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Demand for green finance: Resolving financing constraints on green innovation in China

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ABSTRACT

This paper investigates the effects of financing constraints on prompting green innovations using a sample of Chinese listed firms in the period 2001–2017. Also, we explore how green finance policies resolve financing constraints of firms to green innovation. The capability of green innovation is found to be impaired when firms face higher financing constraints, and privately owned enterprises tend to be more vulnerable than state-owned ones in this regard. Although green finance policies can effectively ease financing restraints on green innovation overall, green credits are less likely to be available to privately owned enterprises. However, these enterprises which are deeply affected by financing constraints have relatively high innovation capabilities. We suggest the government to provide more supports to privately owned enterprises for investing in green projects. Further, both financial institutions and privately owned enterprises should be required to disclose more information on green credits and green projects, respectively. In addition, the China Banking Regulatory Commission should design a synthetic mechanism for evaluating green performance.

1. Introduction

At the 2015 United Nations Climate Change Conference (COP 21, the Conference of the Parties), 195 participating countries signed the Paris Agreement on the mitigation of climate change, reaching a consensus to limit the increase in global temperature to well below 2 °C above pre-industrial levels. To achieve such long-term climate goals, many countries have made efforts to promote the development of green industry and green innovation (Acemoglu et al., 2016; Li et al., 2018). The capabilities of enterprises in green innovation, however, are limited by financing constraints. Difficulties in accessing financing resources may greatly impede their investments in green technology (Andersen, 2017). Green innovation of enterprises is particularly hindered from financing constraints because it usually has high uncertainty and low return. As a consequence of the global consensus on climate action, green finance refers to investment and loans related to supporting environmentally sustainable development (GFSG, 2016), which has risen sharply in recent years. It is supposed to provide a supportive financing environment for green development. However, whether green finance policies can promote green innovation by effectively resolving the effects of firms' financing constraints is still unclear.

China is engaged in green development actively. Investment in green sectors has been increasing and the country has become the world's leading green investment destination. Recently, China committed to being carbon neutral by 2060, which requires comprehensive investment in green projects and technology (Polzin and Sanders, 2020). Either past successes or future ambitions cannot be achieved without policy support. Intensive efforts have been made by the Chinese government to cope with environmental degradation and pollution. In addition to comprehensive regulations and administrative enforcements, green finance policies have been explicitly introduced to support green development. In 2007, the China Banking Regulatory Commission (CBRC) launched "Opinions on Implementing Environmental Protection Policies and Rules and Preventing Credit Risks" and "Guiding Opinions on the Credit Work for Energy Conservation and Emission Reduction." These guidelines instruct banks to restrict or cease lending to "Two-high & one overcapacity" industries[1] and to implement credit classification management according to the environmental impact of projects. In

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[1] "Two-high" industries are high pollution and high energy intensive, and "one overcapacity" industry is overcapacity.

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2012, the CBRC issued "Green Credit Guidelines." This document established the core framework of the green credit system and ensured that resources can be allocated to low-carbon, recycling and ecological fields. More green finance policies have been launched since then. A list of green finance policies is presented in Table A1 (Natural Resources Defense Council, NRDC, 2019).

A remarkable achievement in green innovation has been seen in China since the introduction of these policies. According to the data on green patents captured by the International Patent Classification (IPC) green inventory of the World Intellectual Property Organization filed at the Chinese National Intellectual Property Administration (CNIPA), granted green patents increased from around 16,000 in 2006 to 223,000 in 2017. The green patent counts of listed industrial firms reached 96,000 in 2017, a 14-fold increase from 6000 in 2006.

Despite this progress, problems and challenges remain. For example, the distribution of green innovation is uneven across firms. As shown in Fig. 1, at least 40% of all listed industrial firms have zero green patents. Most worrying is the fact that the proportion of such firms has increased since 2014. The uneven distribution is found to be mainly between state-owned enterprises (SOEs) and privately owned enterprises (POEs). The rise of zero green innovation firms can be attributed to POEs (see Fig. 1). Arguably, POEs tend to face stronger financing constraints on research and development (R&D) activities because of uneven loan distributions from state-owned banks (Wu, 2018). If financing constraints are the main barrier to green innovations, the inferior performance of POEs implies that POEs lack access to financing resources despite the current green finance policies.

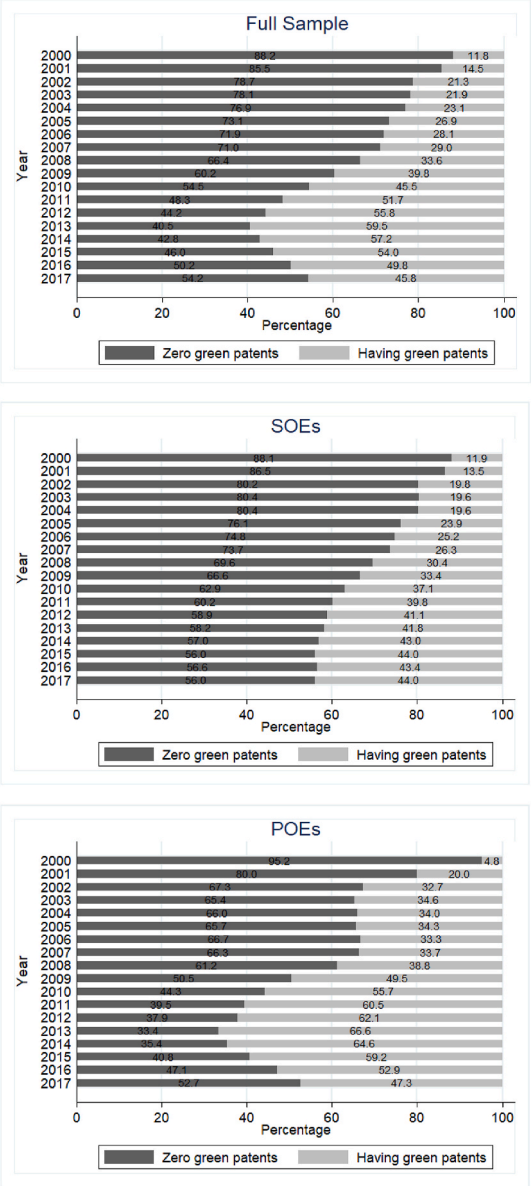

Fig. 1. The proportion of firms with green patents from 2000 to 2017.

To fulfill China's carbon ambition in 2060, it is critical that more firms are involved in green innovation, especially in the private sector. Thus, it is important to investigate whether and how the current green finance policy is working to promote green innovation. In addition, POEs are more vulnerable than SOEs to "ownership discrimination" in the financial system in China, which is dominated by large banks. Not only do SOEs have preferential credit access, loan periods and loan interest rates, they also do not need to provide as many guarantees as POEs have to when obtaining loans from banks. As a result, acquiring external financing is more difficult and costly for POEs. Therefore, it is necessary to examine whether current green finance policies are biased against POEs if easing financing constraints is the main channel leading to higher green innovation capability.

In this study, a sample of listed Chinese firms is used to examine the above issues. The green patenting information retrieved from the CNIPA, including both patent counts and patent claims, is used as the proxy of firms' capabilities in green innovations. We also calculate a green ratio (green patent counts to total patent counts) to reflect the enterprises' emphasis on green innovations. Financing constraints are measured by a synthetic index built on several financing indicators following Musso and Schiavo (2008). Our main finding is that green finance policies can significantly enhance green innovation capabilities by resolving the effects of financing constraints faced by enterprises. POEs are indeed inferior to SOEs in terms of acquiring credits under current green finance policies, which restricts their green innovation capabilities.

The contribution of this paper can be summarized as follows. First, our results confirm a significantly negative impact of financing constraints on green innovation in Chinese firms. Second, we prvoide a new insight on green innovation in current literature by examining the green finance policy effects through the firms' financing constraints. Then we get some implications from investigating the uneven distribution between POEs and SOEs. Third, this paper distinguishes itself from existing studies by using research outputs measured by a combination of factors, thus providing comprehensive measurement of green innovation capabilities.

The rest of this paper is organized as follows. Section 2 reviews relevant literature. Section 3 introduces data and reports descriptive statistics. Section 4 presents and discusses the empirical results. The last section concludes with a few policy implications.

2. Literature review

The existing literature analyzing factors that promote green innovation is mainly concerned with environmental regulations, governmental investments in R&D funds, technology transfer, tax subsidies and stakeholders' roles (van Leeuwen and Mohnen, 2017; Ouyang et al., 2020; Tu et al., 2019; Yang and Lee, 2021). For example, van Leeuwen and Mohnen (2017) examined the role of environmental regulation on eco-investments (including eco-R&D, end-of-pipe eco-investments, and process-integrated eco-investments) and eco-innovations (including pollution-reducing outputs and resource-saving outputs) using a comprehensive panel of Dutch manufacturing firm-level data. They found that both existing and anticipated environmental regulations significantly prompt both eco-investments and eco-innovations.

Financing constraints are always argued to be highly associated with the innovation capability of enterprises. Gorodnichenko and Schnitzer (2013) revealed that innovation capacity is restrained by financial friction. Using Chinese manufacturing industry data, Jin et al. (2019)

found an inverted U-shaped relationship between financing constraints and enterprise productivity. García-Quevedo et al. (2018) believed that financing constraints affect not only enterprises' innovation decisions but also their innovation outcomes. However, Almeida et al. (2013) argued that higher financing constraints result in higher innovation efficiency of enterprises because financing constraints can force enterprises to make optimal investment decisions, which in turn improves capital efficiency.

Recently, a strand of literature has focused on the role of financing constraints on environmental innovations (Johnson and Lybecker, 2012; Ghisetti et al., 2015; Noailly and Smeets, 2016). Johnson and Lybecker (2012) discovered that the literature on financing environmental innovation is limited. Ghisetti et al. (2015) investigated the effects of financial barriers to the environmental innovations of small and medium enterprises using survey data at the European Union level, finding that the perception of financial barriers hampers firms' environmental innovations. They suggested stimulating the adoption of environmental innovations by facilitating firms' access to credit. Noailly and Smeets (2016) examined the role of financing constraints on innovation activities in renewable versus fossil fuel technologies for 1300 European firms in the 1995–2009 period using the number of patents as the measure of innovation and three indicators— cash flow, long-term debt and stock issues— as financing sources. They concluded that financing constraint is a determinant of a firm's decision to launch an innovation project. Despite Noailly and Smeets's (2016) study, which is a preliminary attempt to provide empirical evidence of the relationship between financing sources and energy technological innovations, studies on financing constraints on green innovation are still limited.

Moreover, financing constraints are likely to have heterogeneous effects on innovations among different types of ownership. The extant literature shows that SOEs are largely able to invest in R&D for innovation because of financing constraints being eased by implicit debt guarantees and access to state-owned banks provided by state ownership (Borisova and Megginson, 2011; Megginson et al., 2014). However, another strand of literature believes that state ownership and political characteristics are not dominant in the private equity market, and thus increase financing constraints (Ben-Nasr et al., 2012; Chen et al., 2015; D'Souza and Nash, 2017), which in turn reduces investment in R&D and lowers innovation levels (Lin et al., 2010; Boeing et al., 2016; Bortolotti et al., 2019). For example, Bortolotti et al. (2019) found that state ownership affects investment in R&D by relaxing financing constraints and further restricting the innovativeness of SOEs.

Additionally, enterprises subject to government intervention tend to adopt conservative investment strategies and avoid investing in high-risk innovative projects because innovation is usually time-consuming and has high uncertainty (Fogel et al., 2008; Boubakri et al., 2013; Chiu and Lee, 2020; Zhang and Chiu, 2020). Therefore, policy intervention is considered to affect financing constraints (Amore et al., 2013; Andersen, 2017; Mateut, 2018; Chang et al., 2019; Tu et al., 2018, 2020). Amore et al. (2013) found that the deregulation policies for US interstate banks during the 1980s and 1990s significantly enhanced the innovation activities of enterprises, particularly of firms highly dependent on external capital. They suggested easing the financing constraints of enterprises through deregulation policies, which can increase bank loans and promote the development of non-bank financial institutions. Mateut (2018) also believed that the government's subsidy policies can significantly ease the financing constraints of enterprises in non-European Union countries, which are likely to have less developed financial markets, and further encourage innovative activities.

A strand of literature has studied the role of green finance policy in promoting green development. Zhang et al. (2011) believed that green credit policy contributes to the control of "Two-high & one over-capacity" industries in China. In addition, Liu et al. (2017) argued that green loan policies are likely to restrain investments in energy-intensive industries. Accordingly, green finance policies may affect the financing constraints of enterprises. Andersen (2017) and Chang et al. (2019) found that green credit policies are likely to strengthen corporate financing constraints, stimulating decision makers to invest in tangible assets while reducing intangible assets, such as R&D funds. Liu et al. (2019) and Xu and Li (2020) found that green credit policy and green credit development reduce the debt financing costs of green enterprises. Further, Li et al. (2018) argued for the effectiveness of green bank loans in prompting green innovation by constructing a green loan theory among enterprises, banks and government.

To sum up, few studies have attempted to explore the effect of financing constraints on energy technological innovation, and studies on green innovation are also limited. Though green finance policy is found to affect financing constraints, the effectiveness of green finance policies in prompting green innovations has still not been addressed.

3. Data, descriptive statistics and empirical strategy

This paper's empirical analysis is based on a panel dataset of Chinese listed industrial firms from 2000 to 2017. The indicators for building a synthetic index of financing constraints are collected from financial statements, including balance sheets, income statements and cash flow statements, as reported in the China Stock Market & Accounting Research (CSMAR) Database. Patent data is retrieved from the CNIPA, following the IPC Green Inventory and matched with the data from CSMAR under the names of listed industrial firms and year. Control variables are referred to Cui et al. (2020) and Amore and Bennedsen (2016) and collected mainly from three datasets: firm age, capital–labor ratio, ownership and industrial category[2] are from CSMAR; provincial-level R&D investments is from the China Scientific and Technological Statistical Yearbook; city-level gross domestic product (GDP) per capita, city-level technological investment and city-level ratio of foreign direct investment (FDI) to GDP are from the China City Statistical Yearbook. The variable definitions and data sources are summarized in Table 1.

3.1. Measuring financing constraints

Financing constraints refer mainly to the external financial friction faced by firms when they seek external financing supports. It is manifested by the difference between internal and external financing costs (i.e., internal financing costs should be lower than external financing costs) and cannot be directly observed (Fazzari et al., 1988; Whited and Wu, 2006; Hadlock and Pierce, 2010). Fazzari et al. (1988) suggested the use of investment cash flow sensitivities to indirectly proxy financing constraints. Kaplan and Zingales (1997) categorized sample firms into five groups on a five-point scale from non-financing constraints to financing constraints. Then they applied logit regression to run the financing constraints on five financial variables (operating cash flow, Tobin's Q, asset–liability ratio, dividend payment rate and cash holding), obtaining the regression coefficients to construct the Kaplan–Zingales (KZ) index to present financing constraints. However, Whited and Wu (2006) found that the KZ index contradicts the facts. They thus used the generalized method of moments method of the investment Euler equation to construct an external financing constraint index called the Whited–Wu (WW) index. Later, Hadlock and Pierce (2010) argued that some of the above indicators are endogenous financial variables and suggested constructing the Size–Age (SA) index only using two exogenous variables: firm size and firm age.

[2] Industrial category is used for calculating the value of financing constraints and to identify high-energy-consuming industries. High-energy-consuming industries include chemical raw materials and chemical manufacturing, non-metallic mineral products industries, ferrous metal smelting and calendering industries, nonferrous metal smelting and calendering industries, petroleum refineries, coking and nuclear fuel processing industries, and electricity and heat production and supply industries.

Table 1
Variable definitions and data sources.

Variable	Symbol	Definition	Data Source
Green patent counts	Patent Counts	Natural logarithm of one plus number of green patents	Chinese National Intellectual Property Administration (CNIPA)
Ratio of green patent counts to the total patent counts	Green Ratio	Number of green patents over total number of patents	CNIPA
Green patent claim	Patent Claim	Natural logarithm of one plus average patent claims of patents	CNIPA
Financing constraints	FC	A synthetic index built from firm size, profitability, liquidity, cash flow generating ability, solvency, trade credit over total assets, and net tangible asset ratio	China Stock Market & Accounting Research (CSMAR)
Firm age	Age	Calculated as the number of years since the firm has been listed	CSMAR
Capital–labor ratio	K/L	Natural logarithm of the net fixed assets over employees	CSMAR
Ownership	SOEs/ POEs/ FOEs	According to the nature of the actual controller's shares, ownership is categorized into state-owned, privately owned, and foreign-owned	CSMAR
High-energy-intensive industry	High EI	Enterprises in high-energy-consuming industries are assigned a value of 1; otherwise, 0	CSMAR
Provincial-level R&D investment	Prov. R&D	Natural logarithm of provincial-level R&D investment	China Scientific and Technological Statistical Yearbook
City-level GDP per capita	City GDP	Natural logarithm of city-level gross domestic product (GDP) per capita	China City Statistical Yearbook
City-level technological investment	City Tech	City-level ratio of technological investment to GDP	China City Statistical Yearbook
City-level FDI	City FDI	City-level ratio of foreign direct investment (FDI) to GDP	China City Statistical Yearbook

Following Musso and Schiavo (2008), we measure financing constraints using a synthetic index developed from seven indicators: firm size (measured by total assets), profitability (measured by return on assets [ROA]), liquidity (measured by current assets over current liabilities, i.e., current ratio), cash flow generating ability (measured by net cash flow from operating activities over current liabilities), solvency (measured by own funds over total liabilities), trade credit over total assets (measured by accounts payable over total assets) and net tangible asset ratio (measured by tangible assets over total assets). Larger firm size and higher ROA indicate that a firm faces lower financing constraints. Liquidity and cash flow generating ability mainly reflect the ability of a firm to repay short-term debts. Solvency indicates the ability to repay long-term debts and reveals the stability of the financial structure and the affordability of own funds to debts. The higher the proportion of accounts payable and net tangible assets in total assets, the higher the likelihood that a firm carries out external financing.

The process of constructing the synthetic index is as follows. First, for each year, we sort each indicator of all firms in ascending order, from which we obtain the quantile value of the seven indicators of each firm. For example, the profitability of *i*th firm in year *t* is the highest among all firms, and the quantile value of the indicator profitability for *i*th firm in year *t* is 100%. Second, a scale of 1–5 is given if the indicator of a sample firm is in the highest 20% quantiles (1), 60%–80% quantiles (2), 40%–60% quantiles (3), 20%–40% quantiles (4) and the lowest 20% quantiles (5). We, therefore, have seven scales ranging from one to five for each firm/year observation. Third, we construct the synthetic index of financing constraints by combining the scale information in two ways. The first way is by taking the sum of the seven scaled values of each firm/year observation; we then obtain the aggregated index of 7–35, which is rescaled to a range of 1–10 (named Index A). The other way to construct the index is by taking the sum of the number of indicators on which the firm/year lies in the first quantile, and this has a range of 0–7. For example, if three of the seven indicators of *i*th firm lay in the first quantile in year *t*, the value of index for *i*th firm in year *t* is recorded as three. The second index is named Index B, which is highly correlated with Index A ($\rho = 0.7$). Both indices represent the synthetic index of financing constraints with higher values presenting higher financing constraints faced by a listed industrial firm.

3.2. Measuring green innovation

Since patent applicant information can help identify innovation classification (Amore and Bennedsen, 2016) and patents are easily and accurately measured (Gorodnichenko and Schnitzer, 2013), this paper uses green patent application data to measure the capability of green innovations of a listed industrial firm. Patent data is available on the CNIPA website (http://www.sipo.gov.cn/) that provides all patent application information on invention patents, utility models and design patents since 1985, when the Chinese patent system was established. Patent application information includes the application number, application date, IPC classification and applicants' names and addresses (for details, see Dang and Motohashi, 2015), and "green" patents are classified based on the IPC Green Inventory classification. To accurately measure the capability of green innovations, we only consider invention patents and utility models. Information on primary independent claims is also available from the CNIPA. Note that there is an 18-month publication lag for patents after filing.

We thus obtain firm-year patent counts from the applicants' names and application date, and the patent counts can measure patent quantity. Innovation quality is measured by the patent claim, which is the number of claims each patent has. It can be used as an indicator of innovation quality because it can measure claim breadth (Lanjouw and Schankerman, 2004). Many patent claim counts signify a large technical scope and the improved quality of a patent.[3]

3.3. Descriptive statistics

Our analysis relies mainly on a sample set of all industrial firms listed

[3] Although a patent with high citations implies high quality, citations are usually affected by time. Newer patents are likely to be cited less than older patents, but it cannot be asserted that a newer patent has lower value.

on the main board of the Shanghai and Shenzhen Stock Exchanges during 2000–2017. Variables of firm-level characteristics, including patent counts, green ratio, patent claims, financing constraints and capital–labor ratio, are winsorized at the 1% and 99% levels to avoid the influences of outliers and bad data points. In addition, we delete industrial categories with too few firms to ensure the exogeneity of the instrumental variable (IV) obtained by averaging the financing constraints at the provincial industrial level. We also take one-year lag on Index A, Index B, K/L, Prov. R&D, City GDP, City Tech, and City FDI because of the lagged effects of these variables. Accordingly, our analysis is restricted to the years 2001–2017, comprising a total of 13,360 observations representing 1699 firms. Table 2 reports the descriptive statistics. Note that the statistics on lagged variables are based on the observations from 2000 to 2016. As shown in Table 2, the average patent counts, green ratio and patent claims of POEs are all higher than those of SOEs, indicating that POEs have a greater capability of green innovation than SOEs. Further, the average financing constraints measured by both Index A and Index B of SOEs are higher than those of POEs.

Fig. 2 illustrates the distributions of the green patent counts of POEs (left graph) and SOEs (right graph), showing that POEs significantly have had green patents since 2006, and SOEs start to significantly have green patents two years later than POEs. Both POEs and SOEs have had a significant increase in patent counts since 2008. Fig. 3 presents the average patent claims of POEs (dashed line) and SOEs (solid line), showing that the quality gap between SOEs and POEs is enlarged during 2009 and 2014. Since 2015, interestingly, the patent claims of POEs have declined, whereas those of SOEs have increased.

Table 2
Descriptive statistics.

Variables	Obs.	Mean	S.D.	Min	Max
Panel A: Full Sample					
Patent Counts	13,360	1.238	1.621	0	5.749
Patent Claims	13,360	0.831	0.96	0	2.485
Green Ratio	13,360	0.077	0.141	0	0.693
FC Index A	13,360	5.92	1.223	3.429	8.857
FC Index B	13,360	1.295	1.165	0	5
Age	13,360	8.292	5.807	1	23
K/L	13,360	12.479	0.997	10.006	15.668
High EI	13,360	25.1% is High EI			
Ownership	13,360	44.33% SOEs; 51.08% POEs; 4.60% FOEs			
Prov. R&D	13,360	15.096	1.288	9.71	16.829
City GDP	13,360	10.959	1.023	7.727	17.513
City Tech	13,360	0.005	0.005	0	0.063
City FDI	13,360	0.005	0.003	0	0.025
Panel B: SOEs					
Patent Counts	5922	0.915	1.543	0	5.749
Patent Claims	5922	0.589	0.867	0	2.485
Green Ratio	5922	0.063	0.141	0	0.693
FC Index A	5922	5.992	1.228	3.429	8.857
FC Index B	5922	1.343	1.213	0	5
Age	5922	10.387	5.696	1	23
K/L	5922	12.603	1.076	10.006	15.668
High EI	5922	33.8% is High EI			
Prov. R&D	5922	14.564	1.346	9.71	16.829
City GDP	5922	10.753	1.23	7.727	17.513
City Tech	5922	0.004	0.005	0	0.046
City FDI	5922	0.005	0.004	0	0.025
Panel C: POEs					
Patent Counts	6824	1.512	1.64	0	5.749
Patent Claims	6824	1.031	0.986	0	2.485
Green Ratio	6824	0.089	0.139	0	0.693
FC Index A	6824	5.876	1.209	3.429	8.857
FC Index B	6824	1.257	1.124	0	5
Age	6824	6.614	5.318	1	23
K/L	6824	12.391	0.909	10.006	15.668
High EI	6824	18.2% is High EI			
Prov. R&D	6824	15.532	1.047	11.065	16.829
City GDP	6824	11.109	0.752	8.146	17.513
City Tech	6824	0.005	0.004	0	0.063
City FDI	6824	0.005	0.003	0	0.025

Note: Firm-level characteristics, including patent counts, green ratio, patent claims, financing constraints and capital–labor ratio are winsorized at the 1% tails to avoid the influence of extreme values.

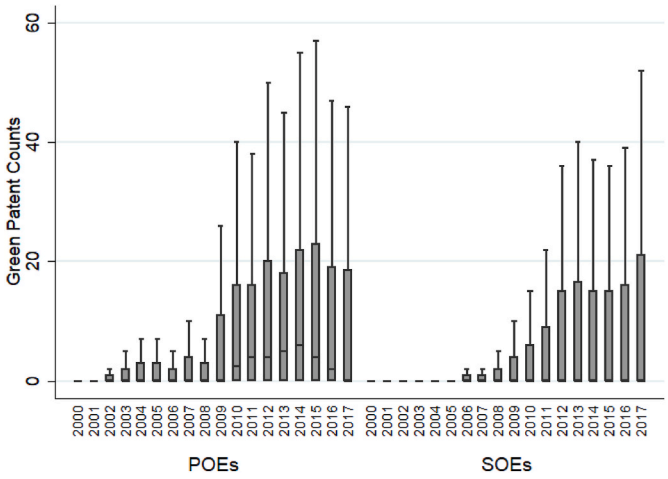

Fig. 2. Distributions of green patent counts for SOEs and POEs.

Fig. 4 shows the changes in the averaged financing constraint scores. In the beginning, the score of POEs is higher than that of SOEs, but the gap begins to shrink in 2005 as the score of POEs significantly continues to decline, whereas that of SOEs significantly continues to rise. This could be due to the China Securities Regulatory Commission launching the order "Interim Measures for the Stock Issuance and Listing Sponsorship System," which more strictly regulated the issuance of new stocks and the disclosure quality of information of listed firms in 2004. This regulation resulted in an increase in the financing constraints of SOEs because equity issuances by SOEs are usually slow, complex and expensive processes (Bortolotti et al., 2019). Moreover, SOEs may have no incentives to issue new stocks because the issuance is likely to dilute state shares, thereby reducing the state's control over the enterprises (Xu and Wang, 1999).

3.4. Empirical strategy

To explore the effects of financing constraints on green innovative capability, we consider the following reduced form of an econometric model:

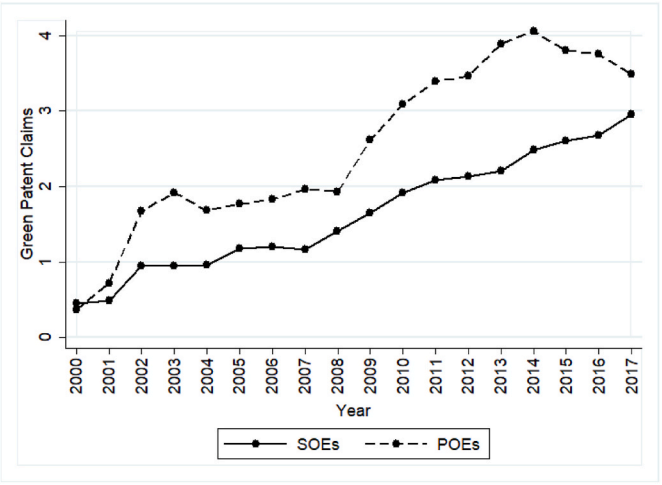

Fig. 3. Trends of average green patent claims for SOEs and POEs.

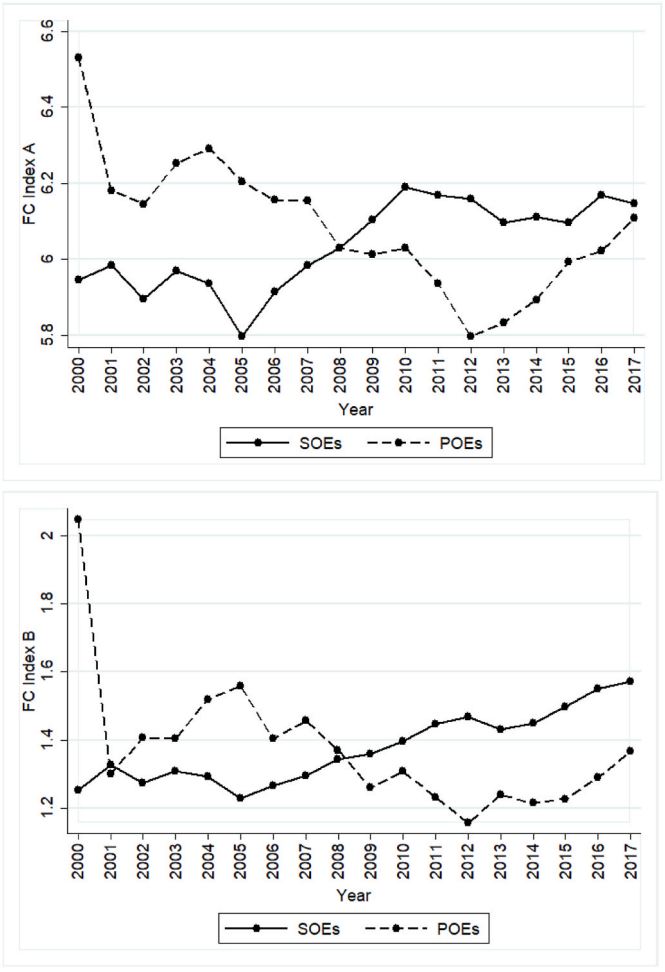

Fig. 4. Trends of average financing constraints for SOEs and POEs.

$$Y_{ip,t} = \alpha_0 + \beta_1 FC_{ip,t-1} + \boldsymbol{X_{ip,t-1}}\gamma + \boldsymbol{W_{p,t-1}}\delta + \eta_t + u_p + \varepsilon_{ip,t} \quad (1)$$

where $Y_{ip,t}$ is the green patent count, green patent ratio and green patent claim, respectively, of firm i that is in province p in year t; $FC_{ip,t-1}$ is the lagging financing constraints of i^{th} firm that is in province p in year t; $\boldsymbol{X_{ip,t-1}}$ is a vector of firm-level control variables, including firm age, capital–labor ratio, dummies of ownership structure and high-energy-intensive characteristic; $\boldsymbol{W_{p,t-1}}$ is a vector of regional-level control variables in province p in year $t-1$, including provincial-level R&D investment, city-level GDP per capita, city-level technological investment and city-level FDI; η_t and u_p are the year fixed effect and provincial fixed effect, respectively; β_1 is a scalar coefficient; γ and δ are vectors of the parameters; $\varepsilon_{ip,t}$ is the random disturbance error term.

To examine the effectiveness of green finance policies in reducing the effects of financing constraints, the sample period is divided into three segments based on the launch of two main green finance policies: the "Guiding Opinions on the Credit Work for Energy Conservation and Emission Reduction" in 2007 and the "Green Credit Guidelines" in 2012. We, therefore, have three sub-periods, namely, 2001–2007, 2008–2012 and 2013–2017, and Equation (1) is modified as follows:

$$Y_{ip,t} = \alpha_0 + \beta_1 FC_{ip,t-1}D_{1t} + \beta_2 FC_{ip,t-1}D_{2t} + \beta_3 FC_{ip,t-1}D_{3t} + \boldsymbol{X_{ip,t-1}}\gamma + \boldsymbol{W_{p,t-1}}\delta + \eta_t + u_p + \varepsilon_{ip,t} \quad (2)$$

where D_{1t}, D_{2t}, and D_{3t} are dummy variables to indicate 2001–2007, 2008–2012 and 2013–2017, respectively.

It is likely that green innovation also affects financing constraints, resulting in a reverse causality problem. One possible reason for this is that green innovations may bring a better reputation and performance to the firms, thereby reducing the difficulty of acquiring external financing and, in turn, the effect of financing constraints. Further, omitted variables may also cause endogeneity. Hence, we apply a two-stage least squares (2SLS) regression model using the provincial industrial average financing constraint score as the IV following Fisman and Svensson (2007). The provincial industrial average is ideal since it is positively correlated with each firm's characteristic but slightly affects the innovation decisions of an individual firm. The identification test and the first-stage regression results of 2SLS are reported in the Appendix (Tables A2 and A3).

4. Empirical results

In this section, we first confirm the relationship between financing constraints and green innovative capabilities. We then examine the effectiveness of green finance policies in reducing the effects of financing constraints on green innovations.

4.1. Basic results

Table 3 provides the basic results from our examination of the determinants of patent counts, patent claims and green ratio, in which financing constraint is measured using Index A. Columns (1), (3) and (5) report the 2SLS estimates, and columns (2), (4) and (6) provide ordinary least squares (OLS) estimates for comparisons. The first-stage results of the 2SLS estimates are reported in Table A3. Note that patent counts and patent claims are in the natural logarithm form.

The results show that financing constraints are significantly negatively associated with green patent counts and green patent claims, which decrease by 16.4% and 10.5%, respectively, when financing constraints increase one score point. Moreover, the impact of financing constraints on green ratio is significant at the 10% level, implying that financing constraints slightly hinder firms from increasing investments in green innovations relative to general innovations. It indicates that the access ability of firms to external credit restrains their green innovation capabilities. This is mainly because investing in green innovative activities not only is quite risky and costly but also has high failure rates, requiring sufficient and stable supportive funds. A greater difficulty in financing through external funds implies a higher uncertainty of financing sources, increasing the possibility of unsuccessful innovative activities. Financing constraints do hinder green innovation capabilities, which also explains why many firms apply clean development mechanism (CDM) projects to support their emission reduction innovative activities. In the CDM project design document (CDM-PDD), most participants emphasize that the purpose of the application is to overcome the financial barriers they encounter. Their projects have no financial attraction because they have a lower internal rate of return and are unable to obtain the construction funds by a bank loan or self-financing to maintain the project.

In addition to financing constraints, we briefly discuss the estimates of high-energy-intensive and ownership variables reported in Table 3. A firm in a high-energy-intensive industry has lower patent counts but a higher green ratio than a non-high-energy-intensive firm. Specifically, firms significantly have 25.7% fewer patent counts but 1.3% higher green ratio (16.9% relative to the mean) if they are in a high-energy-intensive industry, indicating that high-energy-intensive firms are more likely to proceed with green innovations. Further, there seems no significant quantitative difference among different types of ownership, whereas POEs have better quality green innovations than SOEs. That is, the patent claims of POEs are 16.3% higher than those of SOEs. The lower innovation performance of SOEs may be due to the majority of SOEs being more supportive of government policies to meet green innovation targets, and therefore they pursue quantity above quality (Rong et al., 2016).

Table 3
Basic estimates.

VARIABLES	Patent Counts		Patent Claims		Green Ratio	
	(1)	(2)	(3)	(4)	(5)	(6)
	2SLS	OLS	2SLS	OLS	2SLS	OLS
FC Index A	−0.164***	−0.159***	−0.105***	−0.091***	−0.005*	−0.004**
	(0.039)	(0.024)	(0.024)	(0.014)	(0.003)	(0.002)
High EI (1 = Yes)	−0.257***	−0.258***	−0.067	−0.070	0.013*	0.013*
	(0.081)	(0.082)	(0.051)	(0.051)	(0.007)	(0.007)
Age	−0.011	−0.011	−0.011***	−0.012***	−0.003***	−0.003***
	(0.008)	(0.008)	(0.004)	(0.004)	(0.000)	(0.000)
K/L	−0.014	−0.015	−0.008	−0.009	0.003*	0.003*
	(0.033)	(0.033)	(0.018)	(0.018)	(0.002)	(0.002)
Prov. R&D	0.022	0.022	−0.028	−0.026	−0.036***	−0.036***
	(0.115)	(0.115)	(0.069)	(0.069)	(0.012)	(0.012)
City GDP	0.242***	0.243***	0.081*	0.084**	−0.005	−0.005
	(0.067)	(0.067)	(0.043)	(0.043)	(0.005)	(0.005)
City Tech	20.905**	20.849**	8.205*	8.048*	−0.515	−0.529
	(8.637)	(8.647)	(4.808)	(4.816)	(0.538)	(0.540)
City FDI	−25.256***	−25.285***	−11.113**	−11.195**	−0.343	−0.350
	(9.610)	(9.610)	(5.635)	(5.640)	(0.748)	(0.747)
POEs (1 = Yes)	0.124	0.123	0.163***	0.160***	0.010	0.009
	(0.094)	(0.094)	(0.052)	(0.052)	(0.006)	(0.006)
FOEs (1 = Yes)	−0.074	−0.075	0.055	0.053	0.008	0.008
	(0.163)	(0.164)	(0.092)	(0.093)	(0.011)	(0.011)
Constant	−2.661	−2.704	0.112	−0.008	0.601***	0.591***
	(1.807)	(1.777)	(1.103)	(1.081)	(0.177)	(0.175)
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Province fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	13,360	13,360	13,360	13,360	13,360	13,360
	0.147	0.147	0.147	0.147	0.051	0.052
Firms	1699	1699	1699	1699	1699	1699

Note: FC (Index A), K/L, Prov. R&D, City GDP, City Tech and City FDI are one-year lagged terms. The IV used in the 2SLS estimates is provincial industrial average financing constraint, and the first-stage results are reported in Table A2. Robust standard errors clustered at the firm level are in parentheses. ***, ** and * represent 1%, 5% and 10% statistical significance levels, respectively.

We present the estimates of robustness tests in Table 4. First, since around 55% of our samples have a zero green patent count, we apply the Tobit model with provincial industrial average financing constraint as the IV for estimation, and the results are reported in columns (2), (4) and (6) of Table 4. Second, we use another measure of financing constraint (i.e., Index B) to run both 2SLS and Tobit regressions, which are reported in Panel B of Table 4. The results show that patent counts and patent claims are still significantly hindered by financing constraints, and the estimates of green ratio are slightly inconsistent between the 2SLS and the Tobit models (columns (5) and (6) of Table 4). We can still believe

Table 4
Robustness of estimates.

VARIABLES	Patent Counts		Patent Claims		Green Ratio	
	(1)	(2)	(3)	(4)	(5)	(6)
	2SLS	Tobit	2SLS	Tobit	2SLS	Tobit
Panel A: FC Using Index A						
FC Index A	−0.164***	−0.416***	−0.105***	−0.255***	−0.005*	−0.026***
	(0.039)	(0.096)	(0.024)	(0.058)	(0.003)	(0.008)
High EI (1 = Yes)	−0.257***	−0.513***	−0.067	−0.183	0.013*	0.004
	(0.081)	(0.196)	(0.051)	(0.120)	(0.007)	(0.017)
POEs (1 = Yes)	0.124	0.358*	0.163***	0.328***	0.010	0.033**
	(0.094)	(0.208)	(0.052)	(0.121)	(0.006)	(0.016)
R-squared	0.147		0.147		0.051	
Panel B: FC Using Index B						
FC Index B	−0.239***	−0.563***	−0.130***	−0.313***	−0.005	−0.031***
	(0.037)	(0.095)	(0.022)	(0.058)	(0.003)	(0.008)
High EI (1 = Yes)	−0.251***	−0.503***	−0.067	−0.185	0.013*	0.003
	(0.080)	(0.193)	(0.050)	(0.118)	(0.007)	(0.017)
POEs (1 = Yes)	0.135	0.360*	0.165***	0.324***	0.010	0.032**
	(0.092)	(0.205)	(0.051)	(0.119)	(0.006)	(0.016)
R-squared	0.154		0.153		0.052	
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	13,360	13,360	13,360	13,360	13,360	13,360
Firms	1699	1699	1699	1699	1699	1699

Note: FC Index A and FC Index B are one-year lagged terms. The IV used in all estimates is provincial industrial average financing constraint, and the first-stage results are reported in Table A2. Controls include Age, K/L, Prov. R&D, City GDP, City Tech, City FDI, FOEs, year fixed effect, and province fixed effect. Robust standard errors clustered at the firm level are in parentheses. ***, ** and * represent 1%, 5% and 10% statistical significance levels, respectively.

that stronger financing constraints make enterprises more reluctant to choose high-risk and high-cost green innovative activities when making innovative decisions.

4.2. Functions of green finance policies

To investigate the effectiveness of green finance policies, we examine whether the effects of financing constraints on green innovations vary across three periods: 2001–2007, 2008–2012 and 2013–2017. Table 5 reports the results.

As shown in both Panel A and Panel B of Table 5, financing constraints significantly impose tighter restrictions on green innovations in 2008–2012 compared with 2001–2007. More specifically, if the financing constraint measured by Index A increases one score point, patent counts in 2001–2007 and 2008–2012 are lowered by 13.4% and 28%, respectively, and patent claims in 2001–2007 and 2008–2012 are lowered by 8.9% and 15.7%, respectively. However, firms significantly produce more patents in 2008–2012 than in 2001–2007 (Fig. 2), and the capability of green innovations in 2008–2012 significantly improves from 2001 to 2007 despite the tighter financing constraints on patents faced by the firms during 2008–2012 (Figs. 3 and 4). The results imply that the first official launch of green finance policies in 2007 had an effective stimulation on green innovations. The 2007 green credit policy imposes stricter credit requirements for projects with significant negative environmental effects and firms with high-energy-intensive and severe pollution problems. In this respect, firms are prompted to innovate using green technologies to protect the sources of bank loans. Moreover, Aghion et al. (2012) argued that firms' productivities are likely to be more sensitive to exogenous shocks when firms face tighter credit constraints. Therefore, the 2008 financial crisis may be a reason why financing constraint has a tighter restraint on patent counts during 2008–2012.

Compared with those in 2008–2012, there are fewer financing constraints in 2013–2017 on the green patents of enterprises. We believe that several green credit policies issued during 2013–2017 make it easier for firms to obtain green financing from commercial banks and, in turn, ease the financing constraints of firms regarding green innovations. However, as mentioned earlier, the proportion of POEs having zero green patents has increased since 2014 (Fig. 1); green patent counts of POEs have decreased in 2016 and 2017 (Fig. 2), and patent claims of POEs have also decreased since 2015 (Fig. 3). The easing effects of financing constraints during 2013–2017 seem to not benefit POEs. One possible explanation for this is that commercial banks are more willing to allocate extra credit funds to SOEs because SOEs are usually guaranteed by the government (Brandt and Li, 2003). Green funds are not reasonably allocated to POEs, which have relatively high innovation capabilities but are more hindered by financing constraints. Such credit discrimination makes POEs more likely to maintain and expand production with limited green financing funds. A more conservative investing norm in green innovation will result in restricted green innovation. Therefore, we further explore the heterogeneous effects of green finance policies on SOEs and POEs, respectively, in the following section.

Table 5
The effects of green finance policies.

VARIABLES	Full Sample 2SLS		
	(1)	(2)	(3)
	Patent Counts	Patent Claims	Green Ratio
Panel A: FC Index A			
FC Index A * Period 2001–2007	−0.134***	−0.089***	−0.011**
	(0.039)	(0.028)	(0.004)
FC Index A * Period 2008–2012	−0.280***	−0.157***	−0.012***
	(0.052)	(0.030)	(0.004)
FC Index A * Period 2013–2017	−0.105*	−0.081**	0.004
	(0.062)	(0.034)	(0.004)
Panel B: FC Index B			
FC Index B * Period 2001–2007	−0.127***	−0.082***	−0.008*
	(0.040)	(0.030)	(0.005)
FC Index B * Period 2008–2012	−0.325***	−0.157***	−0.009**
	(0.048)	(0.028)	(0.005)
FC Index B * Period 2013–2017	−0.264***	−0.148***	0.000
	(0.056)	(0.031)	(0.004)
Controls	Yes	Yes	Yes
Observations	13,360	13,360	13,360
Firms	1699	1699	1699

Note: FC Index A and FC Index B are one-year lagged terms. The IV used in all estimates is provincial industrial average financing constraint, and the first-stage results are reported in Table A2. Controls include Age, K/L, Prov. R&D, City GDP, City Tech, City FDI, FOEs, year fixed effect, and province fixed effect. Robust standard errors clustered at the firm level are in parentheses. ***, ** and * represent 1%, 5% and 10% statistical significance levels, respectively.

4.3. Heterogeneous effects of green finance policies

Table 6 shows the heterogeneous effects of green finance policies for SOEs and POEs. First, the results in Table 6 show that financing constraints of POEs are significantly tighter than those of SOEs in all periods. If the financing constraint measured by Index A increases one score point, for example, the patent counts in 2008–2012 for SOEs are lowered by 20.7%, while those for POEs are lowered by 36.9%; patent claims in 2008–2012 for SOEs are lowered by 10%, while those for POEs are lowered by 23.2%. Though financing constraints of SOEs significantly impose tighter restrictions on green innovations in 2008–2012, the results of both Panel A and Panel B show that green innovations of SOEs are not significantly hindered by financing constraints in 2013–2017. For POEs, patent counts and patent claims are still significantly hindered by financing constraints in 2013–2017, and the restraints are significantly reduced only in the estimates of Panel A. Hence, we believe that the green finance policies since 2013 have mainly alleviated the effects of financing constraints on green innovation of SOEs. The green finance policies stipulate the green credit work of financial institutions, but green credit funds seem to be allocated mainly to SOEs.

The CBRC includes green credit businesses in the performance evaluation mechanism of financial institutions but also lists 12 categories of green projects that should be prioritized for support. Moreover, green credit statistics are published for 21 major banking financial institutions twice a year. This enables the banking industry to reach various indicators under the green credit framework while considering its ROA and corporate default risks. The resulting problem is that, although the green projects of POEs may be more promising and innovative than those of SOEs, commercial banks are more willing to provide green credit funds to SOEs for green projects. This is because SOEs are endorsed by the government, and the risk of default is relatively low, whereas POEs must be responsible for their profits and losses and have relatively high risks of default. Commercial banks prefer financing SOEs to meet the criteria of various green credit indicators and to guarantee their ROA simultaneously. POEs still find obtaining green credit funds from financial institutions more difficult than SOEs, and the financing constraints on POE green innovations have not eased.

4.4. Further examinations from corporate environmental responsibility disclosure

The green finance policies require financial institutions to strictly review the environmental protection information of firms before issuing loans to them; therefore, green credit funds are likely to be invested more in firms that disclose such information. Thus, in this section we further confirm the effectiveness of green finance policies through our investigation of the heterogeneous effects of firms with and without disclosing corporate environmental responsibility (CER) information.

Table 6
Heterogeneous effects of green finance policies.

VARIABLES	SOEs 2SLS			POEs 2SLS		
	(1)	(2)	(3)	(4)	(5)	(6)
	Patent Counts	Patent Claims	Green Ratio	Patent Counts	Patent Claims	Green Ratio
Panel A: FC Index A						
FC Index A * Period 2001–2007	−0.110**	−0.066**	−0.009*	−0.268***	−0.218***	−0.029***
	(0.046)	(0.033)	(0.005)	(0.072)	(0.052)	(0.008)
FC Index A * Period 2008–2012	−0.207***	−0.100**	−0.002	−0.369***	−0.232***	−0.020***
	(0.077)	(0.041)	(0.006)	(0.070)	(0.042)	(0.006)
FC Index A * Period 2013–2017	−0.020	−0.029	0.008	−0.202**	−0.141***	0.000
	(0.097)	(0.049)	(0.007)	(0.084)	(0.048)	(0.005)
Panel B: FC Index B						
FC Index A * Period 2001–2007	−0.096*	−0.049	−0.004	−0.219***	−0.181***	−0.024***
	(0.052)	(0.038)	(0.006)	(0.064)	(0.045)	(0.007)
FC Index A * Period 2008–2012	−0.220***	−0.107***	−0.001	−0.436***	−0.210***	−0.016***
	(0.070)	(0.039)	(0.007)	(0.063)	(0.037)	(0.006)
FC Index A * Period 2013–2017	−0.118	−0.079**	−0.001	−0.436***	−0.224***	0.000
	(0.082)	(0.040)	(0.006)	(0.078)	(0.046)	(0.006)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	5922	5922	5922	6824	6824	6824
Firms	587	587	587	1166	1166	1166

Note: FC Index A and FC Index B are one-year lagged terms. The IV used in all estimates is provincial industrial average financing constraint, and the first-stage results are reported in Table A2. Controls include Age, K/L, Prov. R&D, City GDP, City Tech, City FDI, year fixed effect, and province fixed effect. Robust standard errors clustered at the firm level are in parentheses. ***, ** and * represent 1%, 5% and 10% statistical significance levels, respectively.

Table 7
Heterogeneous effects of firms with and without CER disclosure.

VARIABLES	Firms with CER Disclosure			Firms without CER Disclosure		
	(1)	(2)	(3)	(4)	(5)	(6)
	Patent Counts	Patent Claims	Green Ratio	Patent Counts	Patent Claims	Green Ratio
SOEs						
Observations	1393	1393	1393	2380	2380	2380
Firms	250	250	250	454	454	454
Panel A: FC Index A						
FC Index A * Period 2008–2012	−0.283	−0.163*	−0.007	−0.108	−0.072	−0.007
	(0.190)	(0.087)	(0.008)	(0.081)	(0.048)	(0.009)
FC Index A * Period 2013–2017	−0.023	−0.036	0.003	0.037	−0.026	0.005
	(0.157)	(0.080)	(0.008)	(0.129)	(0.071)	(0.011)
Panel B: FC Index B						
FC Index B * Period 2008–2012	−0.483**	−0.238***	−0.010	−0.144**	−0.092**	−0.004
	(0.202)	(0.088)	(0.008)	(0.070)	(0.044)	(0.009)
FC Index B * Period 2013–2017	−0.208	−0.088	0.004	−0.078	−0.103*	−0.013
	(0.164)	(0.077)	(0.007)	(0.096)	(0.053)	(0.009)
POEs						
Observations	920	920	920	5190	5190	5190
Firms	208	208	208	1083	1083	1083
Panel C: FC Index A						
FC Index A * Period 2008–2012	0.099	−0.060	−0.038*	−0.374***	−0.244***	−0.022***
	(0.287)	(0.149)	(0.023)	(0.069)	(0.045)	(0.007)
FC Index A * Period 2013–2017	0.316	0.051	−0.026	−0.232***	−0.173***	−0.000
	(0.274)	(0.128)	(0.020)	(0.085)	(0.053)	(0.005)
Panel D: FC Index B						
FC Index B * Period 2008–2012	−0.355*	−0.220**	−0.028	−0.421***	−0.207***	−0.017***
	(0.198)	(0.103)	(0.019)	(0.065)	(0.041)	(0.006)
FC Index B * Period 2013–2017	−0.278	−0.071	−0.005	−0.430***	−0.256***	−0.004
	(0.204)	(0.102)	(0.013)	(0.078)	(0.050)	(0.006)
Controls	Yes	Yes	Yes	Yes	Yes	Yes

Note: FC Index A and FC Index B are one-year lagged terms. The IV used in all estimates is provincial industrial average financing constraint, and the first-stage results are reported in Table A2. Controls include Age, K/L, Prov. R&D, City GDP, City Tech, City FDI, year fixed effect, and province fixed effect. Robust standard errors clustered at the firm level are in parentheses. ***, ** and * represent 1%, 5% and 10% statistical significance levels, respectively.

The information on CER disclosure is also obtained from CSMAR but only covering the period 2007–2017. We divide our sample into two groups, firms with and firms without CER disclosure, and run the estimates for SOEs and POEs independently. Table 7 reports the results.

Compared with firms that do not disclose their CER, firms that disclose CER have no significant financing constraints on green innovations. For SOEs, the effects of financing constraints become insignificant during 2013–2017 regardless of whether firms disclose CER. Nevertheless, the results of POEs differ markedly between firms with and without CER disclosure. Green innovation of POEs that disclose CER is not hindered by financial constraints, particularly in 2013–2017, while that of POEs without CER disclosure is still significantly hindered by financial constraints. We believe that several green credit policies issued during 2013–2017 make it easier for firms to obtain green financing from commercial banks and, in turn, ease the financing constraints of firms regarding green innovation, which is consistent with what we show in Tables 5 and 6.

However, we note that green innovation of SOEs without CER disclosure is not hindered by financing constraints, implying that these firms might still acquire loans from banks with fewer restrictions. Banks prefer financing SOEs because SOEs have lower levels of defaults on loans than POEs, and green finance policies do not allocate funds to POEs to effectively alleviate financing constraints, thus restricting POEs' green innovation capabilities.

5. Conclusion and policy implications

This paper explores how the barriers to acquiring financing obstruct the greening capability of enterprises in China and whether green finance policies can prompt green innovations by reducing the effects of financing restraints. The green innovative capabilities of Chinese enterprises are significantly restricted by financing constraints, and the greening capabilities of POEs are more sensitive to financing constraints than those of SOEs. Green finance policies can significantly reduce the effects of financing constraints on green innovations; however, green finance policies seem unable to benefit POEs through effectively alleviating financing constraints, thus restricting POEs' green innovation capabilities.

As mentioned earlier, green innovation is crucial to achieving the goal of being carbon-neutral in 2060, and it is a challenge for the government to internalize the carbon-neutral goal when stipulating green finance policies. Further, the government must encourage both the financial industry and enterprises to consider climate change risk when investing and financing. In addition, the government should encourage green innovations and allocate financial resources across different types of firms when designing green finance policies.

We thus have several suggestions for designing green finance policies. First, while vigorously promoting green finance, the government could establish regional green development funds to support the environmental governance of POEs and the development of ecological environmental protection industries. Second, the government should establish a mechanism that fully discloses green project information and provides credible green credit evaluation indicators to increase the credit rating of POEs. Moreover, the CBRC should ask financial institutions to strengthen the evaluation of relevant corporate social responsibility indicators when providing loans to SOEs. Third, when evaluating the green investment and financing performance of financial institutions, the central bank should consider the proportion of investment in green projects by POEs instead of the proportion of their green credit. Fourth, to reduce the search costs of responsible investors, POEs with financing needs should disclose environmental information in a timely manner and highlight their green attributes by having certified assessment agencies conduct green assessments. Lastly, the central CBRC should encourage financial institutions to disclose green credit investment and financing information by incorporating such disclosure into the assessment of financial institutions' green credit performance. This can ensure that a certain percentage of green funds are allocated to POEs and facilitate relevant institutions to evaluate green credit benefits.

The limitation of this study is that it is unable to identify the effects of different green finance policies on financing constraints and to examine how bank loans are reallocated to enterprises adequately. A bank loan is an important financing means for enterprises, particularly during periods of economic downturn when economic stimulation policies are required. As emphasized in Cong et al. (2019), capital is likely to be inadequately reallocated to either low productivity POEs or SOEs during periods of economic stimulus. The green finance policies were launched just before the 2008 financial crisis, and the crediting system seems to have been eased by the 2008 Economic Stimulus Package of China. However, bank loans do not effectively allocate funds to enterprises with green innovative projects, which restricts green innovations. Therefore, how these green finance policies can allocate credit funds to POEs of high green innovative capabilities still needs to be examined in future research.

CRediT authorship contribution statement

Chin-Hsien Yu: Methodology, Writing – original draft, Project administration. **Xiuqin Wu:** Formal analysis, Investigation, Software. **Dayong Zhang:** Writing – review & editing, Validation, Funding acquisition. **Shi Chen:** Data curation, Resources. **Jinsong Zhao:** Conceptualization, Writing – original draft, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

Table A1
Detailed Green Finance Policies in China since 2007

Policy	Institution and Date	Significance
Guiding Opinions on the Credit Work for Energy Conservation and Emissions Reduction	CBRC [2007] No.83 11/23/2007	(1) Implementing different credit policies according to the energy-saving situation of enterprises and regions. (2) Restriction on credit for projects with a significant negative environmental impact. (3) The CBRC has begun to incorporate credit for energy conservation and emission reduction into its regulatory assessment.
Green Credit Guidelines		

(*continued on next page*)

Table A1 (*continued*)

Policy	Institution and Date	Significance
	CBRC [2012] No. 4 2/24/2012	(1) Core framework of the green credit system. (2) Make clear stipulations on policy boundaries, management methods, and assessment policies of energy-saving and environmental protection credit and green credit for banking financial institutions to ensure that credit funds are invested in low-carbon, recycling, and ecological fields.
Supervisory Guidelines for Performance Appraisal of Banking Financial Institutions	CBRC [2012] No.34 6/12/2012	The CBRC will incorporate green credit into the performance appraisal mechanism and put forward requirements for banks' green credit work and social responsibility.
Opinions on green Credit Work	CBRC General Office [2013] No.40 2/7/2013	Important guiding opinions on the subsequent green credit policy formulation have clarified and refined the specific requirements of green credit work.
Green Credit Statistics System	CBRC General Office [2013] No. 185 7/4/2013	Green credit statistics are conducted every six months for 21 major banks. The main contents are as follows: (1) the credit situation of banks involved in major risk enterprises, e.g., backward production capacity, environment, and safety; (2) the green credit situation of banks.
Key Evaluation Indicators for the Implementation of Green Credit	CBRC General Office [2014] No. 186 6/27/2014	(1) A specific indicator system under the framework of "Green Credit Guidelines." (2) Coverage: policy banks, state-owned commercial banks, joint-stock commercial banks, and postal savings banks.
Energy Efficiency Credit Guidelines	CBRC [2015] No. 2 1/13/2015 CBRC NDRC	(1) Clarify the scope and method of the "energy efficiency credit" business. The two credit methods are energy-saving project credits and contract energy management credit. (2) Promote financial innovation and incentives and conduct asset securitization pilots, green financial bonds, and innovations in guarantee methods.
Guidance on Building a Green Financial System	PBOC [2016] No.228 8/31/2016 PBOC MOF NDRC MEP CBRC CSRC CIRC	(1) Implements the requirements of ecological civilization construction in the financial field. (2) Leading document of the follow-up green financial policy.
Notice on Issuing the Implementation Plan for Green Bank Evaluation (Trial Implementation)	CBA [2017] No.171 12/26/2017	Undertakes the green credit evaluation of the CBRC, aims at all kinds of banks.
Notice on Establishing a Special Statistical System for Green Loans	PBOC [2018] No.10 1/5/2018	Specifies the statistical caliber and method for quantitative indicators of green credit performance evaluation.
Green Credit Performance Evaluation Scheme for Banking Depository Financial Institutions (Trial Implementation)	PBOC [2018] No.180 7/27/108	Marks whether the results of the green credit performance evaluation are included in the macro-prudential assessment of deposit financial institutions in the banking industry.
Guidance Catalogue for Green Industry	NDRC HZS [2019] No. 293 2/24/2019	Standardizes borders and unifies benchmarking.

Note: CBRC: China Banking Regulatory Commission; NDRC: National Development and Reform Commission; PBOC: The People's Bank Of China; MOF: Ministry of Finance; MEP: Ministry of Environmental Protection; CSRC: China Securities Regulatory Commission; CIRC: China Insurance Regulatory Commission.

Table A2
An Identification Test of IV

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	Patent Counts		Patent Claims		Green Ratio	
Panel A: FC Using Index A						
FC Index A		−0.157***		−0.085***		−0.003*
		(0.029)		(0.016)		(0.002)
IV of Index A	−0.158***	−0.007	−0.101***	−0.019	−0.005*	−0.002
	(0.038)	(0.045)	(0.023)	(0.027)	(0.003)	(0.003)
R-squared	0.138	0.147	0.140	0.147	0.051	0.052
Panel B: FC Using Index B						
FC Index B		−0.195***		−0.108***		−0.004**
		(0.027)		(0.015)		(0.002)
IV of Index B	−0.236***	−0.043	−0.128***	−0.022	−0.005	−0.001
	(0.037)	(0.044)	(0.022)	(0.027)	(0.003)	(0.004)
R-squared	0.141	0.154	0.142	0.153	0.051	0.052
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	13,360	13,360	13,360	13,360	13,360	13,360
Firms	1699	1699	1699	1699	1699	1699

Note: We follow Ashraf and Galor (2013) in conducting the test for instrument validity. In columns (1), (3), and (5), we run the regressions using IV variable and other controls, and the results show that the IV is significantly associated with the dependent variables. While the variable of financing constraints is further included in columns (2), (4), and (6), the IV is insignificantly associated with the dependent variables. Hence, we argue that the IV variable has no significant correlations with green innovations. Robust standard errors clustered at the firm level are in parentheses. ***, ** and * represent 1%, 5% and 10% statistical significance levels, respectively.

Table A3
1st-Stage Regression Results of 2SLS

VARIABLES	(1)	(2)
	FC Index A	FC Index B
IV of Index A	0.964***	
	(0.024)	
IV of Index B		0.986***
		(0.024)
High EI (1 = Yes)	−0.033	0.010
	(0.052)	(0.048)
Age	0.040***	0.023***
	(0.004)	(0.004)
K/L	0.029	0.001
	(0.020)	(0.018)
Prov. R&D	0.075	0.057
	(0.112)	(0.104)
City GDP	−0.133***	−0.092**
	(0.042)	(0.040)
City Tech	11.091**	9.372*
	(5.443)	(5.228)
City FDI	−0.032	−2.632
	(6.100)	(5.420)
POEs (1 = Yes)	0.221***	0.203***
	(0.050)	(0.048)
FOEs (1 = Yes)	0.153	0.214**
	(0.098)	(0.083)
Constant	0.671	0.514
	(1.591)	(1.470)
Year fixed effect	YES	YES
Province fixed effect	YES	YES
Observations	13,360	13,360
R-squared	0.356	0.333
Firms	1699	1699

Note: Robust standard errors clustered at the firm level are in parentheses. ***, ** and * represent 1%, 5% and 10% statistical significance levels, respectively.

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