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Environmental regulation, high-quality economic development and ecological capital utilization

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The key to realizing sustainable human development is to improve the utilization of ecological capital. Under the requirements of innovation-driven and green economic development, how to formulate appropriate environmental regulation policies and accurately implement high-quality economic development strategies to promote the utilization of ecological capital has become the focus of theoretical research and practical exploration. This paper examines the effects of environmental regulation, high-quality economic development, and the interaction term between the two on ecological capital utilization using a fixed-effects model based on panel data for 30 provincial-level political regions (excluding Tibet) in China from 2008 to 2020. The empirical results show that both environmental regulation and economic quality development have a significant positive effect on ecological capital utilization. However, environmental regulation can inhibit technological innovation, which in turn affects economic quality development, and the interaction term between environmental regulation and economic quality development has a significant negative effect on ecological capital utilization. Based on this, the government should enhance environmental regulations while increasing support and technological innovation subsidies for heavily polluting enterprises and new industries to promote high-quality economic development while improving the utilization of ecological capital.

KEYWORDS

ecological capital utilization, environmental regulation, high-quality economic development, fixed-effects model, panel data

1 Introduction

Amid the rapid growth of the global economy and the ongoing expansion of the population, environmental issues have emerged as a global challenge (Fang and Cao, 2019). The traditional model of economic growth has resulted in severe environmental pollution and ecological degradation, including but not limited to the decline in air and water quality, land desertification, and the loss of biodiversity (Santika et al., 2020; Chen et al., 2021). Concurrently, global climate change has exerted profound impacts on ecosystems and human societies, positioning environmental issues as a major constraint on the pursuit of high-quality economic development (Zhang et al., 2022a). Against this backdrop, there is a growing recognition of the critical role of environmental regulation in maintaining ecological balance and fostering high-quality economic development. However, while environmental regulation can improve ecosystem health, it may also impose certain constraints on high-quality economic development. Some businesses and governments express concerns that environmental regulation could increase production costs, reduce competitiveness, and even lead to job losses (Mi et al., 2018; Tian et al., 2020). Therefore, finding a balance between environmental regulation, economic development, and ecological preservation has become an urgent and significant issue to address.

The impact of environmental regulation on the economy is a complex and far-reaching issue. Stringent environmental regulations can motivate businesses to increase their investment in and research and development of clean production technologies. This, in turn, drives technological innovation, enhances production efficiency, and thereby facilitates the upgrading and transformation of industrial structures (Ouyang et al., 2020; Jiang et al., 2021; Nazir et al., 2023). Additionally, environmental regulation aids businesses in utilizing resources more efficiently, reducing production costs, and enhancing the economic efficiency of resource use, which, over the long term, is beneficial for the healthy development of the economy (Testa et al., 2011; Yan et al., 2020; Yang et al., 2021). However, certain environmental regulations may lead to increased production costs for businesses, negatively impacting their profitability and potentially causing operational difficulties for some, thus exerting an impact on the economy (CHUNG and Sun-Hwa, 2016; Shi and Huang, 2019). Simultaneously, strict environmental regulations might lead to a reduction in jobs in labor-intensive industries, while giving rise to new environmental industries, thus exerting certain adjustments and impacts on the labor market. In summary, reasonable and scientific environmental regulations can promote the upgrading of economic and industrial structures, technological innovation, and the efficiency of resource utilization, playing a positive role in the high-quality development of the economy. However, in implementing environmental regulations, it is necessary to consider the needs of economic development, avoiding overly stringent regulations that may cause unnecessary difficulties for business operations, thereby achieving a positive interaction between environmental protection and high-quality economic development (Ahmed et al., 2022).

Similarly, high-quality economic development has a significant impact on the utilization of ecological capital. Ecological capital, as part of natural assets, provides crucial support for economic activities in terms of water resources, soil, air quality, and biodiversity, playing an indispensable role in energy production, agricultural development, and tourism (Pan et al., 2021). However, with the intensification of economic activities, ecological capital also faces continual degradation and depletion, such as excessive resource extraction and environmental pollution (Wang et al., 2021; Wang and Zhou, 2021). Thus, there has been a gradual shift from merely focusing on economic development to prioritizing high-quality economic development, which places greater emphasis on environmental protection and sustainable growth. This shift can prompt governments to establish ecological compensation mechanisms or markets for ecological services, making businesses responsible for the protection and restoration of ecosystems, and ensuring they pay a corresponding price for these efforts (Ren, 2018; Zhou and Huang, 2020). Moreover, high-quality development implies increased investment in research and development, encouraging the growth of green technologies and innovations to reduce resource wastage and environmental pollution (Cao and Ge, 2021; Li et al., 2021a; Li and Hu, 2021). Therefore, high-quality economic development can effectively protect and enhance the utilization of ecological capital. It involves considering the value of ecological capital in economic policies and planning, actively promoting the implementation of green development concepts, and thereby achieving a beneficial interaction and sustainable development between the economy and the ecosystem.

To ensure sustainable development in our country, this paper delves deeply into the relationships among environmental regulation, high-quality economic development, and the utilization of ecological capital, also offering insights for global development. The empirical research in this paper unfolds in the following aspects: Firstly, we have constructed an econometric model that encapsulates the interplay between environmental regulation, high-quality economic development, and the utilization of ecological capital. We found that both environmental regulation and high-quality economic development significantly promote the utilization of ecological capital. However, it was observed that the interaction between environmental regulation and high-quality economic development is negatively correlated with the utilization of ecological capital, leading us to hypothesize a link with corporate technological innovation. Consequently, we further examined the impact of environmental regulation on technological innovation. Our findings reveal a negative correlation between environmental regulation and technological innovation, which could be detrimental to high-quality economic development and impede the enhancement of ecological capital utilization, thus confirming our hypothesis. We also noted a negative correlation between industrial structure and technological innovation, indicating that a higher proportion of the tertiary sector suppresses technological innovation. This is particularly notable since, starting from 2013, the total value of China's tertiary industry surpassed that of the secondary industry for the first time. Therefore, we conducted a time heterogeneity analysis. The empirical results indicate that from 2008 to 2013, the industrial structure was negatively correlated with the utilization of ecological capital, whereas from 2014 to 2020, the correlation turned positive.

In our research, we also identified and addressed certain limitations in the existing literature, making corresponding improvements. Previous studies have predominantly focused on the impact of environmental regulation on aspects like high-quality economic development, with less attention given to the influence of environmental regulation and high-quality economic development on the utilization of ecological capital. Moreover, the current conclusions in this area are still mixed, indicating the need for further analysis using more detailed data. Additionally, academic research in the ecological domain often revolves around ecological welfare performance, ecosystem changes, and ecological risk assessments. In contrast, our study adopts a novel perspective by focusing on the utilization of ecological capital. This approach not only contributes to the field but also lays a foundational base for further research by other scholars. By exploring this new angle, our study enriches the understanding of ecological capital and its interconnections with economic and regulatory factors, offering a fresh perspective to the ongoing discourse in environmental economics and sustainability studies.

2 Literature review

The concept of ecological capital was first introduced in the 1987 Brundtland Commission report, "Our Common Future," which pioneered the view of environmental resources as ecological capital. Presently, ecological capital is understood as ecological resources and environments that yield economic and social benefits. This encompasses the total volume of natural resources, the quality of the environment and its self-purification ability, the use value of ecosystems, and the potential to generate use value for future outputs (Yan et al., 2010). Current research on ecological capital primarily concentrates on understanding and assessing the value of resources and services provided by the natural environment, as well as how these capitals can be utilized effectively and sustainably within the framework of economic development. Yu et al. (2019) argue that ecological capital consists of renewable natural capital stocks and ecosystem services. Zou and Li (2022) argue that agro-ecological capital inputs make a significant contribution to the development of a green circular economy in general. Based on the description of the current situation of ecological resources in Poyang Lake Ecological and Economic Zone, Li & Meng (2018) pointed out that ecological capital operation in Poyang Lake Ecological and Economic Zone is a way to realize the ecological economic development of Poyang Lake, to realize the value preservation and appreciation of ecological capital and promote sustainable development. However, today, with the continuous expansion of economic scale, it has approached or may exceed the carrying capacity of the ecosystem (Zhang and Peng, 2020). To change the *status quo*, human beings have to be concerned with minimizing the consumption of ecological capital while enhancing the economy, that is, to improve the utilization of ecological capital (Liu et al., 2014). Scholars have done relatively little research on ecological capital utilization, so it needs to be further explored.

There is a close relationship between high-quality economic development and ecological capital utilization, which is inherent in high-quality economic development and has a unity of effective ecological capital utilization. High-quality development is different from the traditional development approach. Traditional development pays more attention to economic growth and solves the problem of insufficient material wealth (Wang et al., 2016). High-quality development pays more attention to a more comprehensive, not only to material wealth but also to spiritual wealth, but also resources, environment, and ecology, to achieve coordinated development between human beings and ecology (Zhang and Fu, 2021). Within this framework, ecological capital, comprising natural resources and ecosystem services, forms the foundation for achieving these objectives. They provide the essential resources and environmental conditions necessary for fostering innovation and technological development, supporting the sustainability of economic activities (Yan et al., 2010). On the other hand, the nature and intensity of economic activities directly impact the state of ecological capital. Excessive exploitation and improper utilization of natural resources can lead to ecosystem degradation and resource depletion, thereby limiting the long-term developmental potential of the economy (Santika et al., 2020). Therefore, one of the key elements in achieving high-quality economic development is finding a method that not only stimulates economic growth but also ensures the sustainability and resilience of ecological capital. This necessitates a collaborative effort among policymakers, businesses, and all societal sectors to develop and adopt more environmentally friendly technologies and management strategies. Such efforts are aimed at ensuring that economic growth coexists harmoniously with the ecological environment, balancing the immediate needs of development with long-term environmental sustainability. In the report of the 19th National Congress of the Communist Party of China, it is pointed out that "we should not only create more material and spiritual wealth to meet people's growing needs for a better life but also provide more high-quality ecological products to meet people's growing needs for a beautiful ecological environment". Since the reform and opening up, China's industrialization has entered a highly developed stage, and people have started to use ecological capital recklessly to meet their basic needs, causing serious environmental pollution and ecological damage. However, when basic needs are met, people's demand for a beautiful ecological environment begins to emerge (Li et al., 2021b). However, only the effective use of ecological capital can reduce environmental pollution and ecological damage while developing the economy. Therefore, high-quality economic development necessarily contains the effective use of ecological capital, which not only responds to the development of the economy and society but also the requirements of the development of the times. China is known as a large manufacturing country, with a large area, a large population, and enough low-cost labor, land, resources, etc. It has always been at the low end of the international division of labor, producing products for the world while paying the price of ecological damage (Davidg et al., 2006). China wants to change this situation, from a large manufacturing country to a strong manufacturing country, so it puts forward the strategy of high-quality economic development. High-quality economic development requires technological innovation, which provides technical production support and promotes industrial structure transformation and upgrading, thus improving ecological capital utilization (Cao and Ge, 2021; Xie and Zuo, 2022).

The ability of environmental regulations to affect ecological capital utilization has been verified, but the results of their effects are more controversial. On the positive side, the greater the intensity of environmental regulation, the more obvious the compensation effect of enterprise innovation, and the improvement of environmental quality brought by technological progress, which is conducive to the utilization of ecological capital. A reasonable set of environmental regulations can motivate firms to further optimize resource allocation efficiency and improve technology levels, thus, creating an innovation compensation effect for firms (Yan et al., 2020; Yang et al., 2021; Fang and Cao, 2019; Zhang et al., 2022b). The reasonable setting of environmental regulation intensity can also compensate for the increased cost of pollution control and reduce the pressure on enterprises. Zhang et al. (2019) also found that there was regional heterogeneity in the impact of environmental regulation on environmental quality, which promoted the improvement of environmental quality in the economically developed regions, while inhibiting the improvement of environmental quality in the economically underdeveloped western regions, thus having different impacts on the utilization of ecological capital. On the negative side, the implementation of environmental regulations will increase the cost of enterprises, which will crowd out investment in technology research and development, and enterprises will expand their production scale to compensate for this cost, resulting in a larger scale of environmental pollution and deterioration of environmental quality, which is not conducive to the use of ecological capital. Farzin and Kort (2000) investigated the enterprises in the perfect competition market. If the pollution tax ratio or environmental regulation is within a certain range, increasing the pollution tax or improving the environmental regulation level will increase the investment in pollution control of enterprises. The increase in enterprises' costs not only inhibits their original technological innovation but also drives high-polluting industries from provinces with stricter environmental regulations to provinces with weaker environmental regulation (Conrad and Wastl, 1995; Wang and Zhou, 2021). Zhang et al. (2019) pointed out that the degree of industrial agglomeration in various parts of China was increasing, which greatly aggravated environmental pollution. Since the industry is the largest polluting industry, scholars have mostly explored the impact of environmental regulation from the perspective of the industry. Li et al. (2021b) argue that an environmental tax on high pollutant emitting firms can increase their production costs, thereby reducing energy demand and CO_2 emissions and improving environmental quality. Environmental regulation can also reduce carbon emissions by influencing industrial structure, foreign direct investment, and technological innovation (Wang and Liu, 2019; Neves et al., 2020; Shao et al., 2021). Yu and Shen (2020) pointed out that an increase in the intensity of environmental regulations not only significantly improves industrial capacity utilization but also increases industrial capacity utilization through innovation offset effects. Whether the improvement of environmental quality or the increase of the utilization rate of industrial capacity can promote the utilization of ecological capital.

Environmental regulations also act on high-quality economic development and have an impact on the utilization of ecological capital. Three different perspectives on the impact of environmental regulation on quality economic development can be broadly summarized based on the existing literature. Firstly, it is believed that environmental regulations will have a negative impact on economic quality development, that is, there is the "compliance cost" effect. Traditional neoclassical economists argue that after the government imposes environmental regulations, the cost of investment of enterprises to control environmental pollution will increase as a result, which in turn will weaken the market competitiveness of enterprises and is detrimental to the development of enterprises and the growth of the regional economy. Greenstone et al. (2011) measured the change in total factor productivity of tens of thousands of U.S. manufacturing plants before and after the implementation of environmental regulations based on detailed production data and suggested that the implementation of environmental regulations led to a decrease in productivity, which was detrimental to U.S. economic growth. Liu et al. (2021) argue that the costs associated with improved environmental regulations increase the burden on firms and have a crowding-out effect on other productive investments, hindering the improvement of green total factor productivity. Therefore, the implementation of environmental regulations inhibits high-quality economic development. Secondly, it is believed that environmental regulations have a positive impact on the quality of economic development, that is, there is an "innovation compensation" effect. Yang et al. (2019) argue that although environmental regulations can put cost pressure on firms, they can also prompt firms to choose to strengthen internal management, improve efficiency, and increase innovation, ultimately leading to increased output and efficiency. Shi et al. (2022) and Yu and Wang (2021) illustrate that environmental regulation can promote high-quality economic development from the perspective of enterprises and industrial structure respectively. It has also been shown that environmental regulations can influence the quality development of the economy by promoting technological innovation of firms (Li and Hu, 2021), and significant differences have been found in different regions and batches (Yang, 2021). Thirdly, it is believed that there is no obvious causal relationship between environmental regulation and high-quality economic development. Ma and Xu (2022) argue that there is an inverted "U" shape relationship between environmental regulation and high-quality economic development in general and that the impact varies across regions. Zhang and Zhou (2021) argue that environmental regulation may lead to higher economic operating costs and lower economic efficiency in the short run, but in the long run, environmental regulation strongly contributes to the long-term healthy and sustainable development of the economy by promoting technological progress.

Through literature review, it is found that there are great differences in the results of existing empirical studies. This is mostly related to the regional and industry differences of the research objects, and also to the research methods only selecting a single variable in environmental regulation or high-quality economic development without considering the joint effect of the two. Therefore, this paper incorporates environmental regulation, high-quality economic development, and ecological capital utilization into the same framework and analyzes the impact of environmental regulation, high-quality economic development, and the interaction term of both on ecological capital utilization. The rest of this paper is arranged as follows: The third section is the empirical model construction, variables, and data explanation, and all variables are statistically analyzed; The fourth section is the empirical results, using the fixed effect model to test the impact of environmental regulation, high-quality economic development and their interaction terms on the utilization of ecological capital, and then the robustness test, and further study on the impact of the controversial control variables on ecological capital utilization; The fifth section summarizes the relevant conclusions based on the research results and puts forward relevant policy suggestions for ecological capital utilization.

3 Model establishment and index selection

To identify the synergistic effects of environmental regulation and high-quality economic development on ecological capital utilization, an interaction term between the two is included. The constructed econometric model is shown in Equation 1.

$$\text{In}ECU_{it} = \alpha + \beta_1 \ln Q_{it} + \beta_2 \ln HQED_{it} + \beta_3 \ln Q^* \ln HQED_{it} + \beta_Z \ln Z_{it} + \varepsilon_{it} \tag{1}$$

Where, i denotes the province, t denotes the year, ECU denotes the level of ecological capital utilization, Q denotes the intensity of environmental regulation, $HQED$ denotes the level of high quality economic development, Z_{it} denotes control variables. εit is the error term. To overcome the effect of heteroskedasticity on the model regression results, the above variables are treated as logarithmic.

Provincial panel data from 2008 to 2020 are used in this paper. Due to the lack of data in Tibet, the remaining 30 provincial panel data are selected as samples for analysis. The explanatory variable is ECU and the explanatory variables are Q and HQED and the interaction term of both. The variables affecting ecological capital utilization were considered comprehensively, and technological innovation, human capital, industrial structure, and infrastructure level were finally selected as control variables. To eliminate the effect of heteroskedasticity on the model estimation, all the above data were treated as logarithms, and the data were mainly obtained from China Statistical Yearbook, China Environmental Statistical Yearbook, and China Energy Statistical Yearbook, etc., the descriptive statistics of the data are shown in Table 1. We elaborate on each indicator separately below.

3.1 Ecological capital utilization (ECU)

Ecological carrying capacity was measured. Humans take resources and services from nature to meet their own development needs, but if they plunder or destroy excessively, they can cause ecosystems to become vulnerable or even collapse. In the long run of development, China's economy keeps growing, and if we keep using ecological capital without improving its utilization, the carrying capacity of resources and the environment will only get lower and lower. The carrying capacity of resources and the environment is just a part of ecological carrying capacity, so we choose ecological carrying capacity as the measure of ecological capital utilization.

Ecological carrying capacity refers to the supporting capacity of regional water, soil, and other ecological environment elements under the comprehensive influence of human activities and climate change. There are many factors affecting ecological carrying capacity, including economic, social, resource, and environmental factors. In view of this, this paper introduces the DPSIR conceptual model and constructs a comprehensive ecological carrying capacity evaluation index system from five aspects: driving force subsystem, pressure subsystem, state subsystem, impact subsystem, and response subsystem. Among them, three indicators, namely GDP *per capita*, disposable income per urban resident, and disposable income per rural resident, are selected for the driving force subsystem to reflect the socio-economic development. The pressure subsystem selects three indicators of industrial solid waste generation, urban unemployment rate, and the proportion of industry to GDP to reflect the environmental, resource, and social pressure situation, and all three indicators have negative effects. In the status subsystem, water resources *per capita*, electricity consumption *per capita*, and beds per thousand people are selected to represent the status of the ecosystem. In the influence subsystem, urbanization rate, forest coverage rate, and afforestation coverage rate of built-up areas are selected to reflect the impact of ecology on society and the economy. In the response subsystem, the proportion of environmental pollution control investment in GDP, the ratio of industrial waste synthesis and utilization rate, and the proportion of tertiary industry in GDP are selected to reflect the government's response to the improvement of ecological carrying capacity. After dimensionless processing of these 15 indicators and then calculating the weights, h is obtained, and then the entropy weighting method is used to calculate the comprehensive score of ecological carrying capacity F. The formula is shown in formula 2:

$$F_i = \frac{1 + \sum_{i=1}^{I} h_{ij} \ln\left(h_{ij}\right) \Big/ \ln(\mathrm{I})}{\sum_{j=1}^{J}\left(1 + \sum_{i=1}^{I} h_{ij} \ln\left(h_{ij}\right) \Big/ \ln(\mathrm{I})\right)} \times h_{ij} \tag{2}$$

Where, h denotes the weight, $h_{ij} = Y_{ij} / \sum_{j=1}^{n} Y_{ij}$ obtained by calculation. Y is the index after dimensionless treatment; F denotes the composite score of ecological carrying capacity; I is the total number of samples.

3.2 Environmental regulation (*Q*)

Industrial sulfur dioxide emissions were measured. Environmental regulation includes the formulation and implementation of environmental policies, and the intensity of environmental regulation is usually expressed by the effect of policy implementation. The industry is the largest polluting sector and the most directly and visibly subject to government environmental regulation, and SO2 is a pollutant with a clear source and good industry compatibility that provides a good picture of industrial pollutant emissions (Song et al., 2021). In summary, referring to Yabar et al. (2013) and Shen et al. (2017), in this paper, industrial SO2 emissions are chosen to represent the intensity of environmental regulation, and to reduce the effect of outliers, we first logarithmically process them and then take the inverse. On the one hand, environmental regulation can force enterprises to make technological innovation, and technological progress will improve the efficiency of resource utilization, making ecological capital effective. On the other hand, environmental regulations can increase the cost and reduce the profit of enterprises, and they have to reduce their investment in technological research and development, which is detrimental to the use of ecological capital. Therefore, the impact of environmental regulation on ecological capital utilization is uncertain, and the prediction coefficient of this index is unknown.

3.3 High-quality economic development (HQED)

According to previous studies (Li et al., 2021a; Zhang et al, 2022a; Zhang et al, 2022b), we constructed a comprehensive evaluation index system of high-quality economic development from five aspects of economic development level, coordination, innovation, sharing, and green development. The most representative evaluation indexes are selected for each aspect, and *per capita* GDP is used to represent the level of economic development, the ratio of the tertiary industry to secondary industry is used to represent the coordination of development, the sales revenue of new products is used to represent innovation ability, the passenger volume of public transport is used to represent sharing, and the forest coverage rate is used to represent green development level. The five indicators are dimensionless processed and then weights are calculated to obtain m. The same entropy weighting method is used to calculate the comprehensive score of economic quality development H. The formula is shown in formula 3:

$$H_i = \frac{1 + \sum_{i=1}^{I} m_{ij} \ln\left(m_{ij}\right) \Big/ \ln(\mathrm{I})}{\sum_{j=1}^{J} \left(1 + \sum_{i=1}^{I} m_{ij} \ln\left(m_{ij}\right) \Big/ \ln(\mathrm{I})\right)} \times m_{ij} \tag{3}$$

Where, m denotes the weight, $m_{ij} = Y_{ij}$ obtained by calculation. Y is the index after dimensionless treatment; H denotes the composite score of ecological carrying capacity; I is the total number of samples.

3.4 Technology innovation (RDe)

R&D expenditure is used to measure. If an enterprise wants to change the traditional extensive production mode, the key is to improve its technical level and strengthen its independent innovation ability, to make the production of the enterprise become high quality and high efficiency. The expenditure on R&D funds plays a great role in boosting production (Du, 2021). Therefore, the predictive coefficient of this index is positive.

3.5 Industry structure (IS)

The proportion of tertiary industry/proportion of the secondary industry is used to measure. The change of industrial structure is manifested in the industrial change of the whole society, the development of new industries, and the transformation of three industries. According to the law of social development, human society always changes gradually from the primary industry to the secondary and tertiary industries, and the emergence and development of new industries also often exist in the secondary and tertiary industries. Changes in industrial structure often mean the emergence of new social needs, and for enterprises, it also means the emergence of new interests and profit growth points. In order to better compete with other enterprises, it is especially important to reduce the relative costs of production of new industries, new products, and new services, and technological innovation is one of the most important means to reduce relative costs. Therefore, with the change and improvement of industrial structure, the investment in scientific and technological innovation of the whole society will often increase substantially, and the progress of science and technology will improve the utilization of ecological capital. Therefore, the predictive coefficient of this index is positive.

3.6 Human capital (EDU)

Education is the most important way of human capital formation, and the number of people receiving higher education is the main indicator of the high level of human capital. Therefore, this paper adopts the number of students in ordinary institutions of higher learning to measure. It has been shown that human capital can be used as a tool for technological innovation and technology application to determine technological progress (Magno et al., 2022), thus allowing the efficient use of ecological capital. Therefore, the predictive coefficient of this index is positive.

3.7 Infrastructure level (INF)

The infrastructure level is measured by the urban road area *per capita*, which is calculated from the urban road area/urban population. The urban road area *per capita* can reflect the ability of urban transportation infrastructure to serve the urban population and the development of urban transportation infrastructure and can be used to evaluate the level of regional infrastructure. The level of infrastructure reflects the development of the region to a certain extent, and a well-developed infrastructure also accelerates socio-economic activities and promotes the utilization of ecological capital. Therefore, the predictive coefficient of this index is positive.

4 Empirical analysis

4.1 Empirical results

The Hausman test is performed before the panel data are regressed to determine whether to use a fixed effects model or a random effects model. Based on the test results it is concluded that regression should be performed using a fixed effects model with panel data. The regression of the core explanatory variables on ecological capital use is presented in column (1), and the robustness is demonstrated by adding control variables in columns (2), (3), (4), and (5) in turn, while examining the effects brought by the control variables. The regression results are shown in Table 2.

The regression results in Table 2 show that environmental regulation is positively related to ecological capital utilization, which indicates that enhanced environmental regulation can promote ecological capital utilization. On the one hand, the government's increased environmental protection regulation and the intensity of environmental regulations will force enterprises to innovate, which will reduce their energy consumption rate and improve ecological capital utilization. On the other hand, enhanced environmental regulation can promote green technological progress by facilitating the optimization of enterprises' green production processes and product quality improvement, thus having a catalytic effect on ecological capital utilization.

TABLE 1 Descriptive statistics of the variables.

Variables	Sample size	Maximum value	Minimum value	Mean value	Standard deviation	Predicted coefficient symbol
lnECU	390	4.292	2.984	3.656	0.222	—
lnQ	390	14.749	6.993	8.126	1.052	?
lnHQED	390	4.178	0.886	2.983	0.571	+
lnRDe	390	17.03	7.06	13.859	0.571	+
lnIS	390	6.275	3.910	4.632	0.419	+
lnINF	390	3.288	1.396	2.658	0.365	+
lnEDU	390	14.729	10.650	13.411	0.815	+
lnOU	390	9.762	4.336	7.470	0.971	+
lnLED	390	12.013	9.085	10.686	0.532	+
lnUR	390	4.495	3.371	4.010	0.223	+

TABLE 2 Results of empirical analysis on the influencing factors of ecological capital utilization.

Variables	(1)	(2)	(3)	(4)	(5)
lnQ	0.052 (0.22)	0.072* (0.09)	0.086** (0.04)	0.080** (0.04)	0.070* (0.07)
lnHQED	0.292*** (0.00)	0.324*** (0.00)	0.367*** (0.00)	0.324*** (0.00)	0.280*** (0.00)
lnQ*lnHQED	−0.020** (0.04)	−0.024** (0.01)	−0.028*** (0.00)	−0.023** (0.01)	−0.018** (0.04)
lnRDe		0.027** (0.03)	0.010 (0.44)	0.005 (0.71)	0.001 (0.95)
lnIS			−0.091*** (0.00)	−0.077*** (0.00)	−0.051** (0.05)
lnINF				0.185*** (0.00)	0.133*** (0.00)
lnEDU					0.175*** (0.00)
Constant	2.643*** (0.00)	2.144*** (0.00)	2.614*** (0.00)	2.234*** (0.00)	0.094 (0.87)
Time fixed effects	Yes	Yes	Yes	Yes	Yes
Regional fixed effects	Yes	Yes	Yes	Yes	Yes
F	208.57	198.04	192.42	207.40	211.12
P	0.0000	0.0000	0.0000	0.0000	0.0000
N	390	390	390	390	390
R^2	0.901	0.902	0.905	0.916	0.922

Note: *, **, *** indicate significant at the 10%, 5%, and 1% levels, respectively.

There is a positive correlation between high-quality economic development and ecological capital utilization, indicating that the improvement of high-quality economic development will also promote the utilization of local ecological capital, which is the same as the expected result. The high-quality development of the economy has led to the gradual optimization of the energy use and development system, and new opportunities for science and technology projects in energy. At the same time, the high quality of economic development has prompted many scientific and technological developments toward environmental protection, more and more ecological construction projects are receiving attention, and ecological capital utilization is gradually improving.

Most of the control variables are the same as the expected results. There is a positive correlation between R&D expenditure and ecological capital utilization. For enterprises, R&D funding can relieve the financial pressure on their R&D activities and improve their technological innovation capability. For universities and scientific research institutions, R&D funds can improve technological innovation ability by training innovative talents and producing original knowledge achievements. The improvement of technological innovation in all aspects promotes the utilization of ecological capital. Human capital is positively correlated with ecological capital utilization, that is, improved human capital brings a large number of skilled people, which promotes technological innovation, which in turn enhances ecological capital use. There is a positive correlation between infrastructure construction and the utilization of ecological capital, which indicates that the perfect infrastructure drives the social and economic activities in the region, and economic development promotes ecological capital utilization. Different from the expected results, the industrial structure is negatively correlated with ecological capital utilization, indicating that ecological capital utilization will be inhibited when the tertiary industry occupies a large proportion. The tertiary industry refers to all kinds of service industries, which have relatively low resource consumption and less environmental pollution, and is an important factor to promote the heightened industrial structure, which can improve the quality of economic growth at the structural level. At the same time, the increase in the share of the tertiary sector, which implies an increase in the country's technological capacity, is positively correlated with ecological capital use and is not consistent with the regression results. We take into account the possible temporal heterogeneity and, therefore, need to retest the effect of industrial structure on ecological capital use at different periods.

Different from the expected results, the interaction term of environmental regulation and high-quality economic development was negatively correlated with ecological capital utilization, indicating that the interaction between environmental regulation and high-quality economic development would inhibit ecological capital utilization. It may be because, after the enhanced environmental regulation, the cost investment of enterprises to combat environmental pollution is increasing significantly, which has a crowding-out effect on other technological investments and discourages enterprises from technological innovation, or the profits generated by enterprise innovation are not enough to offset the costs invested in combating environmental pollution, inhibiting the high-quality economic development, while the reduced level of high-quality economic development hinders the utilization of ecological capital. According to the previous section, both environmental regulation and high-quality economic development will promote ecological capital utilization, and environmental regulation will force enterprises to invest more in technological innovation and increase their productivity, to obtain innovation compensation, which will promote high-quality economic development and enhance ecological capital utilization at the same time, but this may not be the case in reality.

To verify that the interaction between environmental regulation and high-quality economic development inhibits ecological capital use, we propose the following conjecture:

Conjecture 1: The implementation of environmental regulations discourages firms from engaging in technological innovation and inhibits high-quality economic development, thereby hindering the utilization of ecological capital.

To test conjecture 1, the model is set up as shown in Equation 4.

$$RDE_{it} = \alpha + \beta_1 \ln Q_{it} + \beta_Z \ln Z_{it} + \varepsilon_{it} \tag{4}$$

Where, Zit denotes the province, εit denotes the year, i denotes technological innovation capability, t denotes the intensity of environmental regulation, ECU denotes the control variables, here the level of economic development, industrial structure, openness to the outside world, and urbanization level are taken. IS is the error term. All variables were treated as logarithmic. The indicators not covered above are described below.

TABLE 3 Results of the empirical analysis of factors influencing technological innovation.

Variables	(1)	(2)	(3)
lnQ	−0.067** (0.03)	−0.054** (0.02)	−0.501*** (0.00)
lnLED	0.870*** (0.00)	1.648*** (0.00)	1.857*** (0.00)
lnIS	−0.407*** (0.00)	0.088 (0.24)	−0.254 (0.39)
lnOU	0.125*** (0.00)	0.116*** (0.01)	0.181* (0.08)
lnUR	−0.257 (0.46)	−0.290 (0.34)	0.655 (0.46)
Constant	6.380*** (0.00)	−3.423*** (0.00)	−4.714*** (0.00)
F	175.36		42.38
P	0.000		0.000
N	390	390	390
R^2	0.897		0.356

Note: *, **, *** indicate significant at the 10%, 5%, and 1% levels, respectively.

4.1.1 Openness (OU)

The ratio of total import and export to GDP is used as the measure. The larger the value, the higher the economic openness. Opening up to the outside world can introduce advanced foreign technology to promote the transformation and upgrading of industrial structure, while the introduction of foreign capital can also provide the material basis for regional industrial upgrading, while technology-driven industrial upgrading will promote ecological capital utilization. Therefore, the predictive coefficient of this index is positive.

4.1.2 Economic development level (LED)

The GDP *per capita* measure was used. Regions with a high level of economic development will have more funds flowing to universities or research institutions, which plays a role in promoting technological innovation. Therefore, the predictive coefficient of this index is positive.

4.1.3 Urbanization level (UR)

The urbanization rate measure is used, which is measured by the share of the urban population in the total population. The level of urbanization reflects the living standard of the inhabitants of a region and is an important guarantee for conducting scientific and technological innovation activities. Areas with better urbanization have a good cultural atmosphere and educational environment, which can promote the cultivation of high-quality and high-skilled talents and facilitate the formation of original human capital for science and technology innovation. Therefore, the predictive coefficient of this index is positive.

Based on the test results it is concluded that the regression should be performed using the fixed effects model (1) for panel data. Meanwhile, to further test the robustness of the fixed-effects model estimation results, the random-effects model (2) and mixed regression (3) are estimated again in this paper. The regression results are shown in Table 3.

From the regression results in Table 3, it is clear that environmental regulation is negatively related to technological

TABLE 4 Robustness tests (Explained variables:*ECU*).

Variables	(1)	(2)	(3)
lnQ	0.496*** (0.00)	0.171*** (0.00)	0.167*** (0.00)
lnHQED	0.552*** (0.00)	0.273*** (0.00)	0.243*** (0.00)
lnQ*lnHQED	−0.042*** (0.00)	−0.034*** (0.01)	−0.033*** (0.00)
lnRDe	−0.023* (0.07)	−0.008 (0.47)	0.006 (0.57)
lnIS	0.053** (0.04)	−0.022 (0.33)	−0.014 (0.53)
lnINF	0.103*** (0.00)	0.101*** (0.00)	0.099*** (0.00)
lnEDU	0.078** (0.03)	0.180*** (0.00)	0.078** (0.03)
Constant	−3.951*** (0.00)	−0.128 (0.78)	
Time fixed effects	Yes	Yes	Yes
Regional fixed effects	Yes	Yes	Yes
F	230.53	254.88	
P	0.0000	0.0000	
N	390	390	390
R^2	0.928	0.934	0.014

Note: *, **, *** indicate significant at the 10%, 5%, and 1% levels, respectively.

innovation, which indicates that enhanced environmental regulation inhibits technological innovation. When environmental regulations are implemented, companies will take measures to meet the pollution emission standards set by the government, such as treating the emitted pollutants, using more environmentally friendly production and processing materials, and strengthening real-time testing of environmental pollution. All of these make the cost of environmental management increase, thus to a certain extent reducing the profits of enterprises, their market competitiveness decreases, and they have to reduce investment in technology research and development, which inhibits the technological innovation of enterprises, which is not conducive to high-quality economic development, and the reduction of the level of high-quality economic development, which hinders the use of ecological capital. This verifies our conjecture1.

4.2 Robustness tests

In order to ensure the validity of the research results, this paper further conducts a robustness test on the regression results in Table 2. Per capita GDP represents the economic value generated by each individual in a country or region. A higher *per capita* GDP typically indicates a higher standard of living and better citizen welfare. It signifies that economic growth encompasses not just quantitative increases but also qualitative improvements such as technological advancements and enhanced efficiency. The proportion of environmental pollution control investment in GDP directly reflects the extent of financial commitment and social investment a country or region makes in environmental protection. A higher ratio usually implies a greater emphasis on environmental conservation. This indicator serves as a crucial measure of how a nation or region prioritizes its environmental health relative to its economic development, signifying a balance between economic growth and sustainable ecological practices. Therefore, in this paper, the regression results are re-estimated in three different forms: replacing the measure index of high-quality economic development with *per capita* GDP (1), replacing the measure index of environmental regulation with the proportion of investment in environmental pollution control in GDP (2), and replacing the OLS model (3) with the spatial Dubin model. As shown in Table 4, the impact results of environmental regulation, high-quality economic development, and their interaction terms on ecological capital utilization are generally similar to those before replacement, which indicates that the results in Table 2 are robust and reliable.

4.3 Time heterogeneity analysis of the impact of industrial structure on ecological capital utilization

It is noteworthy that industrial structure and technological innovation are also negatively correlated, indicating that a larger share of tertiary industry inhibits technological innovation. However, the tertiary industry is mostly knowledge-intensive and more market-oriented, which is more likely to promote technological innovation through endogenous technological progress and capital accumulation under the competitive mechanism. On the contrary, the secondary industry is mostly dominated by state-owned enterprises, which themselves are less market-oriented and lack incentives to pursue technological innovation under the role of government protection, which is what inhibits technological innovation. This reinforces the need to re-test the impact of industrial structure on ecological capital use across time.

Since the total value of the tertiary sector exceeded the secondary sector in China for the first time in 2013, this section divides the study years into 2 time periods for analysis, 2008–2013 and 2014–2020, to examine whether the industrial structure brings different impacts on ecological capital use in these 2 periods. The setup model is shown in Equation 5.

$$\ln ECU_{it} = \alpha + \beta_1 \ln IS_{it} + \beta_z \ln Z_{it} + \varepsilon_{it} \tag{5}$$

Where, εit denotes the province, denotes the year, denotes the level of ecological capital utilization, denotes the level of industrial structure, denotes control variables, here technological innovation, human capital and infrastructure development are taken. εit is the error term.

The regression results are shown in Table 5, with column (1) showing the effect of industrial structure on ecological capital use from 2008 to 2013 and column (2) showing the effect of industrial structure on ecological capital use from 2014 to 2020. Meanwhile, column (3) and column (4) are estimated with the spatial Dubin model instead of the fixed effects model to test their robustness. The regression results are shown in Table 5.

According to the regression results in Table 5, there is a negative correlation between industrial structure and ecological capital utilization from 2008 to 2013, indicating that industrial structure

TABLE 5 Time heterogeneity regression results (Explained variables:*ECU*).

Variables	(1)	(2)	(3)	(4)
lnIS	−0.007 (0.88)	0.070** (0.02)	−0.001 (0.99)	0.075*** (0.00)
lnRDe	−0.085*** (0.00)	0.021 (0.17)	−0.047* (0.07)	0.024* (0.08)
lnEDU	0.370*** (0.00)	0.154*** (0.00)	0.302*** (0.00)	0.068 (0.15)
lnINF	0.145** (0.02)	0.044 (0.16)	0.163*** (0.00)	0.051* (0.05)
Constant	−0.715 (0.54)	0.880 (0.13)		
F	83.65	106.70		
P	0.000	0.000		
Time fixed effects	Yes	Yes	Yes	Yes
Regional fixed effects	Yes	Yes	Yes	Yes
N	180	210	180	210
R^2	0.842	0.863	0.001	0.000

Note: *, **, *** indicate significant at the 10%, 5%, and 1% levels, respectively.

inhibits ecological capital utilization. The reason may be that before 2013, the tertiary industry was still lagging in most regions of China, the service and information industries had not yet fully emerged, and the secondary industry was still the mainstay of economic development. The development mode of high energy consumption and high pollution in the early stage of the secondary industry has damaged the ecological environment. The implementation of environmental regulation makes most of the funds used to control environmental pollution, crowding out the input of scientific and technological innovation, and the utilization of ecological capital is affected. In 2014–2020, the industrial structure is positively correlated with ecological capital utilization, indicating that the role of industrial structure on ecological capital utilization shifts from inhibiting to promoting. After the gross value of China's tertiary industry exceeded that of the secondary industry for the first time in 2013, China has taken industrial restructuring and upgrading as an important task to transform its economic development mode at present and in the future. China has further consolidated the foundation of agriculture, continued to optimize the industrial structure and promoted the development of strategic emerging industries and the service industry. Remarkable results have been achieved in the adjustment of the industrial structure, the economic development has become more stable, and the utilization of ecological capital has been promoted.

5 Conclusions and policy recommendations

This paper empirically analyzes the effects of environmental regulation, high-quality economic development, and the interaction term between the two on ecological capital use, using provincial panel data from 2008 to 2020 as a sample. The main findings are as follows. Both environmental regulation and high-quality economic development have significant positive effects on ecological capital utilization. However, environmental regulation inhibits technological innovation, which in turn affects economic quality development, so the interaction term between environmental regulation and economic quality development has a significant negative effect on ecological capital utilization. In addition, R&D expenditure, human capital, and infrastructure level all promote ecological capital utilization, and there is temporal heterogeneity in the effect of industrial structure on ecological capital utilization, which has also promoted ecological capital utilization in recent years. Based on this, the study proposes the following policies and recommendations.

Firstly, improve the environmental regulation system and reasonably increase the intensity of environmental regulation. The study shows that environmental regulation has a significant positive impact on ecological capital utilization, but it inhibits technological innovation and hinders high-quality economic development. Therefore, while improving the intensity of environmental regulation, the government needs to accurately determine the policy focus and regulation direction, encourage enterprises to carry out green technology research and development, reduce energy consumption, achieve clean production, and green development, and obtain more compensation for innovation. It is also necessary to increase support for heavily polluting enterprises and subsidies for technological innovation, promote regional coordinated development, and improve the utilization rate of ecological capital. At the same time, we should also strongly support the development of new industries to drive high-quality economic development. In addition, the government should focus on raising public awareness of low carbon and environmental protection, guiding residents to green consumption and green travel, and reducing the emission of pollutants from their lives.

Secondly, vigorously promote high-quality economic development. The study shows that high-quality economic development has a significant positive impact on ecological capital utilization. The primary force to promote high-quality economic development is technological innovation, but the current level of innovation development in China is short board. Therefore, in future development, we should focus on promoting technological innovation, solving technical difficulties, and improving ecological capital utilization. At the same time, it is necessary to strengthen the construction of the economic circle between neighboring regions and provinces with close economic ties, establish the inter-provincial economic circle with regional characteristics, realize the win-win development of the inter-provincial economy, and promote the utilization of ecological capital.

Thirdly, the active role of technological innovation, human capital, and infrastructure levels in contributing to ecological capital utilization goals should be fully guided and leveraged. R&D funding should be boosted, while the government should do a good job of monitoring and supervising to ensure that it is used for technology development rather than supporting backward enterprises. And constantly improve our scientific and technological innovation ability, stimulate enterprise organizational innovation and management innovation, then promote technological innovation, accelerate technological progress, and promote ecological capital utilization. We should continue to implement the strategy of "strengthening the country with human resources" and train more skilled personnel while improving the quality of the nation so that the knowledge and technology of human capital can become an endogenous force to promote ecological capital utilization. We should accelerate the establishment of sound social infrastructures such as education, medical care, and environmental protection, and improve the level of comprehensive infrastructure services by expanding new areas, guiding new subjects, and innovating investment.

Fourthly, the reform should be deepened comprehensively to promote the development of the tertiary industry. Through temporal heterogeneity analysis, it is found that the tertiary sector positively affects ecological capital utilization when its share is higher than that of the secondary sector. Therefore, the overall planning and guidance of the tertiary industry should be strengthened in the future to promote the orderly, healthy, and coordinated development of the modern tertiary industry. However, the development of society and people's life cannot be separated from the manufacturing industry, we cannot develop the tertiary industry in isolation from industry, but should implement the "two-wheel drive" strategy of modern manufacturing and tertiary industry in the division of labor and interaction, embedding high-end service elements firmly in the manufacturing industry, and promoting the transformation and upgrading of the manufacturing industry through the development of the tertiary industry.

This paper also acknowledges certain limitations. Due to the heterogeneity across various industries, a more detailed classification of industries was not conducted. In future research, a deeper investigation into the impact of environmental regulation and high-quality economic development on the utilization of ecological capital across different industries could be pursued. Furthermore, the study is constrained by the availability and completeness of data, with the data selection limited to 30 provinces and cities in China. If future research could access data from multiple countries, the test results would be more robust and persuasive. Consequently, the policy recommendations proposed in this study could be applicable not just to China, but to a broader international context. This approach would enhance the generalizability and relevance of the findings, contributing to a more comprehensive understanding of the global implications of environmental regulation and high-quality economic development.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/supplementary material.

Author contributions

TL: Investigation, Methodology, Writing–original draft. WT: Conceptualization, Software, Writing–original draft. SW: Formal Analysis, Supervision, Writing–original draft. SZ: Conceptualization, Investigation, Writing–review and editing.

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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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