14	Xiaojuan Zhang (41)	2013	A poor county in a mountainous area	*NA*	*NA*
15	Chao Gong (42)	2020	Tianjin	2019	Stratified random sampling
16	Pengqian Fang (43)	2014	Hubei Province	2012.07∼2012.08	Multi stage stratified cluster sampling
17	Yue Lu (44)	2018	Shandong Province	2016.10∼2016.11	Stratified cluster random sampling
18	Qianqian Yu (45)	2018	Shandong Province	2015.10∼2015.11	Multi stage stratified random sampling
19	Haipeng Wang (46)	2020	Shandong Province	2017.12	Multi stage random cluster sampling
20	Yiqing Mao (52)	2020	Hubei and Henan Provinces	2016.12∼2017.03	Convenience sampling

NA, not reported.

TABLE 2 A characteristic of 13 included studies of turnover intention among Chinese VDs.

Study ID	Study quality score	Sample size (qualified rate %)	TI assessment tool	Prevalence of turnover intention *N* (%)
10	10	2,272 (84.4)	Dichotomous question	1,076 (47.36)
11	6	2,554 (82.6)	Dichotomous question	1,541 (60.34)
12	8	254 (92.2)	Dichotomous question	171 (67.32)
6	10	1,669 (100)	Dichotomous question	568 (34.03)
13	10	162 (100)	Michael & Spector Turnover Intention Scale	140 (86.42) (score of >3 out of 5)
14	4	68 (100)	Dichotomous question	10 (14.7)
4	9	379 (95.95)	Dichotomous question	272 (71.77)
15	8	2,652 (93.5)	The self-made 11-item 5-point Likert Turnover Intention Scale	464 (17.5) (score of >33 out of 50)
8	9	2,693 (96.6)	Chinese Turnover Intention Scale	1,263 (46.3)
16	9	1,889 (97.88)	Dichotomous question	695 (36.8)
17	5	1,037 (98.57)	The self-made 10-item 5-point Likert Turnover Intention Scale	498 (48.02) (score of >32 out of 50)
18	6	1,018 (92.5)	Cammann Turnover Intention Scale	265 (26.03) (quite agree and very agree)
19	8	699	The self-made 5-point Likert Turnover Intention Scale	115 (score of >3 out of 5)

you want to leave your job? Yes/No), six studies used scales [Note: all used the five-point Likert scale, which was collapsed into a binary category of disagree (highly disagree, disagree, and average) and agree (agree and highly agree) to evaluate the status of turnover intention, and people who chose /agree/ were regarded as participants with turnover intention], and all studies reported prevalence. Meanwhile, 11 original studies, including 11,378 VDs, were included in the analysis of job burnout.

A characteristic of the 11 included studies of job burnout among Chinese VDs is shown in Tables 1, 3. These studies were conducted in 19 provinces of China between 2015 and 2020. In the literature studies that defined the scope of this study, five studies were conducted in eastern China (2, 46, 48–50), four in central provinces (36, 47, 51, 52), and one in the western region (53). All studies were based on the MBI series scale.

Table 4 demonstrates the quality evaluation of studies from the original literature, including 12 high-quality studies, seven medium-quality studies, and one low-quality study. The average overall study quality score was 7.50 and SD was 2.04. A summary plot of the risk bias assessment of all studies is shown in Figure 2. Simultaneously, the concrete traffic light plot is presented in Supplementary Appendix B. After quality evaluation, it was evident that the overall quality of the original study was relatively high. Therefore, by excluding one low-quality study, other literature studies included in the final study can be directly analyzed qualitatively and quantitatively. For the low-quality study, we intended to use sensitivity analysis to evaluate its effects.

Prevalence and significant contributors of turnover intention among VDs

Table 5 presents the prevalence of turnover intention among VDs in China. The pooled prevalence was 44.1% (95% CI: 34.1–54.2). Egger's test showed no publication bias in the summary results ($p = 0.2227 > 0.05$, $t = 1.29$, intercept = 0.2364). Its forest plot is shown in Figure 3. Xie et al. (40) reported that the highest prevalence was 86.4%, whereas Zhang (41) reported that the lowest prevalence was 14.7%. Subgroup analysis by region showed that the highest prevalence was observed in the central regions (45.6%), followed by eastern China (44.9%); however, there were no significant statistical differences between them ($p > 0.05$). According to the investigation period, a higher prevalence occurred among VDs during 2011–2016 (46.1%), followed by the period 2017–2021 (43.5%), though there were no significant differences between them ($p > 0.05$). With respect to sample size, we selected the midpoint (1,669) of the sample size across all included studies as the critical value, and the prevalence of turnover intention was higher in studies having a sample size <1,669 (47.3%) than in those with a sample size ≥1,669 (40.5%). Simultaneously, subgroup analysis using the survey method showed that the highest prevalence was observed using a non-probabilistic scheme (63.7%), followed by random sampling (38.4%) and census (34.0%), even if the census only contained one study and 1,669 VDs.

In addition, we also clarified the prevalence of turnover intention among VDs in China according to the different demographic characteristics. Firstly, subgroup analysis by gender showed that a higher prevalence was observed among male VDs (46.9%), followed by female VDs (41.8%), combined with a significant difference between two different genders ($p < 0.05$). Secondly, a Classification and summary were done according to the age of VDs at the time of investigation, whose turnover intention was from 45.4 to 49% in the different age groups. Furthermore, according to the monthly income level, the highest prevalence of turnover intention was in VDs whose income level remained below USD 163.4 (52.8%), followed by USD 163.5–490.1 (46.5%) and greater than USD 490.1 (39.5%), and statistically significant differences between them were presented. Finally, we reported the prevalence by different kinds of educational level, and VDs who had a high educational

TABLE 3 A characteristic of 11 included studies of job burnout among Chinese VDs.

Study ID	Assessment tool	Sample size (qualified rate%)	Total number of burnout	Burnout score (Mean ± SD)	NLB	NMB
1	MBI-HSS	2,272 (81.0)	*NA*	*NA*	*NA*	*NA*
2	MBI-GS	316 (98.8)	239	*NA*	145	84
3	MBI-GS	499 (97.84)	325	*NA*	265	57
4	MBI-GS	379 (95.95)	260	38.56 ± 12.56	189	67
5	MBI-GS	759 (81.4)	*NA*	*NA*	*NA*	*NA*
6	MBI-HSS	1,669 (100.0)	*NA*	*NA*	*NA*	*NA*
7	MBI-HSS	1,248 (97.5)	295	*NA*	*NA*	*NA*
8	MBI-GS	2,684 (96.2)	1,762	42.46 ± 21.099	*NA*	*NA*
9	MBI-GS	528 (91.7)	*NA*	52.3 ± 12.7	*NA*	*NA*
19	MBI-HSS	699	*NA*	*NA*	*NA*	*NA*
20	MBI-HSS	325	*NA*	*NA*	*NA*	*NA*

(Continued)

TABLE 3 (Continued)

NHB	LEE	MEE	HEE	SEE	LDE	MDE	HDE	SDE	LPA	MPA	HPA	SPA
NA	1,021	1,251*		19 ± 12.2	1,500	772*		*NA*	197	2,075*		17.2 ± 13.3
10	87	119	110	*NA*	108	87	121	*NA*	111	93	112	*NA*
3	*NA*	*NA*	*NA*	18.98 ± 8.24	*NA*	*NA*	*NA*	11.62 ± 5.34	*NA*	*NA*	*NA*	14.34 ± 6.66
4	228	126	25	14.13 ± 7.54	95	91	193	11.57 ± 6.36	168	91	120	12.86 ± 6.9
NA	574	123	62	11.42 ± 8.31	449	218	92	5.87 ± 6.03	673	86	0	18.82 ± 9.17
NA	571	511	587	*NA*	423	980	423	*NA*	479	355	835	*NA*
NA	*NA*	*NA*	*NA*	29.61 ± 16.19	*NA*	*NA*	*NA*	4.84 ± 6.74	*NA*	*NA*	*NA*	36.03 ± 10.16
NA	1,230	652	811	18.97 ± 12.28	1,778	316	599	5.96 ± 6.913	1,034	359	1,300	17.53 ± 13.42
NA	*NA*	*NA*	*NA*	16.6 ± 6.1	*NA*	*NA*	*NA*	13.3 ± 5.2	*NA*	*NA*	*NA*	22.4 ± 6.8
NA	*NA*	*NA*	186	*NA*	*NA*	*NA*	39	*NA*	*NA*	*NA*	245	*NA*
NA	194	46	85	*NA*	249	25	51	*NA*	176	53	96	*NA*

NLB, total number of people with low burnout; NMB, total number of people with medium burnout; NHB, total number of people with high burnout; LEE, total number of people with low emotional exhaustion; MEE, total number of people with medium emotional exhaustion; HEE, total number of people with high emotional exhaustion; SEE, score of emotional exhaustion (mean ± standard deviation (SD)); LDE, total number of people with low depersonalization; MDE, total number of people with medium depersonalization; HDE, total number of people with high depersonalization; SDE, score of depersonalization (mean ± SD); LPA, total number of people with a low degree of low personal achievement; MPA, total number of people with a medium degree of low personal achievement; HPA, total number of people with a high degree of low personal achievement; SPA, score of low personal achievement (mean ± SD).
*The total number of people with medium and high degrees was summarized.

TABLE 4 Quality evaluation results of job burnout and turnover intention among Chinese VDs.

Study ID	First author	*D1*	*D2*	*D3*	*D4*	*D5*	*D6*	*D7*	*D8*	*D9*	*D10*	*D11*	Overall
1	Xu Zhou (48)	1	1	1	1	1	0	1	1	Unclear	1	1	9
2	Siyu Chen (49)	1	0	1	1	Unclear	0	0	1	Unclear	1	1	6
3	Ye Wu (50)	1	0	1	1	0	0	1	1	Unclear	1	1	7
4	Yun Sun (7)	1	1	1	1	Unclear	1	1	1	Unclear	1	1	9
5	Li Du (53)	1	0	0	Unclear	0	0	0	0	Unclear	1	1	3
6	Bingjie Shen (36)	1	1	1	1	1	1	1	Unclear	1	1	1	10
7	Xinyi Zhao (6)	1	0	0	1	1	0	0	1	Unclear	1	1	6
8	Xuewen Zhang (17)	1	1	1	1	Unclear	1	1	Unclear	1	1	1	9
9	Xiaodong Yao (51)	1	1	1	1	Unclear	1	1	Unclear	1	1	1	9
10	Jialin Wang (37)	1	1	1	1	Unclear	1	1	1	1	1	1	10
11	Zhiyuan Li (38)	1	0	1	1	Unclear	0	0	1	0	1	1	6
12	Hao Li (39)	1	0	0	1	1	0	1	1	1	1	1	8
13	Haiming Xie (40)	1	1	1	1	1	1	1	Unclear	1	1	1	10
14	Xiaojuan Zhang (41)	Unclear	0	0	Unclear	1	0	1	0	Unclear	1	1	4
15	Chao Gong (42)	1	0	1	1	0	1	1	1	Unclear	1	1	8
16	Pengqian Fang (43)	1	1	1	1	Unclear	1	0	1	1	1	1	9
17	Yue Lu (44)	1	0	1	1	0	0	0	Unclear	0	1	1	5
18	Qianqian Yu (45)	1	0	1	1	1	0	0	Unclear	Unclear	1	1	6
19	Haipeng Wang (46)	1	1	1	1	1	0	0	Unclear	1	1	1	8
20	Yiqing Mao (52)	1	1	1	1	Unclear	1	0	1	Unclear	1	1	8

D1: define the source of information (survey and record review); D2: list inclusion and exclusion criteria for exposed and unexposed subjects (cases and controls) or refer to previous publications; D3: indicate the time period used for identifying patients; D4: indicate whether or not subjects were consecutive if not population-based; D5: indicate if evaluators of subjective components of the study were masked to other aspects of the status of the participants; D6: describe any assessments undertaken for quality assurance purposes (e.g., test/retest of primary outcome measurements); D7: explain any patient exclusion from analysis; D8: describe how confounding was assessed and/or controlled; D9: if applicable, explain how missing data were handled in the analysis; D10: summarize patient response rates and completeness of data collection; D11: clarify what follow-up, if any, was expected and the percentage of patients for which incomplete data or follow-up was obtained.

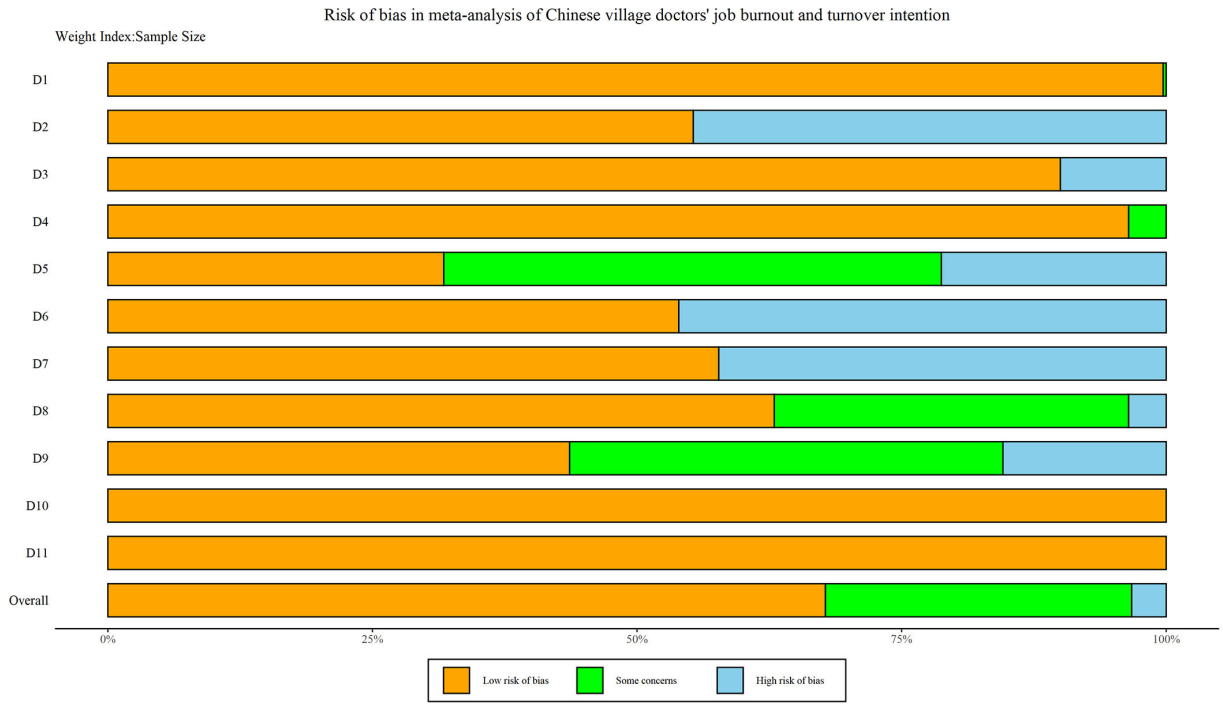

FIGURE 2
A summary plot of risk bias.

level had the highest turnover intention with 52.7%, followed by the medium level (47.5%) and the low level (37.1%). In particular, excluding one study (43), other studies defined the low education level as junior middle school and below, the medium education level as senior high school and technical secondary school, and the high education level as junior college and above. In one study (36), low educational level was defined as secondary technical school and below with the prevalence of 36.9%, while senior high school was the medium educational level with the prevalence of 36.5%, and the high educational level was defined as bachelor or master and above, whose prevalence was 35%. High heterogeneity was observed across the included studies due to inconsistency of research sites, regions, and objects; indeed, the results of a meta-analysis of the detection rate itself would be very heterogeneous (33, 54, 55). Only one study reported the prevalence of turnover intention among VDs after the COVID-19 pandemic, which was 47.36% (37).

As for significant contributors of turnover intention among VDs, they were examined in six studies (33–36, 40, 41), whose reports meet the metaconsolidation criteria for as mentioned in the data synthesis. Gender [male vs. female, OR: 1.22 (1.05–1.43)], income [below 163.4 USD vs. >163.4 USD, OR: 3.06 (1.94–4.82)], educational level [low or medium educational level vs. high educational level, OR: 0.88 (0.78–0.98)], and age [below 40 years old vs. ≥40 years old, OR: 1.27 (1.16–1.40)], which presented that VDs with the higher risk of turnover intention were men, those with monthly income below 163.4 USD, those with a high educational level and below 40 years of age. Forest plots on each of these contributors can be found in Supplementary Appendix C.

The prevalence and a significant characteristic contributor of job burnout among VDs

The prevalence and score of job burnout and all its dimensions among them are shown in Table 6. According to our evaluation results, all surveys (2, 6, 36, 46–53) on the job burnout status among VDs were based on the Chinese revised versions of the Maslach Burnout Scale general scale (MBI-GS) (29) and Maslach Burnout Scale—Human Services Survey (MBI-HSS) (56), both of which were widely used in the evaluation of job burnout among Chinese health workers (30, 57–59). The two types of questionnaires included three dimensions: EE, DE, and personal achievement. The EE subscale mainly measured the psychological and physiological extreme fatigue caused by individual emotional and emotional excessive pay, while the DE subscale mainly measured how individuals treated work with a negative and indifferent attitude or emotion. The personal achievement subscale mainly measured individuals' subjective evaluation of the value of work and of themselves (47). Answers

TABLE 5 Prevalence of turnover intention among VDs in China.

Variables	Characteristic	Included studies	Prevalence (95% *CI*)	*Q*-test (I^2) (%)	*p*-Value
Overall		13	0.441 (0.341–0.542)	99.5	–
By region	East	8	0.449 (0.312–0.586)	99.6	0.913
	Central	3	0.456 (0.332–0.581)	98.2	
By sample size	<1,669	7	0.473 (0.282–0.663)	99.4	0.017
	≥1,669	6	0.405 (0.27–0.539)	99.7	
By gender	Male	5	0.469 (0.365–0.573)	98.6	0.045
	Female	5	0.418 (0.319–0.516)	96.9	
By survey method	Random sampling	7	0.384 (0.258–0.51)	99.5	0.009
	Non-probabilistic sampling	4	0.637 (0.452–0.823)	99.4	
	Census	1	0.34 (0.318–0.364)*	–	
By period	2011∼2016	3	0.461 (0.098–0.824)	99.4	0.687
	2017∼2021	10	0.435 (0.321–0.549)	99.6	
By age	<30	5	0.49 (0.41–0.57)	51	0.056
	30∼40	5	0.486 (0.37–0.602)	97	
	>40	4	0.454 (0.351–0.557)	98.1	
By income	<163.4 USD	3	0.528 (0.480–0.570)	73.7	0.022
	163.5–490.1 USD	3	0.465 (0.423–0.507)	83.2	
	>490.1 USD	3	0.395 (0.297–0.514)	76.6	
By educational level	Low**	4	0.371 (0.349–0.393)	21.9	0.034
	Medium**	5	0.475 (0.367–0.584)	98.2	
	High**	5	0.527 (0.386–0.667)	96.9	

*Clopper–Pearson confidence interval (CI).
**Low: junior high school and below; Medium: high school and technical secondary school; High: junior college or above [excluding the study of Fang et al. (43)].

to both types of questionnaires were seven Likert score ranging from 0 (never) to 6 (daily). Among them, the higher the score of EE, DE, and low personal achievement (reverse score), and the heavier the degree of burnout (2). In addition, the Cronbach's α of MBI-GS is between 0.79 and 0.94 (2), which had high reliability and validity in China and was further revised and improved by relevant scholars (59–61). The three dimensions of EE, DE, and personal achievement contained five, four, and six entries, respectively, and potential scores range from 0 to 30, 0 to 24, and 0 to 36, respectively. For the MBI-HSS scale (6, 36, 48), the three dimensions of EE, DE, and personal achievement contained nine, five, and eight items, respectively, and potential scores ranged from 0 to 54, 0 to 30, and 0 to 48, respectively.

Among the studies concerning the total detection rate of job burnout, four items were based on the MBI-GS scale (2, 47, 49, 50). The definition of job burnout was at least one of the three dimensions exceeded the critical value. If the scores of the three dimensions were lower than the critical value, it was defined as no burnout. The rest of the study was based on the MBI-HSS scale (6), and its criterion for judging job burnout was "a high EE score (≥27) along with a high DE score (≥13), or a low personal achievement score (≤31)." According to our evaluation results, the overall detection rate of job burnout among VDs in China is 59.8% (95% CI: 38.7–79.1). Egger's test showed no publication bias in the summary results ($p = 0.8623 > 0.05$, $t = 0.19$, intercept = 0.7985). The forest plot is shown in Figure 3. Among the quantifiable results, three studies (2, 47, 51) reported the overall score of job burnout. These studies were designed using the MBI-GS scale, with a total score of 90, and the answers for the items were seven Likert score ranging from 0 (never) to 6 (daily). The higher the score, the stronger the job burnout. According to the meta combination results, the overall score of job burnout was 44.44 (95% CI: 37.0–51.86). Then, we conducted a meta-analysis based on the three studies that reported the severity of job burnout among VDs based on the MBI-GS scale (47, 49, 50). These studies defined mild burnout as a score higher than the critical value in a certain dimension. If the score of some two dimensions was higher than the critical value, it was moderate burnout, while the score for all three dimensions was higher than the critical value, which was high burnout. According to our combined results, the detection rate of low job burnout was 49.9% (95% CI: 45.8–54.0), the detection rate of moderate job burnout was 18.4% (95% CI: 10.1–26.7), and the detection rate of high job burnout was 1.3% (95% CI: 0.2–2.4).

In addition, we also made a detailed evaluation and report on the three dimensions of EE, DE, and personal achievement shared by all studies. Of the six studies (2, 36, 47–49, 53) that reported the number of people detected with different severity

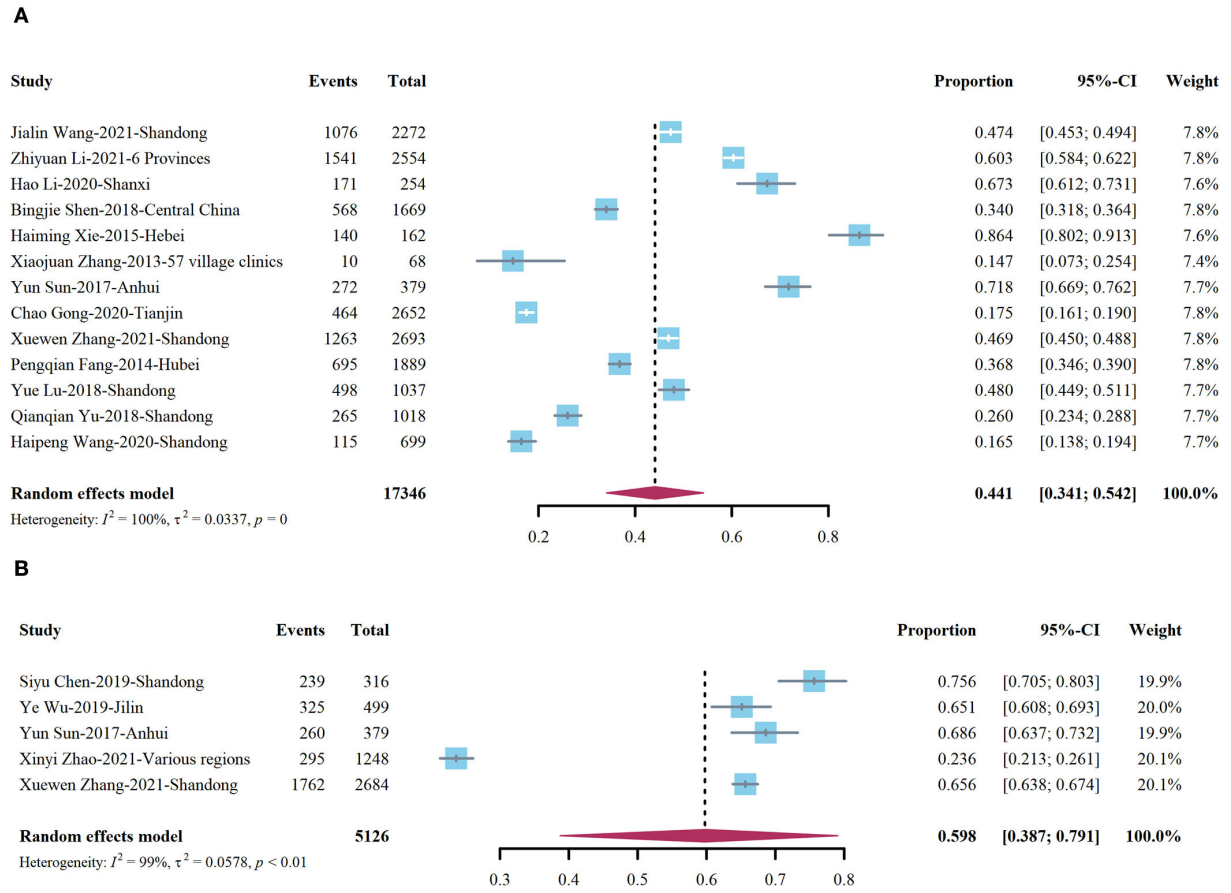

FIGURE 3
Forest plot of turnover intention **(A)** and job burnout **(B)** among village doctors (VDs).

of these three dimensions, four were based on the MBI-HSS questionnaire (36, 46, 48, 52). According to the abovementioned criteria, we conducted a meta-analysis of studies that reported detection rates for three dimensions with different severity (2, 36, 47–49, 53). We found that the detection rate of medium and high degrees EE among VDs in China was as high as 50.4% (95% CI: 39.8–61), medium and high degrees of DE was 51% (95% CI: 31.4–70.6), and medium and high degrees of low personal achievement was 57.5% (95% CI: 34.3–80.6). Detailed meta-consolidation rates of the three dimensions of different severity levels are shown in Table 6. After excluding a low-quality study (53), the detection rates of moderate and high degrees of EE, DE, and low personal achievement became 50.8% (95% CI: 45.6–56), 52.7% (95% CI: 47.5–57.9), and 65.2% (95% CI: 58.7–71.7), respectively. Simultaneously, we could clearly find that it was low personal achievement that contributed the most for job burnout and a significant difference was observed among these three groups ($p < 0.05$) through subgroup analysis. Furthermore, we also summarized only studies that reported scores for different dimensions (2, 6, 47, 48, 50, 51, 53). Due to the different criteria for judging the scores of the different scale tools, we conducted a meta-analysis based on the MBI-GS and MBI-HSS scales. The summary results of the scores of the other two dimensions are shown in Table 6.

Discussion

This study systematically summarized and evaluated the prevalence of turnover intention and job burnout among Chinese VDs in global publications for the first time, and evaluated significant contributors. Our evaluation results showed that the overall prevalence of turnover intention among VDs in China was as high as 44.1%, indicating that almost half of them wanted to leave their current occupation. The high turnover intention among VDs in China was almost two to four times than the high turnover intention among VDs in several high-income countries, which caused a widespread

TABLE 6 Prevalence and score of job burnout and relevant dimensions among VDs in China.

Variables	Characteristic	Included studies	Prevalence (95% *CI*)	Score (95% *CI*)	*Q*-test (I^2) (%)
Overall burnout		5	0.598 (0.387–0.791)		99.5
Overall burnout score	MBI-GS	3		44.44 (37.02–51.86)	99.4
By severity	Low	3	0.499 (0.458–0.54)		50.9
	Medium	3	0.184 (0.101–0.267)		93.1
	High	3	0.013 (0.002–0.024)		67.3
Emotional exhaustion	Low	7	0.497 (0.391–0.603)		99
	Medium	6	0.258 (0.198–0.318)		96.2
	High	7	0.239 (0.142–0.336)		99
	Medium + High	6	0.508 (0.456–0.56)		99
Score	MBI-HSS	2		24.3 (13.9–34.7)	99.8
	MBI-GS	5		16.02 (13.15–18.9)	99.2
Depersonalization	Low	7	0.504 (0.347–0.661)		99.6
	Medium	6	0.264 (0.09–0.438)		99.6
	High	7	0.241 (0.154–0.328)		98.9
	Medium + High	6	0.527 (0.475–0.579)		99.7
Score	MBI-HSS	1		4.84 (4.47–5.21)	-
	MBI-GS	5		9.66 (6.41–12.91)	99.7
Low personal achievement	Low	7	0.426 (0.194–0.658)		99.9
	Medium	6	0.19 (0.144–0.236)		95
	High	7	0.329 (0.095–0.563)		99.9
	Medium + High	6	0.652 (0.587–0.717)		99.9
Score	MBI-HSS	2		26.61 (8.16–45.07)	100
	MBI-GS	5		17.19 (14–20.39)	99.3

concern. A survey of 1,174 primary care doctors aged 50 years and under in the UK by Hann et al. (62) found that only 11.8% of this group had a high turnover intention. Another survey of 2,263 physicians in the USA showed that only 18.4% of them considered to leave their current job (63). Similarly, in a survey of 23,159 nurses in 385 hospitals in 10 European countries, Heinen et al. (64) found that the proportion of them with a significant turnover intention was only 9%, and the figure was between 5 and 17% in different countries. A study in Japan showed that even after being harassed by patients, doctors' turnover intention was only 17.1% (65). However, the prevalence of turnover intention among doctors in some countries was also relatively high, but generally speaking, it was still lower than that of VDs in China. For instance, a survey of 2,719 doctors in Korea from 2016 to 2017 showed that 30.5% (66) had a high turnover intention. However, compared to various developing countries, this proportion seemed to be little different. For example, a survey of rural nurses in the Philippines found that almost half of them considered to leave their jobs (67), while another report from South Africa showed that this proportion was also as high as 51.1% (68).

Our study also found that approximately six in 10 VDs experienced job burnout, with up to 20% of this group having medium or higher severity. Compared to health workers in other countries, this proportion was also prominent. For example, in a survey of urologists in England, the incidence rate of job burnout was only 28.9% (69). A survey of Polish medical personnel conducted in 2018–2019 showed that the average MBI scale score was 36.08, which was much lower than our results (70). According to the resource conservation theory, the individual's own resources are relatively limited. When there is a potential threat from an external environment or the resources are not supplemented accordingly, individuals experience pressure. In the long run, it is easy to produce job burnout. Resignation is the most common behavior of individuals to deal with job burnout and protect their physical and mental resources. Many studies in China and in other countries showed that job burnout among medical workers was closely related to turnover intention, and there was a significant positive correlation between them, that is, the higher the degree of job burnout, the stronger the turnover intention (46, 54, 71, 72). A study on the relationship of job burnout and turnover intention among medical workers covering 25 provincial administrative regions from 2007 to 2020 in China showed that the *R*-value of the correlation coefficient between job burnout and turnover intention reached 0.43, indicating a high correlation effect (8). Job burnout not only led to a loss of enthusiasm for work, alienation from the organization

and work, and increased the degree of turnover intention, but also lead to the decline of work quality and efficiency, which directly threatened the construction of the originally weak rural primary healthcare system (30, 54, 73). Simultaneously, job burnout was also one of the important causes of serious physiological problems such as hypercholesterolemia, type 2 diabetes, coronary heart disease, hospitalization for cardiovascular disorders, and musculoskeletal pain (73). Our evaluation results on the three dimensions of job burnout showed that although the detection rate of each dimension of medium and high degrees was >50%, the proportion of medium and high degrees of low personal achievement was significantly high (57.5%). This result was consistent with the conclusion of a systematic review of primary care nursing, that is, low personal achievement was also the most important factor affecting job burnout among nurses in primary medical institutions (74). Nevertheless, this proportion was still considerably lower than that of VDs in China (31%). The score of low personal achievement measured by O'Kelly et al. (69) using the MBI-HSS scale was 17.1, which is much lower than 26.61 of VDs. This phenomenon was brought on not only by the low social status of VDs but also by the fact that VDs served as "gatekeepers" for patients, making them more likely to be under higher pressure than doctors in urban hospitals in case of adverse medical events (such as workplace violence), and the impact on their low personal achievement would be more evident (54, 75). Likewise, due to the large proportion of mild patients in many hospitals at grass roots level, the low admission rate greatly increased the working hours and workload of VDs, which made low personal achievement less and worse (36, 37).

This systematic review also demonstrated that education, gender, income, and age were significant contributors that affected turnover intention among VDs. It is well-established that VDs with a higher educational level may have higher a turnover intention because VDs with a higher education level had more career choices and promotion opportunities. Several studies also showed that (36, 37, 39, 46, 47), the overall educational level of VDs was low, even most of them were below undergraduate. However, compared to doctors in urban three-level public hospitals in China, the educational level of this group improved significantly (22, 75). This might mean that, under the same conditions, if VDs had a higher educational level, they would have a tendency to go to higher-level hospitals rather than remaining at the very bottom of the rural medical system. The low educational level might further weaken the medical level of the already scarce medical resources in the village. Income was undoubtedly another important factor affecting turnover intention. We noted that the lower the income, the higher the turnover intention. With the advancement of medical reforms, especially since the implementation of the "zero difference" sales of drugs and the equalization of basic public health services, the workload of VDs increased greatly, but the basic drug subsidies and public health subsidies did not increase significantly (16, 17, 76, 77), resulting in their income level not rising but falling, which greatly improved turnover intention among this group. Similarly, gender was also one of the factors affecting turnover intention. Turnover intention among male VDs was significantly greater turnover intention among women, which meant that female VDs might pursue "job stability (37)" to a certain extent. It was interesting to note that VDs below 40 years of age also tended to choose to leave their current job, which might be explained by the fact that the majority of the younger VDs had more choices to make an occupational career decision. Though a small part of this population had turnover behavior for reasons such as lack of interest or severe workload, most of them might still choose it based on income and social status (78). Similarly, in job burnout, low personal achievement become the most important factor affecting the occurrence and severity of job burnout among VDs, as mentioned above. Compared with the other ordinary occupational groups in China, medical work is a high-risk occupation, which has the characteristics of urgent working hours, high task intensity, high-risk nature of work, and high mental and occupational pressure (79). If VDs choose this career not for intense passion, in a context of high mental and occupational pressure, coupled with low salary and poor welfare, they would lose enthusiasm and patience for work and generate negative emotions about their career, which lead to their low sense of professional identity, low personal achievement, and increased job burnout (2). Consequently, VDs should construct reasonable and achievable career expectations, improve time management skills, and participate in psychological counseling programs to mitigate their anxiety. Simultaneously, the government should guide the masses toward developing a correct understanding of VDs, clarify the indispensable role of VDs, improve their sense of professional respect for VDs, so as to improve residents' trust in village clinics and cooperation with their work and enhance the harmonious service relationship between VDs and patients, which will be beneficial to improving the sense of professional belonging and personal achievement for VDs. It should be noted that, in a context of the COVID-19 pandemic, the prevalence of job burnout and turnover intention among VDs might be higher, but few people conducted relevant surveys during this period. A survey showed that, after the COVID-19 pandemic, 65% of medical staff increased their working hours and worked more than 48 h a week, but their treatment did not improve much and their income even decreased slightly (80), which undoubtedly made the situation worse.

Therefore, according to our research results, high turnover intention and severe job burnout among VDs will inevitably aggravate the turnover rate of this group, which plays an indispensable role in rural residents, and their requirement has not decreased. Hence, we strongly suggest that the government should increase financial subsidies for VDs to ensure that their income level can be equal to the average income level of local village cadres, teachers, and other occupations (81).

Simultaneously, the government should improve the working environment for VDs, further strengthen the construction of standardized village clinics, and enhance the participation of VDs in decision-making. Superior departments or institutions should fully consider the opinions and ideas of VDs when making decisions related to VDs to reduce their unnecessary work pressure. By standardizing the management mechanism of village clinics and the performance evaluation policy of township health centers for village clinics and reasonably setting the workload, it is ensured that the subsidies are paid in full and on time by ensuring the work quality of VDs and encouraging their work enthusiasm (82). The government should speed up the improvement of the old-age insurance policy for VDs, and guarantee that the old-age insurance level of rural doctors is higher than that of ordinary farmers, so as to reflect their contribution to the development of health undertakings and the important missions they are currently undertaking in the rural health service system (77, 81, 82). Concurrently, the health administrative department should formulate preferential policies to encourage and absorb medical college graduates to serve in the village, implement the "directional" training mode, sign contracts with students interested to work in the village clinic, train the service talents in the village clinic, and ensure the reserve force of VDs, so as to reasonably adjust their age structure and enrich and expand the team of VDs (83).

Strengths and limitations

This was the first study to systematically evaluate the current status and striking influencing factors of turnover intention and job burnout among Chinese VDs in global publications. Compared to their colleagues in urban public hospitals, extremely less attention was paid to this specific population, who has undertaken a series of vital and Herculean tasks in the rural medical health service system. Our results further indicated that the high rate of significant turnover intention and severe job burnout were exceedingly worrying in comparison to their colleagues in urban public hospitals or primary healthcare workers in other nations or countries, and the potential significant contributors that lead to this dilemma were also recognized. However, some limitations of this study should also be clarified. Firstly, even though there were only two kinds of measurement methods to test turnover intention in included original research in total (a dichotomous question to measure and the five-point Likert scale), due to inconsistencies in research sites, regions, and even the measurement, high heterogeneity was observed across the consolidated results. Hence, future researchers should try to use unified measurement tools. Secondly, a relatively older approach was applied to estimate the prevailing rates of burnout (low, medium, and high) in this review, which has been replaced with a profile approach by Maslach and Leiter (84–86) in many measurements directed at healthcare professionals such as nurses. Yet, due to the nature of research reviewed in this study toward the exploration of job burnout among VDs, all adopt this methodology to ensure the authenticity of the results as much as possible. This method was also compelled to use to reflect the severity of the dilemma of job burnout among VDs, indicating that researchers should use the latest international measurement standards to probe job burnout among VDs in the future. Last but not least, as only Chinese studies are included, the popularization in this study may have limitations. However, although the Chinese population has the bias of sample source, China's VD system has a long history and is also representative to some extent (3).

Conclusion

Village doctors in China carried out pivotal primary healthcare missions, but in recent years, the situation of staff turnover among this group was very serious. Compared to colleagues in public secondary and tertiary hospitals, little attention was paid to this group. In this study, several core conclusions were summarized as follows: (i) almost half of VDs wanted to leave their current job, which was significantly higher than primary health workers in other high-income countries but not significantly different from some developing countries. Similarly, the severity and proportion of job burnout among VDs were also alarming, with the detection rate in moderate and above reaching almost 20%. (ii) Men with monthly income below USD 163.4, a high educational level, and less than 40 years of age were the important contributors that affected turnover intention among this group. Simultaneously, the most significant contributors that affect job burnout was LPA. Health policymakers should increase financial subsidies for VDs, reasonably set the workload, improve various health policies such as pension insurance for VDs, and encourage "targeted training" of medical students, so as to enrich and expand their team.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

Conceptualization and writing—original draft preparation: YC. Methodology and data analysis: YC and YY. Material search: YS and ZD. Data extraction: YS, ZD, and YC. Writing—review and editing: YC, YY, YS, ZD, and TD. Supervision,

project administration, and funding acquisition: TD. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.970780/full#supplementary-material

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European national health plans and the monitoring of online searches for information on diabetes mellitus in different European healthcare systems

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Diabetes mellitus (DM) is a serious non-communicable disease (NCD) and relies on the patient being aware of their condition, proactive, and having adequate medical care. European countries healthcare models are aware of the impact of these variables. This study evaluates the impact of online health information seeking behavior (OHISB) during World Diabetes Mellitus Day (WDMD) in European countries from 2014 to 2019 by grouping countries according to the changes in citizens' search behavior, diabetes mellitus prevalence, the existence of National Health Plans (NHP), and their respective healthcare systems. We extracted data from Global Burden of Disease, Google Trends (GT), Public Health European Commission, European Coalition for Diabetes, and the Spanish Ministry of Health. First, we used the broken-line models to analyze significant changes in search trends (GT) in European Union member countries in the 30-day intervals before and after the WDMD (November 14) from 2014 to 2019. Then the results obtained were used in the second phase to group these countries by factor analysis of mixed data (FAMD) using the prevalence of DM, the existence of NHP, and health models in each country. The calculations were processed using R software (gtrendsR, segmented, Factoextra, and FactoMineR). We established changes in search trends before and after WDMD, highlighting unevenness among European countries. However, significant changes were mostly observed among countries with NHP. These changes in search trends, in addition to being significant, were reiterated over time and occurred especially in countries belonging to the Beveridge Model (Portugal, Spain, and Sweden) and with NHPs in place. Greater awareness of diabetes mellitus among the population and continuous improvements in NHP can improve the patients' quality of life, thus impacting in disease management and healthcare expenditure.

KEYWORDS

diabetes mellitus, broken-line models, factor analysis of mixed data, Google trends, healthcare system

Introduction

One of Europe's most serious chronic metabolic disorders is diabetes mellitus (DM), and it is on the rise (1). DM affected approximately 463 million people in 2019 and is predicted to affect 578 million by 2030 and 700 million by 2045. However, it was also observed that its prevalence is higher in urban than rural areas (2). Worldwide, an estimated 19.3% of the population between 65 and 99 years live with this non-communicable disease (NCD) (3). Therefore, to achieve good control of this NCD, regardless of its etiological classification, it is necessary to follow exhaustively the guidelines provided by health professionals to have a good quality of life (4–6). Patient prescriptions should always be adapted to the reality of each case and include guidelines related to hypoglycemic medication and healthy lifestyles ranging from a balanced diet to regular physical exercise (7).

Patients and their environment must be aware of the critical nature of DM. In case of poor management, it can have serious consequences that can affect the body in the short- (e.g., most frequently severe hypoglycemia and hyperglycemia) or medium/long-term (e.g., diabetic nephropathy, diabetic neuropathy, diabetic retinopathy, etc.), which can be very serious and can cause death (8–10).

Health systems are the first lines of care for their citizens' health. Although the structure of these systems differs according to the models to which the European countries being analyzed belong, the underlying goal of them is to provide good care to the population in order to look after their health (11–15). There are numerous frameworks that could be used to categorize countries of the European Union into healthcare system typologies (16–20). One of them [(18), p. PE114], defines "Beveridge" Systems, "Bismarck" Systems and Mixed Systems. Amongst other differences between these models, the Bismarck Model finances healthcare through compulsory social security contributions by employees and employers, while the Beveridge model was financed through public taxes. Further, while the Beveridge model is referred to as National Health System, those under the Bismarck model is also referred as Social Health Insurance System. The Mixed model is a different categorization. It's also referred as the Private Health Insurance System.

According to Gaeta et al. [(18), p. E114], these are the European countries following each healthcare system: Bismarck model, Belgium, Czech Republic, Estonia, France, Germany, Hungary, Lithuania, Luxembourg, Netherlands, Poland, Romania, Slovakia, and Slovenia; Beveridge model, Cyprus, Denmark, Finland, Ireland, Italy, Latvia, Malta, Portugal, Spain, Sweden, and United Kingdom; Mixed model: Austria, Bulgaria, Croatia and Greece.

The governments of different countries, public and private organizations, researchers, and healthcare providers are aware of the concerning rise in the number of cases of DM and the related work carried out jointly by the different international organizations. Therefore, they have promoted public policies that have boosted prevention campaigns aimed at the population, encouraging diabetes education, early detection, and promoting healthy lifestyles. These actions aim to raise public awareness of this condition and enable patients to adequately manage the acute symptoms of their chronic condition (1, 2, 21, 22). Additionally, the National Health Plans (NHP) have been established recently, including initiatives targeted toward DM (23, 24). According to a past study (23), the European countries of Austria, Bulgaria, Croatia, Czechia, Denmark, Finland, Greece, Hungary, Ireland, Italy, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, and Sweden would have implemented NHPs. On the other hand, Belgium, Cyprus, Estonia, France, Germany, Latvia, Lithuania, Luxembourg, Malta, and United Kingdom would not have implemented NHPs or would be in the process of implementation.

Patients can use online resources and platforms to promote their well-being and improve that of those around them (25–28). For example, they can use online resources when suffering from a disease, its complications, having an interest in taking care of their health, or to simply be informed and seek real-time answers (29, 30). It should be noted that healthcare providers and official sources can bring the most accurate information as they know the pathology concerned (31). However, suppose users choose to search through the current online resources offered through the Internet (as a public information provider). In that case, such interests of citizens can be monitored through search engine data. Google (32) is one of the relevant search engines, being the most widely used worldwide and having a large market share (33). In this regard, Google Trends (GT) (34) is becoming a tool that is raising special interest for probable forecasts and in understanding the interests of the population (35). Data provided by GT can be used as a "surrogate" of online health information seeking behavior (OHISB) and give useful information on search behaviors related to health or healthy habits (33, 36–38). Some research examines the association between data provided by internet sources and public health policies (39).

Within this framework and as evidenced in previous research papers (40–45), global days dedicated to raising public awareness of specific health issues can lead to Internet search by citizens and provide valuable information on search behaviors. In particular, under the initiative of the International Diabetes Federation and with the support of World Health Organization, November 14 was established as the world DM day (WDMD) (46). This initiative was an attempt to promote information related to the treatment, prevention, and timely diagnosis, as well as raise awareness of DM among the population. It should be emphasized that DM evokes serious impacts at both the human and economic dimensions. Therefore, based on this information and considering the impact of DM on the current healthcare systems, this original research analyzes the prevalence

TABLE 1 Descriptive statistics for diabetes mellitus prevalence and relative search volumes from 2014–2019 for European countries.

	Prevalence.14	Prevalence.15	Prevalence.16	Prevalence.17	Prevalence.18	Prevalence.19
Mean	8172.12	8322.02	8495.52	8685.28	8932.79	9263.45
Variance	5120200.86	5384009.04	5599445.51	5852454.75	6274603.12	6907150.99
Standard deviation	2262.79	2320.35	2366.31	2419.18	2504.92	2628.15
Skewness	0.38	0.45	0.48	0.49	0.49	0.48
Kurtosis	2.48	2.63	2.68	2.70	2.71	2.72
Minimun	4525.27	4639.83	4696.55	4746.50	4855.84	5011.13
Maximun	13275.10	13735.64	14125.13	14509.00	15017.54	15686.45
Range	8749.83	9095.81	9428.59	9762.50	10161.70	10675.32
1st quartile	6305.72	6311.38	6422.73	6539.79	6708.08	6915.11
3rd quartile	9690.07	9692.30	9724.28	9975.68	10299.98	10712.67
Interquartile range	3384.35	3380.92	3301.55	3435.89	3591.90	3797.56
	rsv.14	**rsv.15**	**rsv.16**	**rsv.17**	**rsv.18**	**rsv.19**
Mean	23.91	23.66	20.80	22.63	23.41	23.50
Variance	567.20	589.35	420.58	549.92	395.04	525.93
Standard deviation	23.82	24.28	20.51	23.45	19.88	22.93
Skewness	0.47	0.43	0.06	0.42	−0.04	0.52
Kurtosis	2.33	1.67	1.09	1.62	1.43	2.28
Minimun	0.00	0.00	0.00	0.00	0.00	0.00
Maximun	80.50	66.50	49.50	61.50	58.00	74.50
Range	80.50	66.50	49.50	61.50	58.00	74.50
1st quartile	0.00	0.00	0.00	0.00	0.00	0.00
3rd quartile	39.00	42.50	40.50	39.00	42.00	36.00
Interquartile range	39.00	42.50	40.50	39.00	42.00	36.00

of this disease in Europe. We used the European healthcare system model (Bismarck, Beveridge and mixed models) of countries to monitor the interest raised in the European population on the WDMD and 30 days before and after it, using two different methodologies to reach the output.

This study evaluates the impact of World Diabetes Mellitus Day (WDMD) in European countries from 2014 to 2019, grouping countries according to the changes in the citizens' search behaviors by the prevalence of the disease, the existence of NHP, and their respective healthcare systems. The period of this study began in 2014, when a prior study analyzing the NHP in Europe (23) was published. The period under analysis extends to 2019, namely, before pre-pandemic trends.

This research paper is structured as follows: Section 2 (materials and methods) explains the steps to set up the Database (DB) as well as the methodology and software used. Section 3 (results) shows the results of the research, and Section 4 (discussion) discusses the relevant findings of the present work.

Materials and methods

The research methodology is structured in the following steps: DB approach and sources consulted, and Methodology and software used.

First step: Database approach and sources consulted

Prevalence of DM

Using the data provided by the Global Burden of Disease Collaborative Network-Global Burden of Disease Study (47), it was feasible to set up the database based on the information related to the prevalence of DM.

Monitoring of the population's interest

The Internet is an excellent environment to analyze the users' interests 30 days before and after November 14 (WDMD). The tool used in this case is GT on the European scale, used as an index of the population's interest related to DM. The information set by Relative Search Volumes (RSV) for the search term "Diabetes Mellitus" shows the proportion of queries for this centralized term in a specific time and region. Its standardization structured from 0 to 100 has been linked to the highest proportion of the searched term in each set year (34).

Official sources

The characteristics of healthcare systems in European Union countries have been analyzed based on different official

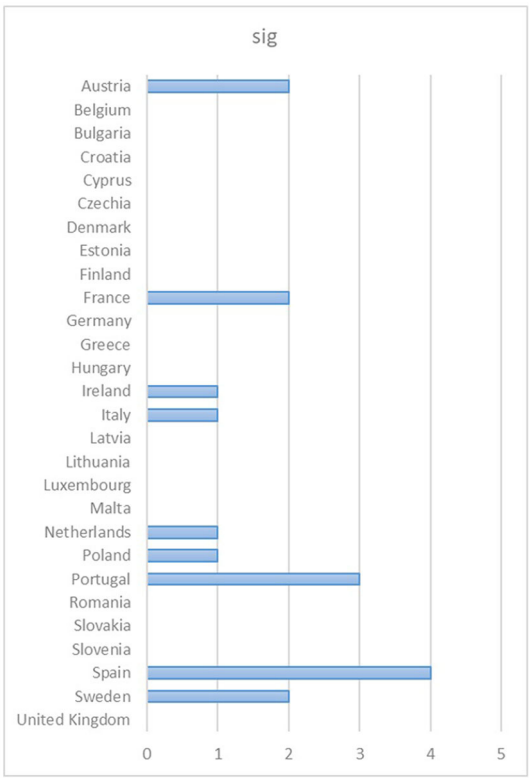

FIGURE 1
Changes in search trends on the designated day in the different European countries. Source: Compiled by the authors with data extracted from GT (2022).

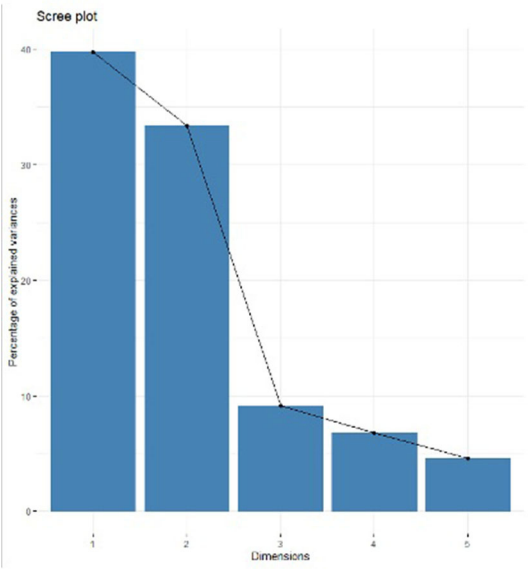

FIGURE 2
Percentages of inertia explained by each factorial analysis of mixed data dimension.

sources from several organizations. The data have been retrieved from the "Public Health European Commission" (48), "Spanish Ministry of Health" (49), and "Health Care Systems in EU-28, National Health Care Service and Social Security System" (15).

European Coalition for Diabetes (EURADIA, FEND, International Diabetes Federation, and PCDE)

Information related to NHP existing in European countries has been compiled (23).

Second step: Methodology and software

Methodology

Two methods were combined to achieve the required outputs of this novel research. First, to process the previously generated databases related to monitoring and search trends, it was necessary to use the broken-line models (BLM). With them, it was possible to track the population's interest during the 30 days before and after the WDMD (50–54). Once this output was achieved and processed to obtain the monitoring data, multivariate analysis was used (55–57). In particular, the factorial analysis of mixed data (FAMD) was used to classify the quantitative and qualitative variables of this research. The combination of these methods provided a major advantage in processing, visualizing, and analyzing the data set.

Broken-line models

Regression analysis analyzes dependent variables as a linear function of explanatory variables. In this framework, the model's response is presented as a linear function of the explanatory variables (58). However, the relationship between the response and some explanatory variables may not be linear. BLM are known to be segmented, and are represented using two or more straight lines; these lines are then connected at unknown values between the response and explanatory variables (53, 54). Here, it can be observed how the effect on the expected response of the breakpoints changes sharply. When this happens, it is necessary to use additional, non-standard optimization techniques to estimate the models because, in the estimation of the parameters of the cut-off points, the log-likelihood differs by segments, and the conditions established in the classical models are no longer fulfilled (50–54). According to Muggeo (52, 53) a segmented relationship is modeled when $\mu = E[Y]$ and variable Z is

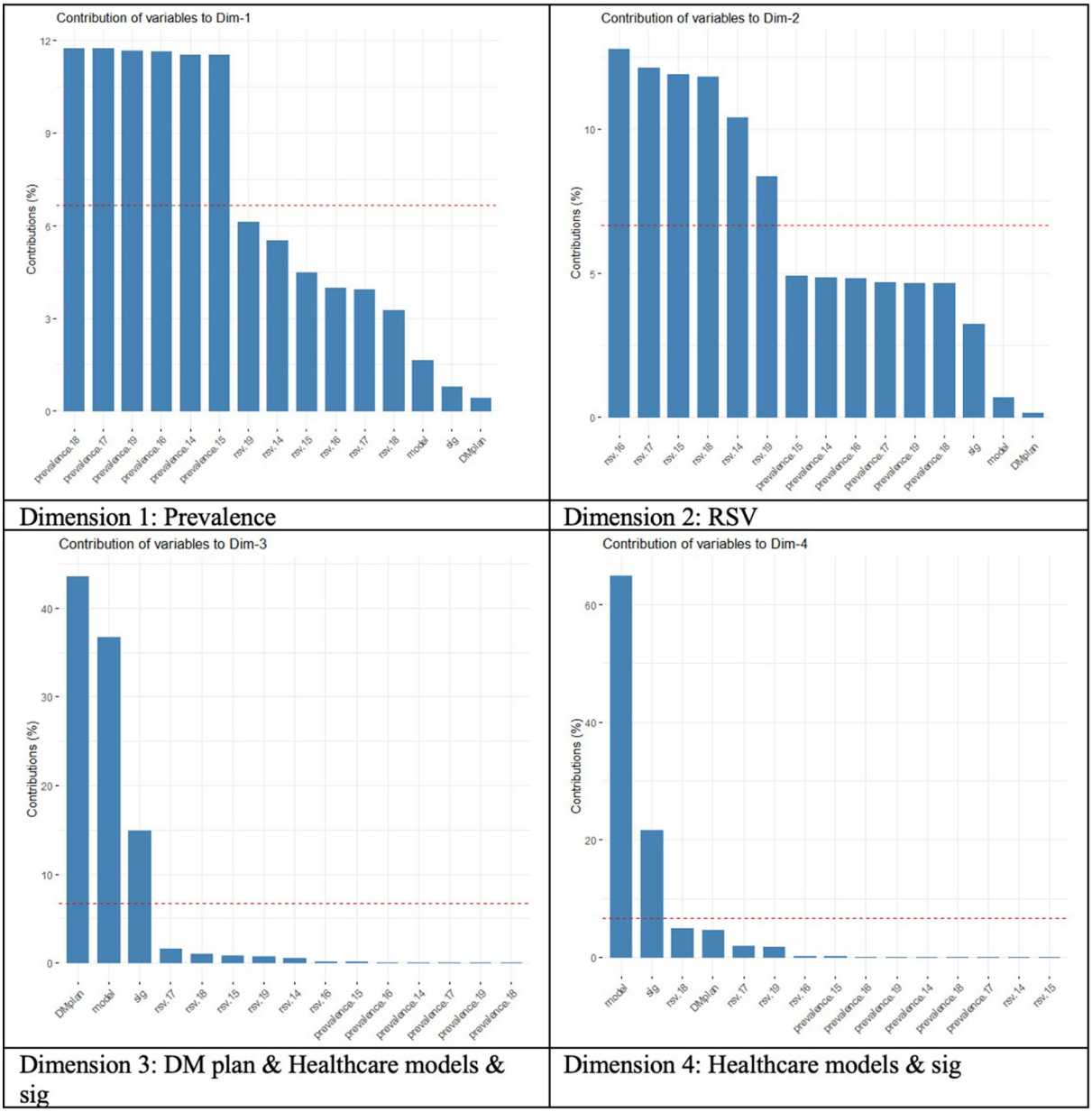

FIGURE 3
Contribution of variables to the principal dimensions ("Prevalence," "RSV diabetes," "DM day," "DM plan, Healthcare models & Sig" and "Healthcare models & Sig").

$i = 1,2,3\ldots\ n$ then

$$\beta_1 z_i + \beta_2 (z_i - \psi)_+$$
$$\beta_1 : left\ slope$$
$$\beta_2 : difference - in - \ slopes$$
$$\psi : breakpoint$$

Where $(z_i - \psi)_+ = (z_i - \psi) \times I(z_i > \psi)$ *and* $I(\cdot)$

When a linear predictor is needed,

$$\beta_1 z_i + \beta_2 \left(z_i - \tilde{\psi}\right)_+ + \gamma I(z_i > \tilde{\psi})^-$$
$$where\ I(\cdot)^- = -I(\cdot)$$

At each iteration, the breakpoint value has to be updated,

$$\tilde{\psi} = \tilde{\psi} + \hat{\gamma}/\hat{\beta}_2$$

because a standard linear model must be fitted.

The Delta method for $\frac{\hat{\gamma}}{\beta_2}$ is obtained due to the standard error of $\tilde{\psi}$ when the algorithm converges.

Davies test (DT)

When breakpoint does not exist, the test for ψ is,

$$H_0 : \beta_2 (\psi) = 0$$

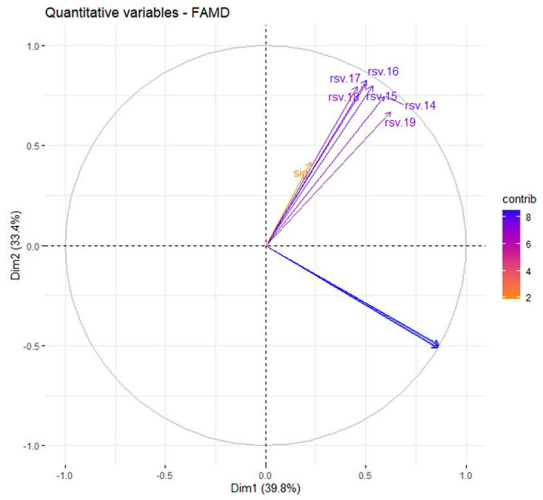

FIGURE 4
Relationship between variables and their contribution to dimensions 1 and 2.

and there is no difference-in-slopes parameter. It is zero. β_2 depends on a nuisance parameter, and ψ fades under H_0. The DT (50) is useful for performing this hypothesis test. It must be noted that statistical tests such as Wald are not satisfied, and p-values are underestimated. Here, it must be pointed out that while DT is not suitable for selecting the number of the joinpoints, it is good for testing a breakpoint.

DT is framed in the range of Z when given the K fixed ordered values of breakpoints $\psi_1 < \psi_2 < \ldots \psi_k$.

When the standard normal distribution ψ_k is fixed, there is a relevant K of the test statistic $\{S(\psi_k)\}_{k=1,\ldots,K}$.

The one-side hypothesis test is,

$$p - value \approx \Phi(-M) + Vexp\left\{-M^2/2\right\}(8\pi)^{-\frac{1}{2}}$$

and the respective alternative is,

$$H_1 : \beta_2 (\psi) > 0.$$

Being that the maximum of the K statistic $M = \max\{S(\psi_k)\}_k$, $\Phi(\cdot)$ is a function of standard normal,

$$V = \sum_k \left(\left|S(\psi_k) - S(\psi_{k-1})\right|\right)$$

$\{S(\psi_k)\}_k$ is total variation.

Factorial analysis of mixed data

As aforementioned, the database used included qualitative and quantitative variables. The FAMD technique was

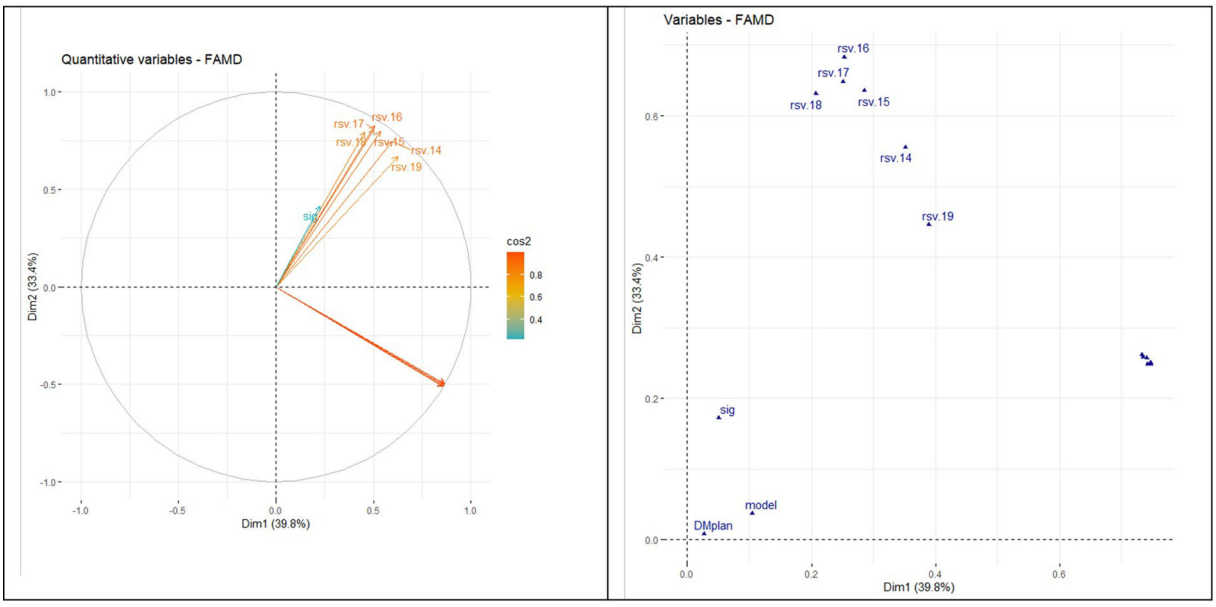

FIGURE 5
Relationship between quantitative and qualitative variables (dimensions 1 and 2).

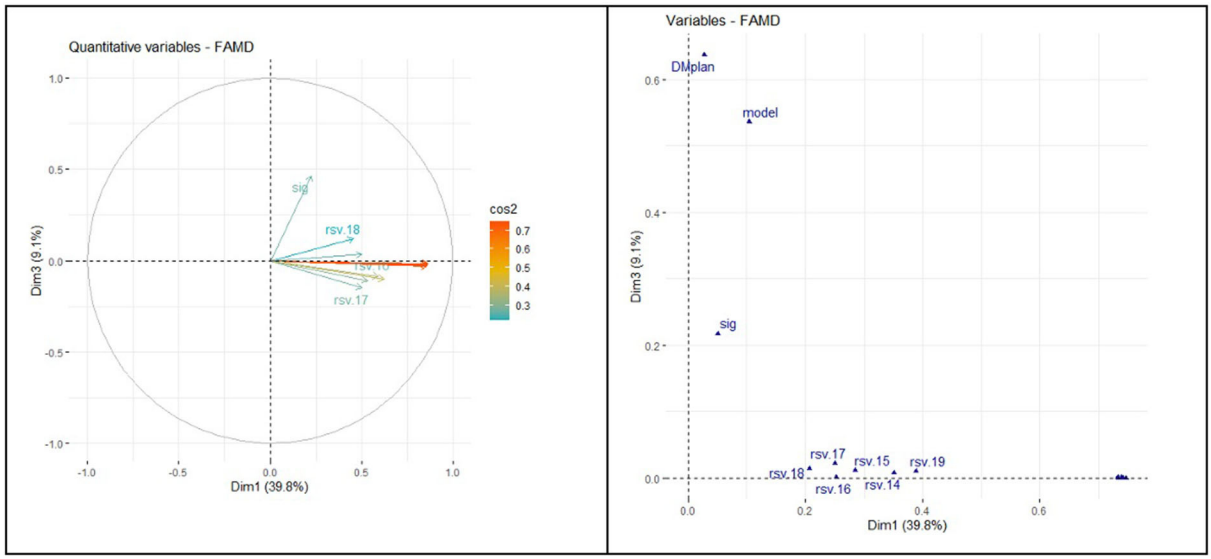

FIGURE 6
Relationship between quantitative and qualitative variables (dimensions 1 and 3).

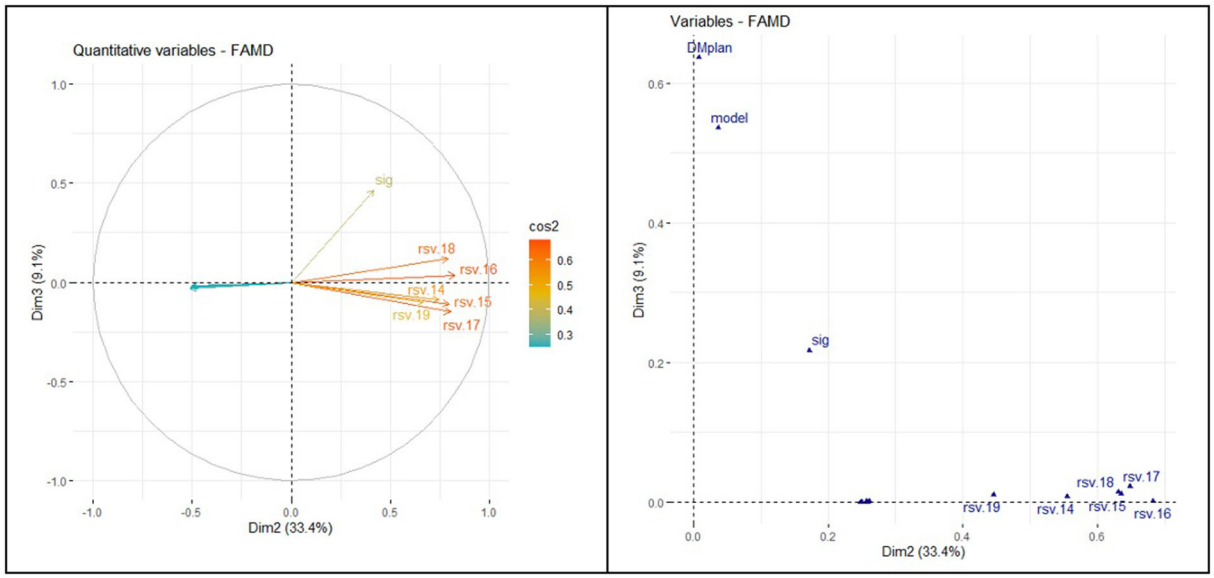

FIGURE 7
Relationship between quantitative and qualitative variables (dimensions 2 and 3).

employed because it allows both types of variables to be used simultaneously, generating a space of smaller dimensions. The quantitative variables were normalized, and the qualitative variables were treated in a normalized data table to balance all the variables under study. Principal component analysis and multiple correspondence analysis (59, 60) were combined to visualize the differences and the similarities (distances) of the analyzed elements, thereby helping us find the correlation of the continuous variables.

According to Pagès [(60), p. 71], there are two types of relationships:

a) From R^K toward R^1.

Case 1) A quantitative variable:

$$G_s(k) = \frac{1}{\sqrt{\lambda_s}} \sum_i p_i x_{ik} F_s(i) = r(k, F_s)$$

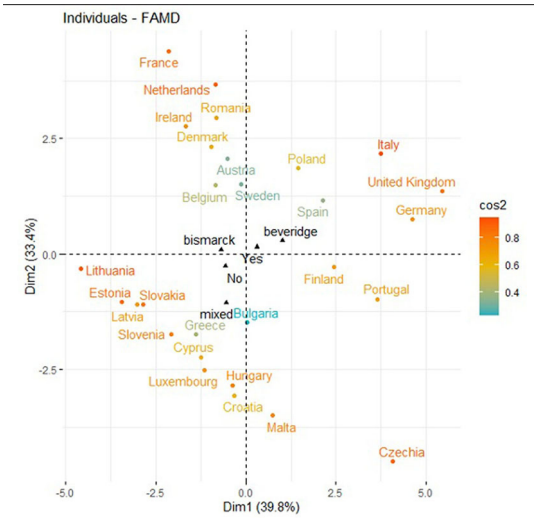

FIGURE 8
Distribution of the countries between dimension 1 and dimension 2.

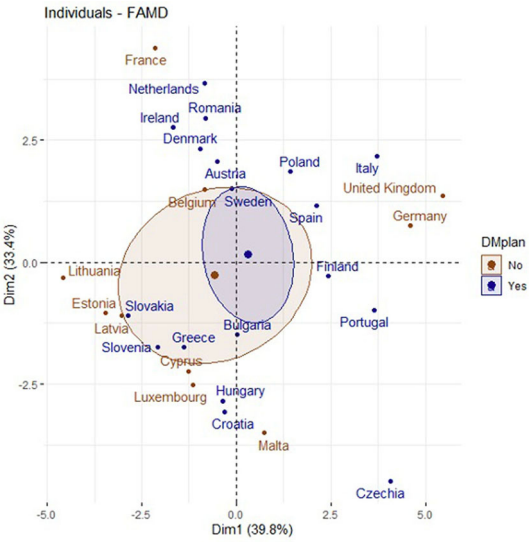

FIGURE 9
Countries with a NHPs and dimension 1 and dimension 2.

Case 2) A category k_q of variable q: $F_s\left(k_q\right)$ is the coordinate of the center of gravity of individuals with category (k_q):

$$G_s\left(k_q\right) = \frac{1}{\sqrt{\lambda_s}}\frac{1}{p_{k_q}}\sum_i p_i y_{ik_q} F_s\left(i\right) = \frac{1}{\sqrt{\lambda_s}} F_s(k_q)$$

b) From R^I toward R^K

It is expressed as follows:

$$F_s\left(i\right) = \frac{1}{\sqrt{\lambda_s}}\sum_{k\in K_1} x_{ik} G_s\left(k\right) + \frac{1}{\sqrt{\lambda_s}}\sum_{k_q\in K_2} p_{k_q}\left(\frac{y_{ik_q}}{p_{k_q}} - 1\right) G_s(k_q)$$

Software used

We used open-source software libraries to obtain the results based on the abovementioned methodologies (53, 56, 59–62); specifically, we used gtrendsR and Segmented package for the BLM and FactoMineR and FactoExtra package for FAMD.

Results

We obtained the results needed to develop this study with the DB created and previously mentioned techniques. Table 1 shows the variables related to the prevalence of DM and RSV from 2014–2019 for the European countries studied.

The results of BLM applied in the different European countries are shown in Annex.

The analysis of monitoring achieved through the BLM during the 30 days before and after WDMD was related to the change in the search trend on the designated day in the different European countries during the analyzed period. This variable is denoted as "sig" (Figure 1).

The multivariate analysis (Figure 2) showed that dimension 1 and 2 of the sedimentation graph accounted for 73.15% of the accumulated variance, whereas dimensions 3 and 4 accounted for 9.13 and 6.79% of the variance, respectively.

Figure 3 shows the four dimensions grouping the study variables. Dimension 1 shows the prevalence of DM. Dimension 2 shows the RSV related to DM. Dimension 3 shows the European countries analyzed that have a NHP (DM plan & Healthcare models & sig). Please, be noted that we coded this variable as "DM plan" Finally, Dimension 4 shows the monitoring analysis achieved when the BLM methodology was used 30 days before and after WDMD, getting the "sig" variable (explained above).

Likewise, the correlation circle (Figures 4, 5) shows the relationship between quantitative variables and their contribution to dimensions 1 and 2. There is no correlation between RSV and prevalence of DM, but there are high contributions to dimensions 1 and 2, respectively.

The correlation circle in Figure 6 shows the relationship between the quantitative variables and their contribution to the factor map in dimensions 1 and 3. Prevalence of DM was unrelated to searches in the WDMD.

The correlation circle in Figure 7 shows the relationship between the variable's contribution to the factor map in dimensions 2 and 3.

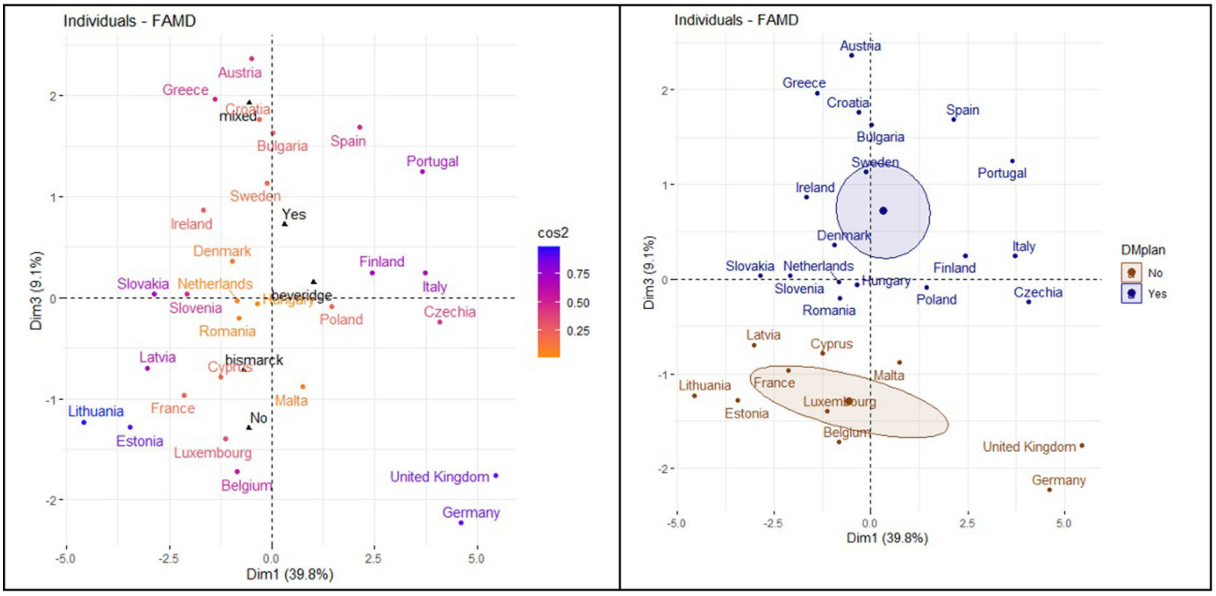

FIGURE 10
Distribution of the countries and dimension 1 and dimension 3.

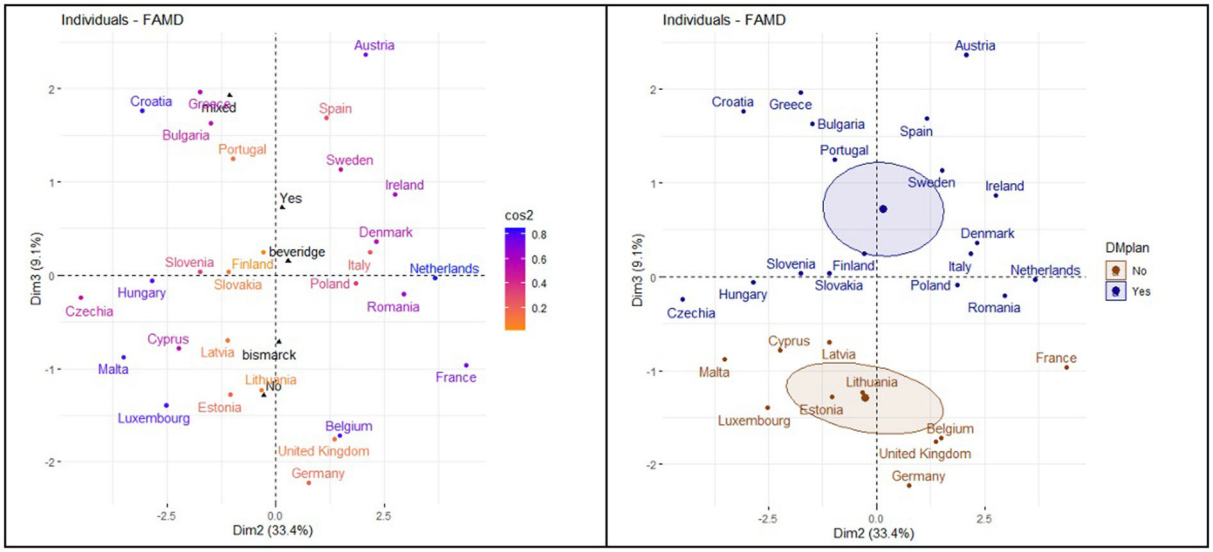

FIGURE 11
Distribution of the countries in dimension 2 and dimension 3.

Figures 8, 9 show the distribution of the countries between dimension 1 and dimension 2. It can be noted that countries with a NHP and with high searches for the term "diabetes mellitus" had a high and low prevalence of this disease.

Figure 10 shows the distribution of the countries in the factor map represented through dimension 1 and 3. Among countries with NHPs and higher prevalence of DM, many changes in internet search trends happened on WDMD.

The Figure 11 factor map is generated from dimension 2 and 3. Among countries with NHPs, higher searches for RSV imply a higher number of times of noticeable changes in internet searches on DM during the WDMD.

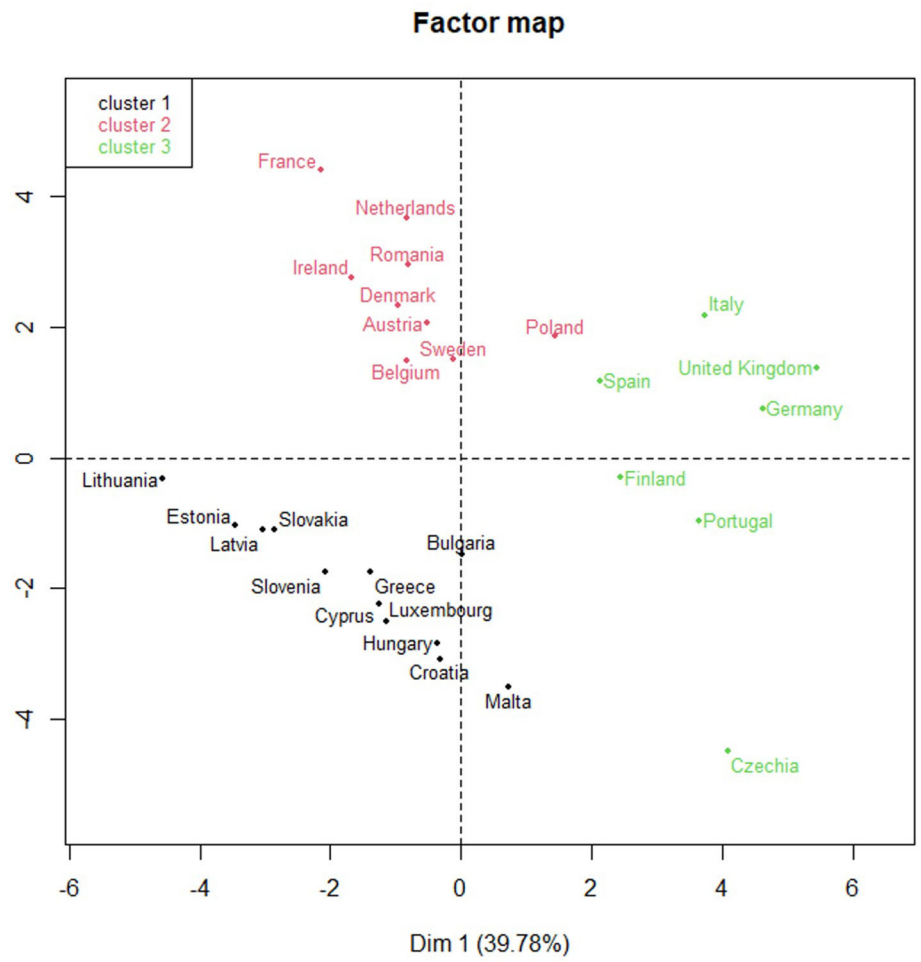

FIGURE 12
Classification of European countries by three clusters.

Consequently, changes in the search trend before and after the WDMD were uneven among European countries during the period analyzed. The most important changes were mostly observed among countries with NHPs. These noticeable changes in the search were reiterated over time and occurred especially in the countries belonging to the Beveridge model (Portugal, Sweden and Spain).

Figure 12 shows the classification obtained through the FAMD method of the European countries analyzed. The three clusters show the following coincidences:

Cluster 1 shows a comparatively low prevalence of DM, low RSV related to DM, half of the country samples with no NHP, and no considerable changes in internet search trends during the WDMD.

Cluster 2 shows, for the most part, a low prevalence of DM, a high RSV related to DM, countries with NHPs, and unevenly noticeable changes in internet search trends during the WDMD.

Cluster 3 shows a high prevalence of DM, a high RSV related to DM, and, for the most part, countries with NHPs. Rarely, they present significant changes in internet search trends during the WDMD.

Table 2 and Figure 13 shows, for each European country, the number of times that the search changes were significant and their respective clusters, the healthcare systems, and whether they have NHPs.

Therefore, the combination of the results using two methods (BLM and FAMD) leads to the following patterns: a high RSV related to DM and higher prevalence of DM was noted in countries with NHPs, which showed a greater number of considerable changes in search trends during the WDMD. These changes in OHISB were reiterated over time and

TABLE 2 Changes in citizens' search behavior, clusters, and healthcare systems.

Country	Model	DMplan	Sig	Cluster
Austria	Mixed	Yes	2	2
Belgium	Bismarck	No	0	2
Bulgaria	Mixed	Yes	0	1
Croatia	Mixed	Yes	0	1
Cyprus	Beveridge	No	0	1
Czechia	Bismarck	Yes	0	3
Denmark	Beveridge	Yes	0	2
Estonia	Bismarck	No	0	1
Finland	Beveridge	Yes	0	3
France	Bismarck	No	2	2
Germany	Bismarck	No	0	3
Greece	Mixed	Yes	0	1
Hungary	Bismarck	Yes	0	1
Ireland	Beveridge	Yes	1	2
Italy	Beveridge	Yes	1	3
Latvia	Beveridge	No	0	1
Lithuania	Bismarck	No	0	1
Luxembourg	Bismarck	No	0	1
Malta	Beveridge	No	0	1
Netherlands	Bismarck	Yes	1	2
Poland	Bismarck	Yes	1	2
Portugal	Beveridge	Yes	3	3
Romania	Bismarck	Yes	0	2
Slovakia	Bismarck	Yes	0	1
Slovenia	Bismarck	Yes	0	1
Spain	Beveridge	Yes	4	3
Sweden	Beveridge	Yes	2	2
United Kingdom	Beveridge	No	0	3

happened mainly in countries with NHPs and belonging to the Beveridge Model (Portugal, Spain, and Sweden). Meanwhile, most countries belonging to the Bismarck model, with NHPs, and a high frequency of searches for DM showed a low prevalence of DM compared to the others. Therefore, they have not presented noticeable changes in search trends during the WDMD.

Discussion

Our research work demonstrates the potential of analyzing user activity collected through Google and GT. Our results concur with those of prior research (33, 36, 40, 43), and it emphasizes the importance of OHISB evaluation in current days for raising public awareness of specific health issues (37, 40–45). Furthermore, our study is novel as it evaluates the impact of OHISB on the WDMD considering selected European countries and depending on whether they have NPHs or not, their healthcare system model, and the prevalence of DM among the population. We have managed to extract the respective patterns framed between 2014 and 2019. We emphasize that the information related to the NHPs of each European country, used to classify them, was extracted from the (23), as shown in section 1 introduction of this study. Two groups were created: whether they were implemented or not (countries that were in the process of establishing the NPHs were classified as "not implemented" as they were in the process of doing so). Please, note that numerous frameworks could be used to categorize countries of the European Union into health system typologies. According to Gaeta et al. [(18), p. E114], we categorized countries into Social Health Insurance System ("Bismarck" model), National health services ("Beveridge" model), and mixed models. This research focused on the European population with access to the Internet and using Google as a search engine, so the limitation of the search data was framed in GT. Therefore, we agree with one prior study (33, 38) which argues that GT is a useful tool for research. These

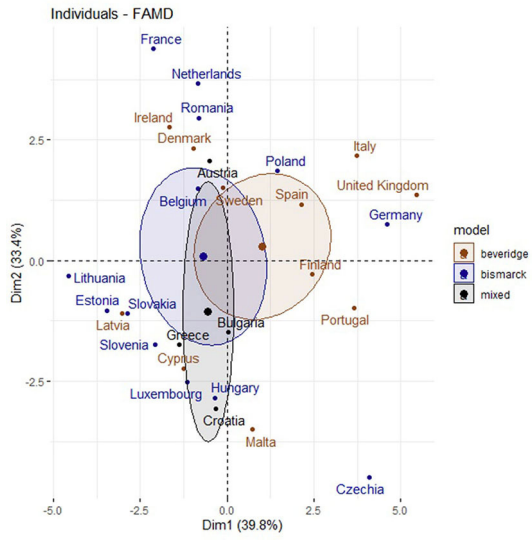

FIGURE 13
Distribution of the countries and dimensión 1 and dimensión 2.

components and the methods presented in this study (BLM and FAMD) enriched the final output. This novel work shows how the combination of the two used methods can provide an advantage in processing, visualizing, and analyzing the data set of interest. For this study, proper statistical methods were used to process data. This DB analyzed variables related to the prevalence of DM, the NHPs, the healthcare systems, and OHISB during the WDMD. It highlighted how European countries were grouped according to the study's variables. The main contribution is the pattern observed, showing that countries with a matching NHP, for the most part, had populations with a greater OHISB related to DM. Additionally, the presence of a high and medium prevalence of DM in these countries coincided with a greater number of changes in search behavior during the WDMD. These contributions can be useful to public bodies to acquire more knowledge and public interest in DM.

Future research might focus on how these combined methods and web-based tools could be used to raise the population's awareness of DM. It can help improve decision-making of public stakeholders regarding the establishment of relevant actions for improving the quality of life of the population interested in this NCD and help those with the disease to deal with it. To this end, it would be worthwhile to focus on more patterns of variables related to DM within the context of socio-economic determinants of health using the methods shown in this research.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: Global Burden of Disease Collaborative Network. Global Burden of Disease Study 2019 (GBD 2019) Results. Seattle, United States: Institute for Health Metrics and Evaluation (IHME), 2020. https://vizhub.healthdata.org/gbd-results. Google Trends (2022): https://trends.google.es. European Coalition for Diabetes (IDF Europe, FEND, PCDE, and EURADIA. https://www.idf.org/our-network/regions-members/europe/publications-and-resources/56-diabetes-in-europe-policy-puzzle.html.

Author contributions

Conceptualization, methodology, software, formal analysis, investigation, and writing—original draft preparation: IBF. Validation and supervision: IBF, FCV, MCL, and MJPL. Resources and data curation: IBF and FCV. Writing—review and editing: IBF, FCV, and MCL. Project administration: MCL and IBF. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.1023404/full#supplementary-material

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Diabetes mellitus and inequalities in the equipment and use of information technologies as a socioeconomic determinant of health in Spain

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Inequalities in the equipment and use of information and communications technology (ICT) in Spanish households can lead to users being unable to access certain information or to carry out certain procedures. Accessibility to ICT is considered a social determinant of health (SDOH) because it can generate inequalities in access to information and in managing access to health services. In the face of a chronic illness such as diabetes mellitus (DM)—for which a comprehensive approach is complex and its complications have a direct impact on current healthcare systems—all the resources that patients may have are welcome. We aimed to analyze hospitalizations and amputations as direct consequences of DM among the autonomous communities of Spain (ACS) in 2019, along with socioeconomic factors related to health, including inequalities in access to ICT between territories, as well as citizens' interest in online information searches about DM. We used different databases such as that of the Ministerio de Sanidad (Spain's health ministry), Ministerio de Asuntos Económicos y transformación (Ministry of Economic Affairs and Digital Transformation), Google Trends (GT), and the Instituto Nacional de Estadística (Spain's national institute of statistics). We examined the data with R software. We employed a geolocation approach and performed multivariate analysis (specifically factor analysis of mixed data [FAMD]) to evaluate the aggregate interest in health information related to DM in different regions of Spain grounded in online search behavior. The use of FAMD allowed us to adjust the techniques of principal component analysis (PCA) and multiple correspondence analysis (MCA) to detect differences between the direct consequences of DM, citizen's interest in this non-communicable disease, and socioeconomic factors and inequalities in access to ICT in aggregate form between the country's different ACS. The results show how SDOH, such as poverty and education level, are related to the ACS with the highest number of homes that cite the cost of connection or equipment as the reason

for not having ICT at home. These regions also have a greater number of hospitalizations due to DM. Given that in Spain, there are certain differences in accessibility in terms of the cost to households, in the case of DM, we take this issue into account from the standpoint of an integral approach by health policies.

KEYWORDS

diabetes mellitus, factor analysis of mixed data, social determinants of health, economics, inequalities

Introduction

The equipment and use of information and communications technology as a social determinant of health

The social determinants of health (SDOH) are essential for achieving good public health. They are framed in an environment where political, social, and economic forces interact and where people are born, grow, live, work, and age. Surveillance in the field of public health is therefore crucial. Surveillance encompasses not only the systematic, continuous collection of data on the population's health; information analysis and interpretation are also critical to plan, implement, and evaluate public health actions (1–4). According to (5), both digital literacy and Internet connectivity can be understood as "super [SDOH]" because they include all other social determinants related to health. In this regard, there are remarkable inequalities in the world. According to (6), between 2005 and 2019, the number of internet users grew by 10% on average. In 2019, the global penetration rate increased over 53%, and Europe had the highest internet usage rates. In 2019, the vast majority of the world's population lived within reach of a mobile network and, in developed countries, about 87% of the population used the internet.

Organisation for Economic Co-operation and Development OECD, (7) stresses that access to and use of information and communications technology (ICT) translates into real social benefits. In OECD countries, the population that has come to use the internet has grown by 30 percentage points over the last decade. In most member states, almost all young people between the ages of 16 and 24 use the internet on a daily basis. However, among individuals between 55 and 74 years old, the median stands at 55%, with very considerable differences depending on the country analyzed (8).

The use of ICT by all people—including fundamental human rights such as privacy and ensuring the ethical use of data—must prevail. Although there may be a risk of fostering inequality and prejudice between groups who have access to data and know how to use them, and those who do not, the discrepancies that may arise and that could end up hindering access to ICT must be avoided (9). Although exclusion related to the information society can take place passively (due to social and cultural environmental conditions) or actively (for reasons external to the individual, whether governmental or political), some authors consider that although access to digital resources is more costly for people without incomes, when they have access to ICT and are going to use it, they may be more interested in it. Hence, not having access to ICT does not imply social exclusion, but not having ICT means that the situation of exclusion is exacerbated for the population without access to it. Given this scenario, it is vital to highlight the role of the "digital divide" and to distinguish between the impact of "access" and "use" of ICT (10, 11).

Health care services and digital health technologies

The emergence of electronic health (eHealth) marks a breakthrough as it represents support for citizens' health related to (among other aspects) healthcare services, education, and surveillance (12). Currently, eHealth is implemented in different governments as well as public administrations, and embodies one more step toward so-called electronic government, since the use of eHealth, in some countries, denotes support for universal health coverage (13–15).

While digital health technologies aim to promote the efficiency of healthcare delivery by offering better medical services to citizens (both in the public and private sectors), their application might not always be homogeneous (16, 17).

Health informatics interventions are designed to improve the quality of health and the safety of healthcare, even though they might lead to inequalities and might not benefit the most disadvantaged people (18). There may be a relationship between an individual's social status, the probability of contracting a disease, and his/her life expectancy; in this context, social inequalities could end up affecting people (19). Faced with this

reality, the citizen's experience is essential in terms of patient-centered health care delivery and involvement (20).

Diabetes mellitus in the equipment and use of ICT

Diabetes mellitus (DM) is a serious chronic disease (CD) that is on the rise (21–23). Regardless of the patient's age, good care in the context of this CD is not easy, and has to be approached with the help of ongoing medical care and multifactorial interventions that do not simply focus on glycemic control (24, 25). To achieve this, there is a need to reduce (as much as possible) the risk of developing complications associated with DM through good self-management (26). Additional factors to consider include a proper diet, supervised physical exercise, healthy behaviors, and control of indicators such as blood pressure, lipid values, and thrombotic control (27, 28). A lot of sacrifice is required and will only be attained if the patient has a lot of discipline, support from his/her environment, and seeks help from professionals to establish guidelines to avoid dreaded consequences, such as the need to be hospitalized due to diabetic decompensation, or limb amputations with all the emotional and economic implications that they entail (29–34).

Ongoing digitization in DM management offers new opportunities for patients, their environment, and healthcare professionals. Improvements have had a particular impact on patients' glycemic control, as well as enhancing patient autonomy and quality of life (35). The (36) uses the term "diabetes technology" to describe the hardware, devices, and software that people use to manage DM, ranging from controlling blood glucose levels to lifestyle. Previously, DM technology consisted of insulin administered by various devices, as well as monitoring using a meter or a continuous glucose monitor. Currently, hybrid devices have been available that not only monitor glucose; they can also administer insulin, and some of them have built-in software that assists the patient and others in his/her environment in terms of diabetic control (22, 37).

Thus, awakening interest and encouraging the involvement of patients (young and old) and others in their environment will raise awareness of this reality. The technology developed in recent decades can be of great help to patients, others in their environment, and health professionals in order to provide patients with resources to face their CD (38–40). New innovations include the Móvil electronic device (MED) (41–50).

Special emphasis should also be placed on the fact that on the internet, users can exchange information with other people, as well as discuss any queries they may have in relation to DM. To this end, users must have the appropriate technological equipment (e.g., suitable hardware and software, an internet connection, etc.). Since the most widely used search engine is Google, it is possible to use Google Trends (GT) to monitor what the population can find out about DM through this search engine (51).

Diabetes mellitus and the impact of digital competency on healthcare in Spain

As discussed above, accessibility to ICT is considered an SDOH; inequality in access to information for the population, as well as managing access to health services, are critical. Given the need to establish digital governance, digital competence is one of the factors that can have the greatest impact on social inequality (52).

Furthermore, the importance of the educational structure in explaining proper use of the internet should be emphasized (53). According to (54), studies carried out in Spain on the determinants of the use of e-Government found that digital skills and confidence in the internet could have an impact on the use of e-Government. This also suggests that digital skills are affected by citizens' resources, economic and education level, age, and gender. The same study noted that trust in the internet was conditioned (among other factors) by the concern of being the object of advertising. Extrapolating these findings to health issues in Spain, within the context of ongoing improvement, the Quality Plan for the National Health System of Spain (2006–2010) included issues such as protection, health promotion, and prevention. These actions are in line with the principles established in the Tallinn Charter, signed in 2008 by the Spanish government. Within this framework, we carried out the present study to reduce health inequality. The abovementioned actions are framed within the general policies of Spain's Ministry of Health and Social Policy, and one of those actions relies on ICT to improve care provided to the Spanish population (55).

From the standpoint of worrisome data related to inequality, death, prevalence, and cost in Spain (56), a CD such as DM must be seriously considered. Previous referrals to the need for patient care must always be present, because poor care related to DM can have serious consequences for the patient's health, as well as for economic costs (56–61). Unfortunately, two of the sequelae of this poorly controlled illness are hospitalizations (62–64) and amputations (65–68).

We aimed to analyze the impact of inadequate diabetic control as direct consequences of DM among the autonomous communities of Spain (ACS), along with socioeconomic factors related to health, including inequalities in access to ICT as an SDOH (between territories, as well as citizens' interest in online information searches about DM. Hence, we aimed to scrutinize hospitalizations and amputations as direct consequences of DM in ACS, as well as their relationship with socioeconomic

TABLE 1 Descriptive summary of the variables of broadband technology coverage in Spain in 2019.

	adsl.2mb	adsl.10mb	vdsl	hfc	ftth	in.30	umts	lte	sp30mb	spl00mb
Mean	0,88171	0,71159	0,12274	0,5103	0,7606	0,3704	0,998776	0,996471	0,94055	0,80481
Variance	0,00420	0,00586	0,00056	0,0377	0,0132	0,0521	0,000003	0,000015	0,00092	0,00897
Standard deviation	0,06481	0,07654	0,02369	0,1941	0,1151	0,2282	0,001642	0,003855	0,03034	0,09471
Skewness	−1,5479	−0,9029	0,7205	−0,3798	−0,3299	0,6439	−3,0127	−1,5979	0,0389	−0,1188
Kurtosis	5,7595	3,8053	3,0353	3,7106	3,3878	3,3008	13,4080	5,0310	2,0319	2,7320
Median	0,89190	0,73450	0,12000	0,5337	0,7814	0,3915	0,999400	0,998600	0,94190	0,81160
Minimun	0,70020	0,52710	0,09040	0,0660	0,5030	0,0300	0,993000	0,986500	0,89600	0,64120
Maximun	0,95820	0,82180	0,17670	0,8870	0,9729	0,8323	1,000000	0,999900	0,98910	0,97300
Range	0,25800	0,29470	0,08630	0,8210	0,4699	0,8023	0,007000	0,013400	0,09310	0,33180
Count	17	17	17	17	17	17	17	17	17	17
1st cuartil	0,86400	0,67340	0,10580	0,4239	0,6888	0,1834	0,998400	0,995700	0,91450	0,75550
3rd cuartil	0,92530	0,75790	0,13320	0,6189	0,8113	0,4235	0,999700	0,999100	0,96150	0,85620
Interquartile range	0,06130	0,08450	0,02740	0,1950	0,1225	0,2401	0,001300	0,003400	0,04700	0,10070

Source: Ministry of economic affairs and digital transformation (state secretariat for digitalization and artificial intelligence department).

TABLE 2 Percentage of inertia explained by each FAMD dimensions.

	Eigenvalue	Variance percent	Cumulative variance percent
Dim.1	4,177596	32,135357	32,135357
Dim.2	2,981351	22,933469	55,068826
Dim.3	1,976681	15,205236	70,274062
Dim.4	1,423336	10,948736	81,222798
Dim.5	1,042255	8,017348	89,240146

factors of health, including inequality in access to ICT throughout the ACS and the population's behavior toward online information searches about DM in 2019 (before pre-pandemic trends).

This research paper is structured as follows: Section 2 "materials and methods" explains the steps to set up the database as well as the methodology and software used. Section 3 "Results" shows the results of the research. Section 4 "Discussion" shows the relevant findings of the present work.

Materials and methods

We performed our study in the following steps:

(1) Database design and sources searched

In order to build a database, we needed to check different sources.

(a) **Government sources**

(a1) Spain health ministry (69).

- *A profile of the Spanish population: Education level and poverty*. We coded these variables as "education" and "poverty."
- *Health data related to hospitalizations and amputations caused by DM*. We coded these variables as "hospital" and "amputation."
- *Public health spending managed by the ACS per inhabitant*. We coded this variable as "healthcare."

(a2) Ministry of Economic Affairs and Digital Transformation (State Secretariat for Digitalization and Artificial Intelligence Department) (70). We extracted information related to the percentage of broadband coverage through different connection technologies and speeds (Table 1).

- *Asymmetric Digital Subscriber Line ("ADSL ≥ 2 Mbps" and "ADSL ≥ 10 Mbps")*. We coded these variables as "adsl.2 mb" and "adsl.10 mb."
- *Very High-Rate Digital Subscriber Line (VDSL)*. We coded this variable as "vdsl."
- *Hybrid Fiber Coaxial (HFC)*. We coded this variable as "hfc."
- *Fiber to the Home (FTTH)*. We coded this variable as "ftth."

TABLE 3 Contributions of technology–related variables.

	Dim.1	Dim.2	Dim.3	Dim.4	Dim.5
adsl.2mb	0,031	**29,113**	1,243	3,270	0,133
adsl.10mb	2,460	**24,360**	0,342	4,724	4,099
vdsl	7,170	**10,897**	6,145	0,882	9,358
hfc	6,773	0,592	**16,346**	11,190	11,436
ftth	9,351	**16,047**	0,421	1,003	0,454
in.30	2,211	0,211	18,271	**19,879**	1,133
umts	12,756	O,000	0,232	**22,766**	4,907
lte	**14,693**	1,436	2,555	11,827	5,758
sp30mb	6,802	2,150	**24,492**	2,326	0,102
Sp100mb	**17,057**	7,426	0,407	0,439	1,704
Housing.density	20,694	7,766	29,544	21,693	**60,916**

Values in bold show those that are higher.

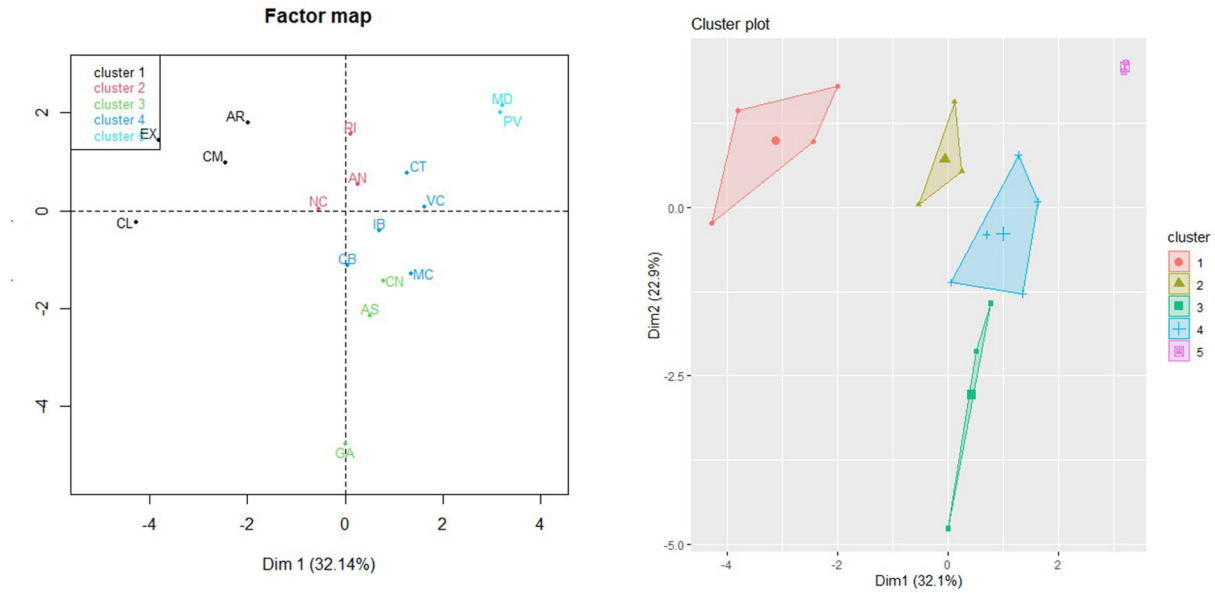

FIGURE 1
Factor map of ACS. Dimension 1, Dimension 2, and "housing_density."

- *Wireless ≥ 30 Mbps*. We coded this variable as "in.30."
- *Universal Mobile Telecommunications System (UMTS) with High-Speed Packet Access (HSPA)*. "umts."
- *Long-Term Evolution (LTE) 4G*. We coded this variable as "lte."
- *Speech per coverage ≥30 Mbps*. We coded this variable as "sp30 mb."
- *Speech per coverage ≥100 Mbps*. We coded this variable as "sp100 mb."
- *Number of households*. We extracted this information from (71) since it contains data on the number of households for 2019.

(b) **Instituto Nacional de Estadística (71)**

Using the data provided by Instituto Nacional de Estadística, it was feasible to set up the database based on the information related to these four areas:

(b1) *Area of ACS per square kilometer*. We coded this variable as "housing_density."

We extracted the information in sections b2, b3, and b4 from the "Survey on Equipment and Use of [ICT] in Households, 2019." The population analyzed was between 16 and 74 years of age.

(b2) *ICT product equipment in homes.*

The internet access of primary households by ACS and type of connection. We considered the number of households and those with broadband and narrowband connections. We coded these variables as "broadband" and "narrowband."

(b3) *Internet services used for specific reasons according to the type of service and by ACS.* This relates to citizens who searched for information about health issues. We coded this variable as "health.info.pop."

(b4) *The main reasons for which main homes do not have internet access by ACS.*

Reasons included the cost of having hardware (we coded this variable as "hardware.cost") or the cost of the connection (we coded this variable as "connect.cost").

(c) Google Trends

The internet is a good environment for understanding individuals' concerns and needs. GT is a very good tool to monitor citizens' interests, parameterizing the information collected through the search engine's users (51). In this way, GT collected data in 2019 through users who searched for the term "diabetes mellitus," which shaped the respective proportion through the relative search volume (RSV). The information obtained by the GT has been used as a subrogate of online health information seeking behavior. We parameterized the respective normalization from 0 to 100 and matched it to the highest proportion of the searched term. We coded this variable as "hits.dm."

(2) Methodology and software

(a) Methodology

To identify patterns to carry out the current research, it became necessary to set up the database, relying on the sources indicated above. This involved the following steps:

(a1) We created the corresponding projection on different maps of Spain (see Appendix 1).

(a2) We used a multivariate method to treat the variables. We took into account that the variables extracted were both quantitative and qualitative. As such, we used factorial analysis of mixed data (FAMD) to classify the data (72, 73).

(b) Software

We used several free R software libraries to achieve the abovementioned outputs (72–74). We used FactoMineR package and FactoExtra package for FAMD. To create the maps included in this article and in the appendices (Appendix 1 and Figure 4), we employed several libraries, including the tmaptools package, the maptools package, the tmap package, the rgdal package, the tidyverse package, the sf package, the raster package, the rworldxtra package, the leaflet package, and the spdep package.

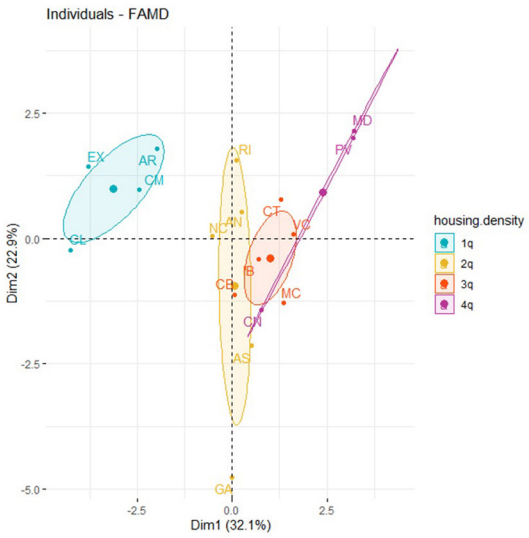

FIGURE 2
Factor map of ACS in Dimension 1, Dimension 3, and "housing_density."

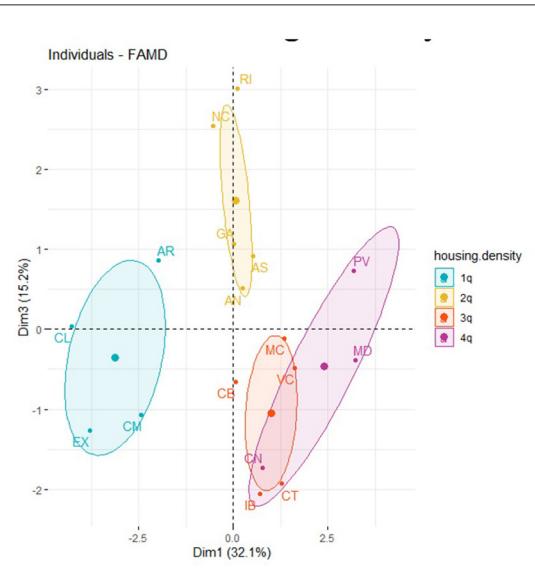

FIGURE 3
ACS clustering: Five clusters identified by FAMD.

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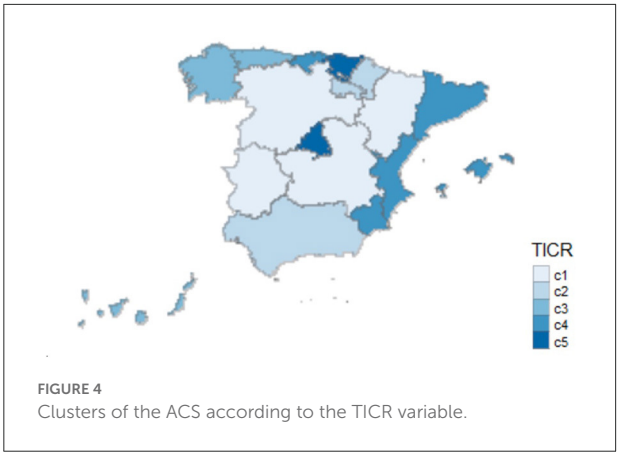

FIGURE 4
Clusters of the ACS according to the TICR variable.

Results

We had to find the density of households in each ACS ("housing_density"). This variable is obtained by dividing the number of households (ACS) by the surface area (in km^2) (ACS).

From these data, we extracted the quartile corresponding to this ratio for the ACS among the Spanish regions analyzed. This variable represents the quartile that denotes the density of the number of households between surface area (in km^2) in relation to Spain as a whole. The "housing_density" variable characterizes each region according to the population of households and its dispersion in the region as an approximation of the pressure of the demand for technological coverage existing in each ACS.

We obtained a variable from the broadband coverage data. This qualitative variable represents the group to which the ACS belongs according to the percentage of broadband technology implementation and coverage speed in the region. Note that we coded this variable as "TICR." Please, be aware that it refers to the existing technological coverage in 2019 for each of the ACS: *ADSL ≥ 2 Mbp, ADSL ≥ 10 Mbps, VDSL, HFC, FTTH, wireless ≥ 30 Mbps, UMTS with HSPA, LTE, sp30 mb and sp100 mb*.

Using FAMD, we computed a qualitative variable (TICR) that described five possible clusters to which an autonomous region belonged according to the characteristics studied. The results generated by applying FAMD to obtain the TICR variable are shown below.

Supplementary Figure S1 (see Appendix 2) presents the sedimentation graph with the five dimensions, into which we grouped the variables of broadband technology coverage and the existing connection speed in each ACS (see Table 2).

Supplementary Figures S2–S7 (see Appendix 2) outline the variables grouped according to their contribution to each dimension.

Table 3 displays the outcomes of the contributions of the variables analyzed in each dimension. Dimension 1 groups

TABLE 4 Summary of the DM variables, determinants of health, health information searches, type of connection, and reasons for non–use of the internet at home.

	Education	Poverty	Hits.dm	Health.info.pop	Hospital	Amputation	Broadband	Narrowband	Hardware.cost	Connect.cost	Healthcare
Mean	38,58	19,33	52,18	59,96	6,14	0,08	99,65	1,56	27,70	26,33	1633,70
Variance	61,77	58,46	131,63	12,64	1,63	0,00	0,07	0,54	68,56	61,71	19008,96
Standard deviation	7,86	7,65	11,47	3,56	1,28	0,03	0,26	0,73	8,28	7,86	137,87
Skewness	0,19	0,26	−0,11	−0,17	1,33	0,77	−0,33	0,30	1,23	1,04	−0,89
Kurtosis	2,36	1,77	2,64	2,66	5,70	5,14	1,51	2,50	5,44	5,74	3,91
Median	38,60	17,90	52,44	60,50	5,98	0,08	99,70	1,50	26,60	25,70	1621,15
Minimun	25,90	7,70	31,31	53,40	4,59	0,03	99,20	0,50	16,40	13,70	1321,14
Maximun	53,70	31,50	72,90	66,10	9,70	0,16	100,00	3,00	50,50	47,60	1851,86
Range	27,80	23,80	41,60	12,70	5,11	0,13	0,80	2,50	34,10	33,90	530,72
Count	17,00	17,00	17,00	17,00	17,00	17,00	17,00	17,00	17,00	17,00	17,00
1st cuartil	33,10	12,90	44,77	57,80	5,13	0,07	99,40	0,90	21,10	22,90	1572,82
3rd cuartil	42,70	26,20	58,04	61,70	6,61	0,10	99,90	1,90	29,50	27,90	1735,43
Interquartile range	9,60	13,30	13,27	3,90	1,48	0,03	0,50	1,00	8,40	5,00	162,61

Source: Ministry of economic affairs and digital transformation (state secretariat for digitalization and artificial intelligence department); instituto nacional de estadística; ministry of health.

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coverage by LTE broadband technologies and connection speed above 100 Mbps (Supplementary Figure S2, see Appendix 2). Dimension 2 groups broadband coverage technologies by ADSL ≥10 Mbps, ADSL ≥ 2 Mbps, VDSL, and FTTH (Supplementary Figure S3, see Appendix 2).

Dimension 3 includes HFC broadband coverage technologies and connection speeds ≥30 Mbps (Supplementary Figure S4, see Appendix 2). Dimension 4 groups wireless technologies >30 Mbps and UMTS with HSPA (Supplementary Figure S5, see Appendix 2).

Lastly, Dimension 5 is reserved for the qualitative variable "housing_density."

Supplementary Figure S6 (see Appendix 2) shows the data obtained for the density of households per km^2 in each ACS, and the map factor of the distribution of this variable, "housing_density," as a qualitative variable. Correlation circle of the quantitative variables is shown in Supplementary Figure S7 (see Appendix 2).

Figure 1 represents the distribution of the ACS analyzed in the map factor. In addition, each region has been brought together according to its category in the "housing_density" variable. We can see that the ACS with the lowest density of households per km^2 are those with the highest percentage of ADSL ≥10 MBps and VDSL coverage technologies. By contrast, those with a higher density of households are the ones with the greatest percentage of FTTH broadband technology coverage and connection speeds above 100 Mbps.

Supplementary Figure S8 (see Appendix 2) and Figures 2, 3 represents the distribution of the ACS according to Dimension 1 (LTE coverage technologies with connection speeds higher than 100 Mbps) and Dimension 3 (LTE broadband coverage and connection speeds higher than 30 Mbps).

Finally, we obtained the grouping of the ACS into five clusters (Figure 1) using FAMD.

- **Cluster 1** (c1) groups the following ACS: Castilla y León (CL), Castilla La Mancha (CL), Aragón (AR), and Extremadura (EX).
- **Cluster 2** (c2) groups the following regions: La Rioja (RI), Andalucía (AN), and Navarra (NC).
- **Cluster 3** (c3) groups the following regions: Galicia (GA), Asturias (AS), and the Canary Islands (CN).
- **Cluster 4** (c4) groups the following regions: Cantabria (CB), the Balearic Islands (IB), Murcia (MC), Catalonia (CT), and Valencia.
- **Cluster 5** (c5) groups the following regions: Madrid (MD) and Basque Country (PV).

Appendix 1 and Figure 4 plots, geographically, the clusters of the ACS according to variables "TICR", "amputation", "hospital", "healthcare", "broadband", "narrowband", "education", "hits.dm", "health.info.pop", "povertry", "hardware.cost" and "connect.cost". Boxplots of each of these variables are brought together in Appendix 3. We used

TABLE 5 Correlations between variables "education", "poverty", "hits.dm", "health.info.pop", "hospital", "amputation", "broadband", "narrowband", "hardware.cost", "connect.cost", "healthcare".

	Education	Poverty	Hits.dm	Health.info.pop	Hospital	Amputation	Broadband	Narrowband	Hardware.cost	Connect.cost	Healthcare
Education	1,00	0,64	0,25	−0,32	0,08	0,52	−0,20	0,34	0,46	0,46	−0,12
Poverty	0,64	1,00	0,31	−0,02	−0,22	0,75	−0,09	0,16	0,51	0,53	−0,26
Hits.dm	0,25	0,31	1,00	−0,16	−0,49	0,27	0,36	−0,08	0,10	0,08	−0,39
Health.info.pop	−0,32	−0,02	−0,16	1,00	−0,15	−0,25	0,11	−0,44	0,20	0,14	−0,14
Hospital	0,08	−0,22	−0,49	−0,15	1,00	−0,10	−0,27	−0,05	0,32	0,43	0,20
Amputation	0,52	0,75	0,27	−0,25	−0,10	1,00	−0,37	0,41	0,44	0,45	−0,04
Broadband	−0,20	−0,09	0,36	0,11	−0,27	−0,37	1,00	−0,63	−0,04	−0,16	0,10
Narrowband	0,34	0,16	−0,08	−0,44	−0,05	0,41	−0,63	1,00	−0,12	−0,05	0,23
Hardware.cost	0,46	0,51	0,10	0,20	0,32	0,44	−0,04	−0,12	1,00	0,91	−0,17
Connect.cost	0,46	0,53	0,08	0,14	0,43	0,45	−0,16	−0,05	0,91	1,00	−0,18
Healthcare	−0,12	−0,26	−0,39	−0,14	0,20	−0,04	0,10	0,23	−0,17	−0,18	1,00

Source: Ministry of economic affairs and digital transformation (state secretariat for digitalization and artificial intelligence department); instituto nacional de estadística; ministry of health.

TICR as categorical variable in the second phase of this research jointly with variables related to DM, SDOH for all the ACS in Spain.

Table 4 summarizes the descriptive statistics of the variables related to DM, such as the number of hospitalizations ("hospital") and amputations ("amputation"). On the other hand, the database has been filled in with variables related to the SDOH, such as education level and poverty. In addition, an analysis of the technological determinants of these regions was needed, such as the type of connection (broadband or narrowband) and the economic reasons for not having internet access at home, either due to the cost of the computer equipment to connect ("hardware.cost") or the connection cost ("connet.cost"). Degree of broadband coverage for each type of technology and its connection speed (TICR) has been analyzed. It also included the use of the internet (aggregated for the ACS as a whole) for searches on health-related information in general ("health.info.pop"), and the volume of online searches for the keyword "diabetes mellitus" ("hits.dm"). Finally, we included the overall health spending per patient managed by each ACS.

Table 5 outlines the correlations between the abovementioned variables.

In reference to Figure 5, the first two dimensions explain 44.85% of the cumulative variance percent. Dimension 1 (Table 6 and Figure 5) explains 25.86% of the variance, clustering the variables of "education," "poverty," "amputation," and "connect.cost." Dimension 1 (Supplementary Figure S9, see Appendix 2) summarizes (by its level of contribution to this dimension) the number of amputations caused by DM, along with the socioeconomic factors linked to the level of education and poverty as SDOH, as well as the economic reasons given for not having an internet connection at home (Supplementary Figures S9–S14, see Appendix 2).

Dimension 2 explains 18.98% of the variance percent (Supplementary Figure S10, see Appendix 2) clustering the variables "narrowband," "hardware.cost," and "broadband" related to the types of internet connection speed in people's homes and the economic reasons for not using the internet at home in relation to the cost of computer equipment.

Dimension 3 explains 15.63% of the variance percent (Supplementary Figure S11, see Appendix 2) shows the variables related to the volume of online searches for the term "diabetes mellitus" (RSV), together with the number of hospitalizations caused by DM. Dimension 4 (Supplementary Figure S12, see Appendix 2) represents the variable "health.info.pop," which relates to people's use of the internet to search for information on health-related topics in general.

Lastly, Dimension 5 includes the variables of healthcare spending per patient managed by the ACS (healthcare), and the variable that categorizes each region analyzed according to its level of broadband coverage by technology and connection speed (TICR). See Supplementary Figure S13 (Appendix 2).

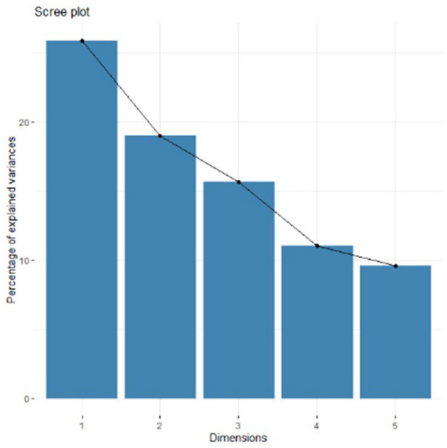
Figure 6 represents the distribution of the ACS in the map factor and in which, in turn, each region is categorized according to the value obtained in the TICR variable. Supplementary Figure S14 (see Appendix 2) plots the circle of correlations of the quantitative variables, which allowed us to check the clusters between variables, as well as their level of contribution to the corresponding dimensions.

Thus, the results obtained previously in the correlation coefficients in Table 5 show these variables related to amputations as a consequence of DM ("amputation"), together with SDOH such as poverty, education level ("education"), and internet connection cost ("connect.cost"). Figure 6 represents ACS with the highest level of amputations caused by DM, with regions that in turn have socioeconomic conditions of greater poverty, lower levels of education, and a higher share of the population whose reason for not having internet access for individual use derives from economic reasons due to the cost of the connection. Regarding Dimension 2 (Supplementary Figure S14, see Appendix 2) and as mentioned before (according to Table 5), the variables related to the proportion of the population that has a narrowband vs. broadband internet connection don't have internet at home due to the economic cost of computer equipment.

In Figure 6, it's highlighted that the existence of a greater number of amputations caused by DM, coincides with more severe socioeconomic conditions (poverty and education level). A greater amount of the population is unable to have an internet connection and computer equipment for economic reasons. It should be noted that there is a coincidence of higher numbers of amputations, higher poverty, and lower education level. We also identified a higher share of the population that is using narrowband for an internet connection. In other words, the areas with the lowest levels of broadband coverage and connection speed (coinciding with the highest share of the population reporting the use of narrowband for an internet connection) are also areas where there are higher poverty rates and lower education levels and, in turn, more economic difficulties in accessing the internet. However, these regions are also characterized, compared to the rest, by higher numbers of amputations due to DM.

Figure 6 also shows ACS with lower amputation rates, but also with better socioeconomic conditions (poverty and education), together with lower rates of narrowband housing, fewer cases of not using the internet due to economic cost, and greater use of broadband. In addition, there is a coincidence of the ACS which, according to the TICR classification, belongs to clusters 2, 4 and 5. This implies that a greater percentage of the population has a broadband connection and speeds higher than 100 Mbps.

Next, we analyzed the relationship between the variables linked to DM ("hospital" and "amputation"), socioeconomic factors ("poverty" and "education"), types of internet connection



	eigenvalue	variance percent	cumulative variance percent
Dim.1	3,879937	25,866245	25,866245
Dim.2	2,848342	18,988948	44,855193
Dim.3	2,344709	15,631391	60,486584
Dim.4	1,652999	11,019995	71,506579
Dim.5	1,436618	9,577456	81,084035

FIGURE 5
Percentage of inertia explained by each FAMD dimensions. SDOH and DM variables.

TABLE 6 Contributions to the dimensions of DM and the SDOH variables.

	Dim.1	Dim.2	Dim.3	Dim.4	Dim.5
Education	16,685	0,075	0,250	4,207	5,882
Poverty	16,793	1,420	2,967	2,154	0,096
Hits.dm	0,945	4,455	24,115	0,022	6,518
Health.info.pop	1,839	6,805	2,098	16,147	1,782
Hospital	0,309	0,061	28,526	9,671	0,429
Amputation	18,450	0,292	1,901	2,542	5,099
Broadband	4,843	13,949	8,373	7,302	1,073
Narrowband	5,194	21,400	0,506	0,161	0,007
Hardware.cost	10,688	13,172	3,270	0,031	2,212
Connect.cost	12,594	8,804	5,332	0,024	0,112
Healthcare	0,441	3,670	0,288	20,477	26,868
TICR	11,220	25,897	22,375	37,261	49,921

speeds ("broadband" and "narrowband"), and the share of the population that uses the internet to search for information about health in general ("health.info.pop") and DM in particular ("hits.dm"). According to Supplementary Figure S15 (see Appendix 2), there is no correlation of the hits.dm variable with socioeconomic factors, type of internet connection band, economic reasons for not using the internet, or the amputation rate. If we compare this relationship in Supplementary Figure S16 (see Appendix 2), we can also observe that the variable health.info.pop is not related to the health determinant variable (the amputation rate), to the type of connection, or to the reasons for using or not using the internet. However, as with the "hits.dm," the variable for searching for information on the internet on health issues ("health.info.pop") also has a negative relationship with the rate of hospitalizations caused by DM ("hospital"), although less than the variable referred to RSV on "hits.dm." Figure 7, Supplementary Figure S17 shows that there isn't a TICR pattern in ACS (Supplementary Figures S16–S18, see Appendix 2).

Dimensions 3 and 4 (Supplementary Figure S18, see Appendix 2), variable "health.info.pop" is not correlated with "hits.dm" or with "hospital." There isn't a TICR pattern in ACS in Figure 8.

Finally, we explored the distribution of the ACS according to dimensions 1 and 5. Based on the clusters obtained according to the correlations between the variables (Supplementary Figure S19, see Appendix 2), healthcare spending per patient managed by the ACS ("healthcare") is not correlated with amputation rate ("amputation") or with the social and economic conditioning factors of the regions ("poverty" and "education"), or with the economic reasons for not having an internet connection for individual use ("hardware.cost" and "connect.cost"). Figure 9 shows that there isn't a TICR pattern in ACS.

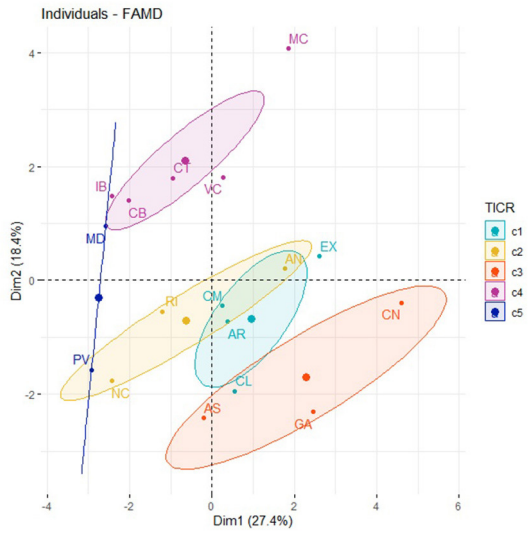


FIGURE 6
Factor map of the ACS, Dimension 1, Dimension 2, and TICR.

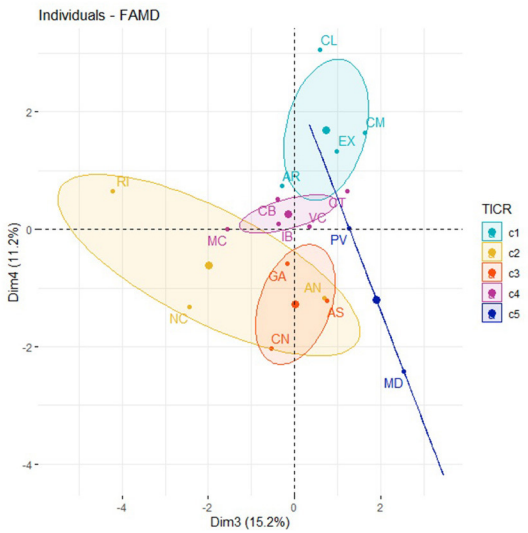


FIGURE 8
Factor map of the ACS, Dimension 3, Dimension 4, and the TICR.

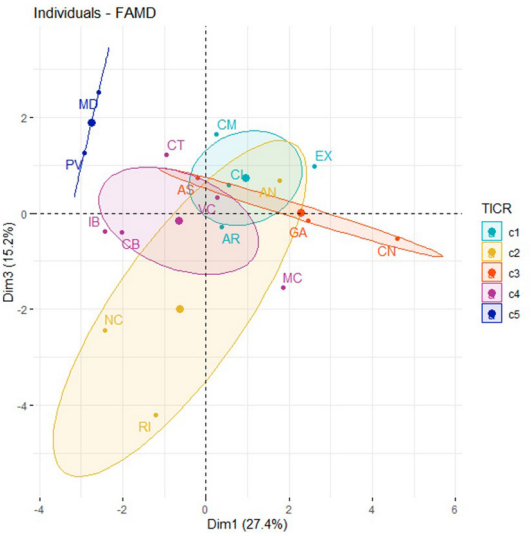


FIGURE 7
Factor map of the ACS. Dimension 1, Dimension 3, and TICR.

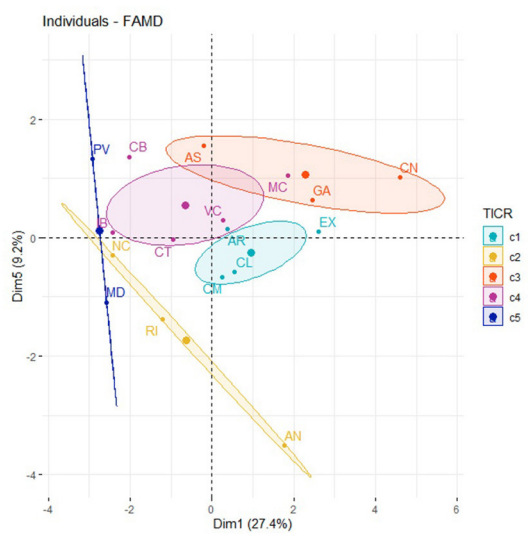


FIGURE 9
Factor map of the ACS, Dimension 1, Dimension 5, and the TICR.

Discussion

The present study coincides with the conclusions of prior research, discussed above, related to inequality and the use of ICT (5, 17–19, 54). Likewise, we also agree with (53) on the importance of education and inequality in internet use, and with (10) approach to internet use. We agree with (2) on what kinds of inequalities can affect society.

Our results revealed a greater number of amputations in regions (ACS) with a higher rate of poverty and a lower level of education. These are regions with the highest number of individuals who have declared, according to official statistics, that they do not use the internet for economic reasons, especially because of connection costs. Among those who do use it, they state that the connections have been through narrowband. Furthermore, according to the variable

obtained in this study, these ACS are regions with the greatest percentage of internet coverage among the set of technologies analyzed and at the lowest speed compared to the other regions.

On the other hand, ACS with fewer amputations have lower aggregate poverty rates, higher levels of education, and fewer individuals who report not using the internet for economic reasons. Moreover, with regard to the variable created, TICR, these are regions with greater internet coverage on average in comparison to the rest of the ACS among the set of technologies, and with higher connection speeds. Regarding the search for online information on health issues in general and DM in particular, we noted that people in ACS with a lower number of hospitalizations had a greater interest in searching for the term "diabetes mellitus," and, unexpectedly, in regions with a higher number of hospitalizations due to DM. We did not detect any relationship between hospitalizations due to DM and use of the internet declared by users regarding searches on topics about health in general. In relation to online searches and internet coverage and connection speeds, the results were disparate, and we observed no pattern between the regions. This was the case with health care costs per patient and the variable TICR, with different relationships between the ACS.

This study on the effects of DM in Spain, related to the rates of amputations and hospitalizations as a consequence of DM, includes as a novelty the use of technological determinants of health. To this end, and as a contribution of this work, we obtained the TICR variable in the initial phase using FAMD. This variable classifies the ACS according to their percentage of broadband coverage based on different existing technologies, as well as connection speeds. Subsequently, this new qualitative variable that categorizes the Spanish regions according to their ICT infrastructure has been linked to variables related to the type of internet connection, the reason for using the internet to search for information on health in general and DM in particular, and economic reasons for not having internet access at home. This set of technological determinants of health has been tied to health-related socioeconomic variables (poverty and education level), in addition to health spending.

Please note that, as a limitation of this study, we extracted the sources (aggregated data) of the database from official institutions. Ceuta and Melilla (two Spanish ACS) were excluded from this study because some variables needed were not available. Furthermore, we extracted the data related to the monitoring of interest in DM through the internet *via* GT; this tool is linked to user searches on the Google search engine. Please, be aware that in this research, the results were not classified by population age ranges in patients with DM due to the technological variables used in this study. Data available did not show these demographic characteristics. In addition, the multivariate methodology applied has been useful for measuring and explaining the degree of relationships between the selected variables.

This research is propitious to open new lines of work, such as performing an exhaustive study of the same in each autonomous community, adding more variables related to the telecommunications sector. It would also be interesting to evaluate more sequelae resulting from DM and, for this purpose, to use microdata. The information generated would be useful for public policymakers and, in this way, helpful for generating proposals for citizens to promote the use of ICT, education, and ultimately contribute to the development of eHealth.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: Spain's Health Ministry, http://inclasns.msssi.es/main.html; Ministry of Economic Affairs and Digital Transformation, https://portal.mineco.gob.es/; Google Trends, https://trends.google.es; Spain's National Institute of Statistics, https://www.ine.es.

Author contributions

Conceptualization, formal analysis, investigation, and writing—original draft preparation: IBF. Methodology, resources, and data curation: IBF and FCV. Validation and supervision: IBF, FCV, MCL, and MJPL. Writing—review and editing: IBF, FCV, and MCL. Project administration: MCL and IBF. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.1033461/full#supplementary-material

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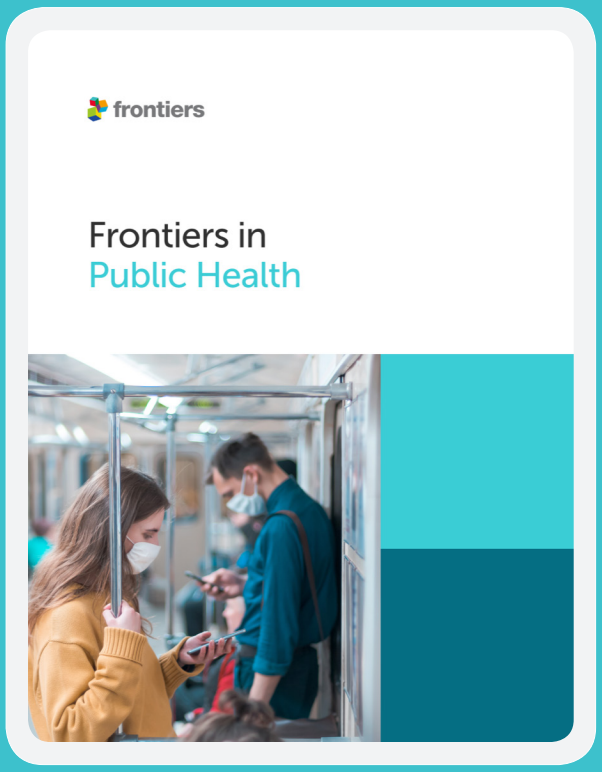

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