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Promoting or inhibiting? The impact of supporting policy for resource-exhausted cities on corporate green technology innovation: evidence from China

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Abstract
Promoting green technology innovation (GTI) is a critical pathway to concurrently address economic development and environmental conservation. Thus, could the supporting policies implemented in resource-exhausted cities foster local firms' GTI? To investigate this question, we collect the data of Chinese listed manufacturing companies from 2003 to 2018, take the "supporting policy for resource-exhausted cities (SPREC)" as a quasi-natural experiment, and apply the DID methodology with multiple time periods to examine how the SPREC effects firms' GTI. Our findings reveal a significant inhibitory effect of SPREC on firms' GTI, and this effect is achieved through mechanisms that involve the alleviation of financing constraints, an increase in the proportion of fixed assets, the escalation of rent-seeking costs, and the suppression of R&D expenditures. In the heterogeneity analysis, we discover that the SPREC has a more obvious inhibitive role in GTI of companies that are state-owned, located in the mid-western area, or under a lower degree of marketization. However, it shows a considerable promotion impact on the GTI of companies that are under a higher level of marketization. This study enhances our comprehension of SPREC's impacts and offers empirical evidence advocating for the advancement of green and sustainable development in resource-exhausted cities.

Keywords DID · Supporting policy for resource-exhausted cities · Green technology innovation (GTI) · Proportion of fixed assets · Rent-seeking expenses · R&D expenditures

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1 Introduction

In this world, there are many famous resource-based cities or regions, such as Ruhr Industrial Base in Germany, Pittsburgh in the USA, Lorraine in France, etc. These resource-based cities are crucial to the swift economic growth of their nations due to huge profits and taxes from processing raw materials like coal mines and woods (Li et al., 2013). However, with the gradual increase in extraction and excessive consumption of resources, some resource-based cities inevitably step into the stage of resource exhaustion. A city is characterized as a resource-exhausted city when the accumulated resource extraction amounts to more than 70% of the entire extractable amount (Xiao et al., 2021; Zhang et al., 2018).

From the Millennium Development Goals in 2000 to the Sustainable Development Goals in 2015, the United Nations has consistently emphasized the safeguarding of non-renewable resources and the promotion of environmental sustainability (Biermann et al., 2017; Ilcan & Phillips, 2010; Sachs, 2012). An increasing number of nations and organizations have recognized the significance of sustainable development and actively assumed responsibility. Noteworthy instances encompass international initiatives such as the Mining Mineral and Sustainable Development program (Azapagic, 2004; Fitzpatrick et al., 2011), Sustainable Minerals Roundtable (SMR) gatherings in the USA (Gomes et al., 2015; Shields et al., 2003), Canada's Minerals and Metals projects (Bond & Quinlan, 2018), and the European Industrial Minerals Association program in Europe (Regueiro & Alonso-Jimenez, 2021; Tato Diogo, 2020). Concurrently, certain resource-dependent cities, supported by diverse policies, have undertaken self-rescue efforts and successfully transitioned toward sustainability. Illustrative examples include Lorraine, France's industrial transformation strategy, the adoption of the "Smoke Control Act" in Pittsburgh, USA, the implementation of the "Future Movement for Mining and Metallurgy" in Germany's Ruhr region, and Japan's "Environmental Technology Industrialization Project" in Kitakyushu (He et al., 2017). These case studies lead us to the conclusion that both government intervention and market forces serve as pivotal drivers in the transformation of resource-dependent cities (Ruan et al., 2020). Nevertheless, it is undeniable that numerous resource-exhausted cities continue to grapple with significant challenges, particularly in emerging economies and other developing nations (Dou et al., 2023; Li et al., 2013).

These challenges can be broadly categorized into two main areas: on the one hand, because of the homogeneous business structure and poor production technology, these cities' economic development is severely limited by the exhaustion of resources, which subsequently gives rise to pressing issues, including unemployment, poverty, and crime, etc. On the other hand, due to the over-exploited and abused resources and crude corporate production patterns, the ecological environments have been destroyed which hinders the green development of cities (Dong et al., 2007; Dou et al., 2023; Yang et al., 2021; Yu et al., 2022). Thus, it is urgent for resource-exhausted cities to find a path to attend simultaneously to both economic growth and environmental protection. So how to achieve this path? Actually, numerous research literature has shown that green technology innovation (GTI) is the crucial remedy to unlocking the conundrum of harmonious coexistence between economic growth and environmental conservation (Shen et al., 2021), which is achieved by improving energy efficiency, adjusting energy structure, and allocating resources rationally (Jin et al., 2022; Xu & Cui, 2020). Therefore, it is essential for resource-exhausted cities to improve GTI.

Innovation efforts focused on advancing green technologies, which include preservation of energy and lowering of emissions, cleaner production, and the adoption of renewable energy sources, are referred to as "green technology innovation (GTI)" (Wang et al., 2019a). In recent years, the data demonstrate that there is still persistent problem with insufficient GTI, despite the policies relating to it have been promulgated constantly. For instance, in China, less than 10% of the total patent applications are for green patents, which is a comparatively low percentage. To explore the reasons, the GTI is marked by large expenditures, elevated risk, long cycle, and also has strong externalities. Therefore, market forces alone cannot address the issue of inadequate GTI, and government forces are required to intervene, guide and stimulate. So are there any special government policies for resource-exhausted cities? Could these government policy interventions promote their GTI?

Actually, to save resource-exhausted cities that are gradually going to the "valley of death," many national governments have already extended their "helping hands." Taking China as an illustration, in 2007, the State Council promulgated "supporting policy for resource-exhausted cities (SPREC)," which initially proposed the establishment of transfer payments for resource-exhausted cities.[1] Subsequently, the lists of resource-exhausted cities were released in three batches in 2008, 2009, and 2011 separately, including 69 cities in total.[2] What needs to be explained here is that although the earliest list of resource—depleted cities was released in 2008, government documents and news reports indicate that the central government commenced transfer payments to these cities as early as 2007 (Ai et al., 2023; Lu et al., 2022; Wu et al., 2023). Up to 2018, the cumulative amount of fiscal transfer to support these cities has reached about 160 billion yuan.[3] Figure 1 illustrates the evolutionary progression of SPREC, delineated along a timeline. So, for GTI in resource-exhausted cities, is the support policy "a timely help" or just like "closing the stable door after the horse has bolted"?

Upon reviewing the existing literature on SPREC, we observe a lack of consensus regarding its effects: Some scholars argue that the SPREC promotes the transformation of manufacturing (Yu & Ma, 2022) and high-quality urban development (Zhang et al., 2022). Conversely, others argue that it inhibits regional innovation (Lu et al., 2022) and slows down urban economic growth (Zhang et al., 2019). Thus, the usefulness of the SPREC is still a question to be verified. In addition, we discover that the majority of the existing study on the SPREC's effects is concentrated on the city level, but there is little literature to study its impact on enterprises, which is a more microscopic perspective. As enterprises are the core strength of a city's development and the hope of countless families, we believe that it is vital to investigate the consequences of the SPREC from the perspective of enterprises.

Therefore, we chose the data of Chinese listed manufacturing companies from 2003 to 2018 as our sample, take SPREC as a quasi-natural experiment, apply the DID with multiple time periods to explore how the SPREC effects firms' GTI.

Why do we choose China as our research context? There are several main reasons: First, China is a resourceful country with 118 resource-based cities, constituting approximately 20% of the nation's total cities. These cities have contributed significantly to Chinese economic development (Wang & Guo, 2012). Nowadays, with more than

[1] https://www.gov.cn/zwgk/2007-12/24/content_841978.htm.

[2] https://www.gov.cn/ztzl/2008-09/19/content_1100369.htm
https://www.gov.cn/gzdt/2009-03/05/content_1250904.htm
http://district.ce.cn/zt/zlk/jjsj/201304/09/t20130409_24275042.shtml.

[3] https://www.gov.cn/xinwen/2018-12/13/content_5348551.htm.

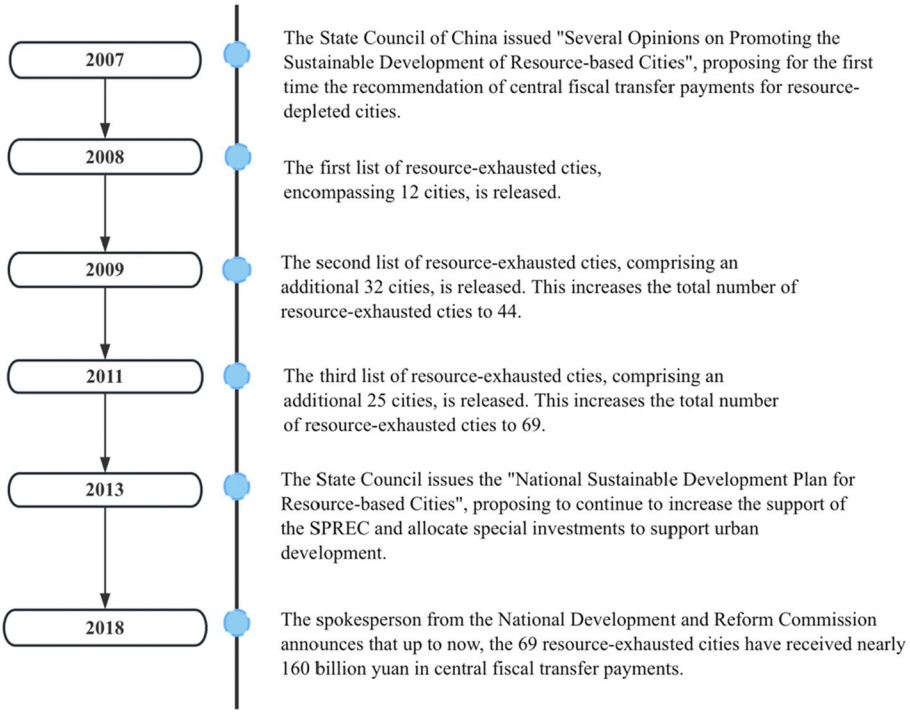

Fig. 1 Timeline of SPREC implementation

half of the resource-based cities exhausted, China urgently needs to find a way to help resource-exhausted carry out green transformation and sustainable growth (Lu et al., 2022; Yang et al., 2021). Second, as a major emerging economy in the world, China has a greater responsibility and challenge to balance environmental protection and green development while pursuing high-quality economic growth. Third, our study, which is conducted in China, could provide empirical evidence for the green and sustainable growth of resource-depleted cities. This experience could become an important part of "Good Governance" and be extended to more developing countries, and even make a pivotal role in the transformation of resource-based cities globally.

The main contributions are as follows: Firstly, our research augments the current literature concerning the micro-level impacts of the SPREC. Prior studies have predominantly centered on the effects of the SPREC at the city or regional levels. By investigating the impact of the supporting policy on firms' GTI, we provide valuable insights from a microscopic perspective. In addition, SPREC is one of the instruments of government intervention, and there has been a constant academic debate around the "visible hand" of government, so our paper also enriches research on government intervention. Secondly, in line with the government's efforts to achieve carbon neutrality, our paper considers the importance of environmental preservation and sustainable growth in the context of resource-exhausted cities, which face limitations in pursuing green development. Thirdly, we employ a structural equation model and Bootstrap test in our mechanism analysis to examine multiple mediating factors, thereby offering a more profound and detailed understanding of the mechanisms through which the SPREC influences GTI.

Lastly, by employing the DID method with multiple time periods, we address potential endogeneity issues, account for variable interactions, and better align our study design with the real-world implementation of the policy pilot, thus enhancing the robustness of our results.

Following is the structure of the remaining parts: The literature review is presented in Sect. 2. Sect. 3, the theoretical analysis and hypotheses are covered. The research design is discussed in Sect. 4, followed by Sect. 5 analysis of the empirical results, Sect. 6 further analysis, and Sect. 7 conclusion and policy recommendations.

2 Literature review

2.1 SPREC

While traditional economic theory generally considers good natural resource endowment as the basis for the start of industrialization and the driver of growth in economy (Shao et al., 2020), Auty (1993) first proposes the famous paradox of the "resource curse," which means that abundant resources of nature are a limitation to regional economic growth, and this argument has attracted widespread attention and debates in academic circles. Subsequently, numerous studies have revealed that the impacts of "resource curse" are prevalent in several countries worldwide (Papyrakis & Gerlagh, 2004; Sachs & Warner, 1995; Shao & Yang, 2010). There have been many different perspectives to explain this paradox, summarized as the Dutch disease effect (Corden & Neary, 1982; Shao et al., 2020), the crowding-out effects of human capital and technology innovation (Papyrakis & Gerlagh, 2003; Sachs & Warner, 2001), the institutional weakness effect (Leite & Weidmann, 1999). Based on previous studies, Shao and Yang (2010) argue that while abundant natural resources can bolster regional economic development, overdependence on these resources is the culprit of the "resource curse" effect.

Up to now, research on SPREC has predominantly focused on its effects, resulting in varied evaluations due to differing research perspectives. For example, several studies highlight the positive impact of SPREC on high-quality development (Yu & Ma, 2022; Zhang et al., 2022), Yu and Ma (2022) posit that the SPREC facilitates the upgrading of the manufacturing industry by fine-tuning production and relieving the tax burden on high-tech enterprises. In their investigation, Yu et al. (2022) contend that SPREC encourages urban areas to diminish their reliance on finite resources, consequently enhancing local energy efficiency. Furthermore, Sun et al. (2020) observe that SPREC, through strategies such as bolstering marketization, expanding openness, and fostering alternative industries, contributes to increased local employment rates and per capita GDP. Moreover, both Li and Wang (2022) and Ai et al. (2023) substantiate that SPREC significantly diminishes urban carbon emissions by propelling technological advancement. However, certain studies cast doubt on the feasibility of SPREC. Zhang et al. (2019) identify a potential "incentive trap" associated with SPREC, which could decelerate urban economic growth. Lu et al. (2022) find that SPREC hinders regional innovation, attributing this inhibitory effect to three primary factors: the increase in zombie enterprises, shifts in government subsidy preferences, and distortions in the land market. Additionally, Sun et al. (2020) contend that SPREC does not stimulate the development of the service industry.

In fact, the SPREC can be considered as one of the instruments of government intervention. Government intervention, which is regarded as a remedy to market failure, is

one of the key predictors of innovation (Wang, 2018). There are two primary contrasting viewpoints surrounding the impacts of government intervention on corporate technological innovation: according to the first point of viewpoint, government intervention could encourage firm s' innovation (Guellec & Potterie, 2003; Howell, 2017; Lee & Cin, 2010; Wang, 2018). Scholars who hold this view think that the government's "visible hand" can intervene in the economy to compensate for the failings of the market's "invisible hand" (Rao, 2016), mitigate the risk associated with companies' R&D expenditures (Guo et al., 2014), and compensate for the loss of revenue due to the externalities of technological innovation (Kang & Park, 2012). Through such interventions, the government could effectively promote corporate innovation. According to the second viewpoint, government intervention actually crowds out enterprises' innovation (Busom, 2000; Li et al., 2020; Marino et al., 2016). Scholars holding this view argue that government intervention may trigger a "moral hazard" that makes firms use subsidies for activities other than innovation (Wu et al., 2022). In addition, government funding of R&D may increase the need for R&D resources in a whole market, which may raise the cost of R&D and thus discourages firms from innovating (Marino et al., 2016).

2.2 Green technology innovation

Another relevant literature to this paper focuses on the determinants of corporate GTI. Previous research has rigorously investigated both internal and external factors that influence corporate GTI (Takalo & Tooranloo, 2021). Concerning internal factors, entrepreneurs with environmental consciousness (Rui & Lu, 2021), academically qualified executives (He et al., 2021), green organizational culture (Gürlek & Tuna, 2018), and the practice of corporate social responsibility (Yuan & Cao, 2022) all have the potential to stimulate GTI within a company. Conversely, the presence of quality management (Li et al., 2018), ineffective corporate governance (Amore & Bennedsen, 2016) and an excessive concentration of power (Gao et al., 2022) can hinder a company's GTI. Turning to external factors, elements such as environmental regulations (ER) (Borsatto & Bazani, 2021), digital financial solutions (Liu et al., 2022), financing options (Xiang et al., 2022), pressures from stakeholders (Rui & Lu, 2021), and collaborative ventures between organizations (Zhu et al., 2017) all possess the capacity to exert an influence on a company's GTI. Among these factors, the influence of ER on GTI remains a subject of debate, with three primary viewpoints. Firstly, the renowned "Porter Hypothesis" (Porter & van der Linde, 1995) postulates that ER may compel companies to engage in green innovation to enhance competitiveness. This, in turn, helps offset the additional costs incurred due to ER, leading to an innovation compensation effect. Subsequent studies by Rubashkina et al. (2015), Song et al. (2019), and Zhong and Peng (2022) have provided support for this hypothesis. Secondly, neoclassical economic theory suggests that ER might escalate production costs and diminish financial flexibility, thereby inhibiting GTI (Du et al., 2021; Lanoie et al., 2008; Li et al., 2021). Thirdly, some scholars propose a nonlinear, inverted U-shaped relationship between ER and GTI (Wang et al., 2019c; Pan et al., 2021; Song et al., 2020b).

2.3 Gap in literature

By combining the literature, we can see that although the relevant research has been fruitful, there are still the following shortcomings: First, whether it is the SPREC or

more generally government intervention, their impact on firms' technology innovation is controversial and no definite conclusions have been reached. In addition, although there are many studies on how government intervention affects firms' technology innovation, a scarcity of research exists in a sample of especially resource-exhausted cities. Compared with other cities, resource-exhausted cities have their particularity, which is that the local resources have been exhausted, economic development and environmental conditions are both worrying, so at this time whether the SPEC is "a timely help" or just like "closing the stable door after the horse has bolted" is worthy of our in-depth discussion. Next, we find that the majority of the existing research on the effects of the SPREC is concentrated at the city level, but there is little literature to study its impact on enterprises, which is a more microscopic perspective. Finally, the majority of current research on resource-depleted cities ultimately strives to support the urban economies, but less attention is paid to their green development. However, the resource-depleted cities rely more heavily on local resources and environments for growth compared to other cities, but years of exploitation and abuse have seriously harmed the local environment, so our study aims to address the equilibrium between economic quality and sustainable development in these cities.

3 Theoretical analysis and hypothesis

Through literature reading and theoretical derivation, we argue that the impact of the SPREC on GTI is unclear, with two possibilities of promoting or inhibiting effects.

On the one hand, we think that the SPREC's impact might be positive.

Firstly, externalities, either positive or negative, occur when the production or consumption of one person or entity affect the existence and well-being of another (Dahlman, 1979). GTI exemplifies a classic case of "positive externality" linked to knowledge spillovers. Specifically, when certain companies implement GTI and introduce it to the market, a portion or the entirety of the innovative knowledge becomes public, leading to the replication, imitation, or even advancement of new technologies. In such scenarios, other participants in the market may benefit from this wave of GTI, while the companies that invested in it might not fully realize the fruits of their labor. Despite the overall societal benefits, where spillover advantages accrue to the public rather than the companies implementing GTI, these innovators may grow disheartened as they bear the entire innovation cost, possibly reducing their investments in GTI (Acemoglu et al., 2012). To address the issue of "market failure," government subsidies and interventions can compensate for the income losses incurred by green technological innovators due to positive externalities (Rao, 2016). The central fiscal transfer payments provided by SPREC can, to some extent, directly alleviate the financial constraints faced by resource-exhausted cities, consequently increasing local government expenditures on technology and research and development subsidies for enterprises (Yu & Ma, 2022). Additionally, during the implementation of SPREC, resource-exhausted cities stimulate the growth of high-end manufacturing and eco-friendly enterprises through tax incentives, reducing the tax burden on such businesses (Song et al., 2020a). Therefore, it is evident that SPREC offers direct government subsidies and tax incentives to enterprises, boosting their research and development investments and effectively counteracting the positive externalities associated with technological innovation, thereby encouraging businesses to engage in GTI (Mamuneas & Ishaq Nadiri, 1996).

Secondly, GTI exhibits distinct characteristics such as substantial investment requirements, heightened risks, and protracted research and development cycles. These factors underline the imperative need for companies to secure long-term and stable financial support (Huang et al., 2019). Nevertheless, owing to the imperfections within China's capital market, companies frequently grapple with agency issues and information asymmetry. This predicament results in escalated external financing expenses for companies and the looming threat of financing constraints (Lin & Ma, 2022; Liu et al., 2021). Research conducted by Yu et al. (2021) underscores that financing constraints can lead to a shortage of funds allocated to research and development activities, impeding their capacity to engage in GTI, and thereby influencing their operational capabilities and developmental trajectories. Leveraging signaling theory, SPREC, functioning as a conspicuous public signal within the market, inherently carries the government's endorsement. It possesses the inherent capability to transmit affirmative signals to external investors and creditors, thereby reinforcing their confidence in making investments in these companies (Jiang et al., 2023; Tong et al., 2022). The dissemination of such signals concurrently diminishes information asymmetry between companies and external investors (Kong et al., 2022). Consequently, companies benefiting from SPREC support can gain increased access to financial resources from shareholders and banks (Xiao et al., 2023). This, in turn, indirectly mitigates their financing constraints and amplifies their endeavors in the realm of GTI.

Thirdly, currently, sustainability is a popular framework. The growing acceptance of the concept of "sustainability" can be attributed to the escalating conflict between economic development and environmental degradation. The rapid economic progress has elevated material living standards for all individuals. However, environmental deterioration, including air, water pollution, soil contamination and the following extreme weather, lead to a significant destroy of life and life expectancy (Polasky et al., 2019). Consequently, humanity has initiated a critical reevaluation of the limitations of "Anthropocentrism" and has come to regard sustainable development as the optimal choice for the future (Kopnina, 2014). Nevertheless, this presents a formidable challenge. Achieving this goal necessitates comprehensive changes in the behaviors of market participants. Consumers are encouraged to embrace "green" consumption practices (Testa et al., 2021); while, businesses are urged to adopt "green" production methods (Xie et al., 2019). It is noteworthy that a study conducted by Opentext discovered that nearly 88% of surveyed consumers expressed a preference for purchasing products from companies with ethical sourcing practices over others, based on a survey of 27,000 respondents worldwide.[4] Thus, environmentally friendly production is not merely an issue of production ethics but also a proactive response to market demands. Therefore, in light of external pressures, the implementation of SPREC will lead to enhanced governmental oversight of enterprises, with external stakeholders demonstrating increased interest in corporate development. These dynamics collectively encourage companies to overcome inertia, cultivate a positive social image, and bolster their motivation to engage in GTI (Henriques & Sadorsky, 1996; Li & Xiao, 2020).

Finally, Florida (2000) demonstrates that lifestyle elements, including amenities and environmental quality, hold equal significance to economic determinants in both attracting talent and fostering the growth of high-tech regional economies. SPREC underscores the urgency to upgrade educational infrastructure and healthcare facilities, and intensify environmental conservation endeavors in resource-depleted cities (Song et al., 2020a). These initiatives foster a more conducive living and working environment, facilitate

[4] https://www.opentext.com/about/press-releases/opentext-survey-shows-increase-in-demand-for-ethically-sourced-goods.

the residents' daily lives, subsequently aiding in the cultivation and attraction of highly skilled professionals. This reservoir of talent serves as the cornerstone for fostering the advancement of GTI within enterprises (Sun et al., 2020).

Therefore, we suggest hypothesis H1a.

H1a. The SPREC could promote corporate GTI.

On the other hand, we believe that the SPREC may inhibit corporate GTI in resource-exhausted cities. The possible reasons are mainly the following.

Firstly, although in the previous section, we discussed how SPREC can directly or indirectly alleviate a company's financial constraints, some researchers contend that this alleviation has no positive impact on GTI (Liu et al., 2019; Marino et al., 2016; Xiaobao & Wu, 2022). In the absence of effective supervision within companies, the risk of "moral hazard" emerges, potentially leading to a diversion from innovation-related uses of subsidies (Mao & Xu, 2018). For instance, after receiving government subsidies and bank loans, companies might choose to invest in large-scale equipment rather than engage in research and development activities. Consequently, the increase in the proportion of fixed assets is at the cost of R&D and human capital investment, thereby impeding the GTI of the company.

Secondly, rent-seeking is the practice of individuals, groups, or entities pursuing special privileges to acquire economic rents or benefits without generating new wealth or enhancing economic productivity (Krueger, 1974). In the context of China, local governments wield substantial influence over crucial factors, including financial resources and land allocation, along with extensive control over fiscal spending (Mao & Xu, 2018). Consequently, to garner support from SPREC, certain enterprises may actively cultivate rent-seeking relationships with local government officials. Nevertheless, these enterprises inevitably incur rent-seeking costs, which fall within the category of non-productive expenses (Yu et al., 2010). As posited by Shleifer and Vishny (1994), rent-seeking activities may be more enticing than productive endeavors, provided the associated costs do not exceed those of production. Once such rent-seeking connections are established, the government often prioritizes affiliated enterprises when allocating financial resources and land assets. This allocation approach weakens the importance of enterprise performance and prospects, detrimentally affecting not only the interests of other enterprises but also eroding market fairness (Aidt, 2016). The rent-seeking behavior of firms could impede the GTI, consequently hindering long-term development. Specifically, substantial rent-seeking costs may crowd out a company's research and development expenditures, impeding innovation in green technologies (Du et al., 2020). Furthermore, enterprises may easily secure substantial government support or subsidies through rent-seeking, and the excessive profits obtained through "unearned gains" may diminish their motivation to invest in high-risk, high-investment GTI (Yao et al., 2023).

Finally, in resource-exhausted cities, resources depletion makes the local economy on the verge of collapse. Productive elements including labor, capital, and technology have already flowed out (Yu & Ma, 2022). In this circumstance, implementing the SPREC seems like "closing the stable door after the horse has bolted." Once coupled with poor government governance and weak local institutional environments, high subsidies therefore exacerbate corruption and resource misallocation (Song et al., 2020a). Corporate GTI is hard to carry on.

Therefore, we suggest hypothesis H1b.

H1b. The SPREC could inhibit corporate GTI.

4 Research design

4.1 Sample selection and data sources

We select Chinese manufacturing enterprises with A-share listings from 2003 to 2018 as our study sample. The following three components listed below are the primary data sources: ① financial data of companies. That data in this part are processed as follows after being taken from the CSMAR database. First, in accordance with the categorization criteria of the "Industry Classification Guidelines for Listed Companies (2012 Edition)," we only keep firms in the manufacturing industry, excluding those in the primary and tertiary industries. Then, we exclude the companies with incomplete financial data or special treatment. Lastly, winsorization is performed on all continuous variables. ② Corporate green innovation data. In accordance with the classification criteria of the "International Patent Classification Green Inventory (IPC Green Inventory)" released by the WIPO, we manually gather and compile the green patent data of firms in the search column of the China National Intellectual Property Administration. By matching, sorting, and computing the raw data, we obtain micro panel data for a total of 17,240 sample observations from 1956 observed firms during 16 consecutive years.

4.2 Definition of variables

4.2.1 Dependent variables

The GTI is represented by the amount of green patent applications (GP) of the firm. There are the following two main causes: The first benefit of green patents is their quantifiability, which may most intuitively reflect the output of firm's efforts in GTI. Furthermore, compared with R&D inputs, patents have a clear technology categorization, allowing patent data to be subdivided based on numerous technological properties to indicate the various values of innovative initiatives. Second, to analyze the influence of the pilot policy on GTI activities in a more timely manner, we utilize patent application data instead of patent grant data due to the lengthy patent application process. Referring to Xu and Cui (2020), we use the logarithmic calculation of the amount of GP to evaluate the degree of enterprises' GTI.[5] In addition, to further depict the different innovativeness and meanings of green patents, we also separate green patent applications (GP) into two dimensions, which are green invention patent applications (GIP) and green utility patent applications (GUP) as sub-studies to test our hypothesis.

[5] To avoid the impact of value 0, the number of GP is added up by 1 before the logarithm is computed. The same treatment is adopted for the number of GIP and GUP below.

4.2.2 Independent variable

The implementation of the SPREC ($\text{Treat}_c \times \text{Post}_{c,t}$) is the independent variable and is represented by the interaction of the policy dummy (Treat_c) and the time dummy ($\text{Post}_{c,t}$).

4.2.3 Control variables

Considering the potential impacts of other corporate elements on GTI, some control variables are also set.

1. The age of a firm (age). A firm's age often indicates how mature the firm is. According to Jin et al. (2022), companies that are more mature also tend to be more innovative. The logarithm of the length of time since a business was founded is applied to calculate its age.
2. Size (size). According to Bu et al. (2020), size shows a significant impact on corporate innovation. Larger firms usually invest more consistently in R&D for sustainable growth. The logarithm of the total capital serves as a gauge for companies' size.
3. Leverage (lev). Numerous literature has shown that leverage affects corporate innovation. Some scholars believe that excessive firm leverage will inhibit innovation (Barclay & Smith, 1995; Rajan & Zingales, 1995), while others argue that moderate firm leverage could improve firms' innovation (Margaritis & Psillaki, 2010; Meyer, 1998).
4. Return on sales (ros), the ratio of profit to operating revenue, is a reflection of an enterprise's profitability. More profitability can provide more endogenous capital for R&D, but there are also some companies that are less motivated to innovate due to excessive profitability (Xu & Cui, 2020).
5. Variables related to the market value (grow), cash flow level (cfo), and governance structure (top10) of the firm. Drawing on (Yang et al., 2023), the impact of factors such as a firm's market value (grow), cash flow level (cfo), and governance structure (top10), which could have impacts on GTI, are also controlled. The market value is calculated by the market value to asset ratio, and the level of cash flow is evaluated by the net cash flow from operations to assets ratio.

Table 1 indicates the definition, and Table 2 indicates the descriptive statistics.

4.3 Empirical model

To ascertain whether the SPREC promotes or inhibits GTI, we design the DID model with multiple time periods by using the policy as a quasi-natural experiment, which has been extensively employed in previous policy studies (Lu et al., 2022; Xu & Cui, 2020; Yu & Ma, 2022).

First, according to the criterion of "whether they are listed as resource-exhausted cities," we divide the sample of cities from 2003 to 2018 into an experimental group (cities with implemented policies) and a control group (cities without implemented policies) and set policy dummy variables. Then, we construct time dummy variables with the approval year

Table 1 Definition of variables

Variables	Variable symbol	Definition
Dependent variables	GP	ln (1 + the number of green patent applications)
	GIP	ln (1 + the number of green invention patent applications)
	GUP	ln (1 + the number of green utility patent applications)
Independent variable	$\text{Treat}_c \times \text{Post}_{c,t}$	The interaction of the policy dummy (Treat_c) and the time dummy ($\text{Post}_{c,t}$)
Control variables	age	The logarithm of the establishment length
	size	The logarithm of total assets
	lev	Total liabilities divided by total assets
	ros	The ratio of profit to operating revenue
	grow	The ratio of the market value to assets
	cfo	The ratio of net cash flow from operations to assets
	top10	The shareholding ratio of the top ten shareholders

Table 2 Descriptive statistics

Variables	*N*	Mean	S.D.	Min	Max
GP	17,240	0.286	0.725	0.000	6.441
GIP	17,240	0.194	0.585	0.000	6.111
GUP	17,240	0.173	0.520	0.000	5.347
$\text{Treat}_c \times \text{Post}_{c,t}$	17,240	0.020	0.141	0.000	1.000
age	17,240	2.642	0.423	1.386	3.401
size	17,240	21.817	1.148	19.630	25.237
lev	17,240	0.435	0.195	0.060	0.900
ros	17,240	0.061	0.140	−0.646	0.441
grow	17,240	1.933	1.195	0.912	7.964
cfo	17,240	0.030	0.059	−0.137	0.201
top10	17,240	0.570	0.150	0.219	0.889

(the year 2007, 2009, and 2011) of the three batches of resource-exhausted cities.[6] At last, we construct the following DID model with multiple time periods.

$$\text{GP}_{ict} = \alpha_0 + \alpha_1 \text{Treat}_c \times \text{Post}_{c,t} + X_{ict}'\theta + p_i + q_t + s_{pt} + \varepsilon_{ict} \quad (1)$$

where the firm, city, province, and year are denoted by i, c, p and t, in turn. GP_{ict} indicates how many green patents have been applied by a firm i in city c in year t. Treat_c is a policy dummy variable that indicates if a city belongs to the resource-depleted cities. If the city c is present in any of the three batches of resource-exhausted city lists, Treat_c takes the value of 1, and 0 otherwise. $\text{Post}_{c,t}$ is denoted as a time dummy variable. The cities in the

[6] The lists of resource-exhausted cities were released in three batches in 2008, 2009, and 2011 separately, including 69 cities in total. What needs to be explained here is that although the earliest list of resource-depleted cities was announced in 2008, actually, according to government documents and news reports, the central government started supplying transfer payments to them as early as 2007. Therefore, the three batches are identified as 2007, 2009, and 2011 in our paper.

Table 3 Baseline regression results

	(1) GP	(2) GP	(3) GP	(4) GP	(5) GP
$\text{Treat}_c \times \text{Post}_{c,t}$	−0.117*** (−3.00)	−0.086* (−1.93)	−0.147*** (−3.08)	−0.101** (−2.28)	−0.163*** (−3.45)
age				0.067 (1.57)	0.021 (0.47)
size				0.080*** (8.35)	0.086*** (8.60)
lev				0.094** (2.51)	0.084** (2.17)
ros				0.029 (0.81)	0.018 (0.49)
grow				−0.026*** (−5.52)	−0.023*** (−4.80)
cfo				0.170** (2.33)	0.156** (2.10)
top10				−0.163*** (−3.48)	−0.158*** (−3.25)
Constant	0.289*** (51.78)	0.288*** (81.34)	0.289*** (81.35)	−1.538*** (−7.01)	−1.547*** (−6.73)
Individual	No	Yes	Yes	Yes	Yes
Year	No	Yes	Yes	Yes	Yes
Province × year	No	No	Yes	No	Yes
R^2	0.001	0.659	0.670	0.664	0.675
N	17,240	17,240	17,240	17,240	17,240

***, **, and * denote 1%, 5%, and 10% significance levels in turn. T-statistics are based on robust standard errors and reported in parenthesis

experimental group are not subject to the policy shock until the year after they are listed. Thus, if the city has already been listed in year t, the value of $\text{Post}_{c,t}$ is 1, otherwise it is 0. As for the cross multiplication term $\text{Treat}_c \times \text{Post}_{c,t}$, when it is 1, it indicates the implementation of the policy in city c in year t, otherwise it is not implemented. A group of control variables are referred to as X_{ict}. p_i is an acronym for individual-fixed effects, q_t stands for time-fixed effects, s_{pt} stands for joint fixed effects of provinces over time. The random error term is indicated by ϵ_{ict}. In model (1), only the amount of GP by companies is listed, while GIP and GUP are analyzed separately in the sub-studies below.

5 Analysis of empirical results

5.1 Baseline regression results

The regression findings of the SPREC's impact on the amount of corporate green patent applications are shown in Table 3. Column 1 displays the findings without the inclusion of control variables and fixed effects, Columns 2 and 3 show the findings with the inclusion of fixed effects but not control variables, and the last two columns show the

Table 4 Sub-index regression results

	(1) GIP	(2) GIP	(3) GUP	(4) GUP
$\text{Treat}_c \times \text{Post}_{c,t}$	−0.100***	−0.128***	−0.068**	−0.126***
	(−2.67)	(−3.23)	(−1.99)	(−3.49)
age	0.029	−0.005	0.017	−0.012
	(0.80)	(−0.13)	(0.51)	(−0.35)
size	0.060***	0.065***	0.059***	0.064***
	(7.50)	(7.77)	(8.07)	(8.38)
lev	0.077**	0.065**	0.056*	0.053*
	(2.44)	(2.00)	(1.95)	(1.78)
ros	0.042	0.036	0.005	−0.000
	(1.41)	(1.15)	(0.18)	(−0.00)
grow	−0.021***	−0.019***	−0.012***	−0.009**
	(−5.25)	(−4.56)	(−3.31)	(−2.53)
cfo	0.135**	0.132**	0.093*	0.076
	(2.20)	(2.12)	(1.68)	(1.33)
top10	−0.105***	−0.100**	−0.116***	−0.107***
	(−2.67)	(−2.44)	(−3.24)	(−2.86)
Constant	−1.137***	−1.156***	−1.099***	−1.138***
	(−6.16)	(−5.98)	(−6.54)	(−6.47)
Individual	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Province × year	No	Yes	No	Yes
R^2	0.636	0.647	0.617	0.629
N	17,240	17,240	17,240	17,240

***, **, and * denote 1%, 5%, and 10% significance levels in turn. *T*-statistics are based on robust standard errors and reported in parenthesis

findings with the inclusion of them both. The results in the five columns demonstrate that the regression coefficients of the independent variable $\text{Treat}_c \times \text{Post}_{c,t}$ are all significantly negative, proving that the implementation of the SPREC significantly inhibits the corporate GTI in resource-depleted cities. These findings support hypothesis H1b.

5.2 Sub-index regression results

To confirm the outcomes of the baseline regression, we subdivide green patent applications (GP) into two dimensions for further testing, and Table 4 presents the outcomes. No matter whether the dependent variable is assumed to be GIP or GUP, the regression coefficients of the $\text{Treat}_c \times \text{Post}_{c,t}$are significantly negative. The results again support the hypothesis H1b that the SPREC significantly restricts the corporate GTI in resource-exhausted cities.

5.3 Parallel trend test

The potential prerequisite underlying the DID for use in policy assessment is that the experimental group and the control group should exhibit a parallel trend, meaning that in the absence of policy intervention, both the experimental and control group should exhibit similar GTI

trends. Therefore, drawing inspiration from Beck et al. (2010), we perform a parallel trend test using event analysis and put up the following model:

$$GP_{ict} = \gamma + \sum_{k=-8}^{k=11} \beta_k \times D_{c,\ t+k} + X_{it}'\eta + p_i + q_t + s_{pt} + \varepsilon_{ict} \quad (2)$$

In model (2), $D_{c,t+k}$ is denoted as a set of dummy variables. When $k \geq 0$ if city c is a resource-exhausted city and is in the kth year after the implementation of the SPREC, then $D_{c,t+k}$adopts the value of 1, otherwise 0. When $k < 0$, if city c is a resource-exhausted city and is in the $-k$th year before the implementation of the SPREC, then $D_{c,t+k}$takes the value of 1, otherwise 0. It is necessary to explain that since the SPREC is implemented in three batches of 2007, 2009, and 2011 in different cities, we need to generate a relative time value k by subtracting the policy's implementation year from each year within the sample period. Thus, the sample period of our study covers 8 years before ($k = -8$) and 11 years after ($k = 11$) the implementation of the policy.

Considering such a long time span before or after the implementation of the SPREC, we refer to Wang and Ge (2022), and truncate the samples that are too early or too late for the implementation of the policy. The specific approach is to aggregate data earlier than 5 years before the policy implementation to period $t-5$, and to aggregate data later than 4 years after the policy implementation to period $t+4$.

According to the model (2), the coefficient β_k reflects that if there are any discrepancy between two groups at the kth year before or after the policy's initiation. If none of the values of β_k is significant during $k < 0$, it is evidence that two groups meet the parallel trend assumption. By contrary, if the values of β_k are partially significant during $k < 0$, it is evidence that the common trend assumption is not met and the two groups have a significant disparity prior to the adoption of the policy. With the GP as the dependent variable, Fig. 1 depicts the parallel trend test.

Figure 2 demonstrates that, prior to the implementation of the SPREC, significant difference does not exist in the degree of corporate GTI between the two group of cities, indicating that the research sample passes the parallel trend test.

5.4 Placebo test

Other undetectable time-varying urban features might interfere with the findings, which is another obstacle with the DID. Different cities have their characteristics in terms of governance level, resource environment and cultural deposits, etc. Despite the preceding section's inclusion of the fixed effects of provinces over time, there are still some undetectable time-varying urban features level that may not be controlled. For this, we run a placebo test with reference to Liu and Lu (2015) and Zhao et al. (2020).

After the random sampling of 1000 times, Fig. 3 demonstrates the significance of the estimated coefficients and their distributions. The findings demonstrate that the distribution of the "pseudo-policy dummy variable" is primarily centered around zero, and the corresponding p values are greater than 0.1, which indicates that the study passes the placebo test and other unobserved factors do not have a significant impact on it.

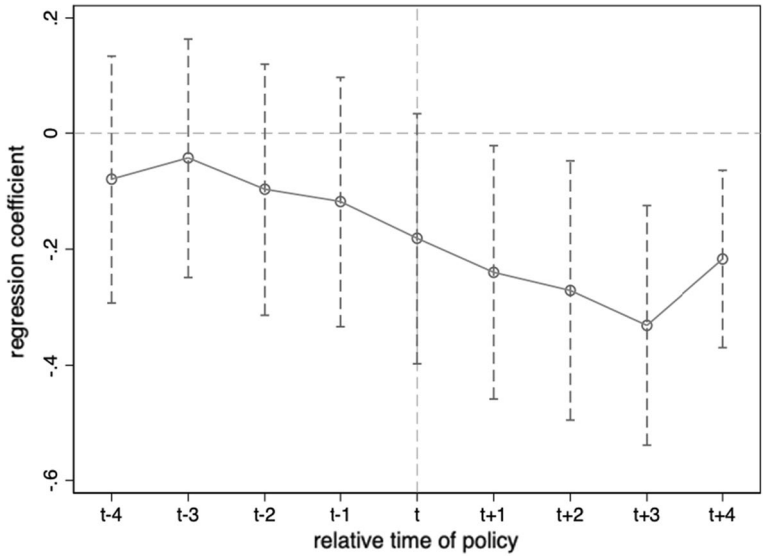

Fig. 2 Parallel trend test

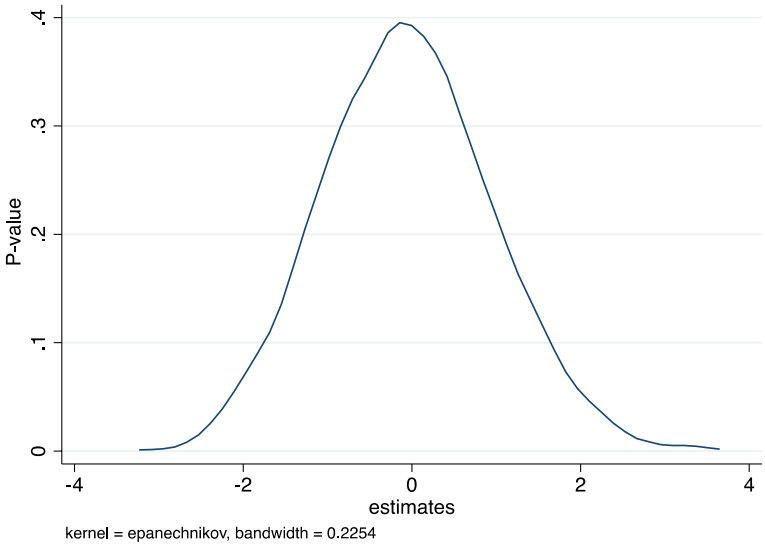

Figure 3 Placebo test

5.5 Other robustness tests

5.5.1 Replacing core variables

It may take some time for the SPREC's influence on corporate GTI, which means a time lag effect may exist. Therefore, we treat the dependent variables with one and two

Table 5 Robustness tests: replacing core variables

	(1) GP	(2) GIP	(3) GUP	(4) GP	(5) GIP	(6) GUP
$Treat_c \times Post_{c,t-1}$	−0.151*** (−2.93)	−0.124*** (−2.86)	−0.122*** (−3.10)			
$Treat_c \times Post_{c,t-2}$				−0.093* (−1.73)	−0.100** (−2.18)	−0.089** (−2.14)
Constant	−1.366*** (−5.01)	−1.017*** (−4.41)	−1.037*** (−4.98)	−1.217*** (−3.85)	−0.919*** (−3.41)	−0.933*** (−3.84)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Individual	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
Province × year	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.690	0.663	0.646	0.712	0.684	0.667
N	14,436	14,436	14,436	12,808	12,808	12,808

***, **, and * denote 1%, 5%, and 10% significance levels in turn. T-statistics are based on robust standard errors and reported in parenthesis

lags, respectively, before conducting regression analysis, and the findings displayed in Table 5 agree with those of the baseline regression.

5.5.2 Reducing selection bias

To lessen the sample selection bias, the PSM-DID method is adopted for robustness tests. A stricter caliper radius (0.0001) is chosen due to the adequacy of the sample and in an effort to eliminate the effect of "selection bias" as much as possible. The first three columns in Table 6 list the DID estimations after matching. The findings indicate that the SPREC continues to inhibit GTI at the 1% level of significance.

Furthermore, municipalities directly under the central government, as the frontier of China's reform and opening-up and regional economic centers, have significantly higher economic, locational, and political superiority than other regions. Therefore, we re-run the regression test after eliminating the four municipalities directly under the central government from the sample, and the outcomes in the last three columns of Table 6 concur with those of the baseline regression.

5.5.3 Excluding the interferences of other policies

During the same time when the SPREC is implemented, enterprises in some energy-exhausted cities might also be affected by other policies. It has been proven that the policy for low-carbon cities (Chen et al., 2022), which started to be implemented gradually in 2010, and the fiscal policy for energy saving and emission reduction (Jin et al., 2022), which started to be implemented gradually in 2011, both significantly advance the corporate GTI. Thereby, to exclude these interferences, we run the regression analysis after controlling for the two policies mentioned above. The findings, as displayed in Table 7, are in accord with those of our baseline regression.

Table 6 Robustness tests: reducing selection bias

	PSM-DID			Excluding the four municipalities directly under the central government		
	(1)	(2)	(3)	(4)	(5)	(6)
	GP	GIP	GUP	GP	GIP	GUP
$Treat_c \times Post_{c,t}$	−0.163***	−0.128***	−0.126***	−0.167***	−0.136***	−0.125***
	(−3.45)	(−3.23)	(−3.49)	(−3.53)	(−3.46)	(−3.43)
Constant	−1.547***	−1.157***	−1.138***	−1.603***	−1.232***	−1.169***
	(−6.74)	(−5.98)	(−6.47)	(−6.34)	(−5.87)	(−6.00)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Individual	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
Province × year	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.674	0.646	0.628	0.666	0.638	0.625
N	17,181	17,181	17,181	14,637	14,637	14,637

*** denotes 1% significance level. T-statistics are based on robust standard errors and reported in parenthesis

Table 7 Robustness tests: excluding the interferences of other policies

	(1)	(2)	(3)	(4)	(5)	(6)
	GP	GIP	GUP	GP	GIP	GUP
$Treat_c \times Post_{c,t}$	−0.160***	−0.124***	−0.127***	−0.162***	−0.124***	−0.131***
	(−3.38)	(−3.11)	(−3.51)	(−3.42)	(−3.10)	(−3.61)
Low-carbon cities	Yes	Yes	Yes	Yes	Yes	Yes
Energy saving and emission reduction				Yes	Yes	Yes
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Individual	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
Province × year	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.675	0.647	0.629	0.675	0.647	0.629
N	17,240	17,240	17,240	17,240	17,240	17,240

*** denotes 1% significance level. T-statistics are based on robust standard errors and reported in parenthesis

6 Further analysis

6.1 Mechanism

As an instrument of government intervention, the SPREC is designed to assist resource-exhausted cities in emerging from the "woods" and promoting sustainable development. However, the above-mentioned study shows that the SPREC inhibits corporate GTI, which is a key way to balancing economic growth with environmental protection and achieving

sustainable development. To explore the specific reasons for the failure of the policy to meet expectations, we further examine the mediating mechanisms by which the SPREC inhibits firms' GTI on the foundation of baseline regressions.

In the previous section of the research hypothesis, we analyze the possible paths by which the SPREC inhibits corporate GTI. On the one hand, the SPREC not only directly alleviates the financial pressure of enterprises, but also serves as a public signal of the market with the natural nature of government endorsement, which could indirectly alleviate the financing constraints of the supported enterprises. However, after receiving support funds and bank loans, firms may use the funds for other activities than innovation, such as raising the proportion of fixed assets, which inhibits corporate GTI. Therefore, there are two possible paths: "Implementing the SPREC—increasing the proportion of fixed assets—inhibiting GTI" and "Implementing supportive policies—alleviating financing constraints—increasing the proportion of fixed assets—inhibiting GTI."

On the other hand, the SPREC may trigger enterprises to actively establish rent-seeking relationships with local governments, in this process, not only the high cost of rent-seeking might cause enterprises to spend less on R&D expenditures, but also enterprises might lose the motivation to conduct R&D due to the excessive profits gained after rent-seeking, both of which will inhibit corporate GTI. Therefore, there are two possible paths: "Implementing the SPREC—increasing rent-seeking costs—inhibiting GTI" and "Implementing the SPREC—increasing rent-seeking costs—crowding out R&D expenditures—inhibiting GTI."

According to Fee et al. (2009), the FC index[7] is utilized to gauge the severity of corporate financing constraint. The larger the FC, the severer the financing constraint, indicating the greater the difficulty or the higher the relative cost of financing for the firm. The R&D expenditure is expressed as the logarithm of the enterprise's R&D expenditure. As for rent-seeking costs, referring to Dechow et al. (1995), we use excess administration expenses (EAE) to measure them. Specifically, we incorporate various factors affecting administration expenses into model (3) and calculate the expected management expenses of firm i in year t. Then, the gap between the actual management expenses and the expected management expenses is the EAE.

$$\begin{aligned}\text{Management}_{it} = {} & \theta_0 + \theta_1 \text{Lnsale}_{it} + \theta_2 \text{Lev}_{it} + \theta_3 \text{Growth}_{it} + \theta_4 \text{Board size}_{it} \\ & + \theta_5 \text{Staff}_{it} + \theta_6 \text{Auditor}_{it} + \theta_7 \text{List age}_{it} + \theta_8 \text{Price level}_{it} \\ & + \theta_9 \text{Captain intensity}_{it} + \theta_{10} H1_{it} + \theta_{11} \text{Margin}_{it} + \sigma_{it}\end{aligned} \tag{3}$$

Management is the ratio of corporate management expenses to operating income for the purpose of normalizing corporate management expenses. Other variables in order represent the logarithm of sales revenue in the previous period, leverage, sales revenue growth rate, board size, whether the audit is from the Big4 accounting firms, years of listing, price index (measured by the average salary of active employees), capital intensity, equity concentration (Herfindahl–Hirschman index of the top five shareholders), and gross margin.

In the section of mediating mechanism tests, first, we use Stata to construct a structural equation model (SEM), the coefficients and significance of each path are shown in Fig. 4. Then, we further test the chain mediation models by using Bootstrap analysis (repeating sampling 5000 times and calculating 95% confidence intervals), the outcomes are displayed in Table 8.

[7] The CSMAR Database served as the direct source for the FC index used in our paper.

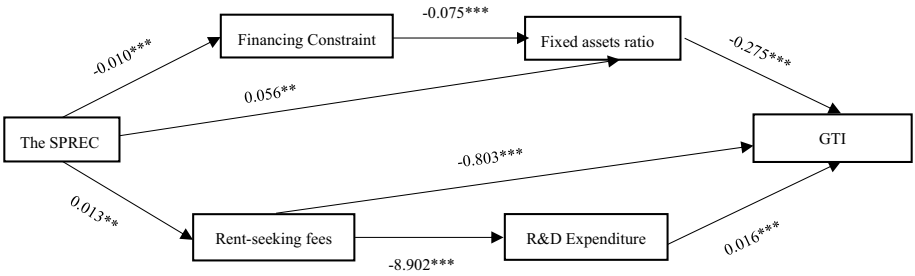

Fig. 4 Results of the SEM test for chain mediation

Table 8 Results of the Bootstrap analysis for chain mediation

	β	SE	LLCL	ULCL
Direct effect	−0.205	0.025	−0.253	−0.154
The SPREC → Fixed assets ratio → GTI	−0.015	0.003	−0.023	−0.009
The SPREC → Financing constraint → Fixed assets ratio → GTI	−0.002	0.000	−0.003	−0.001
The SPREC → Rent-seeking fees → GTI	−0.010	0.002	−0.016	−0.005
The SPREC → Rent-seeking fees → R&D Expenditure → GTI	−0.002	0.001	−0.003	−0.001
Total effect	−0.234	0.024	−0.281	−0.185

6.1.1 Analysis of the path "the SPREC—the proportion of fixed assets—GTI"

According to Fig. 4, we find that the coefficient of the path "the SPREC—the proportion of fixed assets" is 0.056 ($p < 0.05$), the coefficient of the path "the proportion of fixed assets—GTI" is −0.275 ($p < 0.001$), indicating that the SPREC makes the proportion of fixed assets of enterprises increase significantly, and consequently has an effect that crowds out GTI.

Next, the outcomes of Bootstrap in the second row of Table 8 show that the β value of the path "the SPREC—the proportion of fixed assets—GTI" is −0.015 and the 95% confidence interval is [−0.023, −0.009], which excludes 0. The outcomes indicate that the mediating effect of the path exists obviously, which is consistent with that of the structural equation model.

6.1.2 Analysis of the path "the SPREC—financing constraints—the proportion of fixed assets—GTI"

According to Fig. 4, we find that the coefficients of the path "the SPREC—financing constraints—the proportion of fixed assets—GTI" are −0.01 ($p < 0.001$), −0.075 ($p < 0.001$) and 0.275 ($p < 0.001$) in turn, indicating that the SPREC alleviates the financing constraint of enterprises, brings them more abundant funds and makes the proportion of their fixed assets rise significantly, and consequently has an effect that crowds out GTI.

Next, the outcomes of Bootstrap in the third row of Table 8 show that the β value of the path "the SPREC—financing constraints—the proportion of fixed assets—GTI" is −0.002

Table 9 Heterogeneity analysis

	Ownership nature		Region		Degrees of marketization	
	(1)	(2)	(3)	(4)	(5)	(6)
	SOEs	Non-SOEs	Eastern	Mid-western	High	Low
$Treat_c \times Post_{c,t}$	−0.186*** (−3.11)	0.021 (0.25)	0.217 (1.33)	−0.156*** (−3.41)	0.405** (1.98)	−0.155*** (−3.48)
Constant	−2.422*** (−6.62)	−1.684*** (−5.65)	−1.607*** (−5.39)	−2.287*** (−6.53)	−2.040*** (−5.97)	−2.030*** (−6.43)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Individual	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
Province × year	No	No	No	No	No	No
R^2	0.653	0.689	0.677	0.646	0.704	0.667
N	7624	9616	10,829	6411	8690	8550

*** and ** denote 1% and 5% significance levels in turn. T-statistics are based on robust standard errors and reported in parenthesis

and the 95% confidence interval is [−0.003, −0.001], which excludes 0. The outcomes indicate that the mediating effect of this path exists obviously, which is consistent with that of the structural equation model.

6.1.3 Analysis of the path "the SPREC—rent-seeking costs—GTI"

According to Fig. 4, we find that the coefficients of the path "the SPREC—rent-seeking costs—GTI" are 0.013($p < 0.05$) and −0.803 ($p < 0.001$) in turn, indicating that the SPREC triggers rent-seeking behavior of enterprises and increases their rent-seeking costs, and thus inhibits their GTI.

Next, the outcomes of Bootstrap in the fourth row of Table 8 show that the β value of the path "the SPREC—rent-seeking costs—GTI" is −0.01 and the 95% confidence interval is [−0.016, −0.005], which excludes 0. The outcomes indicate that the mediating effect of this path exists obviously, which is consistent with that of the structural equation model.

6.1.4 Analysis of the path "the SPREC—rent-seeking costs—R&D expenditures—GTI"

According to Fig. 4, we find that the coefficients of the path "the SPREC—rent-seeking costs—R&D expenditures—GTI" are 0.013($p < 0.05$), −8.902 ($p < 0.001$) and −0.016 ($p < 0.001$) in turn, indicating that the SPREC triggers rent-seeking behavior of enterprises, and the rent-seeking cost would crowd out their R&D expenditure, and thus might inhibit their GTI.

Next, the outcomes of Bootstrap in the fifth row of Table 8 show that the β value of the path "the SPREC—rent-seeking costs—R&D expenditures—GTI" is −0.002 and the 95% confidence interval is [−0.281, −0.185], which excludes 0. The outcomes indicate that the mediating effect of this path exists obviously, which is consistent with that of the structural equation model.

6.2 Heterogeneity

According to the analysis above, the SPREC exists a significant inhibitory effect on the GTI of manufacturing enterprises based on the entire sample. The different degrees of regional economic growth and marketization in China both have significant differences, and the different ownership nature also has many effects on the development of enterprises. So, does the above conclusion still hold for the samples with diverse ownership natures, in diverse regions, and under diverse degrees of marketization? Addressing this issue will be essential to give us a deeper understanding of the study. Table 9 displays the specific outcomes.

In accordance with the type of ownership, the businesses are separated into state-owned enterprises (SOEs) and non-state-owned enterprises (non-SOEs) for group regressions, and the first two columns of Table 9 present the outcomes. It is clear that the SPREC exists a significant inhibitory effect on GTI in SOEs, while it does not exist in non-SOEs. A possible explanation is that during China's rapid economic growth, there are still inevitable problems of government bureaucracy and formalism, breeding rent-seeking by enterprises, and corruption by officials, which are more common in resource-based cities. At the same time, Chinese SOEs have natural government resources that facilitate the establishment of government-business linkages. Therefore, when confronted with the SPREC released by the government, SOEs are more inclined to pursue rent-seeking activities than technological innovation to obtain excess returns than non-SOEs (Dong & Zhang, 2021).

According to the location, we group the companies according to being in the eastern region and the mid-western region and then regress them separately, and the outcomes are presented in Columns 3 and 4. We discover that the SPREC causes a significant inhibitory effect on GTI of firms located in the mid-western regions, while facilitating those in the eastern regions, with a *T*-value of 1.33, which is already relatively close to the 10% significance level. To explore the possible reasons for this, compared to Chinese backward mid-western region, the eastern region is relatively developed, with a more advanced state of economic development, a better financial system, a more deeply rooted concept of sustainable development, more standardized political governance and more open and transparent information about government affairs. Therefore, when resource-depleted cities in the eastern region obtain government support, the use of support funds and access to financial loans would be more standardized and efficient, and it would be more difficult to implement rent-seeking behaviors that hinder the GTI. Thus, the SPREC could encourage corporate GTI in resource-exhausted cities in the eastern region, while inhibit those in the mid-western regions.

As for the degree of marketization, we utilize the regional index of marketization measured by Wang et al., (2019b). Depending on the median of marketization, the study samples are split into two types: those with high and those with low levels of marketization, and the SPREC's effects on GTI in manufacturing companies under different degrees of marketization are further examined, and the last two columns present the outcomes. We can see that the SPREC remains a disincentive to GTI of companies under a low degree of marketization, while under a high degree of marketization, the SPREC unexpectedly promotes corporate GTI significantly, which support the initial intention of the central government in formulating the policy. This result enlightens us that the SPREC is not useless and we should focus more on the construction and governance of the institutional environment while implementing it.

7 Conclusions and policy recommendations

7.1 Conclusions

We investigate the SPREC's impact on corporate GTI. The following are the research conclusions.

Firstly, there is a significant inhibitory effect of the SPREC on corporate GTI, and the finding is still valid after robustness tests including tests of the dependent variable sub-dimensions, placebo tests, use of dynamic panel models, reduction selection bias, and exclusion of interfering policies.

Secondly, there are multiple paths for the inhibitory effect. On the one hand, the SPREC not only directly alleviates firms' financial pressure, but also indirectly alleviates firms' financing constraints as a public signal from the market. However, firms use the support funds and loans they receive for other activities than innovation, such as increasing the proportion of fixed assets. On the other hand, supportive policies may trigger enterprises to establish rent-seeking relationships with local governments, which would not only generate high rent-seeking costs to crowd out enterprises' R&D expenditures, but also make enterprises lose their R&D incentives due to the excessive profits brought by rent-seeking. All of these above would inhibit enterprises' GTI.

Third, the inhibitory effect shows sample heterogeneity depending on enterprises' ownership nature, location characteristics, and degrees of marketization. The SPREC significantly inhibits GTI among SOEs, enterprises located in the mid-western region, and enterprises under a low degree of marketization. In addition, we unexpectedly find the SPREC is not useless and presents a significant promotion effect on GTI of enterprises under a high degree of marketization.

7.2 Policy recommendations

The initial intention of the SPREC is to advance the transformation, upgrading, and sustainable development of resource-exhausted cities, yet our study shows that it inhibits GTI of manufacturing firms in general and shows variability under different heterogeneity. It can be seen that that there is still a long way to go in the transformation and green growth of resource-exhausted cities. The following policy recommendations may be available to us.

1. The government cannot be static in the formulation and implementation of supporting policies, but should establish a dynamic adjustment mechanism and a strict evaluation mechanism. First of all, when local governments screen and identify support targets, they should conduct the qualification review and result announcement in an open and fair manner. Secondly, the supported enterprises should disclose the information and progress on time and accept public supervision, and the government should increase the punishments on enterprises that violate the rules, abuse, and speculate, so as to stop enterprises from "rent-seeking." Finally, the government should enhance its oversight, regularly assess the performance of supported enterprises, timely track and audit the use of funds, and adjust the decision of whether to continue support based on the results dynamically and promptly. Additionally, the borrowing system of financial institutions should be improved, and financial institutions should be urged to earmark the special loans obtained by enterprises.

2. Government's "visible hand" and market's "invisible hand" should be coordinated adequately with each other. The government should not only formulate supporting policies according to local circumstances, but also promote the level of local marketization. Our findings indicate that the SPREC's effects on corporate GTI varies significantly under different conditions. Financial transfer payments alone are not sufficient to promote green and sustainable growth of enterprises. It is also vital to help improve the economy, environment, and people's livelihood in the backward mid-western regions, eliminate discrimination and injustice against non-state enterprises and fully protect their rights and interests, improve the marketization of cities, reduce government control over key factors and resources and let the market decide the allocation of resources. All of these above would not only regulate the behavior of enterprises and reduce opportunities for rent-seeking, but also encourage enterprises to pursue technological innovation and development actively.
3. Strengthen anti-corruption efforts at all levels of government and establish a healthy and transparent relationship between government and business. In recent years, the Chinese government's determination to fight corruption has been unprecedentedly high, but there is still a long road to go. The government should improve governance capacity, increase anti-corruption efforts, and establish a proper and transparent relationship with enterprises, especially with state-owned enterprises, to avoid damage to the market due to rent-seeking and bribery, and create a fair and positive economic environment.

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References

Acemoglu, D., Aghion, P., Bursztyn, L., & Hemous, D. (2012). The environment and directed technical change. *American Economic Review, 102*(1), 131–166. https://doi.org/10.1257/aer.102.1.131

Ai, H., Tan, X., Zhou, S., & Liu, W. (2023). The impact of supportive policy for resource-exhausted cities on carbon emission: Evidence from China. *Resources Policy, 85*, 103951. https://doi.org/10.1016/j.resourpol.2023.103951

Aidt, T. S. (2016). Rent seeking and the economics of corruption. *Constitutional Political Economy, 27*, 142–157.

Amore, M. D., & Bennedsen, M. (2016). Corporate governance and green innovation. *Journal of Environmental Economics and Management, 75*, 54–72. https://doi.org/10.1016/j.jeem.2015.11.003

Auty, R. M. (1993). *Sustaining development in mineral economies: The resource curse thesis*. Routledge.

Azapagic, A. (2004). Developing a framework for sustainable development indicators for the mining and minerals industry. *Journal of Cleaner Production, 12*(6), 639–662. https://doi.org/10.1016/S0959-6526(03)00075-1

Barclay, M. J., & Smith Jr, C. W. (1995). The maturity structure of corporate debt. *The Journal of Finance, 50*(2), 609–631. https://doi.org/10.1111/j.1540-6261.1995.tb04797.x

Beck, T., Levine, R., & Levkov, A. (2010). Big bad banks? The winners and losers from bank deregulation in the United States. *The Journal of Finance, 65*(5), 1637–1667. https://doi.org/10.1111/j.1540-6261.2010.01589.x

Biermann, F., Kanie, N., & Kim, R. E. (2017). Global governance by goal-setting: The novel approach of the UN sustainable development goals. *Current Opinion in Environmental Sustainability, 26*, 26–31. https://doi.org/10.1016/j.cosust.2017.01.010

Bond, A., & Quinlan, L. (2018). Indigenous gender-based analysis for informing the Canadian minerals and metals plan. Policy paper. Akwesasne, ON: Native Women's Association of Canada/L'Association des femmes autochtones du Canada.

Borsatto, J. M. L. S., & Bazani, C. L. (2021). Green innovation and environmental regulations: A systematic review of international academic works. *Environmental Science and Pollution Research, 28*(45), 63751–63768. https://doi.org/10.1007/s11356-020-11379-7

Bu, M., Qiao, Z., & Liu, B. (2020). Voluntary environmental regulation and firm innovation in China. *Economic Modelling, 89*, 10–18. https://doi.org/10.1016/j.econmod.2019.12.020

Busom, I. (2000). An empirical evaluation of the effects of R&D subsidies. *Economics of Innovation and New Technology, 9*(2), 111–148. https://doi.org/10.1080/10438590000000006

Chen, C., Lin, Y., Lv, N., Zhang, W., & Sun, Y. (2022). Can government low-carbon regulation stimulate urban green innovation? Quasi-experimental evidence from China's low-carbon city pilot policy. *Applied Economics, 54*(57), 6559–6579. https://doi.org/10.1080/00036846.2022.2072466

Corden, W. M., & Neary, J. P. (1982). Booming sector and de-industrialisation in a small open economy. *The Economic Journal, 92*(368), 825–848. https://doi.org/10.2307/2232670

Dahlman, C. J. (1979). The problem of externality. *The Journal of Law and Economics, 22*(1), 141–162.

Dechow, P. M., Sloan, R. G., & Sweeney, A. P. (1995). Detecting earnings management. *Accounting Review, 70*(02), 193–225.

Dong, B., & Zhang, L. (2021). Corporate corruption culture and technological innovation. *Journal of Chongqing University, 06*, 33–48.

Dong, S., Li, Z., Li, B., & Xue, M. (2007). Problems and strategies of industrial transformation of China's resource-based cities. China population. *Resources and Environment, 17*(5), 12–17. https://doi.org/10.1016/S1872-583X(08)60005-4

Dou, S., Zhu, Y., Xu, D., & Amuakwa-Mensah, F. (2023). Ecological challenges in the economic recovery of resource-depleted cities in China. *Journal of Environmental Management, 333*, 117406.

Du, W., Li, M., & Wang, F. (2020). Role of rent-seeking or technological progress in maintaining the monopoly power of energy enterprises: An empirical analysis based on micro-data from China. *Energy, 202*, 117763.

Du, K., Cheng, Y., & Yao, X. (2021). Environmental regulation, green technology innovation, and industrial structure upgrading: The road to the green transformation of Chinese cities. *Energy Economics, 98*, 105247. https://doi.org/10.1016/j.eneco.2021.105247

Fee, C. E., Hadlock, C. J., & Pierce, J. R. (2009). Investment, financing constraints, and internal capital markets: Evidence from the advertising expenditures of multinational firms. *The Review of Financial Studies, 22*(6), 2361–2392. https://doi.org/10.1093/rfs/hhn059

Fitzpatrick, P., Fonseca, A., & McAllister, M. L. (2011). From the Whitehorse mining initiative towards sustainable mining: Lessons learned. *Journal of Cleaner Production, 19*(4), 376–384. https://doi.org/10.1016/j.jclepro.2010.10.013

Florida, R. (2000). Competing in the age of talent: environment, amenities, and the new economy. Report prepared for the RK Mellon Foundation, Heinz Endowments, and Sustainable, Pittsburgh, 60.

Gao, K., Wang, L., Liu, T., & Zhao, H. (2022). Management executive power and corporate green innovation—Empirical evidence from China's state-owned manufacturing sector. *Technology in Society, 70*, 102043. https://doi.org/10.1016/j.techsoc.2022.102043

Gomes, C. M., Kneipp, J. M., Kruglianskas, I., & da RosaBichueti, L. A. B. R. S. (2015). Management for sustainability: An analysis of the key practices according to the business size. *Ecological Indicators, 52*, 116–127.

Guellec, D., & Potterie, B. V. P. D. L. (2003). The impact of public R&D expenditure on business R&D. *Economics of Innovation and New Technology, 12*(3), 225–243. https://doi.org/10.1080/10438590290004555

Guo, D., Guo, J., & Jiang, K. (2014). Government subsidized R&D and innovation outputs: An empirical analysis of china's innofund program. Stanford Center for International Development, Working Paper Series, 494.

Gürlek, M., & Tuna, M. (2018). Reinforcing competitive advantage through green organizational culture and green innovation. *The Service Industries Journal, 38*(7–8), 467–491. https://doi.org/10.1080/02642069.2017.1402889

He, S. Y., Lee, J., Zhou, T., & Wu, D. (2017). Shrinking cities and resource-based economy: The economic restructuring in China's mining cities. *Cities, 60*, 75–83. https://doi.org/10.1016/j.cities.2016.07.009

He, K., Chen, W., & Zhang, L. (2021). Senior management's academic experience and corporate green innovation. *Technological Forecasting and Social Change, 166*, 120664. https://doi.org/10.1016/j.techfore.2021.120664

Henriques, I., & Sadorsky, P. (1996). The determinants of an environmentally responsive firm: An empirical approach. *Journal of Environmental Economics and Management, 30*(3), 381–395.

Howell, S. T. (2017). Financing innovation: Evidence from R&D grants. *American Economic Review, 107*(4), 1136–1164. https://doi.org/10.1257/aer.20150808

Huang, Z., Liao, G., & Li, Z. (2019). Loaning scale and government subsidy for promoting green innovation. *Technological Forecasting and Social Change, 144*, 148–156. https://doi.org/10.1016/j.techfore.2019.04.023

Ilcan, S., & Phillips, L. (2010). Developmentalities and calculative practices: The millennium development goals. *Antipode, 42*(4), 844–874.

Jiang, Z., Xu, C., & Zhou, J. (2023). Government environmental protection subsidies, environmental tax collection, and green innovation: Evidence from listed enterprises in China. *Environmental Science and Pollution Research, 30*(2), 4627–4641.

Jin, H., Yang, J., & Chen, Y. (2022). Energy saving and emission reduction fiscal policy and corporate green technology innovation. *Frontiers in Psychology, 13*, 1056038. https://doi.org/10.3389/fpsyg.2022.1056038

Kang, K. N., & Park, H. (2012). Influence of government R&D support and inter-firm collaborations on innovation in Korean biotechnology SMEs. *Technovation, 32*(1), 68–78. https://doi.org/10.1016/j.technovation.2011.08.004

Kong, T., Sun, R., Sun, G., & Song, Y. (2022). Effects of digital finance on green innovation considering information asymmetry: An empirical study based on Chinese listed firms. *Emerging Markets Finance and Trade, 58*(15), 4399–4411.

Kopnina, H. (2014). Revisiting education for sustainable development (ESD): Examining anthropocentric bias through the transition of environmental education to ESD. *Sustainable Development, 22*(2), 73–83.

Krueger, A. O. (1974). The political economy of the rent-seeking society. *The American Economic Review, 64*(3), 291–303.

Lanoie, P., Patry, M., & Lajeunesse, R. (2008). Environmental regulation and productivity: Testing the porter hypothesis. *Journal of Productivity Analysis, 30*(2), 121–128. https://doi.org/10.1007/s11123-008-0108-4

Lee, E. Y., & Cin, B. C. (2010). The effect of risk-sharing government subsidy on corporate R&D investment: Empirical evidence from Korea. *Technological Forecasting and Social Change, 77*(6), 881–890. https://doi.org/10.1016/j.techfore.2010.01.012

Leite, M. C., & Weidmann, J. (1999). *Does mother nature corrupt? Natural resources, corruption, and economic growth*. International Monetary Fund.

Li, Q., & Xiao, Z. (2020). Heterogeneous environmental regulation tools and green innovation incentives: Evidence from green patents of listed companies. *Economic Research Journal, 55*(09), 192–208.

Li, H., Long, R., & Chen, H. (2013). Economic transition policies in Chinese resource-based cities: An overview of government efforts. *Energy Policy, 55*, 251–260. https://doi.org/10.1016/j.habitatint.2008.05.007

Li, J., Shan, Y., Tian, G., & Hao, X. (2020). Labor cost, government intervention, and corporate innovation: Evidence from China. *Journal of Corporate Finance, 64*, 101668. https://doi.org/10.1016/j.jcorpfin.2020.101668

Li, X., & Wang, D. (2022). Does transfer payments promote low-carbon development of resource-exhausted cities in China? *Earth's Future, 10*(1), e2021EF002339.

Li, D., Zhao, Y., Zhang, L., Chen, X., & Cao, C. (2018). Impact of quality management on green innovation. *Journal of Cleaner Production, 170*, 462–470. https://doi.org/10.1016/j.jclepro.2017.09.158

Li, X., Lai, X., & Zhang, F. (2021). Research on green innovation effect of industrial agglomeration from perspective of environmental regulation: Evidence in China. *Journal of Cleaner Production, 288*, 125583. https://doi.org/10.1016/j.jclepro.2020.125583

Lin, B., & Ma, R. (2022). How does digital finance influence green technology innovation in China? Evidence from the financing constraints perspective. *Journal of Environmental Management, 320*, 115833. https://doi.org/10.1016/j.jenvman.2022.115833

Liu, Q., & Lu, Y. (2015). Firm investment and exporting: Evidence from China's value-added tax reform. *Journal of International Economics, 97*(2), 392–403. https://doi.org/10.1016/j.jinteco.2015.07.003

Liu, Z., Li, W., Hao, C., & Liu, H. (2021). Corporate environmental performance and financing constraints: An empirical study in the Chinese context. *Corporate Social Responsibility and Environmental Management, 28*(2), 616–629.

Liu, J., Jiang, Y., Gan, S., He, L., & Zhang, Q. (2022). Can digital finance promote corporate green innovation? *Environmental Science and Pollution Research, 29*(24), 35828–35840. https://doi.org/10.1007/s11356-022-18667-4

Liu, D., Chen, T., Liu, X., & Yu, Y. (2019). Do more subsidies promote greater innovation? Evidence from the Chinese electronic manufacturing industry. *Economic Modelling, 80*, 441–452. https://doi.org/10.1016/j.econmod.2018.11.027

Lu, H., Liu, M., & Song, W. (2022). Place-based policies, government intervention, and regional innovation: Evidence from China's resource-exhausted city program. *Resources Policy, 75*, 102438. https://doi.org/10.1016/j.resourpol.2021.102438

Mamuneas, T. P., & Ishaq Nadiri, M. (1996). Public R&D policies and cost behavior of the US manufacturing industries. *Journal of Public Economics, 63*(1), 57–81. https://doi.org/10.1016/S0047-2727(96)01588-5

Mao, Q., & Xu, J. (2018). The more subsidies, the longer survival? Evidence from Chinese manufacturing firms. *Review of Development Economics, 22*(2), 685–705.

Margaritis, D., & Psillaki, M. (2010). Capital structure, equity ownership and firm performance. *Journal of Banking and Finance, 34*(3), 621–632. https://doi.org/10.1016/j.jbankfin.2009.08.023

Marino, M., Lhuillery, S., Parrotta, P., & Sala, D. (2016). Additionality or crowding-out? An overall evaluation of public R&D subsidy on private R&D expenditure. *Research Policy, 45*(9), 1715–1730. https://doi.org/10.1016/j.respol.2016.04.009

Meyer, L. H. (1998). The present and future roles of banks in small business finance. *Journal of Banking and Finance, 22*(6–8), 1109–1116. https://doi.org/10.1016/S0378-4266(98)00019-3

Pan, X., Cheng, W., Gao, Y., Balezentis, T., & Shen, Z. (2021). Is environmental regulation effective in promoting the quantity and quality of green innovation? *Environmental Science and Pollution Research, 28*(5), 6232–6241. https://doi.org/10.1007/s11356-020-10984-w

Papyrakis, E, & Gerlagh, R. (2003). Natural resources: a blessing or a curse? Available at SSRN 383482.

Papyrakis, E., & Gerlagh, R. (2004). The resource curse hypothesis and its transmission channels. *Journal of Comparative Economics, 32*(1), 181–193. https://doi.org/10.1016/j.jce.2003.11.002

Polasky, S., Kling, C. L., Levin, S. A., Carpenter, S. R., Daily, G. C., Ehrlich, P. R., Heal, G. M., & Lubchenco, J. (2019). Role of economics in analyzing the environment and sustainable development. *Proceedings of the National Academy of Sciences, 116*(12), 5233–5238.

Porter, M. E., & van der Linde, C. (1995). Toward a new conception of the environment-competitiveness relationship. *Journal of Economic Perspectives, 9*(4), 97–118. https://doi.org/10.1257/jep.9.4.97

Rajan, R. G., & Zingales, L. (1995). What do we know about capital structure? Some evidence from international data. *The Journal of Finance, 50*(5), 1421–1460. https://doi.org/10.1111/j.1540-6261.1995.tb05184.x

Rao, N. (2016). Do tax credits stimulate R&D spending? The effect of the R&D tax credit in its first decade. *Journal of Public Economics, 140*, 1–12. https://doi.org/10.1016/j.jpubeco.2016.05.003

Regueiro, M., & Alonso-Jimenez, A. (2021). Minerals in the future of Europe. *Mineral Economics, 34*(2), 209–224. https://doi.org/10.1007/s13563-021-00254-7

Ruan, F., Yan, L., & Wang, D. (2020). The complexity for the resource-based cities in China on creating sustainable development. *Cities, 97*, 102571. https://doi.org/10.1016/j.cities.2019.102571

Rubashkina, Y., Galeotti, M., & Verdolini, E. (2015). Environmental regulation and competitiveness: Empirical evidence on the porter hypothesis from European manufacturing sectors. *Energy Policy, 83*, 288–300. https://doi.org/10.1016/j.enpol.2015.02.014

Rui, Z., & Lu, Y. (2021). Stakeholder pressure, corporate environmental ethics and green innovation. *Asian Journal of Technology Innovation, 29*(1), 70–86. https://doi.org/10.1080/19761597.2020.1783563

Sachs, J. D. (2012). From millennium development goals to sustainable development goals. *The Lancet, 379*(9832), 2206–2211.

Sachs, J. D., & Warner, A. M. (2001). The curse of natural resources. *European Economic Review, 45*(4–6), 827–838. https://doi.org/10.1016/S0014-2921(01)00125-8

Sachs, J. D., & Warner, A. (1995). *Natural resource abundance and economic growth*. Oxford University Press.

Shao, S., Zhan, Y., Tian, Z., Li, D., & Yang, L. (2020). The regional dutch disease effect within China: A spatial econometric investigation. *Energy Economics, 88*, 104766. https://doi.org/10.1016/j.eneco.2020.104766

Shao, S., & Yang, L. (2010). Natural resource abundance, resource-based industry dependence, and regional economic growth in China. *Management World, 204*(9), 26–44.

Shen, F., Liu, B., Luo, F., Wu, C., Chen, H., & Wei, W. (2021). The effect of economic growth target constraints on green technology innovation. *Journal of Environmental Management, 292*, 112765. https://doi.org/10.1016/j.jenvman.2021.112765

Shields, D. J., Wagner, L. A., & van Zyl, D. (2003). Indicators of mineral systems contributions to sustainability in the USA. In Z. Agioutantis (Ed.), *Proceedings of international conference on sustainable development indicators in the mineral industries* (pp. 35–41). Milos Conference Center.

Shleifer, A., & Vishny, R. W. (1994). Politicians and firms. *The Quarterly Journal of Economics, 109*(4), 995–1025.

Song, D., Li, X., & Li, C. (2020a). The impact of transfer payments in resource-exhausted cities on green technology innovation—Enabling incentives or policy traps. *Journal of Industrial Technological Economics, 39*(11), 19–27.

Song, M. L., Cao, S. P., & Wang, S. H. (2019). The impact of knowledge trade on sustainable development and environment-biased technical progress. *Technological Forecasting and Social Change, 144*, 512–523. https://doi.org/10.1016/j.techfore.2018.02.017

Song, M., Wang, S., & Zhang, H. (2020b). Could environmental regulation and R&D tax incentives affect green product innovation? *Journal of Cleaner Production, 258*, 120849. https://doi.org/10.1016/j.jclepro.2020.120849

Sun, T., Lu, Y., & Cheng, L. (2020). Implementation effect of resource exhausted cities' supporting policies, long-term mechanism and industrial upgrading. *China Industrial Economics, 338*(7), 98–116.

Takalo, S. K., & Tooranloo, H. S. (2021). Green innovation: A systematic literature review. *Journal of Cleaner Production, 279*, 122474.

Tato Diogo, M. (2020). European legal framework related to underground mining and tunnelling concerning commission directive (EU) 2017/164, 31 January establishing a fourth list of indicative occupational exposure limit values. *International Journal of Mining Science and Technology, 30*(4), 541–545. https://doi.org/10.1016/j.ijmst.2020.05.017

Testa, F., Pretner, G., Iovino, R., Bianchi, G., Tessitore, S., & Iraldo, F. (2021). Drivers to green consumption: A systematic review. *Environment, Development and Sustainability, 23*, 4826–4880.

Tong, X., Wang, Z., & Li, X. (2022). The influence of government subsidy on enterprise innovation: Based on Chinese high-tech enterprises. *Economic Research-Ekonomska Istraživanja, 35*(1), 1481–1499.

Wang, J. (2018). Innovation and government intervention: A comparison of Singapore and Hong Kong. *Research Policy, 47*(2), 399–412. https://doi.org/10.1016/j.respol.2017.12.008

Wang, S., & Guo, S. (2012). Study on countermeasures for sustainable development of resource-exhausted cities. *China Soft Science, 253*(01), 01–13. In Chinese.

Wang, Q., Qu, J., Wang, B., Wang, P., & Yang, T. (2019a). Green technology innovation development in China in 1990–2015. *Science of the Total Environment, 696*, 134008.

Wang, F., & Ge, X. (2022). Can low-carbon transition impact employment empirical evidence from low-carbon city pilot policy. *China Industrial Economics, 05*, 81–99. https://doi.org/10.19581/j.cnki.ciejournal.2022.05.004

Wang, X., Fan, G., & Yu, J. (2019b). *Marketization index of China's provinces*. Social Science Academic Press. In Chinese.

Wang, Y., Sun, X., & Guo, X. (2019c). Environmental regulation and green productivity growth: Empirical evidence on the porter hypothesis from OECD industrial sectors. *Energy Policy, 132*, 611–619. https://doi.org/10.1016/j.enpol.2019.06.016

Wu, Z., Fan, X., Zhu, B., Xia, J., Zhang, L., & Wang, P. (2022). Do government subsidies improve innovation investment for new energy firms: A quasi-natural experiment of China's listed companies. *Technological Forecasting and Social Change, 175*, 121418. https://doi.org/10.1016/j.techfore.2021.121418

Wu, G., Gao, Y., & Feng, Y. (2023). Assessing the environmental effects of the supporting policies for mineral resource-exhausted cities in China. *Resources Policy, 85*, 103939. https://doi.org/10.1016/j.resourpol.2023.103939

Xiang, X., Liu, C., & Yang, M. (2022). Who is financing corporate green innovation? *International Review of Economics and Finance, 78*, 321–337. https://doi.org/10.1016/j.iref.2021.12.011

Xiao, H., Zhang, L., & Ren, J. (2021). Sustainability risks of resource-exhausted cities in China: A principal component analysis. In J. Ren (Ed.), *Multi-criteria decision analysis for risk assessment and management*. Springer. https://doi.org/10.1007/978-3-030-78152-1_10

Xiao, H., Yang, Z., & Wang, X. (2023). Coordination of central real estate industry policies corporate social responsibility and green technology innovation. *Journal of Sun Yat Sen University, 63*(01), 177–193. https://doi.org/10.13471/j.cnki.jsysusse.2023.01.017. In Chinese.

Xiaobao, P., & Wu, J. (2022). Do subsidy increases promote or inhibit innovation Evidence from Chinese enterprises listed on the SSE STAR Market. *Chinese Management Studies*. https://doi.org/10.1108/CMS-05-2022-0183

Xie, X., Zhu, Q., & Wang, R. (2019). Turning green subsidies into sustainability: How green process innovation improves firms' green image. *Business Strategy and the Environment, 28*(7), 1416–1433.

Xu, J., & Cui, J. (2020). Low-carbon cities and firms' green technological innovation. *China Industrial Economics, 393*(12), 178–196. https://doi.org/10.19581/j.cnki.ciejournal.2020.12.008. In Chinese.

Yang, B., Zhan, X., & Tian, Y. (2021). Evaluation on the effect of the transformation policy of resource-exhausted cities—An empirical analysis based on the difference-in-difference model. *Energy Reports, 7*, 959–967. https://doi.org/10.1016/j.egyr.2021.09.177

Yang, Z., Chen, J., & Ling, H. (2023). Media attention, environmental policy uncertainty and firm's green technology: Empirical evidence from Chinese a-share listed firms. *Journal of Industrial Engineering and Engineering Management, 37*(4), 1–15. https://doi.org/10.13587/j.cnki.jieem.2023.04.001. In Chinese.

Yao, S., Yu, S., & Jia, W. (2023). Does distorted allocation of capital factors inhibit green technology innovation in Chinese cities? An empirical analysis based on spatial effect. *Environmental Science and Pollution Research, 30*(7), 19234–19249.

Yu, M., Hui, Y., & Pan, H. (2010). Political connections, rent seeking, and the fiscal subsidy efficiency of local governments. *Economic Research Journal, 3*(1), 65–77.

Yu, C. H., Wu, X., Zhang, D., Chen, S., & Zhao, J. (2021). Demand for green finance: Resolving financing constraints on green innovation in China. *Energy Policy, 153*, 112255. https://doi.org/10.1016/j.enpol.2021.112255

Yu, W., Peng, Y., & Yao, X. (2022). The effects of China's supporting policy for resource-exhausted cities on local energy efficiency: An empirical study based on 284 cities in China. *Energy Economics, 112*, 106165. https://doi.org/10.1016/j.eneco.2022.106165

Yu, L., & Ma, B. (2022). Supportive policy for resource-exhausted cities, the manufacturing upgrading and the coordinated regional development. *China Industrial Economics, 413*(08), 137–155. https://doi.org/10.19581/j.cnki.ciejournal.2022.08.008. In Chinese.

Yuan, B., & Cao, X. (2022). Do corporate social responsibility practices contribute to green innovation? The mediating role of green dynamic capability. *Technology in Society, 68*, 101868. https://doi.org/10.1016/j.techsoc.2022.101868

Zhang, H., Xiong, L., Li, L., & Zhang, S. (2018). Political incentives, transformation efficiency and resource-exhausted cities. *Journal of Cleaner Production, 196*, 1418–1428. https://doi.org/10.1016/j.jclepro.2018.06.093

Zhang, N., Lu, H., & Huang, J. (2019). Effects of intergovernmental transfers for resource-exhausted cities on economic growth. *China Population·resources Environment, 29*(04), 147–156. In Chinese.

Zhang, Y., Chen, T., & Chen, H. (2022). Implementation effect of supporting polices on the high-quality development of resource-exhausted cities. *China Population·resources and Environment, 32*(05), 46–56. In Chinese.

Zhao, T., Zhang, Z., & Liang, S. (2020). Digital economy, entrepreneurship, and high-quality economic development: Empirical evidence from urban China. *Management World, 36*(10), 65–76. https://doi.org/10.19744/j.cnki.11-1235/f.2020.0154. In Chinese.

Zhong, Z., & Peng, B. (2022). Can environmental regulation promote green innovation in heavily polluting enterprises? Empirical evidence from a quasi-natural experiment in China. *Sustainable Production and Consumption, 30*, 815–828. https://doi.org/10.1016/j.spc.2022.01.017

Zhu, Q., Feng, Y., & Choi, S. B. (2017). The role of customer relational governance in environmental and economic performance improvement through green supply chain management. *Journal of Cleaner Production, 155*, 46–53. https://doi.org/10.1016/j.jclepro.2016.02.124