Does green financial reform pilot policy promote green technology innovation?—— Empirical evidence from China

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Abstract

As a new financial model that balances economic and ecological benefits, green finance (GF) plays an important role in promoting green economic development and ecological environmental protection. Based on the panel data set of 30 provinces in China from 2010 to 2020, this paper uses the synthetic control method (SCM) to explore the impact of the green financial reform pilot policy (GFRP) on the green technology innovation (GTI) capabilities of pilot areas and evaluate the policy effects. The specific research conclusions are as follows: (1) On the whole, the GFRP has a positive role in promoting the GTI capability of the pilot areas, but this role is different due to the different resources, environment, and economic development levels of each region. The areas with economic development levels in the middle and head are obviously affected by the policy, and the less developed areas are less affected by the policy or even have a restraining effect. (2) Although the pilot policy has improved the GTI capability of the pilot area, the promotion effect is unstable, that is, the implementation effect of the policy is unstable. In the early stage of policy implementation, the promotion effect of the policy on the regional green innovation capacity is the most obvious, and this promotion effect begins to show a downward or stable trend in the 2–3 years after the policy is implemented. Based on the above conclusions, it can provide some reference for the revision and improvement of GFRP.

Introduction

As important core competitiveness of a country, finance carries a big weight in the process of economic development. Since the reform and opening up for more than 40 years, China's economy has developed rapidly, and its GDP has increased by 40 times compared with the initial period of reform. This has become a magnificent feat of world economic development (Sheng et al. 2020). Notwithstanding all this, behind the rapid development, is the development model of high pollution, high emission, and high energy consumption, which also causes the contradiction between economic development and the ecological environment and brings great pressure to the transformation of China's economic development (Liu et al. 2021, Zhao et al. 2020). At the 75th UN General Assembly in September 2020, it was pointed out that China's carbon dioxide emissions strive to peak by 2030 and strive to achieve carbon neutrality by 2060. To achieve this expected emission reduction target, it is necessary to promote the transformation of China from the traditional extensive economic growth mode to the mode of green, low-carbon, and sustainable development (Wang et al. 2022b). Although the development of finance stimulates economic development, it also further aggravates the pollution of the environment (Fang et al. 2020). After green has become a necessary prerequisite for development, the concept of finance and sustainable development has begun to be combined in many aspects, green finance (GF) came into being and developed rapidly all over the world. Recently, green has become the primary prerequisite for development, and GF has also become a significant impetus for green development and transformation. In 2016, China issued the "Guiding Opinions on Building a Green Financial System", and the green financial system was taking shape, under the call of "building a market-oriented green technology innovation (GTI) system" and the new development concepts of "innovation, coordination, green,

openness, and sharing", GTI, as the combination of the two development concepts of green development and innovation-driven development, is a leap out of The vicious circle of "economic development - environmental pollution" is a key measure to pursue the "win-win" development model of the environment and economy (Guo et al. 2018).

GTI has promoted green economic development (Wang et al. 2021a, Wang et al. 2021b), improved environmental quality (Ding et al. 2015, Du et al. 2019), and built a strong country in science and technology. In the process of GTI, the allocation of financial resources will affect the output of innovation achievements and their environmental protection. When more resources flow to green and environmentally friendly industries and enterprises, it will increase the GTI capability and output. Previous studies related to GF pilots are mostly unilateral studies on the policy effects of pilot policies (Hu et al. 2021, Huang &Zhang 2021). There is still a lack of relevant research on the impact of green financial reform pilot policy (GFRP) on GTI in the pilot area. Therefore, in GF reform pilots based on the establishment, exploring the impact of the implementation of the pilot policy on the GTI capacity of the pilot provinces has become a key point to promote further the development of a green economy and green transformation.

In response to the above analysis, this paper will answer two questions: First, will the implementation of GFRP produce affect the GTI capability of the pilot area. Second, if there is an impact, what is the impact, and how is the policy effect. Based on the above problems, this paper uses the panel data set of 30 provinces in China (excluding Hong Kong, Macao, Taiwan, and Tibet) from 2010 to 2020, and uses the synthetic control method (SCM) to explore the impact of GFRP on the GTI ability of the pilot provinces. The main innovations of this study are: First, compared with the Differences-in-Differences model, this paper uses the SCM, which not only overcomes the subjectivity and policy endogeneity of the sample selection of the control object but also overcomes the judgment of excessive extrapolation. Second, the past research only studies the implementation effect of GF policy and rarely studies the impact on a certain aspect. Therefore, this paper probes into the effect of GF development on the GTI ability of each province from the macro level and finds out the relevant policy recommendations that are put forward to provide the basis for the formulation and adjustment of subsequent policies.

The following research framework is as follows: Section 2 is an overview of relevant international research results; Section 3 is the research design, including the background of the policy, research methods, and descriptions of related variables; Section 4 is the specific experimental process and results from the analysis, including the determination of weights, the result analysis and robustness analysis of the SCM; Section 5 is the conclusion and future outlook, which summarizes the full text and make policy recommendations based on policy results.

Literature Review

Policy background

To deal with the growing problem of climate change, in December 2015, nearly 200 parties to the United Nations Framework Convention on Climate Change reached the Paris Agreement at the Paris Climate Change Conference, making arrangements for the global response to climate change after 2020. It marks the beginning of the transformation of global economic activities to green, low-carbon, and sustainable development. On September 6, 2016, under the initiative of China, the G20 Green Finance Research Group was formally established, and the G20 Hangzhou Summit Communiqué issued by the G20 Summit included Green Finance for the first time. The “2016 G20 Green Finance Synthesis Report” published by the G20 Green Finance Research Group clarified the definition, purpose, and scope of GF identified the challenges faced by GF and put forward seven options to promote the development of GF around the world, which has become a guiding document in the field of international GF. Driven by the G20, many countries have begun to issue policy frameworks or roadmaps to support the development of their GF or sustainable finance. Many countries and regions have issued green bonds for the first time. Various green financial products continue to emerge, and an upsurge in the development of GF has begun to form all over the world. As the largest developing country, China has also experienced the road of “development pollution treatment” in the process of economic development. As far as the current situation is concerned, the destruction of the ecological environment has become the biggest obstacle to further economic development and threatens China’s sustainable development. In this context, The Party Central Committee raised the protection and governance of the ecological environment to a more important strategic level and proposed that green should become the main factor to be considered in the process of development. The 18th National Congress of the Communist Party of China held in November 2012 took “Beautiful China” as the grand goal of ecological civilization construction for the first time, and placed ecological civilization construction in the strategic position of the five-in-one overall layout of socialism with Chinese characteristics. In 2016, the “Guiding Opinions on Building a Green Financial System” was promulgated, the top-level design of GF was established, supporting policies were launched one after another, and the green financial system was taking shape; on June 14, 2017, the 176th executive meeting of the State Council decided, Jiangxi Province, Guangdong Province, Guizhou Province, and Xinjiang Uygur Autonomous Region, five provinces (regions) have established the pilot areas of green financial reform, which opened the grass-roots practice of my country’s green financial reform and innovation, marking my country’s green financial development has entered a new stage. The pilot green reforms should focus on the key issues of green financial development. Under the guidance of the government, market-oriented means should be used to allocate more financial resources to energy conservation, environmental protection, and green emission reduction projects, so that the development of a green economy can truly obtain effective financial support, and explore ways to achieve effective financial support. A new road of win-win environmental and economic benefits, stimulate the green transformation of economic development and the transformation of new and old development momentum and start a new growth point.

Research on Green Finance

Over the past few years, GF has risen and developed rapidly, and it has become a new way to balance economic and ecological effects. From the relevant research of international academic circles, GF and

GTI have been discussed to a certain degree, so this section will sort out the relevant research results of the two.

As a new type of finance based on information technology, GF plays a balancing role between the economy and the ecological environment. GF is a financial form that promotes environment-friendly investment and cultivates an ecological society through green-oriented credit, securities, insurance, investment, and carbon finance(He et al. 2019, Liu et al. 2019). Up till now, the related research on GF mostly fastens on the measurement of GF(Lee &Lee 2022, Wang et al. 2021d), the relationship with economic development (Soundarrajan &Vivek 2016), and the impact on the ecological environment (Chen &Chen 2021, Huang &Zhang 2021, Ning et al. 2022). In terms of relevant measures of GF, Yang et al. (2021) selected 18 indicators from three aspects of the economy, finance, and environment, and used the improved entropy method to calculate the GF development index of 25 provinces and cities in China; Lv et al. (2021) constructed a policy and market-oriented GF index system based on provincial data and used the input weight method to obtain a GF development index. In terms of economic development, Zhou et al. (2020) constructed the impact model of GF on economic development based on the panel data set of 30 provinces in China. The model shows that GF development can balance the relationship between economy and ecology and promote a win-win situation. Yin &Xu (2022) discussed the coordinated development degree of GF and economic growth by using the coupling coordination degree model. The results show that the coupling coordination degree of GF and economic growth is not high, and it is in the stage of grinding in and high-rise coordination, which has no obvious role in promoting economic development. In the aspect of environmental protection, Xiong &Sun (2022) analyzed the mixed effect of GF and carbon dioxide emissions by the fuzzy set qualitative comparative analysis method and pointed out that GF has an inhibiting effect on carbon emissions. Furthermore, some scholars have explored the relationship between GF and GTI. For example, Hao et al. (2020) used the green credit guideline as a quasi-natural experiment and found that the green credit guideline can effectively promote the GTI of heavy-polluting enterprises, and the marketization degree The higher the place, the more obvious the promotion effect; Wang (2022) used manufacturing-related statistical data indicators and structural equation model to conduct empirical tests, and the test results showed that GF has a positive effect on the GTI capability of the manufacturing industry.

Green Finance and Green Technology Innovation Capability

With the emergence and development of GF, the deficiencies of traditional finance in GTI are being made up for by GF supported by emerging technologies (Cao et al. 2021). Zeng et al. (2022) clearly stated the intermediary role of technological innovation in the study of GF on urban haze pollution and expounded on the role of GF in promoting enterprise GTI. To better push forward the development of GF, the government has promulgated a large number of relevant policies, such as those related to green credit, Ling et al. (2020) used the Differences-in-Differences method to explore the impact of the green credit guidance policy (GCG) promulgated in 2012 on the GTI of enterprises, the results show that the policy reduces the long-term liabilities of enterprises in pollution-intensive industries, which in turn evidently reduces scientific research investment and innovative output, however, Li et al. (2022) conducted quasi-

natural experiments using the GCG and put forward different opinions. By using the Super-SBM model including non-expected output, and measured the green innovation efficiency (GIE) of multiple industries, and constructing the PSM model to study the impact of the GCG on the GIE of various industries, The research shows that the implementation of the GCG can effectively improve the GIE of heavy pollution industries, in addition, Liu et al. (2020) takes listed enterprises as the research object, and discusses implementing GCG on the innovation performance of heavily polluting enterprises based on a quasi-natural experiment. According to the experimental results, the implementation of a GCG can improve the innovative output and financial efficiency of enterprises. These two different results also show that the effects of GF policies are different for enterprises in different industries. Awawdeh et al. (2022) applied Partial Least Squares (PLS)-based Structural Equation Modeling (SEM) to evaluate the role of green financing in improving corporate environmental performance. The results pointed out that the establishment of green financing and corporate responsibility system can effectively increase the corporate GTI and Environmental performance. Zhou &Du (2021) conducted an empirical study of relevant data on prefecture-level cities in China, demonstrating that increased environmental regulation increases the impact on energy and technology-biased technological progress, and emphasizing that GF development under the SDGs is a key to improving GTI. Hsu et al. (2021) through the econometric estimation, shows that financial development plays a positive role in promoting GTI ability and further point out that research education can increase innovation patents and promote environmental effects. This paper summarizes the relevant research literature in Table 1.

Table 1
Current literature on GF and GTI

Authors	Period	Data	Method	Results
Zeng et al. (2020)	2016–2019	Panel data	The mediating effect model	GF↑-GTI↑
Ling et al. (2020)	2007–2017	Panel data	DID	GCG- GTI↓
Li et al. (2022)	2007–2018	Panel data	The Super-SBM model□DID	GCG- GTI↑
Awawdeh et al. (2021)	2013–2019	Panel data	PLS-based SEM	GF↑-GTI↑
Zhou and Du (2021)	2010–2018	Panel data	Econometric model	GF↑-GTI↑
Liu et al. (2020)	2007–2017	Panel data	DID	GCG- GTI↑
Hsu et al. (2021)	2000–2018	Panel data	OLS	GF↑-GTI↑
Hao (2020)	2007–2018	Panel data	DID	GCG- GTI↑
Wang (2022)	2011–2018	Panel data	The structural equation model	GF↑-GTI↑

By reviewing and summarizing the relevant literature, it can be found that the impact of GF on the GTI ability of different regions or different industries is different, and further research and discussion are needed. This paper evaluates the policy effects of the GFRP implemented in China in 2017 on the GTI

capabilities of pilot areas, explores the impact of GF on GTI capabilities, and provides a reference for policy implementation and adjustment.

Research Design

Research methods

To scientifically evaluate the impact of GFRP on the ability of GTI, it is needful to find a suitable policy evaluation method. Among the current mainstream policy evaluation methods, the Difference-in-Differences method is the most widely used, but this method has certain defects, requiring the treatment group and the control group is required to have similar external conditions and common trends, but due to the differences among provinces in various aspects, this method Requirements are difficult to meet, so it is easy to lead to deviations in the evaluation of policy effects. To overcome the defects of DID, Abadie &Gardeazabal (2003) proposed a new method to identify policy effects, SCM. The SCM takes the area not affected by the policy as the synthetic object, determines the weight of the synthetic object in a data-driven way, and then constructs the control object that is similar to the target group through the weighting method. As a non-parametric method, the SCM uses a data-driven approach to determine the weights of synthetic objects, which not only overcomes the subjectivity and policy endogeneity of control object sample selection (Ren et al. 2020) but also points out that each synthetic object has a “counterfactual effect” while overcoming excessively extrapolated judgments (Athey &Imbens 2017, Tan &Cheng 2018). The specific research methods are as follows:

Assuming that the number of green patents (NGP) in (K $+$ 1) regions and phase T can be collected, the first region (pilot province) is set up as the pilot of green financial reform in T_0 (1 $\leq$ T_0 $\leq$ T), and the other K regions are the control group not affected by the pilot policy. Let P_{it}^{I} indicate NGP in region i as the pilot of green financial reform at time t, and P_{it}^{N} indicates NGP that are not the pilot. Set model P_{it} $=$ P_{it}^{N} $+$ $D_{it}\alpha_{it}$, P_{it}^{N} is NGP when the pilot area has not established a green financial reform pilot, and D_{it} refers to a dummy variable of whether it is a green financial reform pilot. If region i is set as the pilot at time t, the variable is taken as 1, otherwise it is 0. For non-pilot areas, during the whole period T, there are P_{it} $=$ P_{it}^{N}. The research goal is to estimate α_{it}, α_{it} $=$ P_{it}^{I} $-$ P_{it}^{N} $=$ P_{it} $-$ P_{it}^{N}. P_{it}^{I} is NGP in the GF reform pilot areas, and is known. What needs to be estimated is P_{it}^{N} that it cannot be observed. In this paper, the factor model proposed by Abadie et al. (2010)to construct a “counterfactual” variable estimation P_{it}^{N}:

$$P_{it}^{N} = \delta_t + \theta_t Z_i + \lambda_t \mu_i + \epsilon_{it} \quad (1)$$

In Eq. (1), δ_t is a time fixed effect ; Z_i represents the observable predictive variable that is not affected by the GFRP ; {\theta }_{t} is a (1\timesK) dimensional unknown parameter vector, {\lambda }_{t} is a common factor vector that cannot be observed in dimension, {\mu }_{i} is an unobservable provincial

fixed effect, and {\epsilon }_{it} is a short-term shock that cannot be observed in each region, assuming that the mean value is 0 at the regional level. The solution solved {P}_{it}^{N} is to weight the control group regions to simulate the characteristics of the experimental group. Therefore, a (K+1) dimensional weight vector {W}^{\text{*}}= ({w}_{2}^{\text{*}}, … {w}_{k+1}^{\text{*}}) is obtained through the predictor variables, which meets the requirements for any k, {w}_{k} \ge 0 and {w}_{2}+ … + {w}_{k+1}= 1. For the pilot areas of GF reform, the vector W represents the potential synthetic control combinations, each of {w}_{k} which represents the synthetic control contribution rate of the regions in the control group to the pilot areas. Therefore, the outcome variable of the synthetic control is:

\sum _{k=2}^{K+1}{w}_{k}{P}_{it}={\delta }_{t} +{\theta }_{t} \sum _{k=2}^{K+1}{w}_{k}{Z}_{k}+{\lambda }_{t}\sum _{k=2}^{K+1}{w}_{k}{\mu }_{k} +\sum _{k=2}^{K+1}{w}_{k}{\epsilon }_{kt} (2)

Suppose there exists ({w}_{2}^{\text{*}}, … {w}_{k+1}^{\text{*}}) such that:

\sum _{k=2}^{K+1}{w}_{k}^{\text{*}}{P}_{k1} ={P}_{11}, …, \sum _{k=2}^{K+1}{w}_{k}^{\text{*}}{P}_{k{T}_{0}} = {P}_{1{T}_{0}}, and \sum _{k=2}^{K+1}{w}_{k}^{\text{*}}{Z}_{k}={Z}_{1} (3)

If \sum _{t=1}^{{T}_{0}}{\lambda }_{t}^{{\prime }}{\lambda }_{t} is non-singular, then Eq. (4) holds:

{P}_{it}^{N} -\sum _{k=2}^{K+1}{w}_{k}^{\text{*}}{P}_{kt} = \sum _{k=2}^{K+1}{w}_{k}^{\text{*}}\sum _{s=1}^{{T}_{0}}{\lambda }_{t}{\left(\sum _{t=1}^{{T}_{0}}{\lambda }_{i}^{{\prime }}{\lambda }_{i}\right)}^{-1}{\lambda }_{s}^{{\prime }}({\epsilon }_{ks}-{\epsilon }_{1s})- \sum _{k=2}^{K+1}{w}_{k}^{\text{*}}\left({\epsilon }_{kt}-{\epsilon }_{1t}\right) (4)

Abadie et al. (2010)proved that under normal conditions, if the time span before the policy is longer than the time span of the GFRP, the left side of Eq. (4) tends to 0. Therefore, during the pilot period, it can be used \sum _{k=2}^{K+1}{w}_{k}^{\text{*}}{P}_{kt}as an unbiased estimate of {P}_{it}^{N}, so as to the estimated value of policy effect {\alpha }_{1t} is:

$\alpha^{\wedge}{}_{1t} = P_{1t}$- $\sum_{k=2}^{K+1} w_k^* P_{kt}, t \in [T0 + 1, \ldots T]$.

Variable description

This study examines the impact of GFRP on GTI capabilities. There is currently no unified system for measuring GTI capabilities. Therefore, this paper uses NGP with more applications as the proxy variable of the GTI ability. There are two forms of green patent application and authorization. Green patent application means that all innovation output achievements can be patented, which also shows the innovation activity and potential innovation ability of a region. The patent authorization is to authorize the innovation achievements that meet the standards after submitting the patent application, which has a certain lag. Although it can reflect the innovation quality of a region, it is vulnerable to external factors. Therefore, this paper selects the number of green patent applications as the index to measure the GTI capability (Wang et al. 2022a). In addition, drawing on the existing research on GTI capability, this paper selects the economic development level (GDP), industrial structure (IS), foreign investment (FDI), science

and technology expenditure (STE), trade openness (OPEN). A series of variables are used as predictors, and the specific variable description and calculation method are shown in Table 2:

(1) GTI capability (GP). GTI capability is the main research object of this paper to investigate whether the development of GF will lead to the change of GTI capability. This paper draws on the practice of Du et al. and uses NGP as a proxy variable of GTI capability (Du et al. 2021, Petruzzelli et al. 2011).

(2) The level of economic development (GDP). The level of economic development determines the richness of resources. A higher economic level can provide necessary resources for GTI capability. Measured by per capita GDP, it indicates the impact of economic development level on the ability of GTI (Du &Li 2019).

(3) Industrial structure (IS). The tertiary industry includes information transmission, computer services, software, and other industries. The higher the proportion of the tertiary industry, the more favorable it will be for the improvement of environmental protection ability and technical level. This paper uses the ratio of the added value of the secondary industry to the added value of the tertiary industry to represent the industrial structure (Wang et al. 2021c).

(4) Foreign investment (FDI). Foreign investment will bring new resources and development models to local enterprises, and the new technologies and funds are the most important resources needed in the process of improving the GTI capability in a region. Foreign investment is represented by the ratio of foreign direct investment to regional GDP (Luo et al. 2021).

(5) Science and technology expenditure (STE). The science and technology expenditure of a region can fully show the importance that the region attaches to innovation ability, and science and technology expenditure can inject a lot of funds into the improvement of innovation ability. It is expressed by the proportion of regional technology expenditure to total regional fiscal expenditure (Peng et al. 2021).

(6) The degree of trade openness (OPEN). The degree of openness is related to whether a region can interact with other regions, and then absorb the resources of other regions to improve its innovation ability. The ratio of regional import and export trade volume to regional GDP is used to express the impact of trade openness on GTI capacity (Shang et al. 2022).

Table 2 Variable definition and calculation method.

Variable	Definition	Calculation	Unit
GP	Green technology innovation capability	Number of green patents applications	piece
GDP	The level of economic development	Regional GDP per capita	hundred million
IS	Industrial structure	The ratio of the added value of the secondary industry to the added value of the tertiary industry	%
FDI	Foreign investment	The ratio of foreign direct investment to regional GDP	%
STE	Science and technology expenditure	The proportion of regional technology expenditure to total regional fiscal expenditure	%
OPEN	The degree of trade openness	The ratio of regional import and export trade volume to regional GDP	%

Data sources

Based on the availability, continuity, and representativeness of the data, this paper takes 30 provinces in China (excluding Hong Kong, Macao, Taiwan, and Tibet) as the research object and builds a panel dataset for the period from 2010 to 2020. The relevant data of the predictor variables come from the Statistical Yearbook of each province, China Statistical Yearbook, and Statistical Yearbook, and the data on NGP in each province comes from the CNRDS database.

Results And Discussion

On August 31, 2016, seven ministries including the People's Bank of China and the Ministry of Finance jointly issued the “Guiding Opinions on Building a Green Financial System”, marking the beginning of the construction of China’s green financial policy system. Since June 2017, the State Council has

successfully set up pilot areas of green financial reform in five provinces, so this paper chooses 2017 as the effect point of GFRP to evaluate the impact of GFRP on GTI capabilities.

Selection of weight coefficient of the synthetic control group

To accurately evaluate the impact of the GFRP on GTI in different provinces, this paper constructs a corresponding synthetic control province for each green financial reform pilot, using GDP per capita, industrial structure, foreign investment, technology spending, and trade openness as prediction variables to fit the synthetic control provinces. The weight coefficients of the control group provinces synthesized by the pilot provinces of GF reform are shown in Table 3.

Table 3 Synthetic control group weight coefficient table

Zhejiang	**Jiangxi**	**Guizhou**
Area Weights	**Area Weights**	**Area Weights**
Anhui 0.236	Anhui 0.049	Gansu 0.241
Henan 0.001	Fujian 0.103	Guangxi 0.270
Jiangsu 0.134	Gansu 0.315	Qinghai 0.417
Shanghai 0.259	Hainan 0.127	Shaanxi 0.072
Sichuan 0.369	Ningxia 0.176	
	Shanxi 0.205	
	Chongqing 0.025	

Xinjiang	Guangdong
Area Weights	**Area Weights**
Fujian 0.098	Beijing 0.472
Gansu 0.001	Jiangsu 0.046
Inner Mongolia 0.366	Shanghai 0.338
Hainan 0.068	Sichuan 0.144
Ningxia 0.256	
Qinghai 0.134	
Shanxi 0.074	
Shaanxi 0.003	

After fitting, the larger the synthetic contribution rate of the control group province, the more similar it is to the characteristics of the pilot province, and the weight is 0, which means that it is far from the characteristics of the pilot province. From this, the weights of the provinces that make up the synthetic control group of pilot cities are obtained. Among them, the provinces with positive synthetic contribution rates to Zhejiang are Anhui (0.236), Henan (0.001), Jiangsu (0.134), Shanghai (0.259), Sichuan (0.369); The provinces with positive synthetic contribution rates to Jiangxi are Anhui (0.049), Fujian (0.103), Gansu (0.315), Hainan (0.127), Ningxia (0.176), Shanxi (0.205), Chongqing (0.025); The provinces with positive synthetic contribution rate to Guizhou are Gansu (0.241), Guangxi (0.270), Qinghai (0.417), Shaanxi (0.072); The provinces with positive synthetic contribution rate to Xinjiang are Fujian (0.098), Gansu (0.001), Inner Mongolia (0.366), Hainan (0.068), Ningxia (0.256), Qinghai (0.134), Shanxi (0.074), Shaanxi (0.003); The provinces with positive synthetic contribution rate to Guangdong are Beijing (0.472), Jiangsu (0.046), Shanghai (0.338) and Sichuan (0.144).

The impact of green financial reform pilots on Green Technology Innovation

First, the SCM is used to evaluate whether the promulgation of the GFRP can have an impact on GTI in each pilot province. Figure 1a-e shows the changes in the GTI capabilities of pilot provinces from 2010 to 2020. The dotted line is the evolution path of the GTI capability of the provinces synthesized by the weight of other provinces except for the pilot provinces, the solid line is the evolution path of the actual GTI capability of the pilot provinces, and the year of the vertical dotted line is the year when the policy is implemented. It can be seen from the figure that before 2017, the GTI capabilities of the synthetic provinces and the real provinces were very similar, and the difference is small, which shows that the synthetic provinces have well-matched the changes in the GTI capabilities of the pilot provinces. After 2017, the dotted line and the solid line gradually began to deviate, and the degree of deviation gradually

increased. The GTI capacity of the synthetic provinces of Zhejiang, Jiangxi, Guizhou, and Guangdong is significantly lower than that of the real pilot provinces, which means that the green financial reform policy can promote the improvement of regional GTI ability. However, the synthetic curve in Xinjiang is higher than the actual curve, indicating that the GFRP has not played a catalytic role in Xinjiang.

In addition, according to the idea of the SCM, the effect size of the GFRP can be determined by using the difference between NGP in the pilot provinces after the policy is implemented and NGP in the synthetic provinces. That is to say, the difference between the solid line and the dotted line is the effect of the pilot policy on the regional GTI capability. Figure 2a-e shows the net effect of the GFRP. It can be inferred from the figure that in the early stage of policy implementation, the GTI capabilities of all pilot provinces except Xinjiang have been significantly improved, but with the passage of time, this promoting effect began to show a downward or stable trend. Since the five pilot provinces are different in terms of economic development level, industrial structure, resource endowment, and environmental carrying capacity, the degree of policy impact will also be different to a certain extent. By 2020, NGP in Zhejiang Province reached 16,325, an increase of 144.77% compared with 2016, while NGP in Guangdong Province in 2020 was 31,311, an increase of 198.17% compared with 2016, Zhejiang and Guangdong are already economically developed regions, and the proportion of their industrial structure has entered the stage of “321”. The tertiary industry has become an important driving force for economic growth, and the industries above the designated size are mainly high-tech industries and equipment manufacturing industries. With the help of pilot policies, its GTI ability has been further improved by virtue of rich resources and strong financial resources, and the degree of policy influence is more obvious than that of other pilot provinces. As a representative of the central provinces in terms of economic aggregate, Jiangxi is rich in green resources and has obvious ecological advantages. To avoid taking the development path of pollution first and then treatment, Jiangxi Province builds a green development model with the help of GFRP. By 2020, NGP in Jiangxi Province reached 2,191, an increase of 178.75% compared with 786 in 2016. It can also be seen from Fig. 2 that the net effect of policies in Jiangxi Province is on the rise. Guizhou Province is also rich in green resources, but its economic aggregate is at the bottom of the country and belongs to an economically underdeveloped area. In the past, Guizhou Province traded economic benefits at the cost of the environment, which led to serious environmental problems. There is an urgent need for a way to alleviate ecological problems by taking into account both economic and ecological effects. The pilot program of GF provides such an opportunity. In 2020, NGP in Guizhou Province was 1519, 1.18 times that in 2016, which has been improved to a certain extent, but the promotion effect of the policy began to decline after 2019, which also shows that the pilot policy lacks certain sustainability. Before the policy took place in Xinjiang, the fit between the actual value and the synthetic value of NGP was very high, but after the policy took place, the deviation between the actual value and the synthetic value began to appear, and the actual value was significantly lower than the synthetic value, which the implementation effect of the pilot policy in Xinjiang is not good, and it has not played a role in promoting the improvement of GTI ability and even reduced the GTI ability in the region.

In general, the implementation of GFRP has different impacts on different provinces. For Zhejiang and Guangdong provinces with relatively complete financial systems and economically developed regions, it

will bring greater promotion and further improve their GTI capabilities, but the promotion effect of policy effects is limited. After reaching a certain peak, this promoting effect will gradually decline. It has a relatively stable promotion effect on the provinces with the economic development level in the middle. Although the economically underdeveloped areas have been affected by the policy, the GTI ability has been improved to a certain extent, but the same problem is the instability of the policy promotion effect. Like Guangdong Province, after the implementation of the policy, the GIT capacity of Guizhou Province has been improved, and after reaching a certain level, the promotion effect begins to weaken. Of course, policy effects are not applicable to all regions. After the policy is implemented, the GTI capacity of the Xinjiang region has increased but the growth rate has dropped sharply. The net effect of the policy is also a stated of negative effect is mainly due to the implementation of the pilot policy in Xinjiang, which pays more attention to improving the utilization rate of various resources and the protection of the environment, while ignoring human resources, technology introduction, technology investment, etc., which are indispensable to improve GTI The lack of these elements hinders the improvement of GTI capabilities in newly built areas and ultimately makes it difficult for the GFRP to promote the development of local GTI capabilities.

Robustness check

To evaluate whether the evaluation effect of the policy is robust and significant, and verify that the difference between real pilot provinces and synthetic provinces is caused by the implementation of the policy rather than other unobservable factors. Here, a Permutation Test method similar to the Rank Test in statistics proposed by Abadie et al. (2010) is used to judge whether other provinces have the same situation as the pilot provinces, how likely is it. First, the SCM is used to construct the synthetic GTI curve, and a series of random “policy effects” (true real value and composite value error) are obtained, and then the comparison between the policy effect of the pilot provinces and the random error distribution is made. If the gap between the policy effects of the two is large enough, it is reasonable to consider that the pilot policies have a remarkable effect. When using this method, to improve the accuracy of the robustness test, we excluded provinces whose RMSPE value was 2 times higher than the pilot provinces. The specific experimental results are shown in Fig. 3.

Figure 3 (a)-(e) shows the difference distribution after excluding provinces with a poor-fitting degree. Before 2017, Zhejiang Province had a very good degree of fitting with other provinces. After the implementation of the policy, the gap between Zhejiang Province and other provinces gradually widened, and it was located outside other provinces. This means that the pilot policy has improved the GTI capacity of Zhejiang Province, and it also shows that there is only a 1/21, or 4.76% chance, that there is such a large gap between Zhejiang and synthetic Zhejiang, and it can be considered that NGP in Zhejiang Province has increased significantly at the 5% level. Similarly, there was only a small difference between Guangzhou and the provinces in the control group before the policy was implemented, and the gap gradually widened after 2017, confirming the role of the GFRP in promoting the GTI capability of Guangdong Province. It can be seen from the figure that there is a 1/22 or 4.55% chance that the gap between Guangdong and synthetic Guangdong will be the same. It can be considered that at least at a

significant level of 5%, the improvement of the GTI capacity of Guangdong Province by the pilot policy is not due to cause by other accidental factors. For Jiangxi Province and Guizhou Province, there is a good degree of fit before the implementation of the policy, and there is no huge gap with other provinces after the implementation of the policy. As of 2020, only two provinces have higher green patents than Jiangxi. Therefore, it can be considered that Jiangxi Province affirms that the increase in NGP is due to policies at a significant level of 5% (1/20), while Guizhou has a probability of 5.56% (1/18), rejecting the impact of external accidental factors on GIT ability at the significant level of 10%. Although Xinjiang has a good degree of fit with other provinces before the occurrence of the policy, it still has no big gap with other provinces after the occurrence of the policy. Therefore, it can be considered that the reason for the reduction of the improvement rate of green innovation ability in Xinjiang is not only due to the policy, but also other external accidental factors, which together lead to the reduction of the improvement rate of GIT ability in Xinjiang, this is also consistent with the above net effect analysis results in Xinjiang.

Time of policy modification. This paper tests the robustness of the policy implementation effect from the pilot policy implementation level by changing the policy occurrence time to 2015. It is assumed that the policy's occurrence time is shifted from 2017 to 2015, and then the implementation effect of the policy is re-tested through the SCM. The specific test results are shown in Fig. 4. After adjusting the policy occurrence time, whether before or after the policy occurred, NGP in the pilot provinces and NGP in the synthetic provinces did not have a large gap, and the degree of fit was good. The gap between the two began to appear in 2017 and gradually widened, indicating that the policy effect will only work after 2017, and it also shows that changing the policy time to 2015 has no effect, proving that the policy effect result obtained by the SCM is robust in time.

Placebo test. To further verify the robustness of the GFRP, this paper draws on the practice of Abadie et al. (2015) and selects a province that has not been set up as a pilot during the sample period. This paper selects various characteristics related to the pilot province, and the similarity is the highest, that is, the provinces in the control group with the highest contribution rate are synthesized when fitting the pilot provinces. Assuming that it and the pilot provinces have implemented the same policy treatment in the same year, and then conduct the same analysis according to the SCM, if the resulting policy effects are much smaller than the differences in the empirical analysis, it means that the pilot provinces and the synthetic provinces The difference in NGP does come from the pilot policy (that is, the results of the empirical analysis are valid), otherwise, the results of the empirical analysis are invalid. Accordingly, this paper selects Sichuan, Gansu, Qinghai, Inner Mongolia, and Beijing according to the weights in Table 1, and uses the SCM to make the actual and synthetic curves of NGP in the five provinces. Figure 5a-e shows the specific experimental results. As shown in the figure, the synthetic paths of Sichuan, Gansu, and Beijing are significantly lower than the real paths, and even have a negative effect, indicating that the policy implementation effect in this province is poor. For Qinghai Province, although the real path is higher than the synthetic path, the difference is small and the policy effect is not obvious. Similarly, the Inner Mongolia region also has a good degree of fit, the difference is small, and the policy effect is not significant. It can be inferred that the province with the highest similarity with each pilot province has an

unsatisfactory policy effect after assuming that it has suffered a policy shock. This proves that the policy effects of the green financial reform pilots obtained above are not due to accidental factors.

Conclusions And Recommendations

Conclusion

This study uses the event of the establishment of the GF reform pilot in 2017, based on the panel data set of 30 provinces in China from 2010 to 2020, and uses the SCM to empirically analyze the impact of GFRP on the GTI capabilities of the pilot provinces, and assess the policy effects. The specific experimental conclusions are as follows:

● The GFRP can improve the regional GTI capability from the overall effect of policy implementation. However, due to the differences in resource endowments and economic development levels among pilot provinces, the implementation effects of the policies will vary. The policy has significantly affected the economically developed regions represented by Zhejiang and Guangdong. By 2020, NGP in the two regions has increased by 144.77% and 198.17% respectively compared with 2016. Jiangxi Province, as the representative of the province whose economic development level is located in the middle of China, has fully seized the opportunity to combine its advantages, and the policy impact is also very obvious. After the implementation of the policy, the green patents are 178.75% of those before the implementation. For the economically underdeveloped regions, the impact of the pilot policies on the GTI capacity is different. Although NGP in Guizhou Province has been increased, the range of change is lower than that in economically developed and central regions, only 118%, the policy implementation effect in the Xinjiang region showed a negative effect, which indicates that the GFRP has inhibited the improvement of the GTI ability in Xinjiang region. The robustness analysis concluded that this inhibitory effect is not caused by the pilot policy alone, but by a variety of factors.

●Although the GFRP has played a certain role in promoting the improvement of the GTI capability, the promotion effect is unstable. That is to say, the policy effect is not sustainable. Through the analysis of the net effect of the policy, it can be seen that the promotion effect of the policy in Guizhou and Guangdong provinces began to decrease year by year after 2019; The promotion effect of Jiangxi Province showed a downward trend from 2018 to 2019, and increased significantly after 2019; From 2017 to 2019, the promotion effect of policies in Zhejiang province continued to rise, but after 2019, the policy effect tended to be stable. This conclusion can provide a reference for subsequent policy revision and improvement.

Recommendations

Overall, this study confirms that the GFRP can positively impact the regional GTI capacity, passes the robustness test, and points out the shortcomings of the policy. Based on this, this paper puts forward the following policy suggestions to further promote the improvement of GTI ability:

●GTI, as one of the key factors leading to ecological environmental protection and high-quality economic development, should take how to better improve the ability of GTI as an important consideration factor in the policy design of GF. The purpose of GF is to provide financial services for promoting green and sustainable development, improving the environment, saving resources, and addressing climate change. At the same time, GTI aims to improve the ecological environment and improve technological innovation to deal with changing climate issues. Therefore, improving the ability of GTI should be a key consideration in green financial policy design.

●Accelerate the nationwide implementation of GFRP, and give play to the role of reform policies in enhancing GTI capabilities. GTI determines future development. With the continuous development of society and the continuous progress of science and technology, all the resources that human beings rely on are limited and cannot be used indefinitely. GTI is bound to become the driving force for development. The application scenarios of GTI continue to emerge, and the scenarios for future development are becoming clearer and clearer, which also determines the future. Therefore, it is imperative to implement green financial reform policies nationwide. Policymakers can use methods such as refining pilot experience and forming typical cases to promote a pilot area of green financial reform nationwide to build a beautiful China and contribute to high-quality economic development.

●We should understand each region's development stage and economic development and implement differentiated green financial reform policies according to the actual situation. The implementation effect of the GFRP will vary according to the economic development level and resource endowment of each region. Therefore, the policy design should be targeted according to the actual development situation of each region. China has a vast territory, and there is a large gap in the development conditions, requirements, and demand for resources in various regions. Therefore, there are also great differences in the implementation effects of the same policy, so the design of the policy cannot be one size fits all. Based on national policies, local governments can redesign according to actual local conditions and formulate policies in line with actual local conditions to promote the improvement of GTI ability.

Declarations

Author contributions:

XW: Conceptualization, Data collection, Statistical analysis, Writing-original draft. **XS:** Conceptualization, Supervision, Funding acquisition and writing, Review and editing. **HZ:** Writing, Review & editing, Supervision. **CX:** Data curation, Project administration, Writing-original draft

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Data Availability

The dataset used in this research are available from the corresponding author on reasonable request.

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Consent to publish: All authors have consent for the publication of the manuscript.

Consent to participate: All authors contributed voluntary to this study.

Competing interests: The authors declare no competing interests.

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Figures

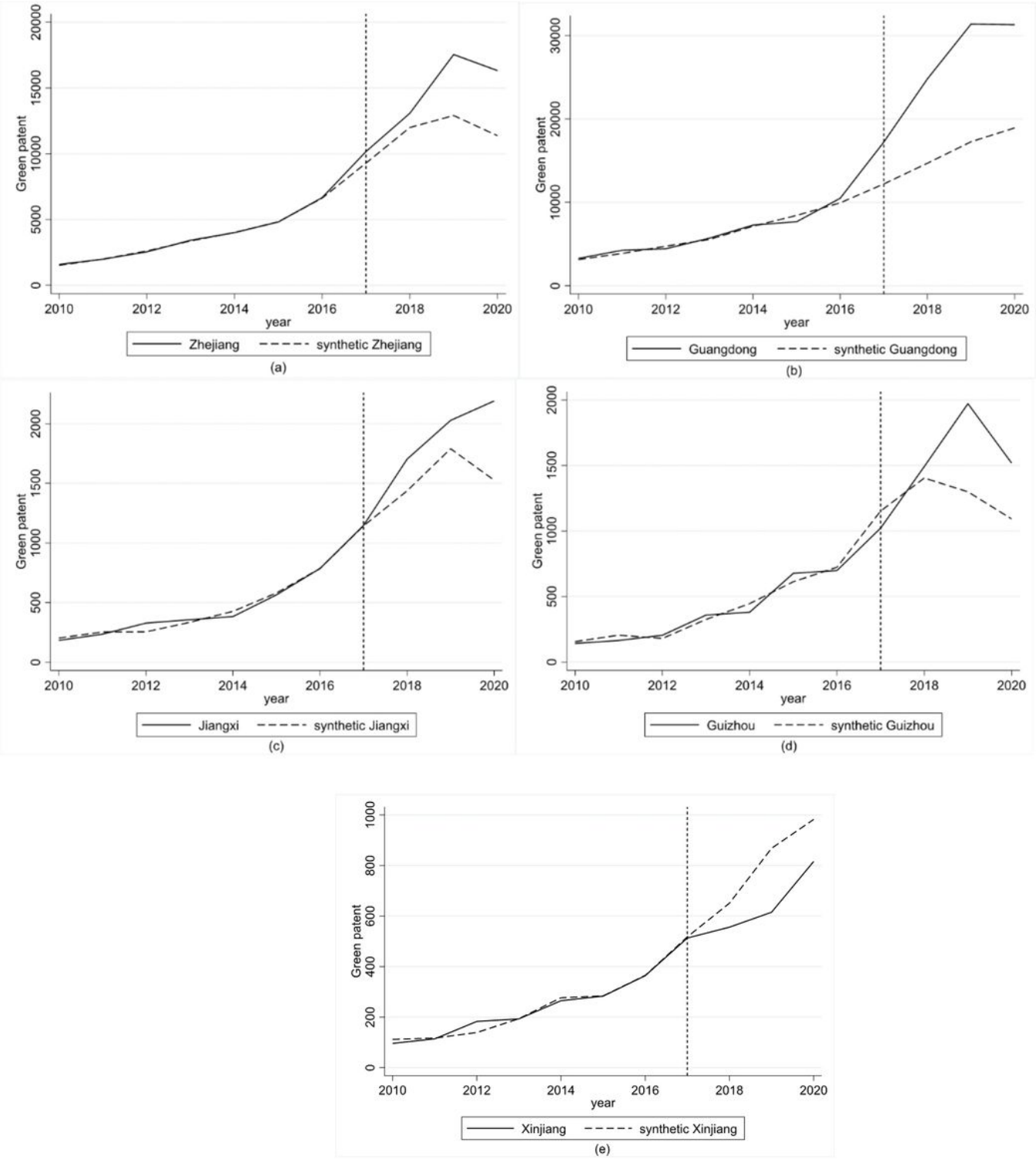
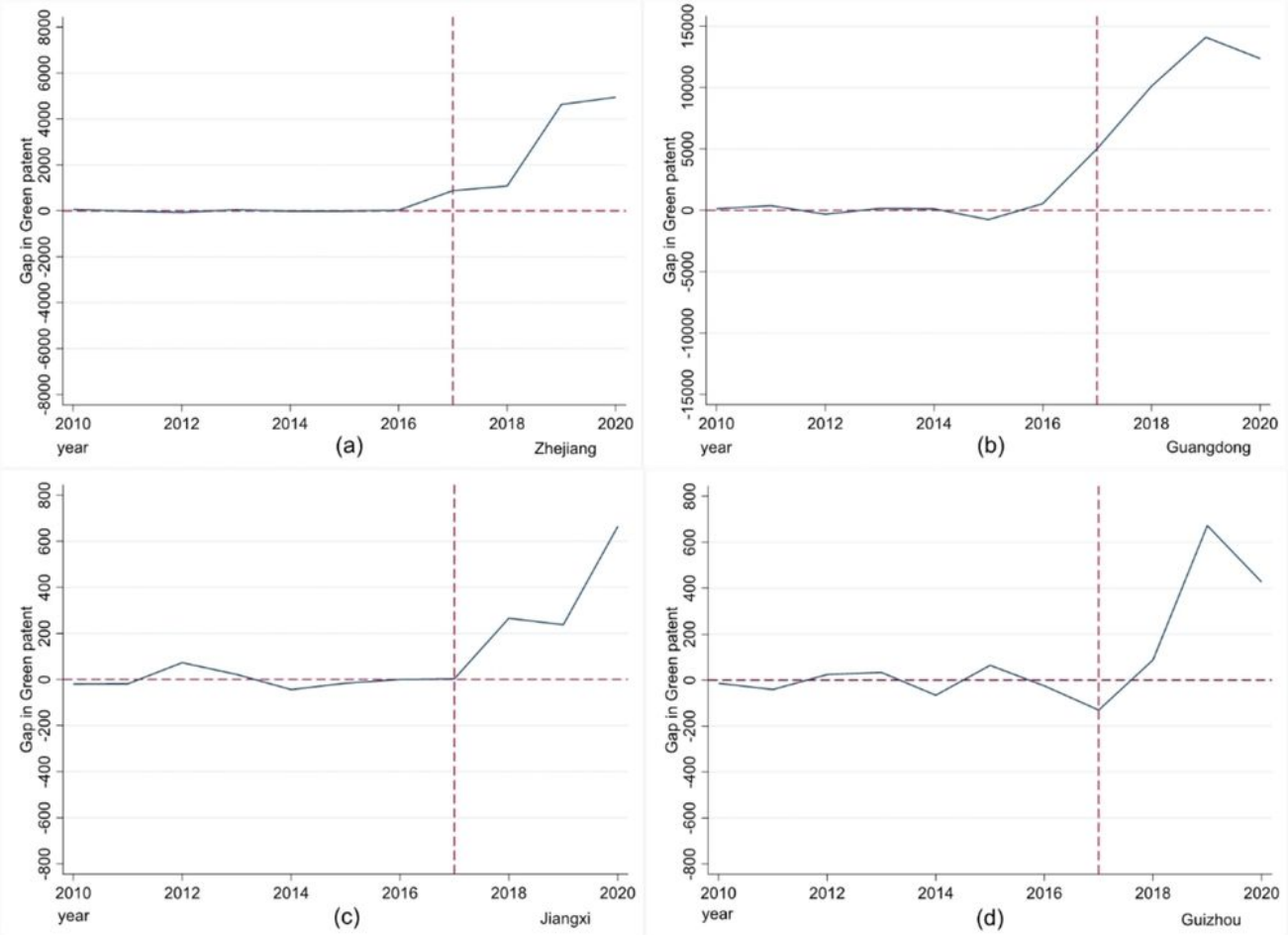


Figure 1

Evaluation results of the policy effects of the pilot green finance reform



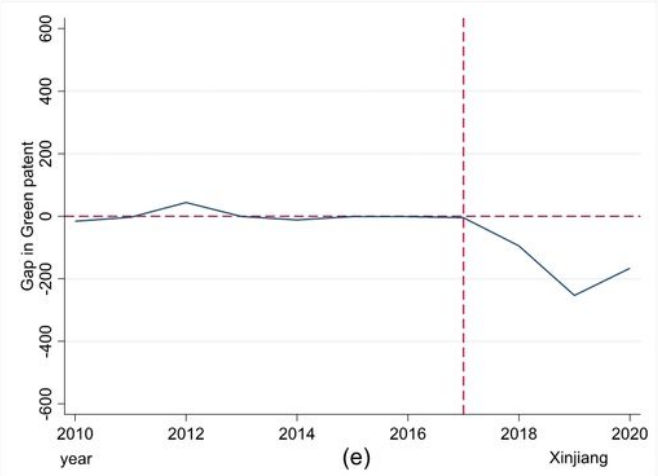


Figure 2

The net effect of green finance reform pilot policies

Figure 3

Sort test results

Figure 4

Policy Time Change Test Results

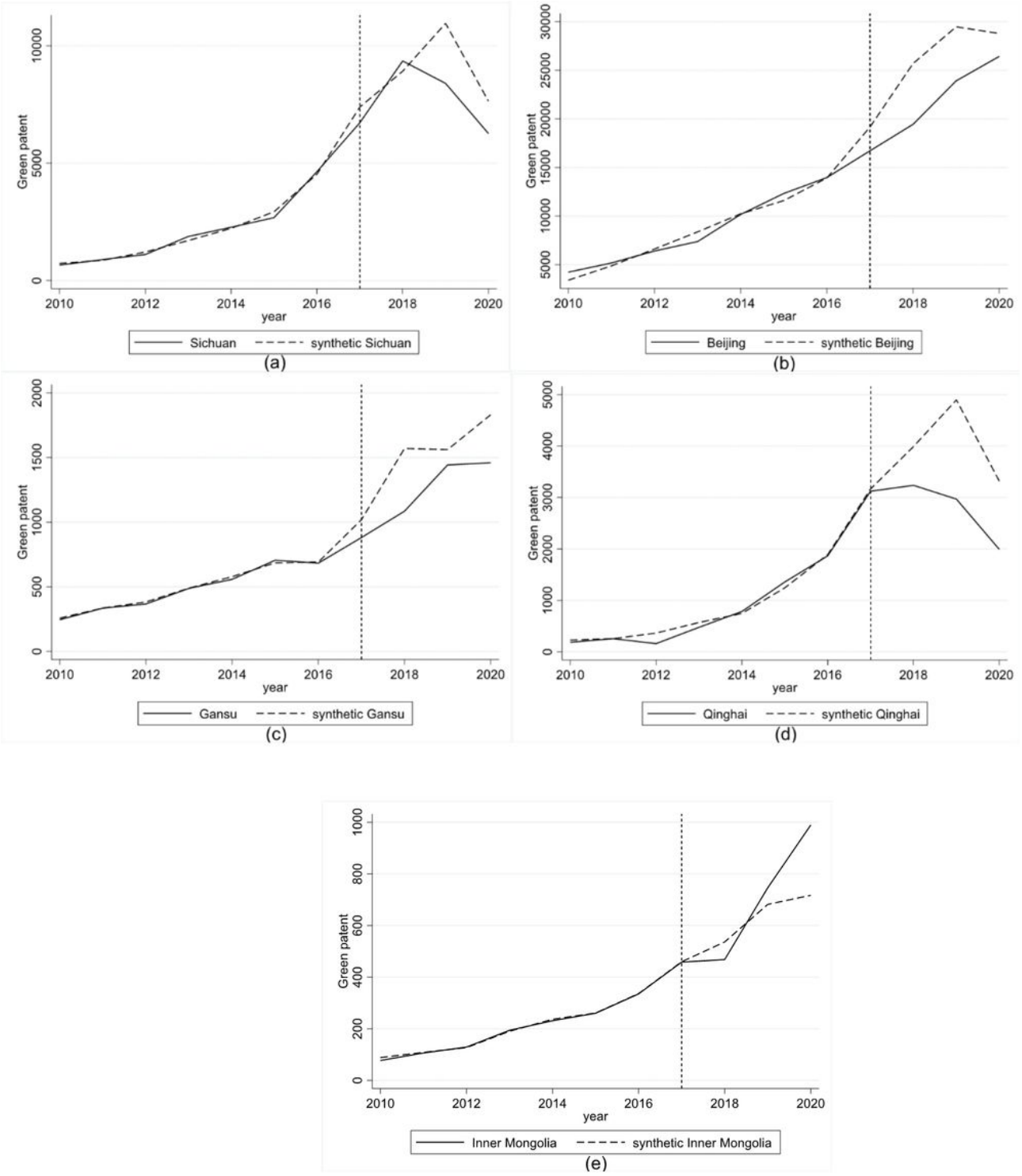


Figure 5

Placebo test results