frontiers | Frontiers in Environmental Science

TYPE Original Research
PUBLISHED 21 January 2025
DOI 10.3389/fenvs.2024.1522259

Check for updates

OPEN ACCESS

EDITED BY
Najabat Ali,
Soochow University, China

REVIEWED BY
Anwar Khan,
Xiamen University, China
Muhammad Nauman Sadiq,
Hamdard University Islamabad, Pakistan
Sher Abbas,
Liaoning University, China

*CORRESPONDENCE
Xuanting Li,
hitxuanxuan@163.com

RECEIVED 05 November 2024
ACCEPTED 23 December 2024
PUBLISHED 21 January 2025

CITATION
Wang X and Li X (2025) Towards a green world: how new urbanization affects green total factor carbon productivity.
Front. Environ. Sci. 12:1522259.
doi: 10.3389/fenvs.2024.1522259

Towards a green world: how new urbanization affects green total factor carbon productivity

Xiaohong Wang and Xuanting Li*

Department Business, Harbin Institute of Technology, Harbin, China

Introduction: New urbanization is a powerful support for regional economic growth and green transformation.

Methods: In this paper, we select data from 237 cities at prefecture level and above in China from 2010 to 2021 for quasi-experimental design, and investigate the effects of new urbanization policy pilots on urban green total factor productivity (*GTFP*) and its mechanism by constructing a multi-period difference-in-differences model.

Results: The study finds that: a) the construction of new urbanization has a positive impact on promoting urban GTFP, and this result is verified by a series of robustness tests; b) the promotion of industrial structure upgrading, the facilitation of green technological innovation, and the reduction of the degree of resource mismatch all partially mediate the relationship between new urbanization and urban GTFP; c) environmental regulation and market integration both modulate the relationship between the construction of new urbanization and urban GTFP in positive directions; d) heterogeneity analysis shows that, in terms of the two-dimensional city attributes of 'location-characteristics', the increase in GTFP is more significant in eastern and central cities, and in non-resource cities; e) further analysis shows that the pilot policies of new urbanization have a spatial spillover effect on GTFP, and the policy spillover effects are mainly affected through mechanisms such as industrial structure upgrading in neighboring municipalities.

Discussion: This study provides new ideas for the next stage of sustainable regional green development in China, thus promoting China's high-quality development with theoretical and practical significance.

KEYWORDS

new urbanization, green total factor productivity, difference-in-differences model, spatial spillover effects, green sustainability development

1 Introduction

New urbanization is an important strategic support for urban planning and sustainable economic development, and the promotion of new urbanization is conducive to the promotion of a harmonious coexistence of the economy, the environment and the humanities. Since the Industrial Revolution, in order to achieve great economic revival and prosperity, most countries, especially developing countries, have adopted the traditional urbanization development model characterised by crude and radical development. It is worth noting, however, that this has also led to a serious urban development crisis: which focuses on quantity rather than quality, has made it difficult to create a synergistic and mutually beneficial relationship between economic development and environmental protection. In this regard, developing countries that are rapidly urbanising have a top-priority agenda to reconcile the developmental conflicts between urbanization and greening in order to address the enormous challenges of urban development issues (Wang and Foley, 2023). Therefore, it has become a topic of global concern how to promote green economic development, effectively enhance environmental quality and comprehensively construct a green development path while advancing urbanization.

At present, the construction of new urbanization is playing an increasingly important role in promoting green and sustainable development. The construction of new urbanization emphasises a green, circular and low-carbon urban development model, and some studies suggest that new urbanization is a reflection and adjustment of the traditional urbanization path, covering the four aspects of human nature, synergy, inclusiveness and sustainability, and transforming the development around the industrial economy, urban construction, public services and environmental protection (Lynam et al., 2023; Wang and Foley, 2021). Different from the previous development models of 'rapid urbanization' and 'reverse urbanization', the new urbanization construction focuses on eliminating the shortcomings of crude development, exerts a significant optimisation effect of coordinated development of the economy and the environment. It not only helps to alleviate the contradiction between economic development and environmental protection, but also helps to form a new pattern of economic growth and green sustainable development on a global scale.

What is the definition of green sustainable development? Huang et al. (2023) and Amirzadeh and Sharifi (2024) based on the theory of urbanization and the theory of efficiency that towns and cities are the core of the region, urbanization plays an important role in green development, and the implementation of the development strategy of urbanization is more likely to achieve green growth. Given that urban green sustainable development is closely related to regional green economic development, green sustainable development is a way of economic growth and social development that aims at efficiency, harmony, and sustainability (Abdeldayem, 2023), and green total factor productivity (*GTFP*) is a kind of resource allocation efficiency that takes environmental resources into account, and its enhancement and the idea of green sustainable development are highly fits, so we adopt green total factor productivity (*GTFP*) to measure the green sustainable development of cities (Feng et al., 2021).

As mentioned above, the country attaches importance to the green and sustainable development strategy, and academics are still very interested in how new urbanization achieves green economic growth and sustainable development. At present, the established literature has explored various aspects of GTFP, and more literature focuses on how to accurately measure GTFP and its influencing factors and other perspectives for systematic research (Schmid et al., 2018; Jiang et al., 2022). However, the differences in the selection of relevant indicators, such as the object of study, the period of study, and the output of the economic environment, have led to differences in the measurement results of GTFP. In addition, some literature has explored the influencing factors of GTFP based on the perspectives of environmental regulation, financial development, innovation drive, and trade openness (Hu and Chen, 2015; Governa and Sampieri, 2020), but little literature has explored the influencing effects of the new urbanization assumptions on GTFP from the perspective of policy evaluation. It is worth noting that the impact effect of implementing the development strategy of new urbanization on sustainable development helps scholars to better understand the effect of the implementation of new urbanization, which is relevant to the implementation of new urbanization in other cities. The current literature highlights the effectiveness of new urbanization construction in enhancing GTFP through mechanisms such as cleaner production technologies, human capital accumulation, and improved energy efficiency. Ultimately, the implementation of new urbanization is a development strategy and plan formulated by the government and influenced by various internal and external factors. Research on whether new urbanization can promote green and sustainable development is still limited, and there is still room for further exploration of in-depth research on the mechanisms by which new urbanization affects GTFP.

In order to fill this research void, based on the policy evaluation perspective, this study considers the implementation of the national comprehensive pilot policy of new urbanization as a quasi-natural experiment of new urbanization construction, empirically examines the impacts of new urbanization on GTFP and its mechanisms using the multi-period difference-in-differences method, and further explores its spatial effects. This study has four potential contributions to the research related to new urbanization construction and green sustainable development. First, compared with previous studies, there is little literature exploring the relationship between new urbanization construction and green sustainable development from the perspective of policy evaluation, and this study effectively identifies the causal relationship between the two, providing macro-level empirical experience on the impacts of green economy and sustainable development in urban construction. Second, existing literature exploring the intrinsic mechanism of the relationship between new urbanization construction on GTFP has not reached a consistent conclusion, and this study examines the mediating roles of industrial structure upgrading, green technological innovation, and the degree of resource mismatch in the relationship between pilot policies for new urbanization construction and green sustainable development. Third, by examining the boundary roles of environmental regulation intensity and market integration in the relationship between new urbanization construction and green sustainable development, it expands the research on contingent conditions in related literature. Fourth, there are fewer studies on the policy spillover effects of new urbanization construction in related studies, and this paper further explores the spatial spillover effects of pilot policies of new urbanization construction on green sustainable development, contributing to the literature in the field of spatial economics of sustainable development.

2 Policy background and theoretical analyses

2.1 Policy background

After years of efforts, China's new urbanization construction has achieved certain results, and the development of urbanization is regarded as an important event affecting the course of mankind in the 21st century. China's urbanization rate has surged from 17.9% in 1978 to 66.16% in 2023, a year-on-year increase of 0.94%, with an increase of 11.96 million people in the urban population (Chen et al., 2024; Ma and Liu, 2024), which has resulted in a drastic change in the urban landscape. In addition, this not only reflects the government's investment in and support for urbanization, but also shows China's determination to green its economy and sustainable development, highlighting its commitment to upholding green and sustainable development.

In 2014, as the pilot guide and planning blueprint for the comprehensive pilot policy of new urbanization, the National New urbanization Plan (2014–2020) has a guiding role in guiding the drafting of the pilot implementation plan for the relevant pilot areas, and for the first time clarified the development path and strategic objectives of new urbanization from the national institutional level, and its basic principles and policy objectives are the important reference for the promulgation of the policy implementation of the local policies. Its basic principles and policy objectives are important references for the promulgation and implementation of policies in different regions. 106 cities (towns) were jointly identified as national pilot areas for new urbanization in three batches in February, November 2015 and 2016, and the pilot cities were required to achieve replicable and generalizable milestone results in each pilot task, so as to accumulate successful pilot experiences for nationwide promotion afterwards. Since then, all three batches of integrated pilot cities for new urbanization have entered the pilot construction phase, and new urbanization has not only established an initial policy framework to support the green transformation of cities, but has also provided practical experience for the sustainable development of cities and the green economic growth of the entire country.

2.2 Theoretical analyses

At present, China's urbanization process is in a critical period dominated by innovation-driven and quality-enhancing development. Unlike traditional urbanization, new-type urbanization needs to change the development mode of urbanization, solve the problems of unbalanced urban and rural development and environmental pollution that existed in the development of traditional urbanization, and ultimately promote the transformation of urbanization in the direction of green, low-carbon and sustainable development. In addition, studies have shown that the influencing factors of green total factor productivity mainly include industrial structure and technological innovation. Therefore, based on the basic principles of "ecological civilization, green and low-carbon", "optimized layout, intensive and efficient" put forward in the National New Urbanization Plan (2014–2020) issued by the State Council of China, we analyze new urbanization from both direct and indirect aspects. And indirectly, we analyze the mechanism of new urbanization construction on green total factor productivity, and further explore the spatial spillover effect of new urbanization construction.

2.2.1 New urbanization and GFTP

China's urbanisation development is a top-down driven process led by the government, and in the face of the demand for green and sustainable urban development, the pilot policy of new urbanisation construction emphasises the core of human beings, and focuses on getting rid of the realistic dilemma of the difficulty of coordinated development of economic growth and environmental protection, and solves the problems of low population density and ecological and environmental pollution that existed in the traditional urbanisation process (Wang et al., 2019; Zhou, 2018). According to the endogenous growth theory, when the green economic growth rate is accelerated in the process of new urbanisation, the green total factor production efficiency can be continuously improved to avoid the occurrence of the "green paradox" (Roon, 2012). The implementation of China's new urbanisation pilot policy is conducive to guiding and stimulating the alleviation of the contradiction between the green economy and the ecological environment, and has a driving effect on the improvement of the sustainable development capacity of cities. On the one hand, new urbanisation explicitly proposes to promote the construction of green cities, implement the green economy combined with the concept of sustainable development (Cobbinah et al., 2015), optimise urban spatial layout, strictly control the development of high-energy-consuming and high-polluting industries, and promote the gradual transformation of urban industries to digitalisation, which provides the main conceptual support for the realisation of green sustainable development. On the other hand, the Environmental Kuznets Theory suggests that economic growth comes at the cost of sacrificing the ecological environment to some extent (Zhang et al., 2018). Therefore, the development of urbanization has brought enormous pressure to the ecological environment, but the construction of new urbanisation emphasises the pilot areas' efforts to eliminate the shortcomings of rough development and give full play to the significant environmental optimisation effect, which enriches the policy toolbox for promoting green sustainable development, reshapes the concept of urban development and emphasises the coordinated development of population, society and environment, thus enhancing the green total factor productivity of cities. Accordingly, we propose Hypothesis 1:

H1. The pilot policy of new urbanisation construction has a positive effect on green total factor productivity.

2.2.2 The mediating role of industrial structure upgrading, green technology innovation and the degree of resource mismatch

Industrial structure upgrading plays an important role in the positive impact of new urbanisation construction on green total factor productivity. According to the theory of Cordy-Clark and the theory of Kuznets industrial structure, the optimisation and upgrading of industrial structure is a process of continuous improvement and innovation through the internal adjustment of industries and industries (Sun, 2022c). On the one hand, in order to implement the concept of green and sustainable development, the new urbanization policy requires pilot cities to accelerate the construction of green cities, and part of the enterprises in the low value-added production lines are shut down and transformed to high-yield and low-pollution production lines, and give rise to a number of environmentally friendly and knowledge-intensive industrial agglomeration and development, which promotes the formation of a green economic model and improves the green total factor productivity (Liu et al., 2022). On the other hand, based on Tibbett's selection-related theory, the new urbanisation construction realises the inter-regional interaction between talents and industries, refines the social division of labour and the rational allocation of resources, and promotes the upgrading and transformation of industrial structure (Zhou et al., 2024). Along with the development of the new urbanisation construction, the population agglomeration and changes in lifestyle also provide human capital support for industrial upgrading and transformation, expand the demand for industrial manufactured goods and production services, promote the settlement of new industries and related production services, such as fibre-optic communication and information transmission and other related industries, focus on the coordinated and balanced development of industries, and help to achieve the rationalisation of the layout of industries to adapt to the standards of green and sustainable development (Lin and Zhong, 2024). Therefore, industrial structure upgrading, as the foundation of green economic development, has the role of controlling environmental pollution and rational allocation of resources, which determines the economic development mode and environmental quality to a certain extent, and improves green total factor productivity. Accordingly, we propose Hypothesis 2a:

H2a. The pilot policy of new urbanisation construction improves green total factor productivity through industrial structure upgrading.

Based on the theory of endogenous growth and agglomeration economy, the construction of new urbanisation is conducive to promoting the agglomeration of high-end talents and capitals in cities and towns, and accelerating the enhancement of innovation productivity, while green technology innovation as an endogenous driving force for economic development can effectively enhance green total factor productivity (Sun et al., 2022a). Specifically, the construction of new urbanisation advocates the use of the city as an innovation carrier, giving full play to the learning effect and knowledge spillover within the city, accelerating the production of new ideas and enhancing the city's innovation capacity. In order to further promote the construction of new urbanisation, the pilot regions will increase the investment in green innovation infrastructure, create a policy and institutional environment for green innovation, and improve the efficiency of innovation transformation by relying on the advantages of education and human resources (Du and Li, 2019), so as to improve the level of the local green economy. In addition, due to the implementation of pilot policies, the concentration of innovative talent capital is conducive to the formation of innovation bases, and enterprises and other relevant subjects can share public resources such as green production technologies and pollution treatment means (Zhao et al., 2022). The construction of new urbanisation can provide a carrier and support for enterprises to carry out technological innovation activities, and the concentration of innovation factors and diffusion of knowledge brought about by it can promote technological innovation to a greater extent (Lin and Zhong, 2024). Therefore, green technological innovation, as a means to optimise the efficiency of resource allocation, can promote the improvement and application of green production technology and promote green sustainable development. Consequently, we propose the third hypothesis.

H2b. Green technology innovation mediates between new urbanisation construction and green total factor productivity.

The implementation of new urbanisation construction has not changed the factor-driven growth model, and the degree of resource mismatch is an important factor constraining green total factor productivity. Compared with the optimal allocation, resource mismatch will lead to a counter-efficient flow of resources, which will constrain the improvement of green total factor productivity (Jiang et al., 2023). According to the theory of induced technological change, the relative prices of production resource factors and available technologies are the key drivers for urban business entities to allocate labour and capital (Li et al., 2022). However, at present, China's capital market mechanism is still immature, and needs to rely on government means to allocate resource factors. The construction of new urbanisation requires pilot cities to achieve specific economic development goals within a certain period of time, and local government officials, as the implementers of the policy, have the dual attributes of being both politicians and economists, which will intervene in the capital market, resulting in the mismatch of capitals and the distortion of the capital price, which will aggravate the degree of resource mismatch (Lu and Lu, 2024). Urban business entities are unable to make real rational decisions, and resource mismatch leads to some backward production capacity enterprises to use capital at a lower price than the market, resulting in backward industrial enterprises being unable to exit the market in accordance with the market mechanism, and the pollution intensity of capital-intensive products is higher than that of labour-intensive products, which is detrimental to the coordinated and stable development (Dai et al., 2024). Deepen the intra-city conflicts, thus negatively affecting the green total factor productivity. Based on the above analysis, this paper proposes Hypothesis 4:

H2c. New urbanisation construction improves green total factor productivity by reducing the degree of resource mismatch.

2.2.3 The moderating role of environmental regulation, market integration

Based on the static analytical framework under the assumption of perfect market competition in the neoclassical school of economics, environmental regulation is an effective policy instrument to solve the problem of environmental externalities (Chen et al., 2019). One of the main features is the intensity of environmental regulation, which can draw local governments' attention to sustainable development issues, influence green sustainable development commitments, and encourage them to adopt corresponding environmentally responsive behaviours (Zhu et al., 2020). On the one hand, in order to achieve green economic growth in each pilot city of new urbanisation, the relevant government departments may, through strengthening the control of emissions behaviour of high-polluting and high-energy-consuming enterprises in their jurisdictions, become an external pressure to force industrial enterprises to carry out technological innovations and improvements in production processes, so as to increase green total factor productivity and gradually reduce energy consumption per unit of output value in the production process, in order to adapt to the market's increasingly high The "quality threshold", i.e., the "forcing effect" of environmental regulation (Lee et al., 2022). On the other hand, following the theory of eco-modernisation, the new type of urbanisation emphasises the construction of low-carbon production and living, and the pilot cities have strengthened the environmental assessment and review of new investment projects, so as to encourage enterprises to have a competitive advantage in the market through technological innovation and industrial improvement in production, and thus to gain more profits, in order to partially or fully offset the rise in production costs and the additional investment in technological innovation and production process improvement. This provides an incentive for industrial firms to continue to improve green product quality and productivity, i.e., the "compensatory effect" of environmental regulation (Sun and Zhang, 2022b). These environmental response behaviours are expected to further enhance the contribution of new urbanisation to GTFP. Therefore, we hypothesize that the positive impact of new urbanisation on GTFP will increase when the intensity of environmental regulation increases. Therefore, we hypothesise.

H3. Environmental regulation intensity positively moderates the relationship between new urbanisation and GTFP.

According to the theory of growth poles and the theory of new structural economics, the free flow of factor resources between regions may play a crucial role in strengthening the overall environmental ecosystem, making it possible for localised development to propel to the whole economy (Wang and Foley, 2023). As the degree of market integration increases, each pilot city of new urbanisation with different comparative advantages and different development conditions is able to create an external environment that contributes to the city's economy through the division of labour, market expansion and knowledge spillover, and through the promotion of the free flow of factors (Zhao, 2023), which not only helps to promote the flow of factors from low-quality to high-quality areas, and guides various types of factors to higher productivity enterprises or industries, it also helps to eliminate zombie enterprises or backward production capacity, which in turn improves total factor productivity and green economic development (Wu et al., 2020). In addition, according to the theory of demand-led innovation, market integration expands the space for urban development and market demand, which helps enterprises to actively carry out product research and development and product innovation, and provides an important impetus for urban innovation and development, which not only encourages formal or informal exchanges of innovative talents between different cities and accelerates the diffusion of innovation results between different cities, but also promotes the improvement of urban green development level (Cheng and Shen, 2024). Based on these findings, we propose H4.

H4. The stronger the degree of market integration, the stronger the impact of new urbanisation pilot cities on GTFP.

2.2.4 Spatial effects of new urbanisation

Due to the existence of exchanges and interactions, the implementation of regional policies or government actions may have an impact on the economic and social development of neighbouring cities (Elhorst, 2010). On the one hand, there are frequent technology diffusion, industrial agglomeration, diversified competition in environmental governance and other economic links between regions, and through the radiation-driven effect of local cities and the learning and imitation effect of neighbouring cities, the policies of local cities will have an impact on the development of neighbouring cities (Vega and Elhorst, 2015). On the other hand, regional policies or measures will also have an impact on the allocation of spatial resources, which will lead to the 'rainbow effect' of the central city on the development of the surrounding areas (You and Lv, 2018). Such exchanges between cities may promote specialisation and effective competition, breaking down administrative barriers and contributing to the green total factor productivity of neighbouring cities.

The upgrading of industrial structure, green technological innovation and regional resource mismatch in terms of green total factor productivity in cities will have an impact on the policy effects of the new urbanisation assumptions. For the pilot cities of new urbanisation, the transformation of their industrial structure and the improvement of their green technological innovation level will have a radiation-driven effect on the surrounding areas. The industrial structure and green innovation level of the cities provide strong human capital support for the development of new urbanisation as well as the level of governmental governance, etc., and therefore, they have a more obvious effect on the enhancement of the green TFP of the cities, and have a more radiation-driven effect on the surrounding cities. Therefore, it is more obvious to enhance the green total factor productivity of the city, and the radiation driving effect on the surrounding cities is also greater. However, at the same time, it may also lead to the directional transfer of resources, increase the resource difference between regions, and the Matthew effect of 'the strong getting stronger and the weak getting weaker' will appear. In addition, although the construction of new towns and cities has strengthened regional transactions in the surrounding areas, due to the differences in the level of development of each city, it is easy to exacerbate the degree of resource mismatch in the neighbouring areas, such as the implementation of the 'R & D in the local area, the transformation of the outside world' model of cooperation between industry, academia and research, which is not conducive to the green sustainable development of the surrounding cities.

Based on the above analyses, we propose the following hypothesis.

H5. There is a spatial spillover effect of new urbanisation on green total factor productivity in cities.

H5a. New urbanisation suppresses the green total factor productivity of neighbouring areas by inhibiting the industrial structure upgrading of neighbouring cities.

H5b. New urbanisation promotes green total factor productivity in neighbouring areas by increasing green technological innovation in neighbouring cities.

10.3389/fenvs.2024.1522259

TABLE 1 Definitions and descriptive statistics of the variables.

Type	Variables	Variable symbols	Description of variables	Data resource	N	Mean	SD	Min	Median	Max
Dependent variable	Green total factor productivity	GTFP	Based on the following formula	China Urban Statistical Yearbook China Energy Statistics Yearbook	2,844	0.319	0.127	0.048	0.307	0.7
Independent variable	New Urbanisation Pilot	DID	Whether or not it is a new urbanisation pilot, yes 1; no 0	National New Urbanization Plan (2014–2020)	2,844	0.216	0.412	0	0	1
Mediating variables	Upgrading of industrial structure	UIS	Share of tertiary sector in GDP/share of secondary sector in GDP	China Statistical Yearbook	2,844	1.034	0.527	0.312	0.914	3.368
	Green Technology Innovation	GPAT	Number of urban green patents plus 1 to take the logarithm	China Science and Technology Statistical Yearbook	2,844	5.062	1.714	1.386	5.004	9.165
	Degree of resource mismatch	RES	Calculated according to the formula	China Statistical Yearbook	2,844	0.304	0.143	0.052	0.284	0.8
Moderating variables	Environmental regulatory intensity	ER	Share of environment-related terms in the total number of terms in local government reports	Official websites of city governments at all levels	2,844	0.343	0.141	0.085	0.327	0.772
	Degree of market integration	INTEG	Calculated according to the formula	China Urban Statistical Yearbook	2,844	16.636	2.39	11.827	16.567	22.538
Control variables	The level of economic development	PGDP	Logarithm of per capita GDP	China Statistical Yearbook	2,844	10.731	0.584	9.299	10.707	12.065
	population density	DENSITY	Logarithm of population per square kilometre	China Statistical Yearbook	2,844	5.787	0.866	3.332	5.916	7.609
	Percentage of secondary sector	IND	Value added of secondary sector/GDP	China Statistical Yearbook	2,844	0.459	0.106	0.193	0.463	0.717
	Scale of fiscal expenditure	GOV	Fiscal expenditure/GDP	China Urban Statistical Yearbook	2,844	0.19	0.094	0.074	0.163	0.621
	Foreign Direct Investment	FDI	Total OFDI/GDP	China Statistical Yearbook	2,844	0.017	0.017	0	0.011	0.075
	Human Capital	EDU	Education Expenditure/ Fiscal Expenditure	China Statistical Yearbook	2,844	0.177	0.039	0.091	0.176	0.272
	Intensity of Science and Technology Expenditure	TECH	Science and technology expenditure/fiscal expenditure	China Science and Technology Statistical Yearbook	2,844	0.017	0.016	0.001	0.012	0.085

(Continued on following page)

10.3389/fenvs.2024.1522259

TABLE 1 (*Continued*) Definitions and descriptive statistics of the variables.

Type	Variables	Variable symbols	Description of variables	Data resource	N	Mean	SD	Min	Median	Max
	Urbanisation Level	URBAN	Non-agricultural population/total population	China Urban Statistical Yearbook	2,844	0.403	0.217	0.104	0.341	0.975
	Infrastructure Construction Level	ROAD	Road area per capital	Chinese Ministry of Housing and UrbanRural Development (https://www.mohurd.gov.cn/)	2844	3.554	0.507	2.254	3.522	5.162

H5c. New urbanisation reduces neighbouring regions' green total factor productivity by exacerbating resource mismatch in neighbouring regions.

3 Research design

3.1 Sample and data

The data for this study comes from the China Urban Statistical Yearbook, and the data range of 2010–2021 is chosen as the study interval, excluding samples with serious missing data. In addition, to ensure that the data are affected by extreme values, this paper uses the shrinkage method to shrink the continuous data at the 1% and 99% levels. We conducted several data-handling procedures to improve the data quality based on previous research (Yu and Luo, 2022; Chen et al., 2023). The definitions of the variables and the results of the descriptive statistics are presented in Table 1.

3.2 Identification strategy

We aim to test whether new urbanisation construction can affect green total factor productivity. Difference-in-differences modeling is a more effective statistical method for assessing policy implementation effects. This method divides the research subjects into a treatment group (regions where policies are implemented) and a control group (regions where policies are not implemented). The difference in time trend before and after policy implementation, as well as the difference in policy implementation between the treatment group and the control group, are used to eliminate other factors that change over time and are unobservable, in order to identify the net effect of policy implementation (Xu and Cui, 2020). The Difference-in-differences model has been widely used in existing policy studies in areas such as socioeconomics and ecology (Ma, 2022; Tu, 2015; Song et al., 2019). This study takes new urbanisation construction as a quasi-natural experiment with national coverage and significant policy effects. New urbanisation construction effects have a certain lag and are not implemented at the same time. Therefore, we use a multiperiod Difference-in-differences model to identify the effects of new urbanisation construction effects on green total factor productivity. The model setup is as follows:

$$GTFP_{it} = \alpha_0 + \beta_1 DID_{it} + \theta X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{1}$$

In Equation 1, i and t are cities and years, respectively, and $GTFP$ denotes the dependent variable. DID_{it} is the core explanatory variable, which is used to indicate whether or not city i has implemented new urbanisation construction in year t, and the coefficient β_1 reflects the net effect of new urbanisation construction on the city's GTFP. X_{it} is the control variables selected in this paper. In Equation 1, β_1 the main focus is on the coefficients and their significance levels. If > 0, it indicates that new urbanisation construction increases green total factor productivity. And this empirical model is used to test the Hypothesis 1.

In order to explore the mechanism of new urbanisation construction on green total factor productivity in more detailed ways, on the basis of the theoretical analysis above, and test the mediating role of industrial structure upgrading (UIS), green technology innovation (GPAT), and resource mismatch (RES) in the mechanism with the mediatingeffect model. The equations of the mediating effect model are as follows.

$$Media_{it} = \alpha_0 + \beta_2 DID_{it} + \theta X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{2}$$

$$GTFP_{it} = \alpha_0 + \beta_3 DID_{it} + \beta_4 Media_{it} + \theta X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{3}$$

In Equations 2 and 3, *Media* indicates an intermediate variables of this study, indicating the industrial structural upgrading, green technology innovation and resource mismatch of the *i*th city in *t*th year. If the coefficient β_2 of Equation 2, the coefficient β_4 of Equation 3 are all significant, it shows the existence of the mediating role. Therefore, the two empirical models are used to test the Hypothesis 2a, Hypothesis 2b and Hypothesis 2c.

We also analyse the moderating effects of environmental regulation intensity and market integration on the construction of new urbanisation and GTFP. The equations used are as follows:

$$GTFP_{it} = \alpha_0 + \beta_5 DID_{it} + \beta_6 Moder_{it} + \beta_7 DID^{*} Moder_{it} + \theta X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{4}$$

In Equation 4, *Moder* is the moderating variables of this study, indicating environment regulation and market integration at the city level. If β_7 is significant, it indicates that environmental regulation and market integration do play the moderating roles in the relationship between the new urbanisation construction can affet GTFP. This study adopts the empirical models to test the Hypothesis 3 and Hypothesis 4.

Based on the new economic geography theory, we use the geographic neighbourhood matrix to measure the spatial spillover effect of new urbanization construction on city GTFP. If two cities share a geographic boundary, we assign their matrix value to 1; otherwise, the value is 0. In addition, by combining the generalised nested spatial econometric model with the classical double difference and constructing the Spatial Difference Approach (SDID) to test the spatial spillover effect of new urbanisation construction on green total factor productivity, this study adopts the empirical models to test the Hypothesis 5.

$$GTFP_{it} = \sum_{it}^{nt} \rho (\kappa \times \nu)_{it} GTFP_{it} + \beta_0 + \sum_{k=1}^{k} X_{it,k} \beta_k + DID_{it} \beta_{k+1} + \varepsilon_{it} \tag{5}$$

In Equation 5, *GTFP* is the dependent variable representing the green total factor productivity of cities. DID is a dummy variable actually defined as the implementation of new urbanisation policies. Further, i = 1,2, . . . , N (N = 237), denotes 237 prefecture-level cities in China; t = 1,2, . . . , t (t = 12), the time point of 2010–2021. $X_{it,k}$ contains k control variables, k = 1,2, . . . , k (k = 9). We set up the spatio-temporal weight matrix $\underset{\cdot}{K}$, where $\underset{\cdot}{K}$ is the temporal weight matrix and $\underset{\cdot}{\nu}$ is the spatial weight matrix. ρ reflects the spatial correlation coefficient; β is the regression coefficient; and ε is the random error term.

3.3 Variables

3.3.1 Dependent variables

The GTFP of cities is the explanatory variable in this paper. Existing more extensive measurements of GTFP mainly include static SBM model, one-step estimation method of GMM, etc. In order to effectively solve the problem of intertemporal efficiency incomparability in the measurement of decision-making units, we measure the green total factor productivity level of the city by applying the dynamic SBM model developed by Zhang and Tian (2019), the time span is from 2010 to 2021. Under the non-radial condition, the dynamic SBM model is constructed as follows:

$$\rho_j^{*} = \min \frac{1 - \frac{1}{m+n_b}\left(\sum_{j=1}^{s} \frac{W_{\bar{t}} S_{\overline{jt^*}}}{X_{jt}} + \sum_{j=1}^{n_b} \frac{S_{jt}^{b*}}{Z_{jt}^{b*}}\right)}{1 + \frac{1}{S+n_a}\left(\sum_{j=1}^{s} \frac{W_{\bar{t}} S_{\overline{jt^*}}}{X_{jt}} + \sum_{j=1}^{n_a} \frac{S_{jt}^{a*}}{Z_{jt}^{b*}}\right)} (t = 1, 2, 3 \ldots T) \tag{6}$$

In Equation 6, the model assumes the existence of t decision-making units, each city includes m inputs, Z expected outputs and S unexpected outputs, and ρ represents the target efficiency value. X represents input factors of production, n_a and n_b represent expected and unintended outputs, respectively. $\{W_{\bar{t}}\}, \{S^{-*}\}, \{S^{+*}\}, \{S_{jt}^{\mp*}\}, \{S^{a*}\}, \{S^{b*}\}$ is the set of optimal solution parameters.

Based on the theory of factors of production, this paper constructs the input-output indicators of urban GTFP with reference to the studies of Lyu et al. (2023) and Zheng et al. (2023). The specific content is as follows:

3.3.1.1 Input indicators: input indicators include capital inputs, labor inputs and energy inputs.

a. Capital inputs. Referring to the relevant studies, it is measured through the perpetual inventory method, and the specific formula is as follows:

$$K_{it} = I_{it} + K_{i,i-1}(1 - \varphi) \tag{7}$$

Where, in Equation 7, K represents the physical capital stock, I is the gross capital formation for the year and φ is the depreciation rate. Referenced to relevant study (Zhang et al., 2004), in order to mitigate the effect of the price factor, discounts the total fixed assets for each year at a depreciation rate of 9.6% based on constant 2004 prices.

b. Labor input. The number of people employed at the end of the year in selected cities is measured.
c. Energy input. Selected municipalities' annual electricity consumption is measured.

3.3.1.2 Expected output

This study chooses the Gross Domestic Product (GDP) of each city to represent the Gross Domestic Product (GDP) converted at constant 2004 prices in order to eliminate the effect of the price factor.

TABLE 2 Results of baseline regression.

Variables	(1)	(2)	(3)
	GTFP	GTFP	GTFP
DID	0.014**	0.042***	0.029***
	(0.007)	(0.006)	(0.006)
PGDP		0.109***	0.061***
		(0.007)	(0.015)
DENSITY		0.029***	−0.040
		(0.004)	(0.054)
IND		−0.216***	−0.002
		(0.026)	(0.050)
GOV		0.063*	0.103*
		(0.033)	(0.054)
FDI		0.098	0.620***
		(0.138)	(0.204)
EDU		0.304***	0.703***
		(0.061)	(0.088)
TECH		−0.378**	0.675***
		(0.176)	(0.248)
URBAN		−0.063***	0.049
		(0.011)	(0.036)
ROAD		0.019***	−0.002
		(0.007)	(0.026)
Year Fixed effect City Fixed effect	No		Yes
Observations	2,844	2,844	2,844
R-squared	0.133	0.440	0.672

Note: The values in parentheses are standard errors of the regression model; and *, **, *** represent *p*-values less than 0.1, 0.05 and 0.01, respectively.

3.3.1.3 Unexpected outputs

The Uncxpected outputs of this paper mainly include including CO_2, SO_2 and PM 2.5. Among them, carbon emissions are mainly extracted by using satellite monitoring data from the global carbon emission vector map published by the Center for Socioeconomic Data and Applications at Columbia University, which can more accurately reflect a city's carbon emissions and trends, and overcome the problem of the lack of historical CO_2 data. In addition, the raster data of global atmospheric PM 2.5 concentration published by the National Aeronautics and Space Administration (NASA) was used as the basic research data in this study (http://earthdata.nasa.gov), with a resolution of 0.1. Sulfur dioxide data were obtained from the China Urban Statistical Yearbook of past years.

3.3.2 Core independent variable

The new urbanisation pilot policy variable (NewUrban) is the core explanatory variable. If a city i is set as a NewUrban pilot city in year t, the DID of the city i in year t and subsequent years takes the value of 1, otherwise it takes the value of 0. The National Development and Reform Commission formally announced the first batch of NewUrban pilot cities (towns) in February 2015, and the second and third batches of NewUrban pilot cities (towns) were announced in November 2015 and December 2016, respectively. Therefore, according to the basic requirements for the establishment of difference-in-differences models, this study sets the policy time dummy variable for 2015 and subsequent years to 1, and the dummy variable for previous years to 0. The pilot cities of new urbanisation are the experimental group, and the subgroup dummy variable is set to 1, and the non-pilot cities are the control group, and the subgroup dummy variable is set to 0.

Based on the consideration of the validity of the sample data, the experimental group and the control group are The selection was handled as follows: first, the pilot provinces of new urbanisation selected provincial prefecture-level and above cities as the experimental group; second, a county or a district of some prefecture-level cities was included in the pilot new urbanisation (e.g., Tongzhou District of Beijing, Jizhou District of Tianjin, etc.), and if these were included in the experimental group, the net effect of the policy would be underestimated, and at the same time, it did not match the sample of this study that used the prefecture-level and above city level, so this category of pilots deleted; thirdly, prefecture-level cities where new urbanisation pilot county-level cities, districts and counties are located were deleted; fourthly, to ensure the net effect of the new urbanisation pilot policy in February 2015, newly emerged new urbanisation pilot areas at the end of 2015 and the end of 2016 were excluded. The final sample data of 237 cities at prefecture level and above are selected, of which 106 are pilot cities, which are categorised into the experimental group, and the remaining 131 cities are the control group.

3.3.3 Mediating variables

The mediating variables in this study are industrial structure upgrading, green technology innovation and the degree of resource mismatch. Industrial structure upgrading is the process of transforming industries from lower to higher forms, and drawing on Mattila et al. the upgrading of industrial institutions is reflected by the ratio of the tertiary industry to the secondary industry. In order to achieve the operationalization of green technological innovation, we adopt the previous literature (Yan et al., 2023; Shi et al., 2024) and logarithmically transform the number of green patents granted in cities, including the total number of green invention and utility model patents granted. Efficient allocation of resources is the allocation state in which the free flow of factors maximizes social output under the conditions of the market mechanism, while resource mismatch or market distortion implies a deviation from this state. Drawing on related studies by Hsieh and Klenow (2009), Zhang et al. (2024), etc., the degree of factor market distortion in each city is measured using the production function method.

3.3.4 Moderating variables

The moderating variables were ER and INTEG. Considering that local government work reports reflect the policy orientation of economic and social development of the region, referring to the related study of Li and Gao (2022), the proportion of the frequency

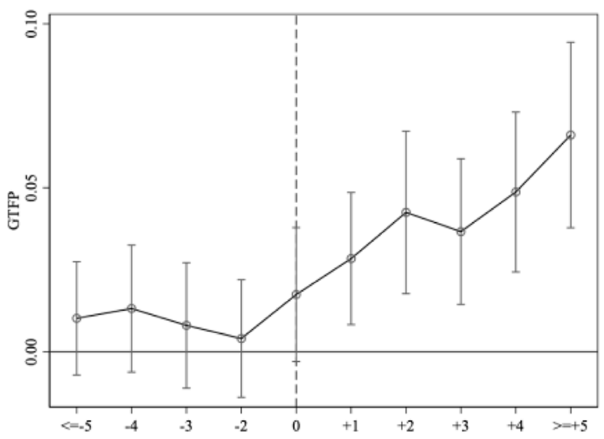

FIGURE 1
Parallel trend test.

of environment-related words to the total number of words in the work reports of the city governments was used to measure the environmental regulation. At the same time, the development goals of new urbanization construction also include “green” and “sustainable development”, and the selected words also include energy consumption, PM2.5, air quality, etc. In order to examine the degree of market integration, the market segmentation index is constructed and measured following the methodology of Parsley and Wei (2001), the core idea of which is to analyze the status of market segmentation by using the differences in commodity prices between regions, and to measure the relative prices in the form of logarithmic first-order differences in price ratios.

3.3.5 Control variables

The impact of new urbanization on city GTFP may be influenced by other factors. To account for this, we refer to previous studies on the determinants of GTFP at the city level and select control variables to mitigate the potentially confounding effects of these factors on the city’s GTFP in order to obtain more accurate estimates. Specifically, they include: level of economic development (*PGDP*), population density (*DENSITY*), size of fiscal expenditure (*GOV*), level of openness to the outside world (*FDI*), human capital (*EDU*), level of urbanization (*URBAN*), and infrastructural development (*ROAD*).

4 Empirical results

4.1 Baseline regression results

Using a multi-period DID approach, we investigate the causal effect of new urbanization on GTFP. Particular attention is paid to the fact that this paper can control well for time-varying trends through fixed time effects of urban GTFP, and robust standard errors for clustered individuals are chosen to control for autocorrelation problems. Table 2 reports the results of the baseline regression, where column (1) shows only the core independent variables. Table 2 reports the results of the baseline regressions, where column (1) shows only the core independent variables, and the explanatory power of the model is low without the control variables, hence the R-squared is 0.133. In addition, to account for potential heterogeneity between cities, we include time and city fixed effects in column (3).

Table 2 reports the estimated values of columns (1)–(3), and it is found that the coefficient of the effect of new urbanization on GTFP is 0.014 without excluding other factors from interference and passes the test of significance level of 5%, which indicates that new urbanization significantly enhances the GTFP of the city. From columns (2) and (3) of Table 2, we find that by including all of the selected control variables in the regression and controlling for time and city fixed effects, the value of the coefficient becomes 0.029 and reaches the 1% significance level. The above analysis shows that the implementation of new urbanization will promote green total factor productivity and green sustainable development. These findings validate Hypothesis 1.

4.2 Robustness checks

4.2.1 Parallel trend test

TheDifference in difference model is based on the assumption that the treatment and control groups had similar trends prior to exogenous shock. Therefore, the use of multi-period DID to assess the policy effects of the new township construction presupposes that the parallel trend assumption is satisfied, i.e., there is no significant difference in GTFP discharge between the experimental group and the control group prior to the implementation of the new township pilot. We conducted a parallel trend test on the baseline regression results to ensure the validity of the DID approach. Pre-reflects the time interval between the current period and the implementation of the new urbanization construction, and post-indicates the time interval between the current period and the period after the implementation of the new urbanization construction. If the parallel trend test passes, the trend of change between the treatment and control groups should remain consistent over the pre-current time without significantly increasing GTFP. the results of the parallel trend test are shown in Figure 1.

There is no significant effect on GTFP prior to the implementation of the new urbanization (Pre-5+ to Pre- 2), and no significant trend prior to the policy shock. This suggests that the staggered DID approach successfully passes the parallel trend test, thus establishing the reliability of the baseline regression results. In addition, from the dynamic results of the Post-effect, we find that the impact of the new urbanization construction on GTFP tends to increase year by year during the policy implementation period.

4.2.2 PSM-DID

In order to overcome the bias caused by the systematic differences between the experimental and control groups, the PSM-DID model was utilised for robustness testing. Before applying the PSM-DID model regression, the propensity to match score method (PSM) was used to conduct the common support hypothesis test, i.e., the treatment and control groups were matched year by year according to the 1:1 nearest neighbour matching with put-back sampling method, and the distribution of kernel density function was plotted. Figure 2 shows that compared with the pre-matching, there is no

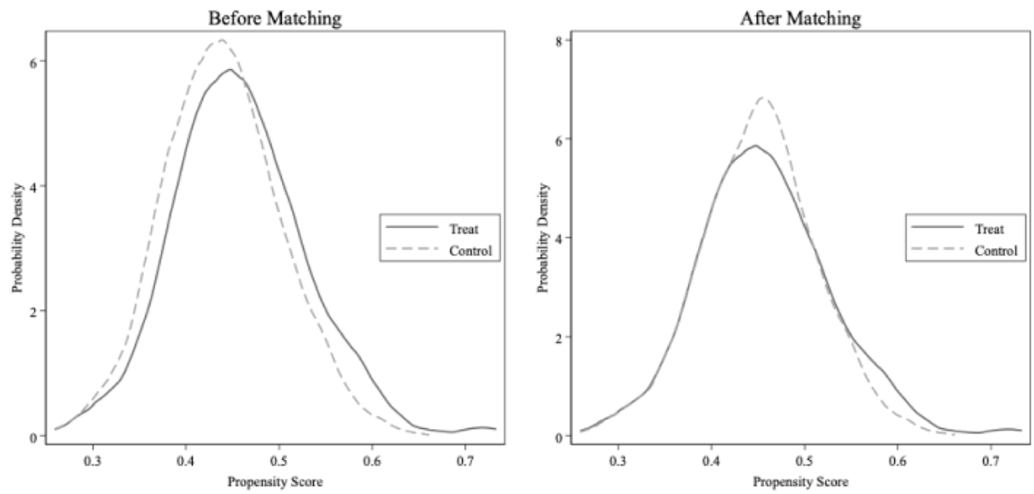

FIGURE 2
Trends in the distribution of density maps before and after matching.

TABLE 3 Results of robustness checks.

Variables	(1)	(2)	(3)	(4)	(5)
	GTFP	GTFP2	GTFP	GTFP	GTFP
DID	0.027***	0.005**	0.023***	0.028***	0.028***
	(0.006)	(0.002)	(0.006)	(0.006)	(0.006)
$LowCO_2$					0.028***
					(0.009)
Control Variables	Yes				
Year Fixed effect	Yes				
City Fixed effect	Yes				
Observations	2,544	2,844	2,796	2,370	2,844
R-squared	0.675	0.125	0.678	0.685	0.673

Note: The values in parentheses are standard errors of the regression model; and *, **, *** represent p-values less than 0.1, 0.05 and 0.01, respectively.

significant systematic difference in GTFP between the experimental and control groups after matching, which satisfies the common support trend hypothesis. Therefore, the PSM-DID model is further used to examine the effect of new urbanization construction on GTFP. The results in column (1) of Table 3 illustrate that after controlling for sample selection bias, new urbanization construction still significantly increases GTFP, further confirming the robustness of the benchmark results.

4.2.3 Alternative dependent variable measurement

In this study, we use a dynamic SBM model under non-radial conditions to measure urban GTFP as the dependent variable in a baseline regression. To enhance the robustness of our findings, we revisited the impact of new urbanization on urban GTFP using an alternative measure, the SBM-Malmquist model. Column (2) of Table 3 shows that the effect of new urbanization on the alternative variable remains significantly positive, indicating that the effect of new urbanization on urban GTFP does not change significantly depending on the measure of the explanatory variables and the regression results are robust.

4.2.4 Excluding the effects of the four largest municipalities

Considering the dual status of some samples in the experimental group as both new urbanization pilots and municipalities, and in order to exclude the interference of municipalities on the effects of new urbanization policies, the four largest municipalities were excluded from this study: Beijing, Shanghai, Tianjin, and Chongqing. The regression is re-run after removing the four municipalities from the full sample. Column (3) of Table 3 shows that the sign and significance of the regression coefficients remain unchanged and the regression results are still robust, even though the policy effects of new urbanization are weakened after the municipalities are excluded.

TABLE 4 CSDID.

Variables	(1)
	GTFP
DID	0.050***
	(0.010)
Control Variables	Yes
City Fixed effect	Yes
Year Fixed effect	Yes
Observations	742

Note: The values in parentheses are standard errors of the regression model; and *, **, *** represent *p*-values less than 0.1, 0.05 and 0.01, respectively.

4.2.5 Shortening the time window

To further demonstrate the impact of new urbanization construction on city GTFP, we further narrowed the time window and examined the short-term impact of the policy. While there was no policy of new urbanization construction between 2017 and 2021, other exogenous shocks such as the 2019 coronavirus disease pandemic may have affected city GTFP during this period. In addition, as Shang et al. (2022) point out, long periods of time may lead to time-series correlation problems and over-rejection of the null hypothesis due to inflated t-values. To avoid such errors, we shorten the time window to between 2010 and 2019. The regression results in column (4) of Table 3 indicate that the implementation of new urbanization has a catalytic effect on the enhancement of GTFP in cities, which further indicates that the results of the empirical analysis are robust.

4.2.6 Exclusion of other policy effects

China formally implemented the Low Carbon City Pilot Policy (LCCP) in 2010 and released about 120 prefecture-level and above cities in batches in 2012 and 2017. Considering that the overlapping implementation time may cause the interference of low carbon policy on the new urbanization pilot policy, this paper introduces a dummy variable for low carbon policy. Where LCCP indicates whether the city is a low-carbon city pilot in the current period, and if it is LCCP then it is 1, otherwise it is 0. The results in column 5 of Table 3 show that there is a significant positive relationship between the new urbanization policy and the city's GTFP after considering the interference of the low-carbon policy pilots, which suggests that the underlying regression results are robust.

4.2.7 Heterogeneity treatment effect problem test CSDID model

As research on DID continues to deepen, it has been found that there may be heterogeneity treatment effects in the use of two-way fixed-effects models for multi-period DID policy identification, leading to potential bias in the estimation of two-way fixed-effects models, which may interfere with the results of the study. This paper draws on the study of Shen et al. (2023), and calculates the 'heterogeneity-robustness' estimator based on Callaway and Sant'Anna, 2020 methodology, which is reported in the table below, with the "untreated group" as the control group, and all groups in all periods as the estimated group. Table 4 below reports the results of the estimated group-period treatment effects for all periods for all groups, and despite the fact that the method loses a large number of samples in the computation, the estimation results show that the average treatment effect is still significantly positive, which again proves the robustness of the present results.

5 Mechanism tests

5.1 Mediating effect analysis

The implementation of new urbanization policies has a significant policy effect of enhancing green total factor productivity, but the ways in which new urbanization contributes to the promotion of green sustainable development need to be analysed specifically. According to the previous analysis, new urbanization may play a mediating role in the relationship between new urbanization construction and GTFP through industrial structure upgrading, green technology innovation and the degree of resource mismatch. Based on this, on the basis of the baseline regression model, the mediation effect model is used to further test whether there is a mediating role of industrial structure upgrading and green technology innovation and the degree of resource mismatch in the relationship between new urbanization and GTFP.

The empirical results are shown in Table 5. The results in columns (1)–(2) provide strong evidence that the construction of new urbanization can significantly promote industrial upgrading, and industrial upgrading plays a partially mediating role between the construction of new urbanization and the city's GTFP, thus verifying Hypothesis 2a. In addition, the results in columns (3)–(4) indicate that the implementation of new urbanization can effectively improve the green innovation level, which introduces that the level of green innovation plays a partial mediating role, verifying Hypothesis 2b. However, the estimated coefficient of the degree of resource mismatch of the results in columns (5)–(6) is −0.041, which passes the test at the 1% significance level, suggesting that the degree of resource mismatch in the relationship between the construction of new towns and GTFP is not conducive to the enhancement of green total factor productivity, which plays a partial mediating role, further supporting Hypothesis 2c.

5.2 Moderating effect analysis

The theoretical analysis section above also suggests that environmental regulation intensity and market integration may be the moderating mechanisms for the relationship between the implementation of new urbanization and urban GTFP. Therefore, we conducted further tests to verify the moderating role of environmental regulation intensity and market integration, and the results are shown in Table 6 and Figure 3.

Referring to Figure 3 and the results as shown in column (1), the coefficient of the interaction term between the implementation of new urbanization and environmental regulation intensity is significantly positive. This suggests that the implementation of new urbanization construction has a stronger positive effect on urban GTFP when environmental regulation intensity is higher. In

TABLE 5 Results of the mediating effect.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	UIS	GTFP	GPAT	GTFP	RES	GTFP
DID	0.062***	0.027***	0.159***	0.027***	−0.041***	0.027***
	(0.010)	(0.006)	(0.032)	(0.006)	(0.006)	(0.006)
UIS		0.029**				
		(0.014)				
GPAT				0.015***		
				(0.005)		
RES						−0.050**
						(0.020)
Control Variables	Yes					
Year Fixed effect	Yes					
City Fixed effect	Yes					
Observations	2,844	2,844	2,844	2,844	2,844	2,844
R-squared	0.945	0.673	0.943	0.674	0.658	0.673

Note: The values in parentheses are standard errors of the regression model; and *, **, *** represent *p*-values less than 0.1, 0.05 and 0.01, respectively.

TABLE 6 Results of the moderating effect.

Variables	(1)	(2)
	GTFP	GTFP
DID	0.028***	0.029***
	(0.006)	(0.006)
ER	0.047***	
	(0.013)	
ER_DID	0.061**	
	(0.029)	
INTEG		0.002***
		(0.001)
INTEG_DID		0.004**
		(0.002)
Control Variables	Yes	
Year Fixed effect	Yes	
City Fixed effect	Yes	
Observations	2,844	2,844
R-squared	0.674	0.674

Note: The values in parentheses are standard errors of the regression model; and *, **, *** represent *p*-values less than 0.1, 0.05, and 0.01, respectively.

column (2), the coefficient of the interaction term between the implementation of new urbanization construction and market integration is significantly positive. This implies that the implementation of new urbanization construction has a positive impact on green total factor productivity in areas with high market integration. Therefore, the above results further support hypotheses H3a and H3b.

6 Further analysis

6.1 Heterogeneity analysis

The implementation of the new urbanization policy needs to take into account the characteristics of China's unbalanced regional distribution, so regional differences are incorporated into the reference basis for the selection of pilots, such as the construction of the "two horizontal and three vertical" urbanization planning pattern. Differences in locational advantages may affect the implementation of new urbanization policies. Therefore, considering the differences in the GTFP of cities depending on their urban attributes, the two-dimensional urban attributes of "location-features" are included to investigate whether the policy effects of new urbanization on GTFP are heterogeneous depending on the urban attributes. The sample is divided into eastern cities and central and western cities based on city location1, and into resource cities and non-resource cities based on the Circular of the State Council on the Issuance of the National Sustainable Development Plan for Resource Cities (2013–2020). Table 7 reports the results of estimating the heterogeneity of city location and city characteristics.

The results in columns (1)–(3) of Table 7 show that from the perspective of urban location: first, the estimated coefficient of new urbanization construction is significantly positive in both eastern and central cities, but the estimated coefficient is larger in central cities compared to eastern cities, indicating that the policy effect of green total factor productivity of new urbanization shows spatial

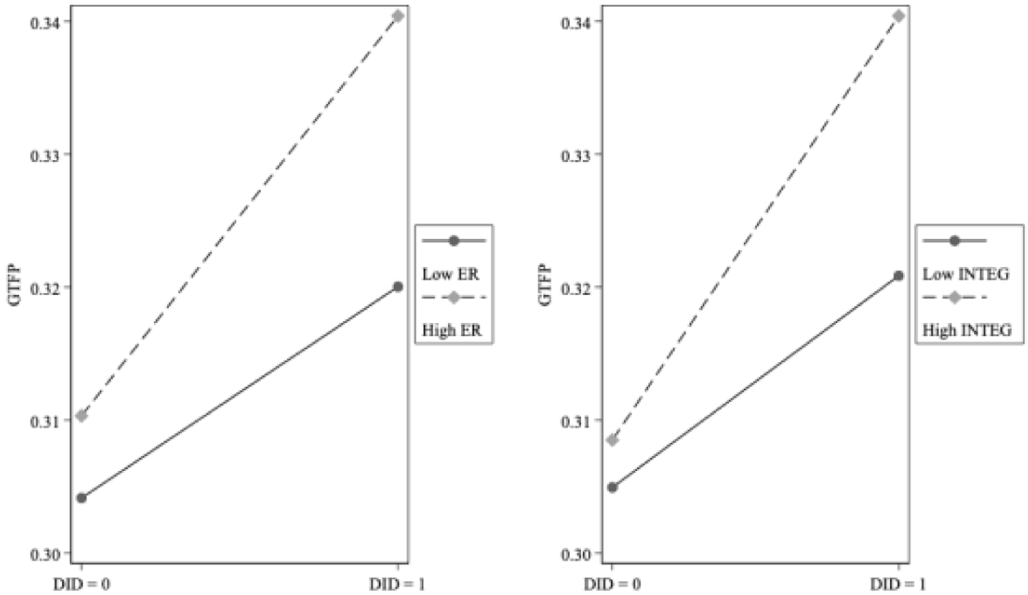

FIGURE 3
Diagram of marginal effects of moderating effects.

TABLE 7 Results of the heterogeneity analysis.

Variables	Eastern region (1)	Central region (2)	Western region (3)	Resource-based cities (4)	Non-resource-based cities (5)
	GTFP	GTFP	GTFP	\GTFP	GTFP
DID	0.022**	0.055***	0.006	0.012	0.040***
	(0.009)	(0.010)	(0.010)	(0.009)	(0.007)
Control Variables	Yes				
Year Fixed effect	Yes				
City Fixed effect	Yes				
Observations	1,140	876	828	1,068	1776
R-squared	0.634	0.748	0.676	0.663	0.662

Note: The values in parentheses are standard errors of the regression model; and *, **, *** represent p-values less than 0.1, 0.05 and 0.01, respectively.

imbalance characteristics. The main reason is that the eastern cities have the advantages of location and economic development environment, high level of economic development, infrastructure is more complete, which is convenient for the implementation of the new urbanization pilot; while in the background of the regional economic development imbalance, the central cities have lower level of economic development, the local government in order to quickly develop the economy, to undertake more pollution-intensive industries, so that the state's financial and other related policies are more inclined to the central region. As a result, the national financial and other related policies are more favourable to the central region, which results in the green development of new urbanization in the central cities than in the eastern cities.

Table 7, column (4)–(5) shows that compared with resource cities, the policy effect of new urbanization in reducing pollution and carbon is more significant in non-resource cities. Resource endowment determines the urban development mode, which may be because resource cities have the advantage of resource endowment, the regional economic development relies on resource-related industries, but the industrial structure of resource cities is single, the degree of industrial deep processing is low, industrial transformation and upgrading is difficult, and the economic development is dominated by the heavy industry of energy development, which will emit more environmental pollutants, resulting in the policy of new urbanization's green total factor productivity The impact effect is weak or even insignificant in resource cities.

TABLE 8 GTFP global Moran's index.

Year	I	E(I)	sd(I)	z	p-value*
2010	0.113	−0.004	0.026	4.475	0.000
2011	0.128	−0.004	0.026	5.049	0.000
2012	0.089	−0.004	0.026	3.571	0.000
2013	0.075	−0.004	0.026	3.047	0.002
2014	0.096	−0.004	0.026	3.848	0.000
2015	0.124	−0.004	0.026	4.901	0.000
2016	0.087	−0.004	0.026	3.491	0.000
2017	0.093	−0.004	0.026	3.726	0.000
2018	0.106	−0.004	0.026	4.239	0.000
2019	0.161	−0.004	0.026	6.323	0.000
2020	0.108	−0.004	0.026	4.277	0.000
2021	0.286	−0.004	0.026	11.191	0.000

TABLE 9 Results of spatial econometric regression model selectivity tests.

Test	Statistical value	p-value*
LM test	23.577	0.000
	15.445	0.000
	14.122	0.000
	5.989	0.014
LR test	63.16	0.000
	43.92	0.001
Wald test	27.48	0.002
	22.66	0.007
Hausman	51.41	0.000

6.2 Spatial spillover effect in the city-level

6.2.1 Spatial globalisation tests and spatial econometric model selection

In this paper, we intend to test the global spatial correlation of GTFP of cities using global Moran's I index, and the results are shown in Table 8. It can be seen that the Moran's I indexes are all significantly positive, indicating that GTFP among prefecture-level cities has significant positive spatial correlation, so it is necessary to use spatial econometric models to study GTFP.

According to the test results in Table 9, it can be concluded that the LM test results should reject the original hypothesis of the mixed OSL model and select the spatial effects model in the non-ordinary panel regression model. The LM test rejects the use of the SEM and SAR models at the 1% level of significance, and the SDM model should be selected. The Wald test and the LR test both reject the original hypothesis of the SDM model simplification at the 1% level, suggesting that constructing a spatial Durbin model is appropriate. Secondly, the Hausmann test significantly rejected the original hypothesis of using a random effects model at the 1% level, and a fixed effects model should be chosen.

6.2.2 Results of the spatial DID

This study proves that the implementation of new urbanization construction has a significant positive impact on urban GTFP, but from the perspective of spatial measurement, the implementation of new urbanization construction will not only affect the GTFP of the region, but also affect the surrounding areas. However, in terms of the spatial radiation effect, we use the interleaved DID method based on traditional panel data to analyse the impact of new urbanization construction on GTFP, which may ignore the spillover effect of the policy. Compared with the traditional DID model, the spatial double difference model takes into account the spatial correlation and spatial spillover effects, which effectively makes up for the shortcomings of insufficient observation of the strength and direction of the effect of policy implementation on the control group by examining the spatial spillover effects. Based on the above considerations, this paper further empirically analyses the spatial spillover effect of new urbanization construction on urban GTFP using the spatial DID method.

Column (1) of Table 10 shows the estimation results of the spatial double-difference of the new urbanization construction on the city's GTFP, which is consistent with the benchmark regression results obtained in the previous section by using the direct effect of the geographic distance matrix to illustrate that the implementation of the significant new urbanization construction promotes the city's GTFP. The results of spillover effect analysis show that the direct and indirect effects of the implementation of new urbanization policies are all significantly positively correlated, which indicates that the implementation of new urbanization policies not only enhances the local GTFP, but also has a favourable impact on the GTFP of the neighbouring provinces and cities, which further supports Hypothesis 5. This is probably due to the fact that the pilot cities have certain advantages over the neighbouring provinces (districts and cities) in terms of industrial structure, cultural practices and market structure. (This may be due to the fact that in terms of industrial structure, cultural practices and market structure, the pilot cities have certain similarities with the neighbouring provinces (autonomous regions and municipalities). The implementation of the new urbanization policy has made the pilot cities the focus of development, and through the promotion of factor mobility, the strengthening of inter-regional cooperation and the upgrading of industrial structure, the pilot cities can achieve green development and co-prosperity in the level of economic growth.

6.2.3 Analysis of mediated spillovers from spatial DID

To further explore whether the local implementation of new urbanization policies affects the GTFP of neighbouring places through industrial structure upgrading, green technology innovation and the degree of resource mismatch. This section verifies this and the regression results are reported in columns (2)–(4) of Table 10. The results of spatial spillovers in column (2) show that the estimated coefficient of the implementation of new urbanization construction on local industrial structure upgrading is significantly positive, but the coefficient of the impact on neighbouring localities is significantly negative, which indicates

TABLE 10 Results of the spatial DID method.

	Spatial DID method			
Variables	(1)	(2)	(3)	(4)
	GTFP	UIS	GPAT	RES
DID	0.015***			
	(0.005)			
W*DID	0.038***			
	(0.013)			
Other variables	YES			
Year Fixed effect	YES			
City Fixed effect	YES			
Direct effect	0.021***	0.063***	0.182***	−0.042***
	(0.006)	(0.009)	(0.030)	(0.006)
Indirect effect	0.254***	−0.067**	1.483***	0.102***
	(0.068)	(0.031)	(0.151)	(0.027)
Total effect	0.275***			
	(0.071)			
Spa-rho	0.808***	0.333***	0.499***	0.502***
	(0.018)	(0.038)	(0.034)	(0.032)
Observations	2,844	2,844	2,844	2,844
R-squared	0.169	0.846	0.797	0.126

Note: The values in parentheses are standard errors of the regression model; and *, **, *** represent p-values less than 0.1, 0.05 and 0.01, respectively.

that the implementation of new urbanization in the local area suppresses the green total factor productivity of neighbouring areas by inhibiting industrial structure upgrading in the neighbouring cities, which verifies Hypothesis 5a. The results of column (3) indicate that the construction of new urbanization construction has a significant positive impact on local green technology innovation level is 0.182, and the impact coefficient on the neighbouring regions is 1.483, which indicates that the local implementation of new urbanization promotes the green total factor productivity in the neighbouring regions by increasing the green technology innovation in the neighbouring cities, and this conclusion supports Hypothesis 5b. The results of Column (4) indicate that the implementation of the new urbanization policy has a significant negative impact on the local resource mismatch level, and the impact coefficient on the neighbouring regions is 0.102, which reduces green total factor productivity in neighbouring regions by exacerbating resource mismatch in neighbouring regions, a finding that tests Hypothesis 5c.

7 Conclusion and discussions

7.1 Conclusion

In this study, the implementation of the national comprehensive pilot policy of new urbanization is taken as the event shock of new urbanization construction, and panel data at the city-wide level of 237 prefectures in China from 2010 to 2021 are selected to empirically test the causal impact of new urbanization on urban GTFP using the multi-period DID method. The findings suggest that the implementation of new urbanization has a significant positive impact on city GTFP, a conclusion that is further supported by a series of robustness tests. In addition, we find that the promotion of industrial structure upgrading and green technology innovation as well as the reduction of the degree of resource mismatch play a partially mediating role in the mechanism by which new urbanization construction enhances GTFP. Environmental regulation and market integration both modulate the relationship between the construction of new urbanization and urban GTFP in positive directions. Not only that, the effect of new urbanization on GTFP is differentiated by city attributes. The effect of new urbanization on eastern and central cities and non-resource cities is more significant. Finally, the study shows that the impact of new urbanization construction on the GTFP of cities is mainly realized through the spatial spillover effects on the industrial structure upgrading, green technology innovation and the degree of resource allocation in neighboring cities.

7.2 Theoretical implications

Our study has several theoretical implications. First, the literature on the relationship between urbanization construction and green sustainable development is diverse but has not yet reached a consensus, and they tend to focus on its effects on ecological quality or economic growth. For example, Li and Gao (2022) explore the carbon emission reduction effect of new urbanization construction only from an ecological perspective. Cheng et al. (2022) found that there is a significant correlation between new urbanization and the green intensive use of land from the research perspective of land use. Li et al., 2024 constructed a URI model to explore the relationship between new urbanization and rural economic development, using ecological sustainability as the research background. Urbanization and rural economic development in a three-round transmission model. However, the quasi-experimental design of this study's analysis of new urbanization pilot policies and their spatial effects more accurately identifies the causal relationship between new urbanization pilots and urban GTFP, which complements the existing literature in this area.

Although scholars have explored the impact mechanism of new urbanization construction on green sustainable development from the perspectives of scale effect and agglomeration factors and ecological concepts (DeVore et al., 2020; Wang et al., 2015). However, few studies have addressed the efficiency factor, and the role of resource markets has not yet been considered. Our study explores the mechanisms of green innovation effect and optimal layout of industries using Matchday-Clark related theories, which extends and extends the existing studies in one step. In addition, different boundary conditions may affect the impact of new urbanization pilot policies on urban GTFP. Currently, most scholars focus on the moderating role of city size and government intervention on the relationship between new urbanization and GTFP (Wu et al., 2024; Yaqoob et al., 2022). However, the moderating role of market integration on this relationship has been less studied. Meanwhile, the green development theory is proposed, which suggests that regions with a higher degree of regulation have a balance between their environment and economy and are prone to achieve sustainable development. Therefore, this study profoundly reveals the complexity of environmental regulation and market integration as boundary conditions, and provides new theoretical support and empirical evidence for related literature based on the new economic geography theory.

Finally, scholars have been discussing the economic impacts of new urbanization pilot policies (Liao et al., 2024; Li and Song, 2020). To address this issue, this paper adopts the SDID research methodology to examine the cross-regional spillover effects of new urbanization pilot policies on GTFP. In addition, this paper further explores the spatial spillover effects of pilot new urbanization policies on the degree of industrial structure upgrading, green technology innovation and resource allocation in neighboring cities through spatial econometrics methods, enriching the literature on the spatial spillover effects of pilot new urbanization policies on green sustainable development.

7.3 Practical implications

Based on these findings, this study also has some practical implications. First, local governments should encourage enterprises and the public to actively sort out the concept of green and sustainable development, expand the scope of new urbanization pilot projects in an orderly and steady manner, promote the high-quality development of urbanization through the construction of new urbanization, and promote intensive, intelligent, green and sustainable production methods to realize the harmonious coexistence of human beings and nature.

Second, stimulate the important role of industrial structure upgrading and green technology innovation in the development of new urbanization in promoting green and sustainable development. Research shows that new urbanization can realize green development effect through industrial structure upgrading and green technology innovation. Therefore, it is necessary to promote the organic linkage of new urbanization, industrial structure upgrading and green technology innovation, and form a new path of synergistic development of new urbanization, industrial structure upgrading and green technology innovation with regional characteristics, so as to realize green development.

Thirdly, the government has strengthened the intensity of environmental regulation, formulated green development strategies, and raised awareness of environmental issues. In addition, it continues to deepen the reform process of market integration, break local administrative protection and monopolization, reduce logistics and other transaction costs, and seek to establish a large domestic market for green and sustainable development.

Fourth, emphasize regional differences and seek balanced regional development. In view of the heterogeneity of the effects of new urbanization pollution reduction and carbon reduction policies, local governments should strengthen the inclusiveness of the policy implementation process. The eastern and central regions should fully release the policy dividends of green development in new urbanization and promote coordinated regional development; resource cities should improve resource utilization efficiency, optimize industrial layout, and promote the construction of new urbanization as a way to promote the improvement of ecological environment quality.

Finally, the government must actively remove policy barriers and make full use of the spatial spillover effect of pilot policies for new urbanization. It is necessary to promote the successful experience of the pilot in a timely manner, to lead by example and to advance in a gradual manner. At the same time, it is necessary to promote the development of new urbanization in different types of cities by guiding them in a categorical manner and adapting to local conditions.

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

XW: Data curation, Formal Analysis, Funding acquisition, Project administration, Supervision, Writing–review and editing. XL: Methodology, Software, Writing–original draft, Writing–review and editing.

Funding

The author(s) declare that financial support was received for the research, authorship, and/or publication of this article. This work was supported by the Fundamental Research Funds for the Central Universities (Grant No. HIT.HSS.202228).

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.

Generative AI statement

The author(s) declare that no Generative AI was used in the creation of this manuscript.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Abdeldayem, W. S. (2023). Disentangling the relationship between urban form and urban resilience: a systematic literature review. *Urban Sci.* 7, 93. doi:10.3390/urbansci7030093

Amirzadeh, M., and Sharifi, A. (2024). The evolutionary path of place making: from late twentieth century to post-pandemic cities. *Land Use Policy* 141, 107124. doi:10.1016/j.landusepol.2024.107124

Callaway, B., and Sant'Anna, P. H. C. (2020). Difference-in-Differences with multiple time periods. *J. Econ.* 225 (2), 200–230. doi:10.1016/j.jeconom.2020.12.001

Chen, J. Q., Li, X. S., Geng, Y. W., Liu, X. z., and Li, G. l. (2024). Mechanism analysis and empirical research on urbanization and carbon emissions in China: based on the perspective of economic development, population transfer, and urban expansion. *J. Nat. Resour.* 39 (06), 1399–1417. doi:10.31497/zrzyxb.20240609

Chen, L. L., Zhang, X. D., He, F., and Yuan, R. S. (2019). Regional green development level and its spatial relationship under the constraints of haze in China. *J. Clean. Prod.* 210, 376–387. doi:10.1016/j.jclepro.2018.11.037

Chen, W. X., Wang, G. Z., and Zeng, J. (2023). Impact of urbanization on ecosystem health in Chinese urban agglomerations Agglomerations. *Environ. Impact Assess. Rev.* 98, 106964. doi:10.1016/j.eiar.2022.106964

Cheng, G. B., and Shen, Y. Y. (2024). Whether integration can enhance urban total factor productivity - a comparative analysis based on three major city clusters in the Yangtze River Economic Belt. *Res. World* (01), 37–50. doi:10.13778/j.cnki.11-3705/c.2024.01.004

Cheng, Z., Li, X., and Zhang, Q. (2022). Can new-type urbanization promote the green intensive use of land? *J. Environ. Manage* 342, 118150. doi:10.1016/j.jenvman.2023.118150

Cobbinah, P. B., Erdiaw-Kwasie, M. O., and Amoateng, P. (2015). Africa's urbanisation: implications for sustainable development. *Cities* 47, 62–72. doi:10.1016/j.cities.2015.03.013

Dai, S., Cheng, J. H., and Chen, J. (2024). Resource mismatch in Chinese cities: degree estimation and dynamic evolution analysis. *Urban Environ. Res.* 01, 64–78. Available at: https://kns.cnki.net/kcms2/article/abstract?v=WpTTvLMLsy07aSbsZIl137jzu0pA-W_DX1tg9SYBXahS9aiEiBq9qMOzK5jE9c-MbFx5s4KmsQBeVP2ZyofCEc6Z3nwRo1d6QigeMsaKgbU5Rts8_Q9vMFGlhliA1ZrH-_ttXutqd1RumDyquuwygUeNMsAeoh8uMs2K3uJFFP1n8WWYuZnBjkga6n84vWES5O9qkNan3E=&uniplatform=NZKPT&language=CHS.

DeVore, J. L., Shine, R., and Ducatez, S. (2020). Urbanization and translocation disrupt the relationship between host density and parasite abundance. *J. Anim. Ecol.* 89 (4), 1122–1133. doi:10.1111/1365-2656.13175

Du, K. R., and Li, J. L. (2019). Towards a green world: how do green technology innovations affect total-factor carbon productivity. *Energy Policy* 131, 240–250. doi:10.1016/j.enpol.2019.04.033

Elhorst, J. P. (2010). Applied spatial econometrics: raising the bar. *Spat. Econ. Anal.* 05, 9–28. doi:10.1080/17421770903541772

Feng, Y. C., Wang, X. H., Liang, Z., Hu, X. Y., Xie, Y., and Wu, G. Y. (2021). Effects of emission trading system on green total factor productivity in China: empirical evidence from a quasi-natural experiment. *J. Clean Prod.* 294, 126262. doi:10.1016/j.jclepro.2021.126262

Governa, F., and Sampieri, A. (2020). Urbanisation processes and new towns in contemporary China: a critical understanding from a decentred view. *Urban Stud.* 57, 366–382. doi:10.1177/0042098019860807

Hsieh, C. T., and Klenow, P. J. (2009). Misallocation and manufacturing TFP in China and India*. *Quaarterly J. Econ.* 124, 1403–1448. doi:10.1162/qjec.2009.124.4.1403

Hu, B. L., and Chen, C. L. (2015). New urbanisation under globalisation and the social implications in China. *Aisa & Pac. Policy Stud.* 02, 34–43. doi:10.1002/app5.68

Huang, Z. Y., An, X. Y., Cai, X. R., Chen, Y., Liang, Y., Hu, S., et al. (2023). The impact of new urbanization on PM2.5 concentration based on spatial spillover effects: evidence from 283 cities in China. *Sustain. Cities Soc.* 90, 104386. doi:10.1016/j.scs.2022.104386

Jiang, J. K., Zhu, S. L., Wang, W. H., Li, Y., and Li, N. (2022). Coupling coordination between new urbanisation and carbon emissions in China. *Sci. Total Environ.* 850, 158076. doi:10.1016/j.scitotenv.2022.158076

Jiang, T. Y., Cao, C., Lei, L. Y., Hou, J., Yu, Y., and Jahanger, A. (2023). Temporal and spatial patterns, efficiency losses and impact factors of energy mismatch in China under environmental constraints. *Energy* 282, 128875. doi:10.1016/j.energy.2023.128875

Lee, C. C., Zeng, M. L., and Wang, C. S. (2022). Environmental regulation, innovation capability, and green total factor productivity: new evidence from China. *Environ. Sci. Pollut. Res.* 29, 39384–39399. doi:10.1007/s11356-021-18388-0

Li, H. H., and Song, W. (2020). Evolution of rural settlements in the Tongzhou District of Beijing under the new-type urbanization policies. *Habitat Int.* 101, 102198. doi:10.1016/j.habitatint.2020.102198

Li, Y. L., and Gao, K. L. (2022). The impact of green urbanization on carbon emissions: the case of new urbanization in China. *Front. Environ. Sci.* 10, 1070652. doi:10.3389/fenvs.2022.1070652

Li, Y. W., Long, W. J., Ning, X., Zhu, Y., Guo, Y., Huang, Z., et al. (2022). How can China's sustainable development be damaged in consequence of financial misallocation? Analysis from the perspective of regional innovation capability. *Bus. Strategy Environ.* 31, 3649–3668. doi:10.1002/bse.3113

Li, Z. Z., Gao, F. W., Hu, X. M., Wu, Y. M., and Li, M. G. (2024). Relative poverty and urban living willingness of new-generation migrant workers-Evidence from the China Migrant Dynamics Survey. *Cities* 153, 105258. doi:10.1016/j.cities.2024.105258

Liao, B., Li, L., and Tian, C. H. (2024). How does the pilot policies of new urbanization improve uneven development? *Econ. Analysis Policy* 82, 86–103. doi:10.1016/j.eap.2024.02.029

Lin, Y. K., and Zhong, Q. M. (2024). Does green finance policy promote green total factor productivity? Evidence from a quasi-natural experiment in the green finance pilot zone. *Clean Technol. Environ. Policy* 26, 2661–2685. doi:10.1007/s10098-023-02729-3

Liu, Y., Yang, Y. L., Li, H. H., and Zhong, K. Y. (2022). Digital economy development, industrial structure upgrading and green total factor productivity: empirical evidence from China's cities. *Int. J. Environ. Res. Public Health* 19, 2414. doi:10.3390/ijerph19042414

Lu, W., and Lu, S. R. (2024). A study of loan interest rate marketisation, bank competition and urban resource mismatch. *Economist* 07, 45–56. doi:10.16158/j.cnki.51-1312/f.2024.07.003

Lynam, A., Li, F. Q., Xiao, G. L., Fei, L. Y., Huang, H., and Utzig, L. (2023). Capturing socio-spatial inequality in planetary urbanisation: a multi-dimensional methodological framework. *Cities* 132, 104076. doi:10.1016/j.cities.2022.104076

Lyu, Y., Wang, W., Wu, Y., and Zhang, J. (2023). How does digital economy affect green total factor productivity? Evidence from China. *Sci. Total Environ.* 857, 159428. doi:10.1016/j.scitotenv.2022.159428

Ma, H. T. (2022). Urbanization under globalization: how does the Belt and Road Initiative affect urbanization levels in participating countries? *J. Geogr. Sci.* 32, 2170–2188. doi:10.1007/s11442-022-2042-1

Ma, Y. R., and Liu, Q. (2024). Effect of the reduc-tion of pollution and carbon emissions in China's new urbanization construction. *China Popul. Resour. Environ.* 34 (1), 33–45. Available at: https://kns.cnki.net/kcms2/article/abstract?v=WpTTvLMLsy1VKD9wd5P9PwRUHaicG0DtpDa60zIRQrKtM8U9LbuKl5O1CpSEyqc4wUGMlHw822p9-0MG15hgVj4ISv5WiV7qrL2ngnSihYHFp-C8wnDwl2-ZNMtqIFzpDy_m7fLnCT3PVF4Eli5J01ZSQ8ysfyWJKgI0lof4oE651XQCEPAbXSwqeo5jIYyyMEL6ZteZJ5M=&uniplatform=NZKPT&language=CHS.

Parsley, D. C., and Wei, S. J. (2001). Explaining the border effect: the role of exchange rate variability, shipping costs, and geography. *J. Int. Econ.* 55, 87–105. doi:10.1016/S0022-1996(01)00096-4

Roon, M. R. (2012). Wetlands in The Netherlands and New Zealand: optimising biodiversity and carbon sequestration during urbanisation. *J. Environ. Manag.* 101, 143–150. doi:10.1016/j.jenvman.2011.08.026

Schmid, C., Karaman, O., Hanakata, N. C., Kallenberger, P., Kockelkorn, A., Sawyer, L., et al. (2018). Towards a new vocabulary of urbanisation processes: a comparative approach. *Urban Stud.* 55, 19–52. doi:10.1177/0042098017739750

Shang, L., Tan, D., Feng, S., and Zhou, W. (2022). Environmental regulation, import trade, and green technology innovation. *Environ. Sci. Pollut. Res. Int.* 29 (9), 12864–12874. doi:10.1007/s11356-021-13490-9

Shen, K. R., Lin, J. W., and Fu, Y. H. (2023). Network infrastructure construction, information accessibility, and enterprise innovation boundaries. *China Ind. Econ.* 01, 57–75. doi:10.19581/j.cnki.ciejournal.2023.01.014

Shi, R., Yao, L. Y., Zhao, M. J., and Yan, Z. M. (2024). Low-carbon production performance of agricultural green technological innovation: from multiple innovation subject perspective. *Environ. Impact Assess. Rev.* 105, 107424. doi:10.1016/j.eiar.2024.107424

Song, H., Sun, Y. J., and Chen, D. K. (2019). Assessment of the effect of government air pollution control: experience research from China's "low carbon city" construction. *Manag. World* 35 (06), 95–108+195. doi:10.1974/j.cnki.11-1235/f.2019.0082

Sun, J. H., Tang, D. C., Kong, H. J., and Boamah, V. (2022a). Impact of industrial structure upgrading on green total factor productivity in the yangtze river economic belt. *Int. J. Environ. Res. Public Health* 19, 3718. doi:10.3390/ijerph19063718

Sun, T. L., and Zhang, Y. C. (2022b). The impact of environmental regulation on agricultural green total factor productivity: evidence from China. *Int. J. Environ. Pollut.* 70, 203–222. doi:10.1504/IJEP.2021.132025

Sun, Y. C. (2022c). Environmental regulation, agricultural green technology innovation, and agricultural green total factor productivity. *Front. Environ. Sci.* 10, 995118. doi:10.3389/fenvs.2022.955954

Tu, Z. G., and Shen, R. J. (2015). Shen Renjun Can the emissions trading mechanism achieve the Porter effect in China? *Econ. Res.* 50 (07), 160–173. Available at: https://kns.cnki.net/kcms2/article/abstract?v=WpTTvLMLsy0wxfFOfOUPqYd8XAFjamwRL1t_wc9Gl1N93NKVIvROSCYeUWzab5CY5zV2xeBiTfORDwIvLgLSRlLopkEFdOOKB8NTwpAIi48CxazrOfTqU6vHHlLRnIvg7UtsyZC9R0q8Wu1xCt5wu5uVdLzyQQRqeHQm8Em9IJe3mmFpMb5UxwAzt0_UJzpggPHHekAA4=&uniplatform=NZKPT&language=CHS

Vega, S. H., and Elhorst, J. P. (2015). The slx model. *J. Regional Sci.* 55, 339–363. doi:10.1111/jors.12188

Wang, J. X., and Foley, K. (2021). Assessing the performance of urban open space for achieving sustainable and resilient cities: a pilot study of two urban parks in Dublin, Ireland. *Urban For. & Urban Green.* 62, 127180. doi:10.1016/j.ufug.2021.127180

Wang, J. X., and Foley, K. (2023). Promoting climate-resilient cities: developing an attitudinal analytical framework for understanding the relationship between humans and blue-green infrastructure. *Environ. Sci. & Policy* 146, 133–143. doi:10.1016/j.envsci.2023.05.010

Wang, X. R., Hui, E. C. M., Choguill, C., and Jia, S. H. (2015). The new urbanization policy in China: which way forward? *Habitat Int.* 47, 279–284. doi:10.1016/j.habitatint.2015.02.001

Wang, Y. F., Bai, Y., Quan, T. S., Ran, R., and Hua, L. (2023). Influence and effect of industrial agglomeration on urban green total factor productivity-On the regulatory role of innovation agglomeration and institutional distance. *Econ. Analysis Policy* 78, 1158–1173. doi:10.1016/j.eap.2023.04.024

Wang, Z. H., Sun, Y. F., and Wang, B. (2019). How does the new-type urbanisation affect CO_2 emissions inChina? An empirical analysis from the perspective of technological progress. *Energy Econ.* 80, 917–927. doi:10.1016/j.eneco.2019.02.017

Wu, H. T., Li, Y. W., Hao, Y., Ren, S. Y., and Zhang, P. F. (2020). Environmental decentralization, local government competition, and regional green development: evidence from China. *Sci. Environ.* 708, 135085. doi:10.1016/j.scitotenv.2019.135085

Wu, Y., Zong, T., Shuai, C., and Jiao, L. (2024). How does new-type urbanization affect total carbon emissions, *per capita* carbon emissions, and carbon emission intensity? An empirical analysis of the Yangtze River economic belt, China. *J. Environ. Manage.* 349, 119441. doi:10.1016/j.jenvman.2023.119441

Xu, J., and Cui, J. B. (2020). Low carbon cities and green technology innovation for enterprises. *China Ind. Econ.* 12, 178–196. doi:10.19581/j.cnki.ciejournal.2020.12.008

Yan, Z. M., Sun, Z., Shi, R., and Zhao, M. J. (2023). Smart city and green development: empirical evidence from the perspective of green technological innovation. *Technol. Forecast. Soc. Change* 191, 122507. doi:10.1016/j.techfore.2023.122507

Yaqoob, N., Jain, V., Atiq, Z., Sharma, P., Ramos-Meza, C. S., Shabbir, M. S., et al. (2022). The relationship between staple food crops consumption and its impact on total factor productivity: does green economy matter? *Environ. Sci. Pollut. Res. Int.* 29 (46), 69213–69222. doi:10.1007/s11356-022-22150-5

You, W. H., and Lv, Z. K. (2018). Spillover effects of economic globalization on CO_2 emissions: a spatial panel approach. *Energy Econ.* 73, 248–257. doi:10.1016/j.eneco.2018.05.016

Yu, Y. T., and Luo, N. S. (2022). Does urbanization improve energy efficiency? Empirical evidence from China? *Technol. Econ. Dev. Econ.* 28, 1003–1021. doi:10.3846/tede.2022.16736

Zhang, B. B., and Tian, X. (2019). Economic transition under carbon emission constraints in China: an evaluation at the city level. *Emerg. Mark. Finance Trade* 55, 1280–1293. doi:10.1080/1540496X.2018.1523056

Zhang, H., Song, Y., and Zhang, M. (2024). How does land resource mismatch affect urban energy low-carbon transition? *Urban Clim.* 58, 102236. doi:10.1016/j.uclim.2024.102236

Zhang, J., Wu, G. Y., and Zhang, J. P. (2004). Estimation of inter provincial material capital stock in China: 1952-2000. *Econ. Res.* 39 (10), 35–44. Available at: https://kns.cnki.net/kcms2/article/abstract?v=WpTTvLMLsy11Xj8MkAenR6NT-0j41dYp0OEIka6HzG4wvV4_2HbZUiWRchSmWG_Meo-z–4b1M1b1EhtZlIaQ-zbuiO6hjag6mCvQAyZk51E8Nq-SN49JynQdfttJx55gF35i2gK0Ipl885PZUmBTLR09iII6simqU09kRxw8gzxRHVZu5opV-754_W415Ox&uniplatform=NZKPT&language=CHS

Zhang, J. Z., Luo, M. T., and Cao, S. X. (2018). How deep is China's environmental Kuznets curve? An analysis based on ecological restoration under the Grain for Green program. *Land Use Policy* 70, 647–653. doi:10.1016/j.landusepol.2017.10.052

Zhao, C. Y. (2023). Is low-carbon energy technology a catalyst for driving green total factor productivity development? The case of China. *J. Clean. Prod.* 428, 139507. doi:10.1016/j.jclepro.2023.139507

Zhao, X., Nakonieczny, J., Jabeen, F., Shahzad, U., and Jia, W. X. (2022). Does green innovation induce green total factor productivity? Novel findings from Chinese city level data. *Technol. Forecast. Soc. Change* 185, 122021. doi:10.1016/j.techfore.2022.122021

Zheng, H., Wu, S., Zhang, Y., and He, Y. (2023). Environmental regulation effect on green total factor productivity in the Yangtze River Economic Belt. *J. Environ. Manage* 325, 116465. doi:10.1016/j.jenvman.2022.116465

Zhou, J. (2018). The New Urbanisation Plan and permanent urban settlement of migrants in Chongqing, China. *Popul. Space Place* 24, e2144. doi:10.1002/psp.2144

Zhou, Y. Y., Lin, Z. H., Zhang, Y. J., Sun, W. X., Lei, F. Y., and Gao, W. Z. (2024). Impact of changes in energy structure and industrial structure on green total factor productivity in the context of environmental protection-evidence from China. *Environ. Sci. Pollut. Res.* 31, 17097–17114. doi:10.1007/s11356-024-32329-7

Zhu, J., He, B. J., Tang, W. C., and Thompson, S. (2020). Community blemish or new dawn for the public realm? Governance challenges for self-claimed gardens in urban China. *Cities* 102, 102750. doi:10.1016/j.cities.2020.102750