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 GTI 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.

Keywords Green finance pilot · Green technology innovation · SCM · Policy effect

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 indirectly aggravates the pollution of the environment (Fang et al. 2020). After green becomes the theme of 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 plays a great role in promoting green economic development (Wang et al. 2021a, Wang et al. 2021b), improving environmental quality (Ding et al. 2015, Du et al. 2019), and building a powerful 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: “Literature review” is an overview of relevant international research results; “Methods, variables, and data sources” is the research design, including the background of the policy, research methods, and descriptions of related variables; “Results and discussion” is the specific experimental process and results from the analysis, including the determination of weights, the result analysis and robustness analysis of the SCM; “Conclusions and recommendations” 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 grassroots practice of my country’s green financial reform and innovation, marking my country’s green financial development has entered a new stage. The purpose and main contents of the GFRP include: taking financial innovation as the main line to promote the development of green industry, focusing on system innovation, giving full play to the decisive role of the market in allocating resources, emphasizing the construction of green financial organization system, innovating green financial products and services, broadening financing channels for the green industry, developing green insurance, consolidating green financial infrastructure. Based on the common reform tasks of building a financial service mechanism for the transformation and upgrading of green industries and green financial risk prevention and resolution mechanism, and in close combination with the respective characteristics of the five provinces, explore differentiated experiments, each with highlights and emphases. 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. Up till now, the research on GF mainly focuses on the measurement of relevant indicators of GF. The relationship with economic development (Ning et al. 2022, Soundarrajan & Vivek 2016), and the impact on the ecological environment (Chen & Chen 2021, Huang & Zhang 2021). The measurement of GF-related indicators can be divided into single indicators and composite indicators. Some scholars take single indicators such as low-carbon asset flow (Hafner et al. 2020) and green credit (He et al. 2019b) as proxy variables of GF. Although a single index can express GF to a certain extent, it is far less representative in breadth and depth than the comprehensive index. Therefore, Chen & Chen (2021), He et al. (2019a), Mngumi et al. (2022) and others constructed a GF index through green credit, green insurance, green securities, and green investment to reduce the limitations of a single index and improve the accuracy of the index. The impact of economic development, on the one hand, increases the scale of green credit and green investment of financial institutions, guides the flow of funds to target areas, and directly or indirectly promotes regional economic growth (Ning et al. 2022, Taghizadeh-Hesary & Yoshino 2019, 2020). On the other hand, the development of GF can realize the optimal allocation of resources, ensure the more efficient use of funds and ensure the steady growth of the regional economy (Wang & Wang 2021, Yang et al. 2021). The impact of GF on the ecological environment is based on many aspects, including technological innovation, industrial structure reform, and so on (Xiong & Sun 2022). These different factors have different effects on the environment under the influence of GF. Under the influence of GF, when the per capita GDP is taken as the threshold, the carbon dioxide emission will be significantly weakened, while when the industrial structure is taken as the threshold, the carbon emission trend will show an inverted “N” shape (Bai et al. n.d.). In addition to these conventional factors, the improvement of the green financing mechanism and green credit system will also have a strong inhibitory effect on the emission of pollutants (Sinha et al. 2021; Wang et al. 2021a). The relationship between economic development and environmental damage has been gradually improved after the emergence of GF. Zhou et al. (2020) incorporated GF, economic development, and environmental quality into the same research system verified the moderating effect of GF on the relationship between them and pointed out that GF is the key to creating a win-win situation between the economy and the environment.
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). Based on the existing research, the impact of GF on GTI ability is mainly divided into two parts. On the one hand, the development of GF will promote the improvement of GTI ability (Hsu et al. 2021, Zhou & Du 2021). For example, with the help of the green credit guidance policy, Hao et al. (2020) and Liu et al. (2020) take listed enterprises as the research object and discuss the impact of the green credit guidance policy on the innovation performance of heavily polluting enterprises based on a quasi-natural experiment. The results show that the implementation of a green credit guidance policy can significantly improve the green innovation and achievement output of enterprises. On the other hand, it is the opposite conclusion. Some scholars believe that the development of GF will reduce the ability of GTI (Ling et al. 2020). In a country or region, enterprises have become the main body of innovation. Therefore, scholars focus their research on enterprises and explore the changes in enterprises’ GTI ability under the influence of GF (Zeng et al. 2022). Using the relevant statistical data indicators of the manufacturing industry and the structural equation model, Wang (2022) explored the impact of GF on the green innovation performance of manufacturing enterprises and shows that GF plays a positive role in promoting the GTI ability of manufacturing enterprises. In addition, enterprises need a lot of financial support in the process of technological innovation, and green credit and green financing can raise a lot of funds for enterprises to solve the capital problem in the process of innovation, to improve the GTI ability of enterprises (Awawdeh et al. 2022; Li et al. 2022). In addition to the problem of capital, R&D activities have endogenous shortcomings such as high risk, long cycle, and asymmetric information, which makes technological innovation easier to fall into financing difficulties than other activities. The emergence of GF may reduce the risk in the process of technological innovation, and then reduce the level of technological innovation. This paper summarizes the relevant research literature in Table 1.

Through the review and summary of relevant literature, it can be found that although there are not a few studies on GF and GTI, there are still deficiencies. First, the impact of GF on GTI capability in different regions or different enterprises and industries is different, which needs further research and discussion. Second, most of the existing green finance policy research focuses on the green credit guidance policy, and the research on the GF reform and innovation pilot area is still very limited. Therefore, this paper evaluates the policy effect of China’s GFRP implemented in 2017 on the GTI ability of the pilot areas, explores the impact of GF on the GTI ability, and provides reference opinions for the implementation and adjustment of the policy.

Methods, variables, and data sources

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,

| Authors            | Period   | Data       | Method                  | Results   |
|--------------------|----------|------------|-------------------------|-----------|
| Zeng et al. (2022) | 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. (2022) | –     | Questionnaire | PLS-based SEM           | GF↑·GTI↓ |
| Zhou and Du (2021) | 2003–2018| 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↑ |
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 \(P^i\) indicate NGP in region \(i\) as the pilot of green financial reform at time \(t\), and \(P_N^i\) indicates NGP that are not the pilot. Set model \(P_i = P_0^i + D_i \alpha_i\), \(P_N^i\) is NGP when the pilot area has not established a green financial reform pilot, and \(D_i\) 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 \(P_i \neq P_N^i\). The research goal is to estimate \(\alpha_i\) \((\alpha_i \neq 0)\) using \(P_i = P_0^i + D_i \alpha_i\). \(P_N^i\) is NGP in the GF reform pilot areas, and is known. What needs to be estimated is \(P_N^i\) that it cannot be observed. In this paper, the factor model proposed by Abadie et al. (2010) to construct a “counterfactual” variable estimation \(P_N^i\): \(P_N^i = \delta_i + \theta_i Z_i + \lambda_i \mu_i + \epsilon_i\) (1)

In Eq. (1), \(\delta_i\) is a time fixed effect; \(Z_i\) represents the observable variable that is not affected by the GFRP; \(\theta_i\) is a \((1 \times K)\) dimensional unknown parameter vector, \(\lambda_i\) is a common factor vector that cannot be observed in dimension, \(\mu_i\) is an unobservable provincial fixed effect, and \(\epsilon_i\) 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 \(W^\pi = (w_2^\pi, \ldots, w_{K+1}^\pi)\) is obtained through the predictor variables, which meets the requirements for any \(k\), \(w_j \geq 0\) and \(w_2 + \ldots + w_{K+1} = 1\). For the pilot areas of GF reform, the vector \(W^\pi\) 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:

\[
\sum_{k=2}^{K+1} w_k^\pi P_{it} = \delta_i + \theta_i \sum_{k=2}^{K+1} w_k Z_i + \lambda_i \sum_{k=2}^{K+1} w_k \mu_i + \sum_{k=2}^{K+1} w_k \epsilon_k
\] (2)

Suppose there exists \((w_2^\pi, \ldots, w_{K+1}^\pi)\) such that:

\[
\sum_{k=2}^{K+1} w_k^\pi P_{i1} = P_{i1}, \ldots, \sum_{k=2}^{K+1} w_k^\pi P_{iT_0} = P_{iT_0}, \text{ and } \sum_{k=2}^{K+1} w_k^\pi Z_i = Z_i
\] (3)

If \(\sum_{i=1}^{T_0} \lambda_i^\prime \lambda_i\) is non-singular, then Eq. (4) holds:

\[
P_{it}^N = \sum_{k=2}^{K+1} w_k^\pi P_{it} = \sum_{k=2}^{K+1} w_k^\pi \sum_{t=1}^{T_0} \lambda_i^\prime \left( \sum_{i=1}^{T_0} \lambda_i^\prime \lambda_i \right)^{-1} \lambda_i^\prime (\epsilon_k - \epsilon_1) - \sum_{k=2}^{K+1} w_k^\pi (\epsilon_k - \epsilon_1)
\] (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 \(\sum_{k=2}^{K+1} w_k^\pi P_{it}\) as an unbiased estimate of \(P_{it}^N\), so as to the estimated value of policy effect \(\alpha_i\), it is:

\[
\alpha_i = P_{it} - \sum_{k=2}^{K+1} w_k^\pi P_{it}, \quad t \in [T0 + 1, \ldots, T].
\]

### 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), and trade openness (OPEN). A series of variables are used as predictors, and the specific variable description and calculation method are shown in Table 2 and Table 3:

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|}
\hline
Variable & Obs & Mean & SD & Min & Max \\
\hline
GP & 330 & 3369 & 5287 & 12 & 31391 \\
lnGDP & 330 & 10.65 & 0.503 & 9.289 & 12.010 \\
IS & 330 & 0.937 & 0.299 & 0.191 & 1.897 \\
FDI & 330 & 0.372 & 0.381 & 0.048 & 3.512 \\
STE & 330 & 0.431 & 2.617 & 0.004 & 23.070 \\
OPEN & 330 & 0.274 & 0.298 & 0.012 & 1.428 \\
\hline
\end{tabular}
\caption{Variable descriptive statistics}
\end{table}
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 (lnGDP). The level of economic development determines the richness of resources. A higher economic level can provide necessary resources for GTI capability. Measured by the natural logarithm of GDP per capita, 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).

### 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 the natural logarithm of per capita GDP, 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 4.

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. 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), and 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), and Chongqing (0.025); The provinces with positive synthetic contribution rate to Guizhou are Gansu (0.241), Fujian (0.417), and 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), and 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 show 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 GFRP 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 show 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 to 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 rich resources and strong financial resources, and the degree of policy influence is more obvious than that

| Zhejiang | Jiangxi | Guizhou | Xinjiang | Guangdong |
|----------|---------|---------|----------|-----------|
| Anhui    | 0.236   | Gansu   | Fujian   | Beijing   |
| Henan    | 0.001   | Fujian  | Gansu    | Jiangsu   |
| Jiangsu  | 0.134   | Gansu   | Qinghai  | Inner Mongolia |
| Shanghai | 0.259   | Hainan  | Shaanxi  | Hainan    |
| Sichuan  | 0.369   | Ningxia | Ningxia  | Shaanxi   |
|          |         | Shanxi  | Qinghai  |            |
|          |         |        | Shanxi   |            |
|          |         |        | Shaanxi  |            |

Table 4: Synthetic control group weight coefficient table
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

Fig. 1 Evaluation results of the policy effects of the green finance reform pilot
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 GTI capacity of Guizhou Province has been improved, and after reaching a certain level, the promotion effect begins to weaken. Of course, policy effects do not apply to all regions. After the policy is implemented, the GTI capacity of the Xinjiang region increased but the growth rate dropped sharply. The net effect of the policy is also a stated 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, 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, and 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) is 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 3a-e show 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 GTI 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 GTI 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 GTI 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

Fig. 5 Placebo test results
five provinces. Figure 5a-e show 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.

Difference-in-differences model. The traditional double difference model is also used to test the robustness of the experimental results. To make the data more stable and weaken heteroscedasticity, take the natural logarithm of green patent data. The results are shown in Table 5, it can be inferred from column (1) that without adding control variables, the coefficient of the interaction term is 0.221 and significant at the level of 5%, which indicates that when a province becomes a pilot province of green financial reform, the ability of GTI will be improved. When the control variable was added, the regression coefficient of the interaction term was 0.234 and passed the significance test at the 1% level. It still shows that the implementation of the GFRP can significantly promote the regional GTI ability, which is consistent with the conclusion of the SCM method.

**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

### Table 5 DID model regression results

| Variables (1) | (2) |
|--------------|-----|
| time*treated | 0.2210** | 0.2340*** |
| lnGDP        | 0.4493** |       |
| OPEN         | 0.8617***|       |
| IS           | 0.4245** |       |
| FDI          | 0.3254***|       |
| STE          | 0.0123 |       |
| Constant     | 6.0137***| 0.6473 |
| Observations | 330  | 330 |
| R-squared    | 0.880 | 0.896 |
| City FE      | Yes  | Yes |
| Year FE      | Yes  | Yes |
| Control variables | No  | Yes |

***, **, and * represent the significance levels of 1%, 5%, and 10% respectively; The values in parentheses represent the value of t.
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:

- According to the development stage and economic development of each region, differentiated GFRP should be implemented according to the actual situation. China has a vast territory, and the development conditions, development requirements, and demand for resources of different regions are quite different. Therefore, the implementation effects of the same policy are also quite different. Therefore, the design of policies cannot be one-size-fits-all. Based on the national policy, local governments can redesign according to the actual situation of each region, and formulate policies in line with the actual situation of the region to promote the improvement of GTI capabilities. Secondly, for local financial institutions that carry out green financial business, local governments should encourage and support them to cooperate with large financial institutions, and actively carry out special training and exchanges and cooperation with the help of professional teams and research capabilities, to improve the innovation of green financial products and risk management. Finally, it is encouraged to design and develop green financial products and services according to local conditions, which will not only effectively promote the development of local green industries and green projects, but also help to promote the sustainable development of financial institutions themselves.

- Accelerate the nationwide implementation of GFRP, and give play to the role of reform policies in enhancing GTI capabilities. The first is to deepen the construction of green financial reform pilot zones. Taking into account the role of promoting GTI, further enrich the reform and innovation tasks of the green financial reform pilot zone, such as building a prevention mechanism for green transition risks, and guiding financial institutions to support the innovation of products and services for the green and low-carbon transition. Strengthen the exchange of experience in GF reform in various regions, and accelerate the promotion of experience and practices that can be replicated and promoted in pilot areas across the country.

The second is to promote the incremental expansion of green financial reform pilot zones. Increase incentives, increase the number of national green financial reform pilot zones promptly, and give better play to the enthusiasm of local governments and financial institutions to participate in green financial reform and promote green and low-carbon development. The third is to encourage qualified regions to take the lead in promulgating local green financial regulations to promote financial support for green transformation and GTI.

- Maintain the continuity and stability of green financial reform policies, enhance pertinence, rationally increase policy efforts, and steadily enhance the promotion of GTI. To achieve the stable and efficient effect of the GFRP, it is first necessary to continuously revise and improve the policy with the changes in time and environment, to ensure that the pilot policy can achieve long-term sustainable development and promote the ability of GTI stably. Effectively, in the process of policy implementation, supervision and management should be strengthened so that the policy can be implemented accurately and the phenomenon of poor policy effect due to improper implementation is avoided. Finally, it is necessary to strengthen policy publicity, continuously strengthen the publicity of GFRP, and increase the support of local governments for policy implementation, so that the development method of the development concept contained in the policy can be better reflected.

**Author contribution**

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

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**Data availability**

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

**Declarations**

**Ethics approval and consent to participate**

This article does not contain any studies with human participants or animals performed by any of the authors.

**Consent for publication**

All authors have consent for the publication of the manuscript.

**Consent to participate**

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**Competing interests**

The authors declare no competing interests.
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