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RESEARCH ARTICLE

Can green finance promote urban green development? Evidence from green finance reform and innovation pilot zone in China

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Abstract

This study aims to evaluate the effect of the green finance reform and innovation pilot zone (GFPZ) policy on urban green development. Based on city-level panel data in China from 2012 to 2019, a difference-in-differences model was employed to examine the effects of China's GFPZ policy on the city's green total factor productivity (GTFP). Results show that (1) the GFPZ policy has promoted the GTFP of pilot cities, a conclusion that still holds after performing multiple robustness tests. (2) Compared to non-pilot cities, the GFPZ policy can increase urban GTFP by promoting urban green innovation and reducing urban energy intensity. (3) The GFPZ policy had a more significant impact on mega cities and resource-based cities than on medium and big-sized cities and non-resource-based cities. This study provides new empirical evidence on how green finance influences urban green development and offers China's experience to policymakers worldwide to develop green finance in top-level policy design and practice.

Keywords Green finance · Green total factor productivity · Difference-in-differences · Pilot policy · Green development · Heterogeneous effects

Introduction

Climate change mitigation is considered a critical challenge for humanity in the twenty-first century. With the ultimate goal of achieving carbon neutrality, countries worldwide have prioritized the implementation of different environmental policies to reduce their carbon emissions. To date, a total of 198 countries have committed to carbon neutrality, 120 of which aim to do so by 2050–2070 (Chen et al. 2022). Developed countries such as the UK, France, and the USA are committed to achieving carbon neutrality by 2050, while the world's two largest developing countries, China and India, are committed to achieving this goal by 2060 and 2070, respectively. According to the "Global Carbon Budget Report 2021", the major contributors to global CO2 emissions in 2020 were China (31%), the USA (14%), the 27 EU countries (7%), and India (7%). As such, as the world's largest carbon emitter, China, is undoubtedly under enormous pressures to reduce its emissions.

Globally, the urban economic activity provides around 80% of gross domestic product (GDP) and over 70% of carbon emissions. Thus, the economic activities of cities are considered by scholars to be crucial in terms of emissions reduction and green development (Huo et al. 2022). Developing countries need a longer time to achieve carbon neutrality because of limitations in their economic development level and economic structure. As the world's largest developing country, to address climate change without sacrificing economic development, China urgently needs to promote a shift in urban development from a resource-intensive, traditional development pattern to an environmentally friendly development pattern, improving the quality of economic development and balancing its relationship with environmental protection. Green finance is the key to promoting urban green transformation and is popular in both developing and developed countries (Wang et al. 2021a). In the

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context of the global race to develop a sustainable economy, the international financial community has reached a consensus to improve environmental quality and promote economic growth through green finance (Scholtens and Dam 2007).

In 2017, China launched the green finance reform and innovation pilot zone (GFPZ) policy. This pilot policy aims to enhance the green financial system, explore diversified green financial tools, and enhance the role of green finance in promoting green economic development. In the past decades, China has grown rapidly, becoming the second largest economy worldwide (Han et al. 2018). The high dependence of the Chinese economy on resources and labor (Hou et al. 2019) implies a huge development "inertia," reflected in high sunk costs and heavy employment burden, which discourage the green transformation of the Chinese economy. Can the GFPZ policy effectively address this "inertia" and encourage regional green development? What are the transmission mechanisms? This study focused on these questions, providing recommendations for policymakers to improve the green financial policy system and the practical experiences of countries around the world, especially developing countries.

The majority of existing studies have adopted the green total factor productivity (GTFP) to measure regional green development (Li and Lin 2016; Peng 2020; Qiu et al. 2021). The GTFP considers the improvement of the economic and environmental performance and is an important approach to assessing green development (Elsadig and Ahmed 2012). Therefore, this study employed the GTFP to measure city green development using city-level panel data of five Chinese provinces in the period 2012–2019 and further investigated the effect of the GFPZ policy on urban GTFP and its transmission mechanism, applying a difference-in-differences (DID) model based on the enactment of the GFPZ policy in 2017 as a quasi-natural experiment.

This study makes the following contributions to existing research. First, existing studies have not reached a consensus on how environmental regulatory policies affect urban green development. The GFPZ policy, as an important environmental regulatory instrument, has been less well studied about how it affects urban green development. Therefore, this study assesses the impact of the GFPZ policy on urban green development and explains the mechanism of this impact, which is an addition to the related studies on how environmental regulation policies affect urban green development. The findings contribute to the understanding of the mechanisms by which government environmental regulatory instruments influence green development and can provide valuable references for developing countries like China and others seeking sustainable development paths. Second, green finance is an important environmental regulatory instrument, but previous empirical studies may have endogeneity problems in assessing its effect. This study applies the DID model to the assessment of the effect of green finance, using the GFPZ policy as a quasi-natural experiment to test how green finance affects GTFP, which overcomes the endogeneity problem to a certain extent and enriches the relevant studies on the assessment of green finance. Third, considering the regional differences in China, this study investigated the heterogeneous effects of the GFPZ policy on GTFP across different types of cities, according to city scale and resource endowment. We compared and analyzed the similarities and differences between the findings of this research and existing studies, providing new empirical evidence demonstrating the heterogeneous effects of the different environmental policies on cities of the same type.

Literature review

Literature on environmental regulation and green development

There is a lack of consensus in previous studies about how environmental regulation policies affect green development. Some scholars suggested that environmental regulation policies such as the low-carbon city pilot (LCCP) policy can promote urban green development (Cheng et al. 2019; Peng 2020; Qiu et al. 2021). Similarly, based on an industry perspective, Li and Lin (2016) argued that the implementation of energy efficiency policies is important to improve green productivity in the manufacturing sector.

However, some researchers hold the opposite opinion. They argued that the environmental regulation is to force enterprises to change their optimal production decisions by internalizing negative environmental externalities, increasing their production cost, and weakening their innovation ability and productivity (Guo et al. 2017; Li and Wu 2017). These studies conclude that a decline in enterprises' GTFP negatively affects urban green growth. A similar conclusion was reached by Zhou and Zhou (2021), who found that the LCCP policy is detrimental to urban low-carbon economic transition.

Existing studies lack consensus also on the heterogeneous impact of environmental regulatory policies on urban GTFP. While Qiu et al. (2021) concluded that environmental policies significantly impact non-resource-based large cities and eastern cities, Guo et al. (2021) found that the effect of environmental policies on GTFP is significant in non-eastern cities and insignificant in eastern cities. Besides, some researchers found that environmental regulations have a non-linear effect on GTFP, which depends on the type of environmental regulations, the industrial characteristics, and the economic development level (Zhao et al. 2018).

These opposing views may be due to differences in research sample and methods, or implementation of those environmental regulatory policies. As an important environmental policy, the GFPZ policy supports green industries, while it has a negative effect on enterprise costs due to the internalization of environmental externalities. Hence, the question addressed by this study is as follows: can the GFPZ policy promote green urban development?

Literature on green finance

Previous studies relevant to green finance mainly focused on green credit policies. Some studies adopting an enterprise perspective found that green credit has significant financing penalty effects and investment disincentive effects on highly polluting enterprises. They argued that green credit can effectively discourage investment in energy-intensive industries (Liu et al. 2017; Wang et al. 2020), significantly increase the financing cost of heavy polluters, and reduce their debt financing maturity (Xu and Li 2020), while at the same time, they improve the overall green innovation and the incremental green innovation of high polluters (Zhang et al. 2022c). Based on macro-level data, some studies have also affirmed that green credit positively influences environmental quality (Zhang et al. 2021b), thereby further improving regional GTFP (Guo et al. 2022). All these studies have explored the policy effects of green finance, focusing on green credit as the research object. However, as green credit is a part of green finance, using the former to represent the latter may bias the assessment of the effect of green finance policies. Some other studies use the entropy method to construct the development level of regional green finance to evaluate the impact of green finance on GTFP (Lee and Lee 2022; Liu et al. 2021); they have enriched the relevant research on the impact of green finance on GTFP but cannot well solve the endogeneity problem that exists in the empirical testing process. More accurate methods are urgently required to evaluate the impact of green finance on GTFP.

The promulgation of the GFPZ policy in China has provided a new perspective for research relevant to green finance, obtaining some crucial results. Through provincial panel data, Huang and Zhang (2021) empirically tested the effect of the GFPZ policies on reducing regional pollution emissions. Similar conclusions were reached by Zhang et al. (2022a); they used province-month panel data and concluded that the GFPZ policy can control the overall air pollution. At the micro level, Zhang and Lu (2022) use enterprise-level data; their findings indicate that the GFPZ policy can reduce illicit emissions. In addition, existing studies affirmed the positive effects of this policy on green innovation (Wang et al. 2022; Wang et al. 2021d; Zhang and Li 2022) and on long-term enterprise value (Hu et al. 2021). However, in the short term, the GFPZ policy significantly inhibits enterprise development in the pilot area, reducing the productivity of polluting enterprises. The GFPZ policy has promoted enterprise innovation, although the constraint effect was greater than the incentive effect. Enterprises have not yet developed "compensatory benefits" that exceed the compliance cost (Wang et al. 2021c), and it remains to be tested whether the GFPZ policy can promote urban green development.

Few studies have been performed about the effects of the GFPZ policy on GTFP. In essence, the GFPZ policy is an environmental regulatory tool that can impact green economic growth. The environmental regulation pilot policy represented by the low-carbon city pilot can promote urban GTFP; so, can the GFPZ policy, which has both environmental regulation and financial features, promote urban GTFP as well? Moreover, apart from promoting the development of conventional green financial tools such as green credit, the GFPZ policy also encourages a variety of capital such as microfinance, financial leasing, venture capital, private equity, and insurance, to participate in green investment, which can promote green finance development more strongly. The GFPZ policy has explored and innovated green financial tools. What are the differences in the policy effects of the GFPZ policy compared to traditional environmental regulatory tools? Studies in this area are still insufficient.

Policy background and research hypothesis

Policy background

Compared to developed countries, China's green finance started later but developed rapidly. In 2016, China issued the "Guidance on Building a Green Financial System," building a macro green financial policy system, and becoming the first country in the world to establish a green financial system promoted by the central government. In June 2017, the People's Bank of China and other ministries jointly issued a general scheme to build the GFPZ. Figure 1 depicts the location of each pilot city. The pilot areas include the following: the Ganjiang New Area (consisting of parts of Nanchang and Jiujiang) in Jiangxi Province, the Guian New Area (consisting of parts of Guiyang and Anshun) in Guizhou Province, Huzhou and Quzhou in Zhejiang Province, Guangzhou in Guangdong Province, and Hami, Changji Hui Autonomous Prefecture, and Karamay in the Xinjiang Uygur Autonomous Region. This scheme provided an overall plan for China's GFPZ, in order to better innovate green financial products and services, explore operational and replicable experiences, and promote green finance development at a national scale. In 2019, through the issue of the General Plan for the "Construction of the GFPZ in Lanzhou New Area (part of Lanzhou) in Gansu Province," this area was

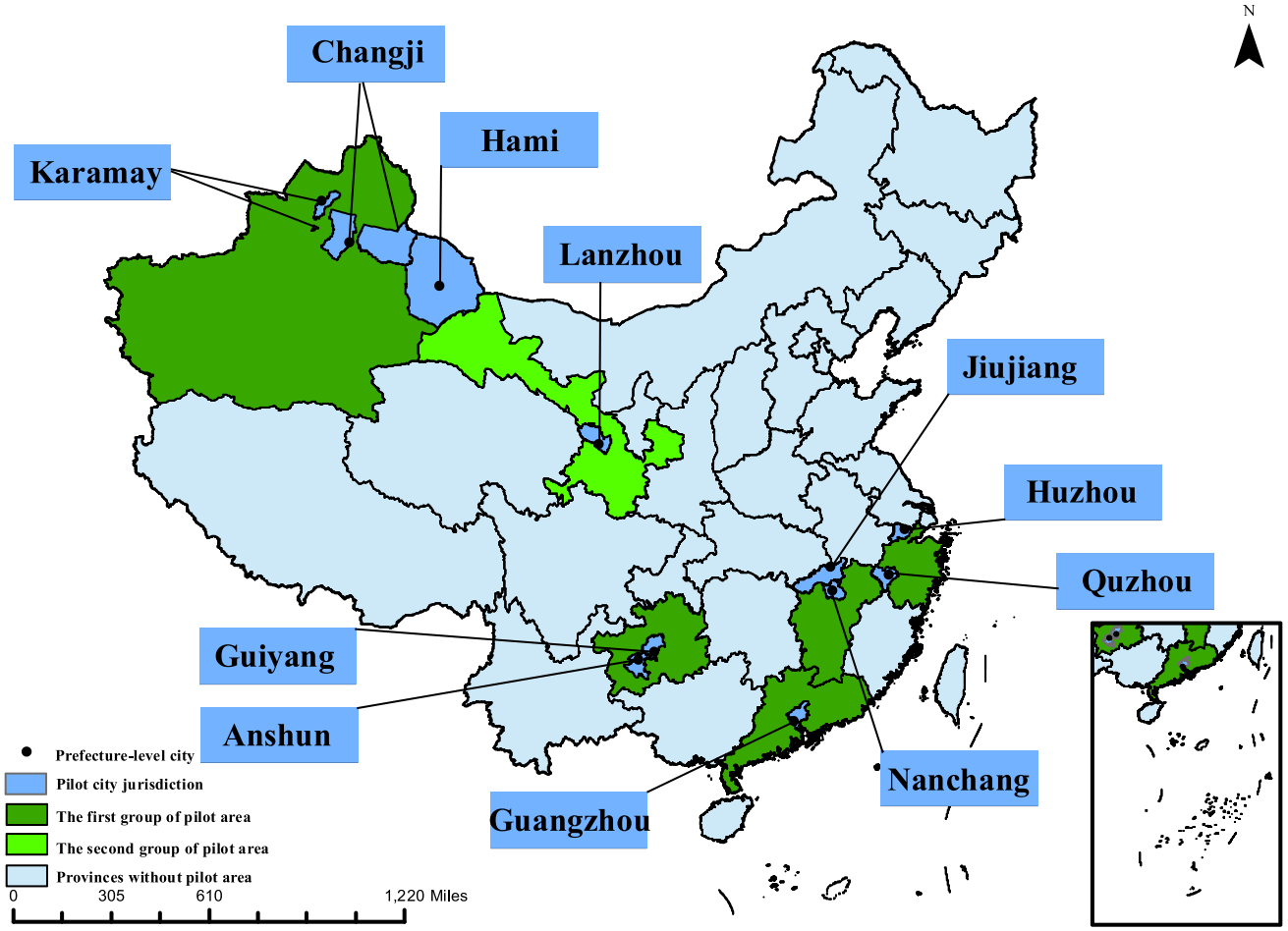

Fig. 1 Location of the pilot cities

included in the national green financial policy framework and the scope of the policy pilot was further expanded. Since then, China has developed the GFPZ including distinctive policy elements based on differences in economic development levels, industrial structure, and environmental carrying capacity across pilot regions. Table 1 shows the specific content of the green finance pilot in each pilot region.

Research hypotheses

The classic theory in the field of environmental regulation, the Porter Hypothesis, holds that when environmental regulation is severe and appropriate, it will stimulate the innovative behavior of enterprises (weak Porter hypothesis) and then produce an "innovation compensation" effect, which will ultimately improve the country's productivity and competitiveness (strong Porter hypothesis). (Jaffe and Palmer 1997; Porter and van der Linde 1995). Environmental regulation can promote innovation (Rubashkina et al. 2015), but the transformation process from innovation to productivity is often affected by many factors. After the implementation of environmental regulation policies, it may be caused by rising production costs. It leads to a decline in productivity and industrial competitiveness (Gollop and Roberts 1983; Gray 1987), and the type and intensity of environmental regulation determine the role of environmental regulation policies (Böhringer et al. 2012). As an important environmental regulation policy, the GFPZ policy, its purpose is to explore emerging and more effective financial tools and to direct capital toward the green industries (Hu et al. 2021). In this process, urban development gradually changes toward an inclusive urban growth pattern centered on environmental protection and environmental quality, thereby increasing urban GTFP. Environmental policies increase the financial constraints of highly polluting enterprises in the initial stage of implementation, increasing production costs through compliance cost effects, depleting innovation inputs, and leading to a decline in enterprise performance (Jaffe and Stavins 1995). When enterprises realize that environmental regulations work in the long run, they will increase their upfront investment in innovation or pollution reduction (Lee

Table 1 Detailed description of the GFPZ policy in each pilot region

Region	Content
Zhejiang Province	Focusing on industrial structure upgrading, Zhejiang Province proposes, with the help of green finance, to integrate the industrial chain, so as to accelerate traditional chemical industry transformation and drive the optimization of the regional economic structure. The city of Quzhou focuses on the green transformation of traditional industries, while the city of Huzhou focuses on industrial innovation and upgrading
Jiangxi Province	Jiangxi Province aims to explore effective methods to support ecological and economic development through green finance, and innovating credit products and finance patterns in the fields of energy conservation, emission reduction, and clean energy
Guangdong Province	Guangdong Province focuses on supporting green industries, broadening financing channels, promoting the deep integration of green industries and finance, and developing a new pattern in which green finance and economic growth are mutually compatible
Guizhou Province	Guizhou Province focuses on facilitating economic transformation and development with the help of green finance in western undeveloped areas, and proposes innovative green credit products for agriculture, centered on supporting agricultural industry projects including urban modern agriculture, organic agriculture, rural water conservancy project construction, and agricultural sewage treatment
Xinjiang Uygur Autonomous Region	Based on its comparative advantages in agriculture, natural resources, clean energy resources, energy-related high-end manufacturing, and environmental foundation, the Xinjiang Uygur Autonomous Region aims to explore institutional mechanisms for green finance to use green insurance to deliver an innovative green financial risk prevention and resolution mechanism
Gansu Province	Gansu Province explores the support of green finance to ecological industry development, accelerating innovation in green financial products and services, promoting the construction of an environmental rights and interests trading market, and expanding green financial cooperation with foreign countries

et al. 2011). For green enterprises, productive investments are crowded out by innovation investments, and the production costs are not compensated in time; this affects the performance of the enterprises in the short term but promotes the long-term innovation of green enterprises (Wang and Wang 2021). Therefore, there is a time lag in the effect of environmental policies (Yang et al. 2012). At the beginning of the implementation of environmental policies, an increase in operating costs may cause a decline in enterprise performance, which negatively impacts the GTFP of cities in the short term (Li and Wu 2017).

The distinctiveness of the GFPZ policy lays in the fact that in China, the development of green financial tools such as green credit was launched nearly 10 years before the promulgation of the GFPZ policy (Zhang et al. 2021c). As such, some of the necessary institutions, as well as society's awareness of green finance, have already been established. Therefore, the GFPZ policy is a further improvement and innovation of the policy system based on the foundation of the original green finance policies, and the policy effect appears to be faster compared to other environmental regulation policies. The GFPZ policy plays a greater facilitating role in promoting innovation, especially the technological innovation oriented to environmental protection. The time for the "innovation-offset effect" to catch up with the "compliance-cost effect" has been shortened, and the negative effects of the GFPZ policy on urban economic development have been largely offset. Another feature of the GFPZ policy is that it has a distinctive market-oriented feature, which can provide enterprises with higher autonomy in making production decisions and achieve moderate environmental regulation through market means, which satisfies the conditions of the "Strong Porter hypothesis" to a certain extent and is more conducive to the improvement of productivity. With the emergence of investment and labor production effects, the negative impact on economic development is eliminated (Dijkstra et al. 2011; Peuckert 2014), the enterprise's innovation investment has been rewarded, and GTFP has been significantly improved. Accordingly, the following hypothesis was put forward:

H1: The GFPZ policy promotes the GTFP in pilot cities.

The essence of environmental regulation is a kind of factor of production that makes the environment and internalizes it into the enterprise production process. It aims to modify the production behavior of enterprises and improve the quality of the environment, but the environmentally friendly technology often requires a huge upfront investment, research, and development funding, and cost-benefit considerations are the keys to affecting enterprises to carry on the green innovation. The command-and-control environmental regulations have a U-shaped relationship with the green technology innovation efficiency, and there is an obvious lag (Zhang et al. 2021a). The GFPZ policy supports the development of green industries such as organic agriculture, new energy, and pollution treatment industries through various financial tools. Through government guidance and market resources reallocation, several green financial policies have been enacted to encourage the green industries

and reduce pollution. Green financial policies direct more capital to green industries (Wang and Wang 2021), providing enterprises with abundant capital sources for technological innovation, especially green technological innovation. The continuous influence of those green financial policies has brought substantial research and development (R&D) funds, enhancing the green innovation capability of enterprises. As the "innovation-offset effect" gradually emerges, the enterprise performance improves, and the enterprises are encouraged to continuously engage in green innovation (Wang et al. 2019). In addition, green technology innovations enable enterprises to fulfill their social responsibility, enhancing their competitive advantage while at the same time solving social problems and achieving sustainable development (Porter and Kramer 2006). The increase of urban GTFP is attributed to green innovation (Wang et al. 2021b). Considering these analyses, the following hypothesis was put forward:

H2: The establishment of the GFPZ promotes green innovation, thereby improving urban GTFP.

The establishment of the GFPZ can reduce the dependence of urban economic development on energy, improving urban GTFP. On the one hand, the GFPZ policy aims to impose strict financing constraints on highly polluting and energy-consuming enterprises through various financial tools, forcing them to implement technological transformation and pollution control, and changing their previous sloppy development patterns toward clean, low energy-consuming production patterns, thereby gradually reducing energy consumption (Liu et al. 2018) and achieving an increase in urban GTFP. On the other hand, the GFPZ policy supports the development of industries such as urban modern agriculture, organic agriculture, and clean energy. Labor, capital, and technology are gradually concentrated in industries dominated by clean production projects. With internal optimization and competition in these industries, green industries are gradually developing, and their contribution to traditional fossil energy is gradually reducing. As a consequence, the primary and tertiary industries with lower energy consumption contribute more to economic development, while the development of new energy industries, such as clean energy, gradually reduces the dependence of the economy on fossil energy (Liu et al. 2017). The orientation of the GFPZ policy is to reduce energy consumption in production activities and daily life, while at the same time promoting economic development. Accordingly, the following hypothesis was put forward:

H3: The establishment of the GFPZ helps reduce urban energy intensity, thereby improving urban GTFP.

Empirical strategy

Econometric model setting

Empirical model

The DID is an important method in the assessment of policy. If the implementation of a policy works on only one part of the economy and has no effect on another part, this can be considered an approximate scientific experiment to assess the impact of that policy on different parts of the economy, and the differences in the final assessment result will be attributed to the effect of the implementation of the policy.

Based on Du and Takeuchi (2019), this study applied a DID Model to examine the relationship between the GFPZ policy and urban GTFP. In fact, the use of a DID Model can effectively identify the policy treatment effect, i.e., the net policy effect, while at the same time, it can effectively control for the endogenous association between the GFPZ policy and urban GTFP. This study controlled for city fixed effects and year fixed effects in the model, which was set up as follows:

$$GTFP_{it} = \theta_0 + \theta_1\, \mathrm{time_t} \times \mathrm{treat_i} + \theta_2 \mathrm{time_t} + \theta_3 \mathrm{treat_i} + \theta_4 X_{it} + \gamma_t + \mu_i + \varepsilon_{it} \quad (1)$$

where the subscripts i and t denote the cities and the year, respectively; the dependent variable $GTFP_{it}$ indicates the GTFP of the i city in year t; and θ_0 is the constant term. $\mathrm{time_t} \times \mathrm{treat_i}$ indicates whether city i was a GFPZ policy pilot city from 2017 onwards, in which case it was assigned a value of 1, and 0 otherwise; the coefficient θ_1 indicates the magnitude and direction of the effect of the GFPZ policy on urban GTFP; X_{it} is the control variable; γ_t, μ_i are the year fixed effects and the city fixed effects, respectively; and ε_{it} is a random factor.

The test of the transmission mechanism

Based on the mechanism analysis, this study adopted the mediating effect model (Lu et al. 2021; Ren et al. 2022a; Ren et al. 2021) to investigate the mediating effect of the GFPZ policy on urban GTFP through green innovation and energy intensity mechanisms. Considering the influence of the variable X on the variable Y, if X can influence Y through another variable M, then M is a mediating variable. The following formulas were used to establish the mediation effect model:

$$Y = aX + e_1 \quad (2)$$

$$M = bX + e_2 \quad (3)$$

$$Y = a'X + cM + e_3 \quad (4)$$

The coefficient a in Formula (2) represents the total influence of variable X on variable Y; the coefficient b in Formula (3) represents the influence of the variable X on the mediator variable M; and the coefficient c in Formula (4) represents the influence of the mediating variable M on variable Y. After controlling the effect of the mediating variable M, the coefficient a' indicates the direct influence of variable X on variable Y. e_1–e_3 are the random error terms.

The causal step method is the most commonly used method to test the mediation effect. In this study, if the coefficients a, b, c were all significant, the mediating effect was considered significant. This approach is also referred to as the test of joint significance.

Empirical framework

To investigate the effect of the GFPZ policy on urban GTFP, the empirical framework of this study is as follows: Firstly, to calculate GTFP, this study constructs the input-output index system. Moreover, a super-efficiency Slacks-Based Measure (SBM) model with unexpected output is employed for estimating GTFP. The difference-in-differences variable *did* is that the cross-term of the policy pilot time dummy variable time and the policy treatment dummy variable treat.

Secondly, the influence of the GFPZ policy on urban GTFP was tested by DID, and the baseline regression results were obtained. The parameter of interest is θ_1 in Formula (1) and θ_1 provides a DID estimation of the net effect of the GFPZ policy on urban GTFP. However, before this, we should first test the parallel trend of GTFP to ensure that there is no significant difference in GTFP of each city before the promulgation of the policy. Only if this assumption is satisfied can the estimation result of DID be credible. Moreover, to further test the robustness of the baseline regression results, this study increases the robustness of the baseline regression results in three ways: forge of policy pilot cities, change of the policy pilot time, and exclusion of the impact of parallel policies.

Finally, to further strengthen the causal relationship between the baseline results of this study, we verify the mediating role of green innovation and energy intensity in the baseline regression results through the mediating effect model. Similarly, a parallel trend test is required for these two mediating variables before the empirical test. Meanwhile, in order to further enrich the mechanism of the GFPZ policy influencing urban GTFP, this study also conducts heterogeneity analysis through Formula (1) based on city size and resource dependence (Fig. 2).

Data and variables

We obtained balanced panel data for 51 cities within the 5 provinces covered by China's GFPZ policy in the period 2012–2019, including 8 green finance pilot cities. The green innovation data were collected through a manual search on the website of the State Intellectual Property Office of China (SIPO), based on the green patent International Patent Classification (IPC) classification numbers included the "International Patent Green Classification List" published by the World Intellectual Property Organization (WIPO) in 2010. This includes patent applications in the following categories: biofuels, other thermal energy manufacturing or utilization, rail vehicles, energy supply lines, general building insulation, recovery of mechanical energy, wind energy, and fuel cells. Except for the variables of green innovation, the data of all variables were obtained from the "China City Statistical Yearbook (2012–2019)". Table 2 shows the descriptive statistics of the variables.

Explained variable

In this study, the explained variable *GTFP* was measured by a super-efficiency slacks-based measure (SBM) model with unexpected output. To measure *GTFP* with this model, input and output variables needed to be selected first. In this model, the input variables include capital, energy inputs, and labor force, and the output variables include the expected output variable GDP and the unexpected output variable CO2 emissions. In relation to input variables, labor force input was measured by the number of employed persons in private sector, self-employed individuals, and enterprises urban units; capital stock was measured by the perpetual inventory method, which is a commonly used calculation method. Limited by the availability of the official "China City Statistical Yearbook," this study adopted the method proposed by Wang and Ni (2016) to measure the capital stock of each city. This study used the indicator of annual electricity consumption of the whole society as a proxy variable for energy input. In terms of output variables, the expected output variable GDP was directly available from the "China City Statistical Yearbook," while the data on the unexpected output variable CO2 emissions are not provided. Therefore, based on Cheng et al. (2019), this study calculated CO2 emissions according to natural gas, liquefied petroleum gas, and the consumption of electricity.

Explanatory variable

The explanatory variable in this study, *did*, was constructed from the cross-term of the policy pilot time dummy variable *time* and the policy treatment dummy variable *treat*. The *time* variable was assigned a value of 1 for the pilot period (2017–2019) and a value of 0 for the non-pilot period (2012–2016). *treat* is a dummy variable for the policy pilot area; it was assigned a value of 1 for each pilot city within the five provinces investigated, and 0 otherwise.

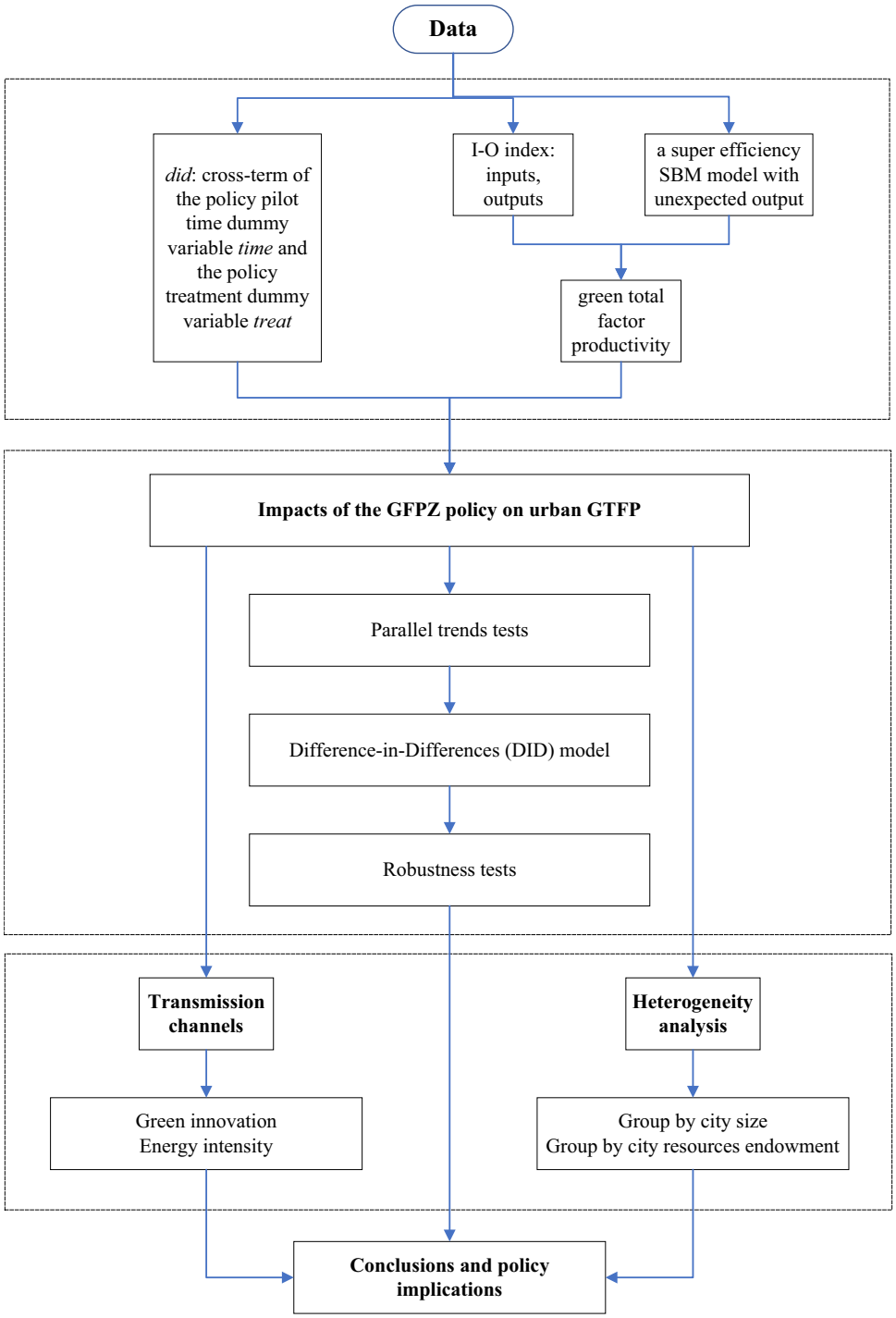

Fig. 2 The proposed integrated model for impacts of the GFPZ policy on urban GTFP

Control variables

To alleviate endogeneity problems due to omitted variables, eight control variables were selected.

Economic development Economic development is an important variable that affects urban GTFP (Mikayilov et al. 2018). Referring to Hao et al. (2021), the level of economic development (*EL*) was represented by the GDP per capita.

Economy openness Foreign direct investment can introduce advanced production technology or advanced management theory and experience, which can contribute to GTFP (Newman et al. 2015). Referring to Cheng et al., economic

Table 2 Descriptive statistics of the variables

Variable	Unit	Mean	Std. Dev.	Min	Max
GTFP	Decimal	0.667	0.347	0.125	1.967
GI	Piece	564.897	1469.354	1.000	13,755.000
EI	Decimal	1365.695	1341.429	80.744	12,389.680
EL	Yuan	64,122.470	46,244.190	11,962.000	467,749.000
Open	10,000 yuan	107,132.300	164,111.200	104.000	820,301.000
IC	m^2	2183.062	2751.091	92.000	18,743.000
HC	Decimal	0.021	0.026	0.001	0.169
GS	Decimal	0.227	0.204	0.065	1.905
Finance	Decimal	1.267	0.932	0.173	9.054
Technology	Decimal	0.005	0.006	0.000	0.057
Informatization	Yuan	1973.313	2153.589	307.343	19,032.260

openness (*Open*) was represented by the utilization of foreign capital.

Infrastructure construction Strengthening the infrastructure construction in urban is conducive to alleviating the resource mismatch, thereby improving urban production efficiency (Sun et al. 2019). Referring to Cao et al. (2021), infrastructure construction (*IC*) was denoted by the road area per capita.

Human capital As the source of technological progress, human capital is particularly important for the role of urban GTFP increasing (Bano et al. 2018), the human capital (*HC*) was reflected by the proportion of students in regular HEIs to household registered population (Qiu et al. 2021).

Government size Referring to Jiang et al. (2021), this study includes the size of government as a control variable in the model; the government size (*GS*) was represented by the proportion of fiscal expenditure to GDP.

Financial development Referring to Ren et al. (2022b), this study takes the financial development as an important control variable. Financial development (*Finance*) was indicated by the proportion of the loan balance of financial institutions to GDP at the end of the year (Ren et al. 2021).

Technological innovation Technological innovation is often considered to be an important factor influencing GTFP (Qiu et al. 2021; Ren et al. 2022b), and we consider that government fiscal support for technological innovation may provide a more complete picture of the city's technological innovation. Therefore, technological innovation (*Tech*) was indicated by the proportion of fiscal expenditure on science and technology to GDP.

Informatization Information and communication technology plays a positive role in promoting GTFP (Hao et al. 2021). Therefore, it is necessary to take it into account in the model. Informatization (*Informatization*) was expressed by the total output value of postal enterprises and communication enterprises per capita.

Mediating variables

Based on the abovementioned theoretical mechanism analysis, two mediating variables were included in this study, namely green innovation (GI) and energy intensity (EI). Green innovation was measured by the number of green patent applications in the sample city. Energy intensity was expressed as the ratio of total energy consumption to GDP; the energy consumption data were based on the inventory method proposed by the Intergovernmental Panel on Climate Change (IPCC) in 2006, which calculates the total energy consumption by energy conversion based on the energy equivalent standard coal reference coefficient.

Results

Parallel trends test

The DID approach presupposes that the trends of the explained variables in both control group and treatment group before the policy shock remain consistent, i.e., the differences in urban GTFP between the control group and the treatment group are relatively fixed. Figure 3 depicts the changing trend of GTFP in the cities in the treatment group and the control group in the 5 years before the promulgation of the GFPZ policy, showing no significant differences between the control group and the treatment group.

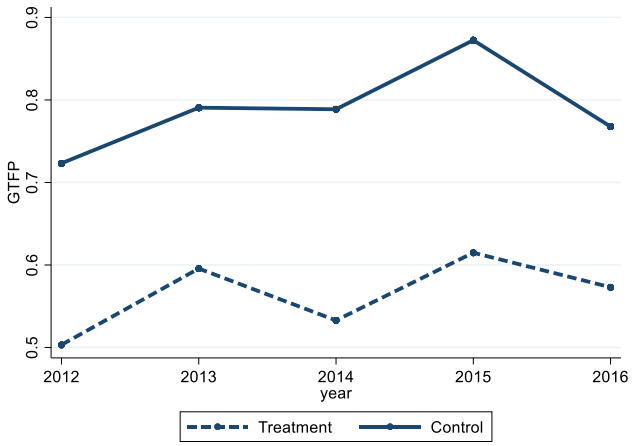

Fig. 3 Change trend of GTFP in treatment and control group cities from 2012 to 2016

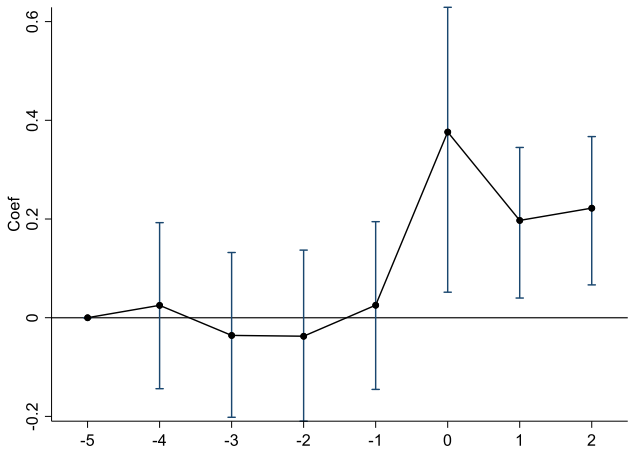

Fig. 4 Year-on-year difference-in-differences estimates

Furthermore, to avoid the subjectivity of intuitive judgments, this study applied the event study approach (ESA) to identify the parallel trends, examining the dynamic effects of the implementation of the GFPZ policy on urban GTFP (Li et al. 2019). The year dummy variable and the treatment group dummy variable were cross-multiplied to generate cross-terms, which were then added to the model. The coefficients of the cross-terms measure the differences between the control and treatment groups. If the coefficients before the policy pilot were not significant, it indicated that the time trends of the control group and the treatment group were not heterogeneous. Figure 4 shows the significance of the coefficients of the cross-terms for each year at the 95% confidence interval, with 2012 as the base period. The results indicate that the regression coefficients were not significantly different from 0 in all four periods before the implementation of the GFPZ policy, indicating that there were no systematic differences between the control and treatment groups. After the implementation of the GFPZ policy, the regression coefficients were significantly different from 0, indicating that the policy effect appeared and the parallel trends were evidenced.

Table 3 Difference-in-difference estimates of the effect of the GFPZ policy on GTFP

	(1)	(2)
did	0.270*** (0.069)	0.211*** (0.064)
Constant	0.595*** (0.107)	0.195 (0.270)
Control vars	No	Yes
City FE	Yes	Yes
Year FE	Yes	Yes
R^2	0.491	0.606
Observations	408	408

Robust standard errors are indicated in parentheses. Superscripts ***, **, and * represent significance at the 1%, 5%, and 10% level, respectively. This note applies to the following tables

Baseline results

As shown in Table 3, Model (1) only includes the cross-term *did*, controlling for year fixed effects and city fixed effects, while Model (2) adds control variables to Model (1), improving the robustness of the estimation results. The results revealed that the coefficient of *did* was equal to 0.211 and remained significantly positive at a statistical significance level of 1%. A further verification of the empirical results indicated that the estimated coefficient of *did* was significantly reduced. Considering that the models that omit these important controls tend to influence the effect of the GFPZ policy on urban GTFP, we employed Model (2) as our baseline model. The regression results indicate that the GFPZ policy increases urban GTFP, thereby verifying H1.

This research result is supported by relevant green finance research (He et al. 2019; Lee and Lee 2022; Zhang 2021). Although the measurement methods of green finance are varied, for example, Lee and Lee (2022) measure the development level of green finance through the entropy method, while He et al. (2019) and Zhang (2021) consider the impact of green credit policy on green productivity, and they believe that green investment and credit can promote green economy and productivity. The conclusions obtained from these studies all support our baseline regression results. This finding is also consistent with the majority of studies about environmental regulation pilot policies (Cheng et al. 2019; Qiu et al. 2021). However, this study revealed that the promotion effect of the GFPZ policy on GTFP was greater than that of other environmental regulation policies, which is consistent with the analysis we conducted to propose H1. This may be because green finance fully developed in China before the implementation of the GFPZ policy, and a green finance

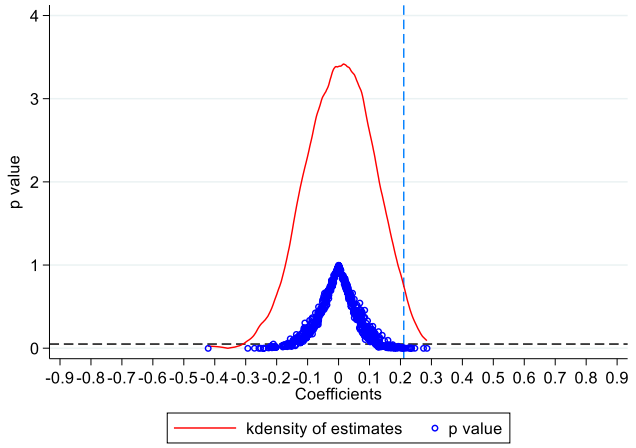

Fig. 5 Placebo test

policy system was established in an early stage, providing a good policy foundation for its implementation. The GFPZ policy emphasizes resource allocation through the market, flexibly promoting urban green development. Moreover, it explores richer and more effective green financial tools for the pilot regions, providing more opportunities for enterprises to achieve cleaner production, thereby promoting the GTFP more significantly.

Robustness checks

Forgery of policy pilot cities

To further exclude the influence of unobservable factors at the "city-year" level, a randomly selected group of pilot cities was used to conduct a placebo test. Specifically, 8 cities were randomly selected from 51 cities in the 5 provinces covered by the GFPZ policy as the treatment group, assuming that they have promulgated the GFPZ policy, while the other cities were in the control group. The erroneous policy pilot area dummy variable treat' and the erroneous cross-term $time_t \times treat'$ were generated and substituted into the baseline model. Then, the coefficients of the erroneous variable $time_t \times treat'$ were extracted, and the abovementioned operation was repeated 500 times. As shown in Fig. 5, all the estimated coefficients of $time_t \times treat'$ were concentrated around 0 and approximately obeyed a normal distribution. Most of the estimates had *p*-values greater than 0.1, and the true estimates of this study were significant outliers in the placebo test. These results show that the estimates in our study were unlikely to be disturbed by unobservable factors in "city-year" and were robust.

Change of the policy pilot time

Following Zhang et al. (2021c), a placebo test was conducted by falsifying the policy pilot time to identify whether it was influenced by other random factors. Assuming that 2016, 2015, and 2014 were the policy pilot times and excluding all samples in 2017, the erroneous policy pilot time dummy variable time' and the erroneous cross-term $time' \times treat_i$ were constructed. If the coefficients of the cross-terms $time' \times treat_i$ were significant, this indicated a pseudo-causal relationship due to other factors; otherwise, it indicated that the treatment effect was indeed generated by the implementation of the GFPZ policy. Models (1)–(3) in Table 4 indicate that none of the cross-term coefficients $time' \times treat_i$ was significant, further supporting the baseline regression results.

Table 4 Cross multiplication term for fictitious policy shocks

	(1) 2014	(2) 2015	(3) 2016
$time' \times treat_i$	−0.085 (0.062)	−0.047 (0.064)	−0.022 (0.083)
Constant	−0.066 (0.660)	0.118 (0.662)	0.156 (0.678)
Control vars	Yes	Yes	Yes
City FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
R^2	0.656	0.654	0.654
Observations	408	408	408

Exclusion of the impact of parallel policies

In order to avoid other policies during the sample period that may have an effect on the green development of the city and thus bias the baseline estimation results, this study identified two pilot policies that may affect the green development of the city by collecting and combing documents, namely the carbon emissions trading pilot (CETP) policy and the LCCP policy. Regarding the LCCP policy, China launched three groups of pilot cities in 2010, 2012, and 2017, respectively. Regarding the CETP policy, China approved six provinces and one city (i.e., Beijing, Tianjin, Shanghai, Chongqing, Hubei, Guangdong, and Shenzhen) to launch a pilot scheme on October 29, 2011. Specifically, Shenzhen was the first to start trading on June 18, 2013, and the national trading market was carried out at the end of 2017 (Xu et al. 2022).

Therefore, this study followed Xu et al. (2022) and Zhou et al. (2020), trying to exclude the impacts of similar policies by constructing two dummy variables, i.e., one to indicate whether the city is a low-carbon pilot area, and the other indicating whether the city is the CETP area. Based on the baseline model, Table 5 shows Model (1) controls for the LCCP policy, Model (2) controls for the CETP policy, and Model (3) controls for both the LCCP policy and the CETP policy. The results indicate that, after controlling the impacts of similar policies, the regression coefficients of the cross-term *did*, which were both significant

Table 5 Control of similar policy shocks

	(1)	(2)	(3)
did	0.221*** (0.068)	0.211*** (0.064)	0.221*** (0.068)
LCP	−0.061 (0.097)		−0.061 (0.097)
CET		0.659** (0.313)	0.672** (0.312)
Constant	0.237 (0.301)	0.195 (0.270)	0.237 (0.301)
Control vars	Yes	Yes	Yes
City FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
R^2	0.607	0.606	0.607
Observations	408	408	408

at a 1% level, remained almost unchanged compared to the baseline results, thereby further supporting the baseline regression results.

Mechanism analysis

In this paper, we apply a DID model to empirically test the transmission mechanism of the GFPZ policy affecting urban GTFP. The prerequisite for applying the DID method is that the parallel trend hypothesis is satisfied. We first test whether the mediating variables satisfy the parallel trend in the same way as before. Figure 6 depicts the changing trend of green innovation and energy intensity for the cities in the control group and the treatment group in the 5 years before the implementation of the GFPZ policy. Figure 7 depicts the results of the parallel trend test using the ESA method. The regression outcomes show that there were no systematic differences between the control groups and the treatment groups before the GFPZ policy was promulgated, while after the promulgation of the GFPZ policy, the effects of the policy became apparent. This indicates that green innovation and energy intensity satisfy the parallel trend hypothesis.

Table 6 presents the estimated results of the mediating effect of green innovation and energy intensity. Model (1) was used to test whether the GFPZ policy affects green innovation. The coefficient of *did* was significantly positive, thereby indicating that the GFPZ policy promoted green innovation in pilot cities. Model (2) was used to test whether the GFPZ policy affects energy intensity. The coefficient of *did* was significantly negative, which indicates the GFPZ policy reduced the energy intensity of pilot cities. In Model (3), GTFP is the explained variable. The coefficients of *did* and *GI* were significantly positive, while the coefficient of *EI* was significantly negative. This indicates that both *GI* and *EI* play an intermediary role in the impact of the GFPZ policy on urban GTFP. In summary, the GFPZ policy improves urban GTFP by enhancing urban green innovation and reducing energy intensity, thereby supporting H2 and H3.

On the one hand, this result is consistent with and enriches the findings of Wang et al. (2022) and Zhang and Li (2022); their study verified the promotion effect of the GFPZ policy on green technology innovation by using data from provinces and enterprises respectively. The GFPZ policy directs more capital to the cleaner production field, enabling green enterprises to receive large amounts of financial support, relieving the pressure on enterprises' innovation costs, and enhancing green enterprises' innovation incentives. In contrast, financing constraints generated by the GFPZ policy on high-polluting enterprises reduce their productivity. Highly polluting enterprises have to consider improving their technological innovation, especially green innovation, to obtain financial support from commercial banks. Green innovation is considered to be an effective way to balance economic growth and environmental protection. Its effects on CO2 emission reduction have received widespread attention from scholars. Lin and Ma (2022) classified green innovations into six categories based on the relationship between green technologies and carbon reduction and discussed the

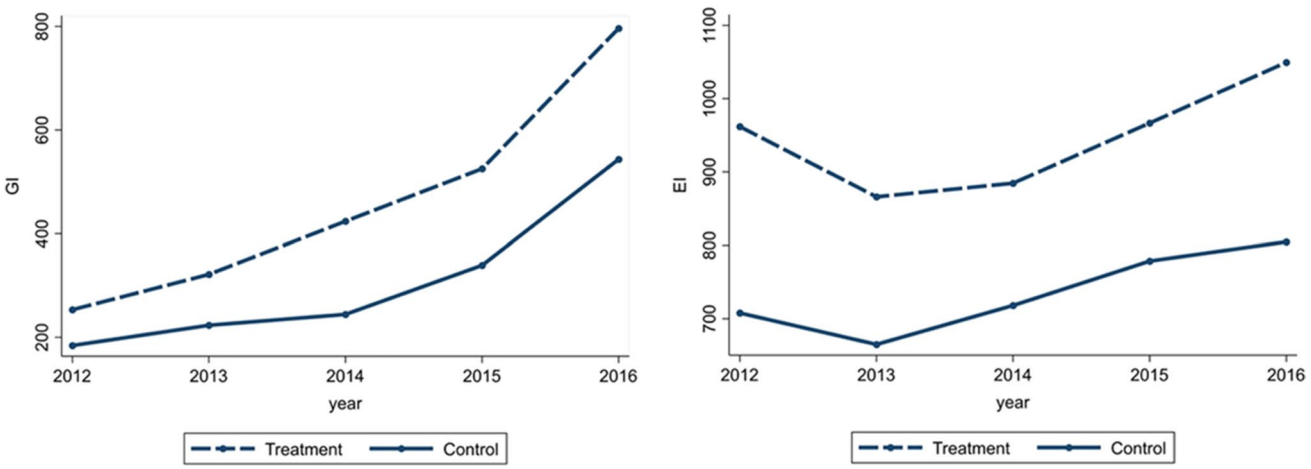

Fig. 6 Change trend of green innovation and energy intensity from 2012 to 2016

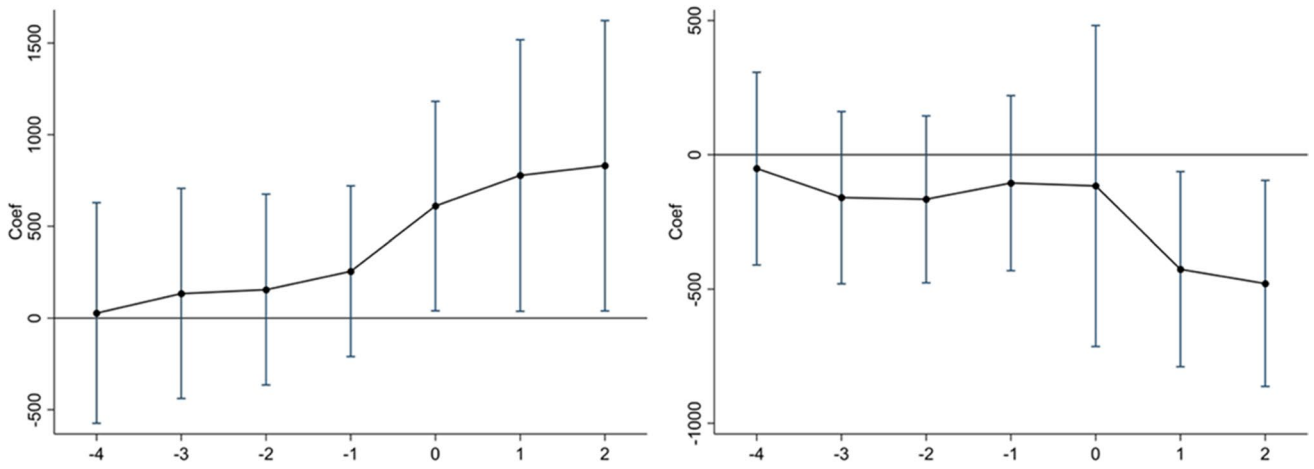

Fig. 7 ESA examination of green innovation and energy intensity

important role of green innovations in carbon emission reduction separately. Xu et al. (2021) also found a positive effect of green technologies on the carbon performance of Chinese cities. The above findings are consistent with the analysis of the green innovation mechanism in this study.

On the other hand, fossil-based energy consumption is the main cause of increases in greenhouse gas emissions such as CO2 and hindering the green development of cities (Zhang et al. 2022b). In China, the energy consumption structure is dominated by fossil energy sources such as coal and oil, and the fossil energy-based energy consumption structure will remain unchanged in the near future (Wang and Jia 2022). This means that at the current stage, improving energy utilization efficiency and reducing energy consumption intensity are the priority for China to control CO2 emissions and promote the green development of cities. The GFPZ policy reduces fossil energy consumption by financially limiting access to capital for high-pollution and high-emission production projects. The GFPZ policy encourages additional clean production projects that produce high-value products with low energy consumption, thereby reducing dependence on fossil energy, improving enterprises performance, and contributing to the reduction of urban energy intensity. This has affected positively the green development of the cities.

Heterogeneity analysis

The results of the baseline model allowed to conclude that the GFPZ policy significantly improves urban GTFP, while the effect of the GFPZ policy on cities with different sizes and resource endowments may be heterogeneous. Due to differences in scaling effects, the marginal costs and benefits of capital, labor force, and technology investments differ depending on city size. Similarly, urban resource endowments may also influence the effects of policy implementation. Therefore, this study further analyzed the heterogeneous impact of the GFPZ policy on diverse cities from the perspectives of city size and resource endowment. Based on the standards in the "Notice of the State Council on Adjusting the Standards for Categorizing City Sizes," issued by the State Council in 2014, this study divided the sample data into two categories according to city size, namely medium-large cities (with a population of less than 5 million) and mega cities (with a population of more than 5 million). About resource endowment, according to the "National Sustainable Development Plan for Resource-based Cities (2013–2020)," this study divided the sample cities into non-resource-based cities and resource-based cities. Models (1)–(4) in Table 7 show the regression results for the resource-based, non-resource-based, mega cities, and medium-large city samples. These results show that the *did* coefficients of all four types of cities were significantly positive at a 5% level, indicating that the GFPZ policy significantly contributed to GTFP in all four types of cities. However, the *did* coefficients of resource-based cities and mega cities were significantly higher than those of non-resource-based cities and medium and large-sized cities, indicating that the GFPZ policy has a more significant promotion effect on GTFP in the former compared to the latter.

Mega cities have advantages in capital, labor force, and technology reserves due to the agglomeration effect of city size, which supports the role of green finance in resource allocation. The specialized division of labor within larger cities improves the possibility and quality of matching production factors, reduces transaction costs, and allows to achieve a centralized utilization of resources and a centralized treatment of pollutants (Qiu et al. 2021). Cities that are larger, in general, will tend to have more of any kind of business. The beneficial impact of green finance on GTFP is much stronger in regions with higher levels of economic

Table 6 Results of the mechanism analysis

	(1) GI	(2) EI	(3) GTFP
did	596.272** (292.821)	−304.405** (137.950)	0.157*** (0.050)
GI			0.000** (0.000)
EI			−0.000*** (0.000)
Constant	4489.840*** (779.255)	−1677.278*** (367.841)	0.082 (0.253)
Control vars	Yes	Yes	Yes
City FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
R^2	0.775	0.917	0.638
Observations	408	408	408

Table 7 Heterogeneity analysis based on city features

	(1)	(2)	(3)	(4)
did	0.260** (0.125)	0.172*** (0.063)	0.442*** (0.110)	0.155** (0.075)
Constant	1.287*** (0.168)	0.111 (0.285)	1.019** (0.497)	0.647*** (0.152)
Control vars	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
R^2	0.676	0.610	0.689	0.584
Observations	96	312	136	272

growth, foreign investment, and financial support (Lee and Lee 2022). Compared to smaller cities, the implementation of the GFPZ policy in larger cities entails lower costs and better policy effects. This conclusion is consistent with the results of most studies.

The heterogeneous effects of different environmental policies may differ also between resource-based and non-resource-based cities. Qiu et al. (2021) concluded that environmental regulation significantly promotes the green transition of non-resource-based cities, while at the same time inhibiting the green transition of resource-based cities. However, this study reached the opposite conclusion, which may be due to the heterogeneity of the policies considered. Resource-based cities rely on local natural resources for their economic development, and the command-and-control environmental policy tools expose these cities to the "resource curse," which weakens the effect of such environmental policies in promoting GTFP. In this respect, market incentive tools such as green finance are more effective (Popp et al. 2011). Green finance can broaden the financing channels of green enterprises, alleviate the financing difficulties of green enterprises, and allow to achieve environmental protection goals through financial leverage (Zhang et al. 2021b). Supported by green finance, resource-based cities are more effective in greening and adjusting their industries due to their resource endowment and industrial base. In addition, the GFPZ policy was enacted late, while green finance has already played a role in related fields and may facilitate the transformation of resource-based cities. With the implementation of the pilot policy, resource-based cities, relying on their resource endowments and supported by a more efficient green finance policy, have significantly promoted their GTFP and transformed to become green cities in a faster way. This is consistent with our findings.

Conclusions and policy implications

Conclusions

To achieve win-win outcomes for both economic development and environmental protection, China promulgated the GFPZ policy in 2017. With the implementation of the GFPZ policy, each city has reformed and innovated its green financial tools according to its features. This study used the GFPZ policy as a quasi-natural experiment to test the impact of the GFPZ policy on urban GTFP through a DID model. The following conclusions were drawn.

Firstly, both the theoretical analysis and the empirical results showed that the GFPZ policy has a positive impact on urban GTFP. Robustness tests were also conducted in this study, including randomly selecting a group of pilot cities, changing the pilot time, and controlling for similar policy shocks. The results of all the robustness tests support the conclusions drawn from the baseline model.

Secondly, our theoretical mechanism analysis indicated that the GFPZ policy increases urban GTFP by promoting urban green innovation and reducing urban energy intensity; the green innovation mechanism and the energy intensity mechanism were verified through empirical tests.

Finally, the impact of the GFPZ policy on GTFP across cities varies according to city features. When considering the heterogeneity of a city's size and resource endowment, the GFPZ policy promotes urban GTFP more significantly in mega cities and resource-based cities compared to large and medium-sized cities and non-resource-based cities.

Policy implications

To facilitate the green finance policy system and urban green development, based on the research results, some policy recommendations are proposed.

First, green finance can effectively promote urban green transformation; the China government should continue to expand the pilot areas and strive to develop more replicable experiences to unify green finance standards and improve the business sustainability of green finance. As a consequence of the COVID-19 epidemic, more small and medium-sized enterprises (SMEs) may be hampered in their green transformation due to a lack of capital, which is an opportunity for the development of green finance. The GFPZ policy encourages local governments to explore a variety of green finance instruments, including microcredit and private equity, which are more friendly to SMEs and are more conducive to rapid economic development and green transformation after the epidemic. Representative cases of the previous pilot cities should be summarized to provide more experiences in green finance development for subsequent pilot regions and other regions worldwide.

Second, the important policy implication from the mechanism analysis is that innovation in green technology and clean energy use is important channels for urban transformation. The government's top priority in urban green development is to promote green innovation and encourage the use of clean energy. In the implementation of the GFPZ policy, the government should continuously improve the incentive mechanism of green innovation and encourage the use and development of new energy sources. The government should provide a better environment for researchers to innovate and pay attention to the protection of intellectual property rights. Promoting clean technologies through financial instruments will be more conducive to urban transformation

Third, the scaling effects and the agglomeration effects of larger cities should be fully utilized to further promote urban green development in the surrounding areas. Smaller cities should strive to achieve emission reduction and energy conservation and explore financial tools that are more applicable at a smaller scale. Another practical and applicable policy recommendation is that green finance is more helpful to the green development of resource-based cities, and the government should consider developing green finance more actively in these cities to accelerate the urban green transformation based on local energy advantages.

Limitations and future research

This study has the following limitations. Due to limited data availability, it examined the impact of the GFPZ policy on urban GTFP using only the first pilot cities of the GFPZ policy, thereby excluding the second group of pilot cities announced in 2019. In the future, we will continue to follow the progress of this policy, collect more city-level data, and examine the heterogeneous impact of the GFPZ policy on GTFP in different cities considering additional city-level features, such as the level of financial technology development, the degree of financial inclusion, and the level of industrial agglomeration to provide abundant empirical evidence.

In addition, this study did not consider the impact of this pilot policy on neighboring areas, which may entail spatial spillover effects. Therefore, the assessment of the effects of the pilot policy should consider not only the impacts generated locally, but also the additional impacts generated during the interaction between neighboring regions and the pilot region. In the future, we will combine spatial econometrics with the DID model to examine the indirect treatment effects and the direct treatment effects of the GFPZ policy.

Finally, this study did not investigate the synergistic effects and mechanisms of the GFPZ policy on other different environmental regulation policies on urban green development. As China emphasizes environmental protection, an increasing number of environmental regulation policies have been enacted. The question of how to coordinate different environmental policies to achieve a "1+1 > 2" effect is worth exploring in depth in the future.

Abbreviations *GFPZ*: green finance reform and innovation pilot zone; *GTFP*: green total factor productivity; *GDP*: gross domestic product; *DID*: difference-in-difference; *LCCP*: low-carbon city pilot; *SBM*: slacks-based measure; *IPCC*: intergovernmental panel on climate change; *ESA*: event study approach; *CETP*: carbon emissions trading pilot; *SMEs*: small and medium-sized enterprises; *R&D*: research and development

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Author contribution Hongfeng Zhang: conceptualization, analysis; Yixiang Wang: conceptualization, methodology, and writing the original draft; Rui Li: methodology, visualization, data curation, and writing the original draft; Hongyun Si: conceptualization, writing—review and editing; Wei Liu: writing—review and editing.

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Data availability Data used in this study can be obtained from the corresponding author for reasonable reasons.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Conflict of interest The authors declare no competing interests.

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