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Does the green patent pre-examination program reduce environmental pollution?

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China's green patent pre-examination program, implemented through Intellectual Property Protection Centers (IPPCs), creates expedited examination procedures for green inventions. This study examines the program's environmental impact by exploiting the staggered establishment of IPPCs across cities. Using a staggered difference-in-differences model with city-level data from 2012 to 2021, the analysis reveals that the program leads to significant reductions in sulfur dioxide and dust emissions in pilot cities. A series of robustness tests confirm that these effects appear causal. Furthermore, the study identifies three underlying mechanisms: stimulating green innovation, promoting the transfer of green technology, and restricting the entry of pollution-intensive firms. These channels contribute collectively to reductions in pollution. Notably, the program's pollution reduction effects are more pronounced in regions with developing technology markets, weaker intellectual property protections, and less developed institutional environments. These results highlight the green patent pre-examination program as an effective policy for balancing economic growth and environmental sustainability, offering valuable insights for emerging economies pursuing green development.

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Introduction

Necessity of the research. In recent years, environmental issues have received growing scholarly attention (Sarkar et al. 2023; Sarkar et al. 2024a; Mridha and Sarkar, 2025). These challenges create significant obstacles to achieving sustainable development objectives (Xue et al. 2021). Previous research has extensively investigated various economic, institutional, and social determinants of environmental quality (Grossman and Krueger, 1991; Lutsey and Sperling, 2008; Du and Li, 2020; Habib et al. 2021), with a substantial body of literature emphasizing the pivotal role of green innovation in environmental remediation (Brock and Taylor, 2010). However, the inherent "double externality" characteristic of green innovation leads to a divergence between private and social returns, undermining the economic incentives for innovative activities. Patent policy is widely recognized as an effective measure for addressing environmental challenges by stimulating green innovation (Coase, 1960), with fast-track programs serving as a refinement of conventional patent policy. While academic interest in accelerated examination mechanisms for green technologies has increased, empirical research on their environmental impacts remains limited. Moreover, existing studies have limited attention to the specific mechanisms through which fast-track programs influence environmental outcomes. In response to these gaps, this study empirically evaluates China's green patent pre-examination program, focusing on its effectiveness in mitigating local environmental pollution within the context of an emerging economy.

Definition for the green patent pre-examination program. Countries face challenges as both patent application volumes and environmental degradation intensify. Recognizing these dual pressures, governments worldwide have implemented patent system reforms to address growing examination backlogs, which hinder the commercialization of new technologies.[1] Numerous countries, such as the United Kingdom, Australia, and Canada, have established fast-track programs targeting green technologies. In this context, China has introduced the green patent pre-examination program as a means to accelerate innovation and mitigate environmental challenges simultaneously.

Since 2016, China has established IPPCs to provide expedited pre-examination services. This innovative program, introduced by the China National Intellectual Property Administration (CNIPA), conducts pre-assessments prior to formal application filing. The program focuses on important technological domains, particularly green technologies. Since 2018, specialized green-technology IPPCs have been gradually established across selected regions, concentrating on sectors such as new energy, resource conservation, and environmental protection. This study examines these green-focused centers and conceptualizes their services as constituting the green patent pre-examination program. By accelerating the protection of environmental technologies, the program is expected to stimulate research and development (R&D) investment, improve local environmental quality, and contribute to economic growth.

Main contents and findings. This study investigates the environmental effects of China's green patent pre-examination program by exploiting the staggered establishment of green-technology IPPCs across Chinese cities between 2012 and 2021. Employing a staggered difference-in-differences (DID) design with city-level data, the analysis reveals that the program leads to significant reductions in sulfur dioxide and dust emissions. These results withstand rigorous robustness checks, including the application of the propensity score matching DID (PSM-DID) model and analyses of heterogeneous treatment effects, thereby reinforcing the causal interpretation of the program's environmental benefits.

The study further identifies three key mechanisms through which the program operates: stimulating green innovation, promoting the transfer of green technologies, and restricting the entry of pollution-intensive firms. These channels contribute to reductions in environmental pollution. Additionally, the analysis demonstrates that the program's environmental benefits are particularly pronounced in cities with underdeveloped technology markets, weaker intellectual property protection systems, and less mature institutional environments, consistent with the theory of diminishing marginal returns to policy interventions. These findings highlight how targeted intellectual property reforms can advance environmental protection and technological development simultaneously.

Contributions of the research. The contributions of this study are mainly in the following three aspects.

First, this study contributes to the growing literature on expedited patent examination programs. Prior research has shown that accelerated patent examination fosters technological innovation, stimulates business development (Hegde et al. 2022), and accelerates technology commercialization (Zahringer et al. 2017; Kuhn and Teodorescu, 2021). While some studies have examined the environmental benefits of green patent fast-track systems (Liu et al. 2023; Xu et al. 2024), the pre-examination program, an institutional innovation unique to China's patent system, has received limited attention. Early fast-track programs are implemented uniformly across regions, thereby constraining empirical analysis to simple before-and-after comparisons. Such approaches cannot adequately identify causal policy effects, as they neglect underlying time trends and omitted variables (Wang and Qian, 2023). This study employs a DID framework that leverages the staggered establishment of IPPCs across Chinese cities, which helps address endogeneity concerns and identify causal impacts. The results demonstrate that the green patent pre-examination program significantly reduces environmental pollution, offering valuable implications for the improvement of accelerated patent examination policies.

Second, this study adds to the literature on green innovation and sustainable development. Green innovation plays a pivotal role in reconciling environmental improvement with economic growth, a key component of sustainable development (Brock and Taylor, 2010). As a policy designed to foster innovation and economic progress, patent policy can promote green innovation and support sustainable development (Kuhn and Teodorescu, 2021; Hegde et al. 2022). Building on this foundation, this study shows that China's green patent pre-examination program reduces environmental pollution by stimulating green innovation, facilitating the transfer of green technologies, and restricting the entry of pollution-intensive firms. These findings underscore the potential of patent policy as an effective tool for achieving sustainable development and offer valuable insights for policymakers aiming to foster green innovation.

Third, this study expands the literature on the determinants of environmental pollution by highlighting the role of patent policy. Existing research has examined environmental pollution from multiple perspectives, including economic growth (Grossman and Krueger, 1991, 1995), population (Liddle and Lung, 2010), environmental regulations (Lutsey and Sperling, 2008; Du and Li, 2020), foreign direct investment (FDI) (Liang, 2008), and economic agglomeration (Ushifusa and Tomohara, 2012). However, few studies have investigated the environmental impacts and underlying mechanisms associated with patent policy. This study shows that China's green patent pre-examination program, a fast-track channel for protecting green technologies, mitigates pollution by stimulating green innovation. The findings provide a novel perspective on addressing environmental challenges through institutional innovation in intellectual property policy.

Orientation. The remainder of this paper is structured as follows. Section 2 provides a comprehensive review of the relevant literature. Section 3 introduces the policy background and develops the research hypotheses. Section 4 describes the variable selection, data sources, and empirical methodology. Section 5 reports the main empirical findings, mechanisms, and heterogeneous effects. Section 6 discusses the key findings and their implications. Finally, Section 7 concludes with policy recommendations and suggests directions for future research.

Literature review

Research on green patents fast-track program. Recently, many countries have implemented measures to expedite the processing of green patent applications. By prioritizing the examination of green technology patents, countries aim to stimulate innovation in this field, addressing environmental challenges and advancing sustainable development. Recent literature has focused on fast-track patent application programs. Scholars have examined firms' decisions regarding whether to request accelerated examination. Dechezleprêtre (2013) analyzes national fast-track programs for green patents and finds that only a limited number of applications undergo expedited review. Applicants tend to request accelerated examination only under specific conditions, considering factors such as the cost of granting the patent, the scope of claims, and the risk of technology disclosure. Similarly, Zahringer et al. (2017) observe that startups often delay examination requests. In addition, accelerated examination is more likely to be pursued for patents perceived to have relatively high value. Harhoff and Wagner (2009) argue that applicants prioritize accelerating patents with high value. Kuhn and Teodorescu (2021) empirically evaluate a U.S. elective program for accelerated patent examination and show that it is important for small firms with limited patent portfolios. Moreover, patents processed through this program will receive more citations and are more frequently subject to litigation compared to those examined under standard procedures.

Additional literature examines the economic impacts of patent examination acceleration programs. Empirical research has established a positive relationship between patent systems, examination efficiency, and entrepreneurial activity. Kuhn and Teodorescu (2021) propose that accelerated examination programs enhance value capture for entrepreneurs by reducing barriers to financing and commercialization, thereby accelerating technology diffusion and incentivizing entrepreneurship. Lu (2013) suggests that the earlier granting of green patents generates more social benefits. Similarly, Dechezleprêtre (2013) argues that early green patent approval accelerates the diffusion of technological knowledge in environmentally relevant sectors. Furthermore, some scholars have empirically investigated fast-track programs for green patents. Liu et al. (2023) report a 1.6% reduction in CO2 emissions among cities adopting green patent fast-tracking policies in China. Xu et al. (2024) find that such programs increase both the private value of green patents and associated public environmental benefits.

The factors influencing environmental pollution. Existing literature examines environmental pollution through various perspectives, including economic growth (Grossman and Krueger, 1991, 1995), population (Liddle and Lung, 2010), environmental policy (Lutsey and Sperling, 2008; Du and Li, 2020), green innovation (Brock and Taylor, 2010), FDI (Liang, 2008), and economic agglomeration (Ushifusa and Tomohara, 2012). A substantial body of research has investigated the relationship between economic growth and environmental pollution. Porter (1991) challenges the misconception that environmental preservation is incompatible with economic development. Grossman and Krueger (1991) propose the Environmental Kuznets Curve (EKC) hypothesis, which posits an inverted U-shaped relationship between pollution and income levels. In the early stages of economic development, pollution tends to rise with increasing per capita income and continues to rise until reaching a specific threshold. The EKC suggests that sustainable development depends on identifying this turning point to achieve a balance between economic growth and environmental improvement.

Environmental regulation represents the most direct approach for the government to control environmental pollution (Yu et al. 2023). Wang et al. (2021) demonstrate an inverted U-shaped relationship between environmental regulation and pollution. Similarly, Mridha and Sarkar (2025) show that carbon emission regulations can reduce carbon emissions. Recent studies have also examined the positive impacts of innovative production methods on pollution mitigation. Sarkar et al. (2022a) argue that circular economy-driven supply chain management can eliminate waste. Sarkar et al. (2025b) demonstrate that photocatalytic ultraviolet processes have emerged over the past decade as eco-friendly methods for treating wastewater, thus removing organic contaminants. Furthermore, scholars highlight the pollution-reducing benefits of alternative fuels. Habib et al. (2021) identify biodiesel as a viable alternative to fossil fuels, citing its higher flash point, improved lubricity, and lower toxicity. Chen et al. (2022) emphasize that expanding solar power generation is essential for China to achieve carbon neutrality, as the replacement of fossil fuels with renewable energy sources can substantially reduce CO_2 emissions. Wang et al. (2023) further demonstrate that ultra-high voltage transmission projects have reduced regional carbon emissions.

Green innovation and sustainable development. A key challenge in achieving sustainable development lies in reconciling environmental protection with economic growth, which necessitates solutions that simultaneously improve environmental outcomes and foster economic opportunities. Rennings (2000) introduces the "double externality" characteristic of green innovation, positing that it generates two distinct positive externalities. First, similar to traditional innovations, green technologies create knowledge spillovers, benefiting future inventors (Arrow, 1962). Second, and more significantly, they yield environmental externalities by reducing resource consumption and mitigating pollution. While technological innovation serves as a key driver of economic growth (Solow, 1957; Romer, 1990; Tian and Xu, 2022), green technological innovation offers dual advantages by combining economic productivity with environmental sustainability (Wagner, 2007). Unlike traditional innovation, green innovation focuses on transforming industrial processes into systems that are more energy-efficient, less wasteful, and environmentally friendly, thus delivering both ecological and socioeconomic benefits (Huang and Li, 2017). This ability to integrate economic and environmental goals makes green innovation indispensable for achieving sustainable development (Brock and Taylor, 2010).

On the one hand, recent studies highlight the dual economic and environmental benefits of green technological investments (Sarkar and Bhuniya, 2022). Carrión-Flores and Innes (2010) find that green innovation is a key driver in reducing toxic emissions. Similarly, Sarkar et al. (2022b) argue that prioritizing green technology investments aimed at profit maximization constitutes an optimal management strategy. Supporting this perspective, Kar et al. (2023) demonstrate that manufacturers implementing advanced green technologies can significantly lower per-unit emissions while improving profitability. Specifically, their findings reveal that the adoption of green technology leads to 6.97% higher profits compared to conventional methods, with the proposed system achieving a 5.74% greater return relative to traditional production approaches. Additionally, Guchhait et al. (2024) provide evidence that renewable energy consumption not only yields substantial cost savings but also mitigates financial risk by lowering the likelihood of a negative net present value.

On the other hand, green innovation is a cornerstone of firms' long-term competitive strategies. High-technology firms often pursue green innovation as a strategic pathway toward sustainable development (Chen et al. 2006). For example, Siemens, a technology-driven multinational, has accelerated the deployment and advancement of cutting-edge green technologies in industrial applications. Through these efforts, Siemens has generated both substantial environmental and economic value, earning consistent recognition among the "Top 100 Most Sustainable Enterprises in the World." Empirical studies corroborate these outcomes. Fernando et al. (2019) establish that innovation capability enhances firm sustainability performance. Similarly, Xie et al. (2019) demonstrate that green process innovation facilitates green product development, contributing to improved financial outcomes. These findings affirm the dual benefits of green innovation in advancing environmental sustainability and enhancing firm performance.

Research gap of the study. Based on the above literature review, the following research gaps are found.

First, existing research has focused on green patent fast-track programs in developed economies, where the requirement of additional filing fees increases application costs and may deter participation, particularly among resource-constrained firms. In contrast, China's practice presents a distinct alternative by offering cost-free accelerated pathways for green patents, mitigating these financial concerns. While some studies empirically examine the effects of the green patent fast-track program, a policy uniformly implemented in China, the green patent pre-examination program remains understudied. This program's design as a city-level pilot policy introduces plausibly exogenous variation, providing an ideal shock that addresses endogeneity concerns and causal identification using the DID model.

Second, extensive research has examined the determinants of environmental pollution and proposed various strategies to mitigate these challenges. However, few studies have examined the role of patent policy in mitigating environmental degradation. In particular, the environmental impacts and underlying economic mechanisms of patent policy innovations remain underexplored. Analyzing how patent policies affect pollution reduction can yield critical insights for optimizing the design and implementation of intellectual property systems to support environmental goals.

Third, previous literature confirms the positive role of green innovation in promoting sustainable development, emphasizing how advanced technologies and production processes contribute to both environmental and economic sustainability. Despite this consensus, relatively few studies have investigated how green innovation can be promoted through patent policy mechanisms. A deeper understanding of how patent policies can stimulate green innovation is essential for designing institutional frameworks that support the dual goals of environmental protection and economic growth.

Theoretical analysis

Institutional background. In the past few years, patent applications have increased, driven by the growing importance of intellectual property. At the same time, increasing technological complexity has led to significant patent backlogs, thereby lengthening examination times (Li, 2012). Excessively long examination periods hinder the development of green technologies. In response, various countries have introduced policies to accelerate the examination of green patents. In 2009, the United Kingdom Intellectual Property Office (UKIPO) first introduced a fast-track examination program for green patents, allowing applicants to submit a letter attesting to the environmental benefits of their invention. According to the data from UKIPO, patents processed through this program can be granted within nine months. Since then, many countries, including Australia, the United States, and South Korea, have adopted similar initiatives to incentivize firms and individuals to engage in green technology R&D.

Patent applications in China can be expedited through several mechanisms, including the Patent Prosecution Highway (PPH), prioritized examination systems, and pre-examination programs. The PPH program, promoted since 2011 through bilateral agreements with 27 countries, has established an extensive international patent examination network. In 2012, the CNIPA issued the *Administrative Measures for Priority Examination of Patent Applications for Inventions*, which introduced a fast-track examination channel for green invention patent applications, allowing qualified applications to be finalized within one year. In 2017, the CNIPA issued the *Administrative Measures for Priority Examination of Patents Applications*, expanding accelerated examination eligibility to include utility model and design patents, further enhancing the system. This system is hereafter referred to as the Green Patent Fast-Track Program.

In 2016, the CNIPA issued the *Circular of the Intellectual Property Office on Carrying Out Rapid Collaborative Protection of Intellectual Property Rights* (hereafter referred to as the *Circular*), which proposed the establishment of IPPCs in regional industrial clusters based on key industries. These centers provide pre-examination services to determine whether applications meet patentability requirements before formal submission to the CNIPA. This mechanism introduces a two-stage examination process by conducting preliminary assessments of patentability before formal submission: IPPCs evaluate pre-examination applications and issue qualification notices for meritorious cases. Successful applicants subsequently submit formal applications to the CNIPA within specified timeframes to access expedited examination channels. As illustrated in Fig. 1, this program has produced measurable efficiency gains, with average examination durations for invention patents declining since its implementation. This trend reflects the program's effectiveness in reducing the patent examination cycle.

The patent pre-examination program targeted specific technological fields, with several cities prioritizing green technologies by establishing IPPCs focused on new energy, energy conservation, and environmental protection. A significant milestone occurred in 2018 when Zhejiang's IPPC became the first authorized to provide pre-examination services specifically for green patents. In the following years, the number of IPPCs specializing in green technologies expanded significantly, as shown in Table 1. This study focuses on these centers and defines their pre-examination services for green patents as the green patent pre-examination program.

Fig. 2 presents the growth trends of IPPCs from 2016 to 2023, emphasizing both the total number of centers and the proportion dedicated to green technologies. The data reveal that the percentage of green IPPCs reached two peaks in 2019 and

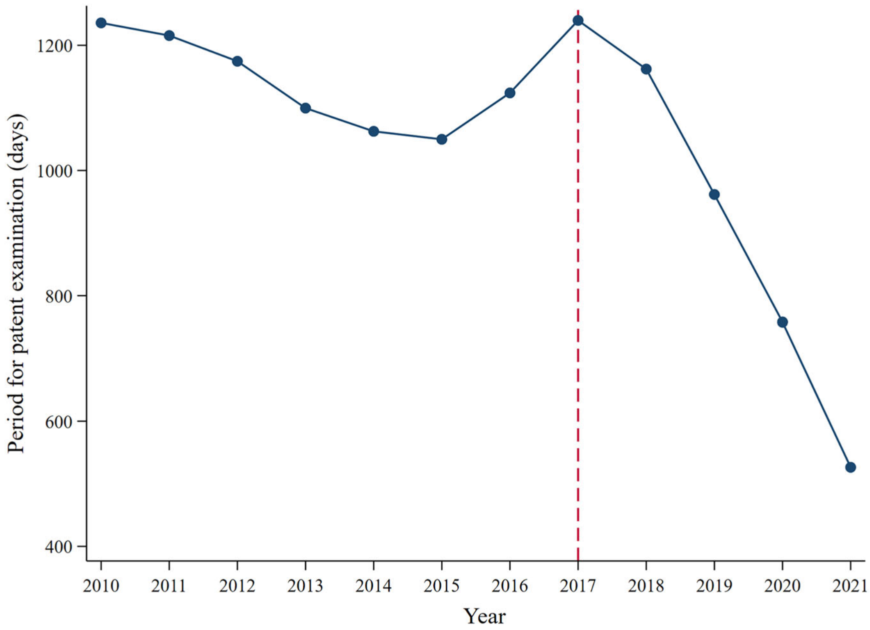

Fig. 1 Average examination time for invention patents (days). Figure 1 illustrates China's annual average examination period (in days) for granted invention patents. The red dotted line marks the establishment of the first IPPC.

Table 1 Intellectual property rights protection centers for green fields.

Center Name	Fields	Year Certified
Zhejiang Intellectual Property Protection Center	New generation information technology; New energy	2018
Shenzhen Intellectual Property Protection Center	New energy; Internet technology	2018
Hebei Intellectual Property Protection Center	Energy conservation and environmental protection; High-end equipment manufacturing	2019
Shanxi Intellectual Property Protection Center	New energy; Modern equipment manufacturing	2020
Ningde Intellectual Property Protection Center	New energy	2020
Gansu Intellectual Property Protection Center	Advanced Manufacturing; Energy conservation and environmental protection	2020
Dalian Intellectual Property Protection Center	New energy; High-end equipment manufacturing	2021
Shanghai Intellectual Property Protection Center	New Materials; Energy conservation and environmental protection	2021
Nanjing Intellectual Property Protection Center	New generation information technology. Biomedicine; Energy conservation and environmental protection	2021
Anhui Intellectual Property Protection Center	New Materials; Energy conservation and environmental protection	2022
Shaanxi Intellectual Property Protection Center	New generation information technology, new energy	2022
Taizhou Intellectual Property Protection Center	High-end equipment manufacturing; Energy conservation and environmental protection	2023
Nanning Intellectual Property Protection Center	New energy; New Materials	2023

2022, culminating in 70 operational or planned IPPCs across China by 2023. This growth pattern reflects the program's increasing institutionalization within China's intellectual property system, particularly about environmentally oriented innovations.

The patent pre-examination program represents an acceleration mechanism that differs from the PPH and green patent fast-track programs. While the PPH program facilitates international patent applications by leveraging prior examination results from partner offices, the pre-examination program focuses exclusively on domestic applications in selected industries. Similarly, whereas the green patent fast-track program applies uniformly nationwide, the pre-examination program targets specific regions and industries, thereby creating quasi-experimental conditions conducive to causal identification using the DID model.

Second, the program's provision of free pre-examination services through local IPPCs differentiates it from other acceleration mechanisms. This cost-free approach eliminates financial barriers to expedited examination, particularly benefiting small and medium-sized firms that might otherwise be deterred by additional fees.

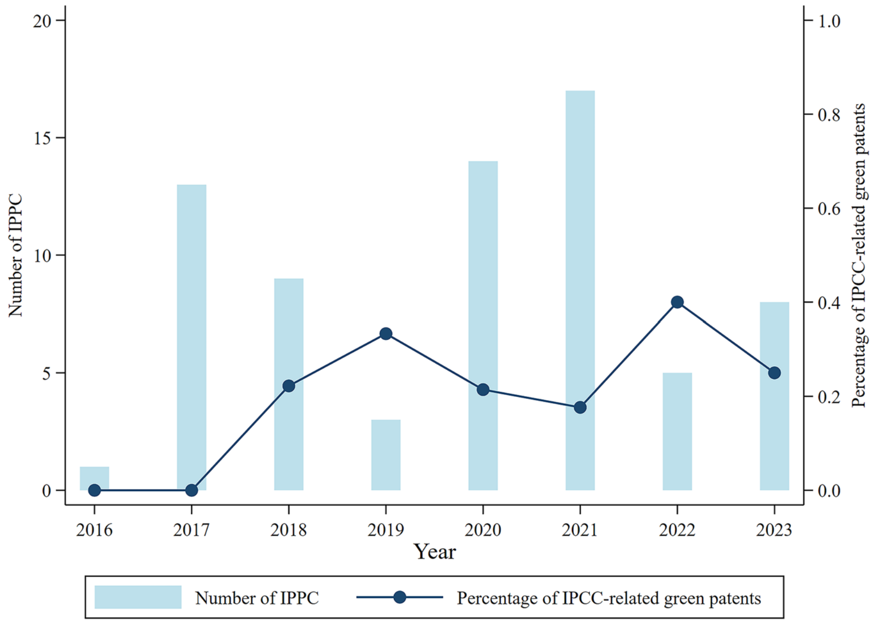

Fig. 2 The number of IPPC and the percentage of IPPC-related green patents. The figure presents two key metrics in a dual-axis chart: (1) annual approvals of IPPC in China (shown as column bars) and (2) the proportion of newly established centers specializing in green patent pre-trial services (represented by a blue connected line).

Third, the decentralization of preliminary examination authority to regional IPPCs constitutes a significant institutional innovation. This distributed governance design empowers local agencies to align patent screening with regional technological priorities, reduces examination backlogs at the national level, and maintains quality standards through centralized oversight by the CNIPA. Thus, the program represents an important evolution in China's patent system and serves as a valuable exploration of the country's patent examination regime.

Hypothesis development. Although green innovation generates both economic and environmental benefits, the "double externality" problem, where innovators do not fully appropriate the returns from their inventions, reduces incentives to develop green technologies (Rennings, 2000). While patent policy seeks to address this issue by granting temporary monopoly rights, the growing application numbers and increasing technical complexity have resulted in examination backlogs, delaying patent protection and dampening incentives for green innovation (Li, 2012; Régibeau and Rockett, 2007; Hegde et al. 2022). In response, many countries have implemented fast-track programs to accelerate green patent examination, stimulating green innovation through timely protection and facilitating technology diffusion through earlier disclosure.

The effectiveness of the green patent pre-examination program can be evaluated by the number of granted green patents, which serve as important indicators of commercially viable innovation (Babina et al. 2023). Once commercialized, these patents are expected to generate substantial environmental benefits, including the development of cleaner and more efficient production processes, improvements in product durability and recyclability, and the substitution of environmentally preferable materials, ultimately contributing to environmental improvement.

The practical implementation of green innovations is essential to advancing sustainable development. Although a patent grant represents an initial step, environmental benefits materialize only through successful commercialization and technological deployment (Sarkar et al. 2024b). Technology transfer plays a pivotal role in this transition (Liu et al. 2022), enabling inventors to commercialize their innovations while disseminating environmentally beneficial technologies. As green technologies achieve market adoption, they drive economic changes: green firms expand, polluting firms contract, and markets are ultimately reoriented toward more sustainable patterns.

Consequently, the program's environmental benefits arise through three core mechanisms: (1) fostering green innovation, (2) promoting the transfer of green technologies, and (3) reducing the entry of pollution-intensive firms.

Green innovation. As an improvement to patent policy, the green patent pre-examination program is designed to stimulate innovation (Arrow, 1962; Galasso and Schankerman, 2015). Specifically, the program promotes innovation through three interrelated mechanisms. First, by shortening examination periods, the program accelerates the clarification of intellectual property rights for green technologies. Drawing on property rights theory (Coase, 1960), this clarification reduces innovation externalities, incentivizes R&D investment, and increases green patent output (Hegde et al. 2022). Second, the expedited grant process extends the commercial exploitation period of green patents. The program enhances returns to innovation by enabling faster realization of exclusive rights (Moser, 2005; Ang et al. 2014). This extended protection period strengthens inventors' ability to monetize their technologies, thereby encouraging further green innovation (Schankerman, 1998). Third, the program facilitates earlier disclosure of patent information, aligning with the patent system's foundational principle: the granting of temporary monopoly rights in exchange for public knowledge sharing (Scotchmer and Green, 1990). According to knowledge spillover theory, patent disclosures provide a valuable source of technical information (Ouellette, 2012), fostering follow-on innovation (Arrow, 1962). Accordingly, the program can generate positive knowledge spillovers that support subsequent innovation (Hegde et al. 2023).

Collectively, these mechanisms illustrate how the pre-examination program fosters a virtuous cycle that promotes green innovation through strengthened property rights and broader knowledge dissemination. Furthermore, green innovation—characterized by energy-efficient, low-waste, and environmentally sustainable industrial processes—generates both environmental improvements and socioeconomic benefits (Wagner, 2007; Carrión-Flores and Innes, 2010; Huang and Li, 2017). Consequently, the program contributes to local pollution reduction by accelerating the patenting process of green technologies.

However, the patent system also hinders innovation by creating monopolies and restricting knowledge spillovers, and excessive protection could adversely affect innovation (Scotchmer and Green, 1990; Kortum and Lerner, 1999; Lerner, 2009). By further reinforcing patent protection, the green patent pre-examination program may affect knowledge spillovers. Consequently, the program's overall impact on innovation may be limited or even negative. In summary, the net effect of the green patent pre-examination program on innovation remains ambiguous.

Based on the above analysis, this study proposes the hypothesis H1:

Hypothesis H1: *The green patent pre-examination program reduces local environmental pollution by stimulating green innovation*.

Green technology transfer. Without formal intellectual property protection, startup innovators seeking commercialization partners may face expropriation risks (Anton and Yao, 1994). Intellectual property rights can facilitate technology transfer by reducing potential expropriation. Patent transfers play a vital role in technology commercialization (Liu et al. 2022). When a patent demonstrates economic value, it may be purchased from the inventor or assignee, resulting in a patent transfer (Maurseth and Svensson, 2020). Three layers of uncertainty limit technology transfer: uncertainty about property rights, technological value, and the patent trading process (Arora and Gambardella, 2010; Marco et al. 2017). Importantly, delays in patent grants introduce uncertainty that undermines the economic benefits of patenting (Lerner and Merges, 1998). Such delays result in missed opportunities to realize welfare-enhancing exchanges of ideas (Gans et al. 2008; Hegde et al. 2022). The program's accelerated examination process reduces uncertainty surrounding technological validity and the scope of protection. This dual reduction in uncertainty lowers transaction costs in technology markets and facilitates faster realization of innovation returns, thereby promoting the transfer of green technologies.

Additionally, under China's current patent system, the validity period of patents begins on the application date, but enforceable rights generally commence only upon grant. Thus, earlier patent grants extend the period of enforceable exclusivity, thereby increasing the monopoly benefits for inventors (Hegde et al. 2022). By shortening the examination period, the program effectively lengthens the duration of market exclusivity. This temporal expansion increases the anticipated monopoly benefits, thereby increasing the commercial value of green patents and making them more appealing for technology transfer (Maurseth and Svensson, 2020).

Technology transfer creates both private and social benefits by reallocating patent rights to firms with superior commercialization capabilities in manufacturing and marketing (Arora et al. 2001; Gans et al. 2008). Specifically, the program promotes specialization based on comparative advantage: it encourages R&D-intensive firms to market green technologies and supports their acquisition and commercialization by firms with practical expertise (Han et al. 2020). This division of labor within the innovation ecosystem promotes green development, thereby stimulating economic growth and advancing social welfare.

Based on the above analysis, this study proposes the hypothesis H2:

Hypothesis H2: *The green patent pre-examination program reduces local environmental pollution by promoting the transfer of green technologies*.

Entry of pollution-intensive firms. Patent rights confer advantages by deterring imitation, enhancing bargaining power in negotiations, and signaling innovation potential to attract investors and customers (Budish et al. 2016). The green patent pre-examination program extends these benefits by incentivizing inventors to establish firms that commercialize their innovations. The system reduces uncertainty and minimizes the costs of transforming innovation into commercialization, thereby increasing expected returns. According to utility theory, higher expected benefits lead to a greater likelihood of innovation commercialization (Kirzner, 1997; Shane and Venkataraman, 2000).

First, by expediting the granting of innovation rights, the pre-examination program enables entrepreneurship to identify opportunities more rapidly. Since both opportunity uncertainty and required investment costs fluctuate over time, expected entrepreneurial returns vary accordingly under this program (Kerr et al. 2014). Second, the program strengthens the market position of green firms by ensuring timely patent confirmation, which raises entry barriers for competitors, increases infringement costs, and reduces innovators' exposure to risk (Gans et al. 2008). Finally, established patent rights serve as credible signals of innovation capability, improving startups' access to financing by enhancing their visibility to financial institutions (Hsu and Ziedonis, 2013; Conti et al. 2013; Saidi and Žaldokas, 2020). This mechanism alleviates financial constraints on entrepreneurship and facilitates the conversion of innovative knowledge into marketable products and services (Farre-Mensa et al. 2020; Nguyen et al. 2023).

The patent system creates two ex-ante incentives for firms to engage in innovation races: the prospect of monopoly rents for successful innovators and the threat of market exclusion for laggards (Kultti et al. 2006; Cappelli et al. 2023). Timely patent grants that establish clear and enforceable property rights confer competitive advantages. The green patent pre-examination program amplifies these effects by accelerating the development and commercialization of green technologies, thereby providing environmentally oriented firms with a decisive edge in the marketplace. This competitive dynamic induces a structural market shift: as green technologies advance and proliferate, pollution-intensive firms face shrinking profit margins and declining market opportunities. In response, market forces reallocate resources toward green firms, supporting their expansion while restricting the growth of more polluting competitors. This reallocation results in a decreasing market share of pollution-intensive firms and contributes to measurable reductions in harmful emissions. Ultimately, the program supports environmental improvement and promotes broader progress toward sustainable development.

However, the green patent pre-examination program's implied "early disclosure" requirement exposes innovations to competitors at an earlier stage, increasing the risk of technological infringement and raising proprietary costs (Gans et al. 2002; Kim and Valentine, 2021; Glaeser and Omartian, 2022). This heightened exposure may reduce the expected benefits of innovation commercialization and consequently diminish the program's overall effectiveness. Furthermore, the acceleration of examination processes imposes greater workloads on patent examiners, which could adversely affect patent quality (Lemley, 2001; Régibeau and Rockett, 2007; Lemley and Sampat, 2012). While the program enhances examination efficiency, it may also result in the granting of protection to inventions with limited value or technologies that limit the expansion of green firms. Such patents are unlikely to influence local market dynamics or contribute to environmental pollution reduction.

Based on the above analysis, this study proposes the hypothesis H3:

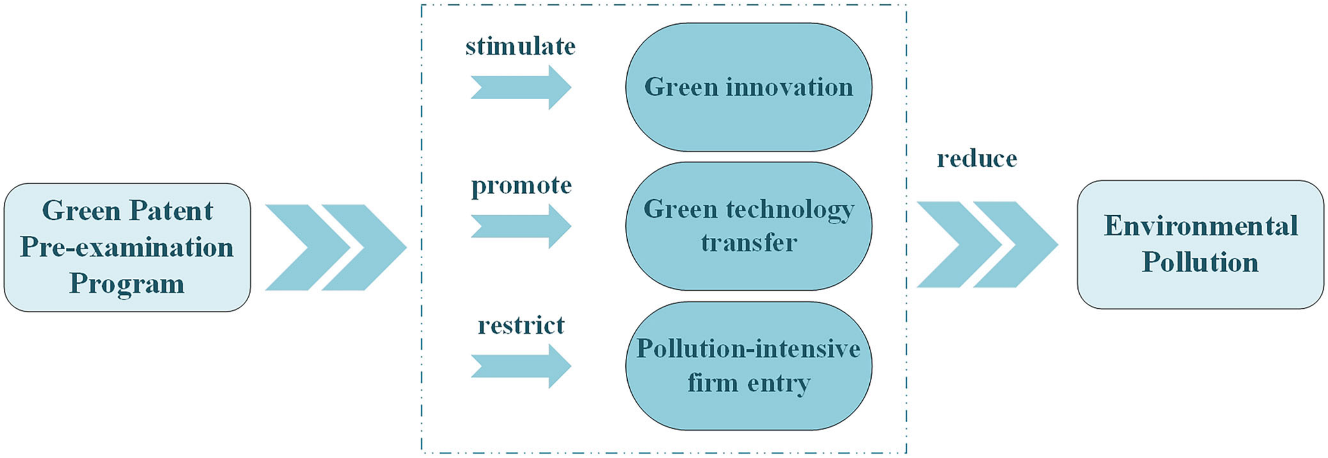

Fig. 3 Theoretical frameworks. Figure 3 illustrates the theoretical framework of this study.

Hypothesis H3: The green patent pre-examination program reduces local environmental pollution by restricting the entry of pollution-intensive firms.

In summary, the green patent pre-examination program operates through three mechanisms that jointly foster environmental improvement by stimulating green innovation, promoting green technology transfer, and restricting the entry of pollution-intensive firms. Figure 3 illustrates how the program realizes measurable pollution reductions via these three mechanisms. Nevertheless, the actual environmental impacts remain uncertain and require further empirical examination.

Research design

Empirical model. Theoretical analysis suggests that green patent pre-examination programs can alleviate local environmental pollution by accelerating the examination process for green patents filed by firms and institutions. While OLS regression using an IPPC dummy variable is a common evaluation approach, it is vulnerable to endogeneity bias (Tian and Xu, 2022). The IPPC approval process, jointly administered by local governments and the CNIPA, ensures policy exogeneity, as firms and institutions only learn about it when informed of IPPC designation following the CNIPA's official announcement. Crucially, the program creates a natural experiment with an explicit treatment group and a control group, thereby supporting the application of the DID model.

The DID model controls for trend-related confounding effects by using changes in the control group to isolate the policy's net impact (Wang and Qian, 2023). The DID estimator yields consistent estimates of the average treatment effect under the two-way fixed effects (TWFE) model, provided that the parallel trends assumption and other identifying assumptions are satisfied (Stock and Watson, 2011). Ashenfelter (1978) highlights that the DID can eliminate individual fixed effects, thereby removing the influence of time-invariant variables on outcome measurements. The methodology was formally introduced to the social sciences by Card and Krueger (1994), who analyzed the effect of a minimum wage increase in New Jersey on fast-food employment relative to Pennsylvania. Beck et al. (2010) similarly leverage the exogenous timing of bank deregulation to assess its causal impact on income distribution. More recently, Zhao and Dong (2025) use China's Broadband Strategy as an exogenous shock in a multi-period DID framework to evaluate the impact of digital infrastructure on firm innovation. The staggered timing of IPPC adoptions across cities offers multiple treatment shocks, mitigating identification challenges faced in single-shock studies, where unobserved, time-varying factors may confound results (Tian and Xu, 2022). Therefore, this study adopts a staggered DID model to identify the causal impact of the green patent pre-examination program.

The CNIPA's IPPC approval announcements disclose the eligible technology fields, which serve as positive signals to relevant industries and may stimulate green R&D investments by local firms and institutions. Accordingly, this study defines the policy implementation date as the official approval time. Cities that received IPPC approval in 2020–2021 are excluded from the analysis for two main reasons. First, the relatively short post-approval period may be insufficient to observe measurable outcomes. Second, some IPPCs approved in 2020 were not fully established during the sample period. As a result, the treatment group consists of cities granted IPPC status in 2018–2019, providing a longer observation window for evaluating the program's effects. To validate the empirical design, this study examines the trends of industrial sulfur dioxide and dust emissions between treatment and control groups. Figure 4 presents the temporal patterns, with the horizontal axis denoting years relative to the implementation of the policy. The point $t = 0$ indicates the year of implementation, highlighted by a red dashed line. The vertical axis displays the average emission levels. The solid black line represents cities in the treatment group, while the dashed black line signifies those in the control group. The figure reveals a decline in pollution emissions in treatment cities after the policy implementation, lending support to the validity of the research design.

Based on the analysis above, this study constructs the following model to assess the impact of the green patent pre-examination program on local environmental pollution:

$$Pollution_{ct} = \beta_0 + \beta_1 DID_{ct} + \theta X_{ct} + \delta_c + \omega_t + \varepsilon_{ct} \quad (1)$$

Where, c and t denote city and year, respectively. $Pollution_{ct}$ denotes the degree of environmental pollution in city c in year t, measured by industrial sulfur dioxide and industrial dust emissions. DID_{ct} is a dummy variable that equals one if a green-oriented IPPC has been approved in year t in city c and zero otherwise. X_{ct} represents a series of control variables. δ_c and ω_t are city-fixed effects and year-fixed effects, respectively. The inclusion of city-fixed effects controls for unobserved heterogeneity across cities, while year-fixed effects account for temporal shocks and nationwide trends, such as macroeconomic fluctuations. ε_{ct} is the residual term. This study focuses on the coefficient estimate β_1 in model (1). If the coefficient β_1 is significantly

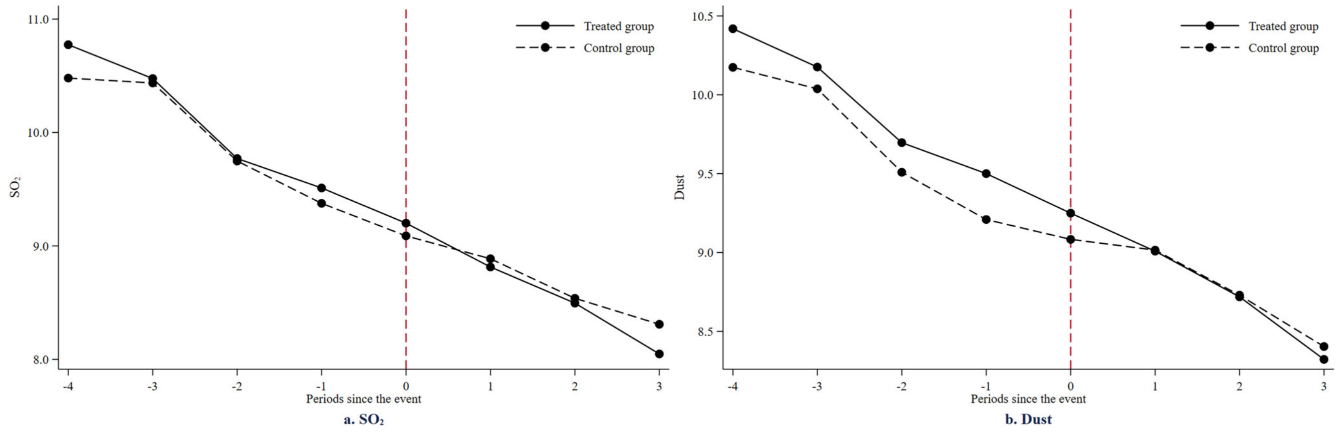

Fig. 4 Trends of local environmental pollution in the treatment and control groups. Figure 4 displays the temporal trends in the average number of industrial sulfur dioxide and dust emissions for treated and control groups. The horizontal axis represents the time relative to policy implementation, while the vertical axis indicates the annual average emission levels. A red dashed line marks the policy implementation year as a reference point for evaluating pre- and post-intervention effects.

negative, indicating that the green patent pre-examination program does reduce local environmental pollution.

Variable specification

Environmental pollution. The dependent variable in this study is local environmental pollution. Referring to related studies (Gong et al. 2024; Chi et al. 2024) and considering data availability, this study uses industrial sulfur dioxide (SO_2) and dust emissions (*Dust*) to measure the environmental pollution in the city level. Given substantial regional heterogeneity in pollution levels, this study employs the natural logarithm of industrial sulfur dioxide and dust emissions as the proxy measure for environmental pollution. Moreover, pollution emissions may also be affected by population, so this study uses per capita sulfur dioxide emissions and per capita dust emissions for further testing in the robustness section.

Green patent pre-examination program. The independent variable in this study is a dummy variable of the green patent pre-examination program. Using the IPPC approval in the green field as a natural experiment for the green patent pre-examination program, this study constructs the dummy variable *DID*. When the city is approved to establish an IPPC for new energy or energy conservation and environmental protection fields in the year, it is set to one, and otherwise zero.

Control variables. Following prior studies (Xue et al. 2021), this study controls for key factors that may influence local pollution levels. The main control variables include: (1) the level of economic development (*GDP*), measured by the logarithm of regional GDP per capita; (2) the degree of government intervention (*Gov*), measured by the ratio of government fiscal expenditure to regional GDP; (3) the level of urbanization (*Local*), measured by the proportion of the local resident population in the total resident population; (4) the level of infrastructure (*Infra*), proxied by the share of fixed asset investment in regional GDP; (5) industrial structure (*Indu2*), represented by the share of value added by the secondary industry in regional GDP. Definitions and data sources for these variables are provided in the Appendix.

Sample selection and data sources. This study employs a panel dataset of Chinese cities from 2012 to 2021 to conduct an empirical analysis. The dataset comprises four components: environmental pollution, city characteristics, firm registration, and patent information. Following relevant research (Tian and Xu, 2022; Xu et al. 2024), this study obtains data from the following official sources. Environmental pollution and city characteristics data are obtained from the *China Local Statistical Yearbook and various Regional Statistical Yearbooks*[2]. Firm registration information is sourced from the *National Enterprise Credit Information Publicity System*[3]. Patent data are drawn from the *incoPat Global Patent Database*[4]. These datasets are matched by city name and year to construct a city-year panel. Table 2 presents descriptive statistics for the main variables. The characteristics of these variables are consistent with those reported in prior studies (Xue et al. 2021; Gong et al. 2024).

Table 2 Descriptive statistics.

Variable	*N*	*Mean*	*SD*	*Min*	*Max*
SO_2	2550	9.619	1.309	0.693	13.142
Dust	2550	9.418	1.213	3.466	14.114
DID	2550	0.032	0.175	0.000	1.000
GDP	2550	10.781	0.664	9.133	13.185
Gov	2550	0.198	0.088	0.044	0.675
Local	2550	0.568	0.142	0.181	1.000
Infra	2550	0.874	0.368	0.007	2.772
Indu2	2550	0.449	0.104	0.107	0.809

Empirical results

Baseline regression. This study examines the environmental effect of the green patent pre-examination program by estimating Model (1), with results presented in Table 3. Column (1) reports the baseline specification, using the natural logarithm of industrial sulfur dioxide emissions (SO_2) as the dependent variable and controlling for city and year-fixed effects. Column (2) extends this specification by incorporating city-level control variables that may influence city pollution. Columns (3) and (4) repeat the analyses using the natural logarithm of industrial dust emissions (*Dust*) as the alternative dependent variable. Across all specifications, the estimated coefficients on the DID variable are negative and statistically significant at the 1% level, indicating that the green patent pre-examination program leads to a reduction in local pollution. Specifically, the fully controlled models in Columns (2) and (4) suggest that treated cities experienced a 24% reduction in industrial sulfur dioxide emissions and a 20%

Table 3 Baseline regression results.

	(1) SO_2	(2) SO_2	(3) Dust	(4) Dust
DID	−0.2226*** (−4.3164)	−0.2447*** (−4.5223)	−0.1874*** (−2.8371)	−0.2016*** (−2.9566)
GDP		0.0473 (0.5261)		−0.0804 (−0.7142)
Gov		−0.0955** (−2.3171)		−0.1244** (−2.1766)
Local		0.3830 (1.3498)		0.0428 (0.1399)
Infra		0.2291 (0.7734)		0.2909 (0.8057)
Indu2		0.3917 (0.8213)		0.0816 (0.1769)
Constant	9.6259*** (1056.4385)	8.8016*** (8.5001)	9.4240*** (892.9369)	10.2292*** (8.3269)
Observations	2550	2550	2550	2550
R-squared	0.8935	0.8939	0.8324	0.8328
City FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

The t-statistics are reported in parentheses based on standard errors. *, **, and * indicate significant at the 1%, 5%, and 10% levels, respectively.

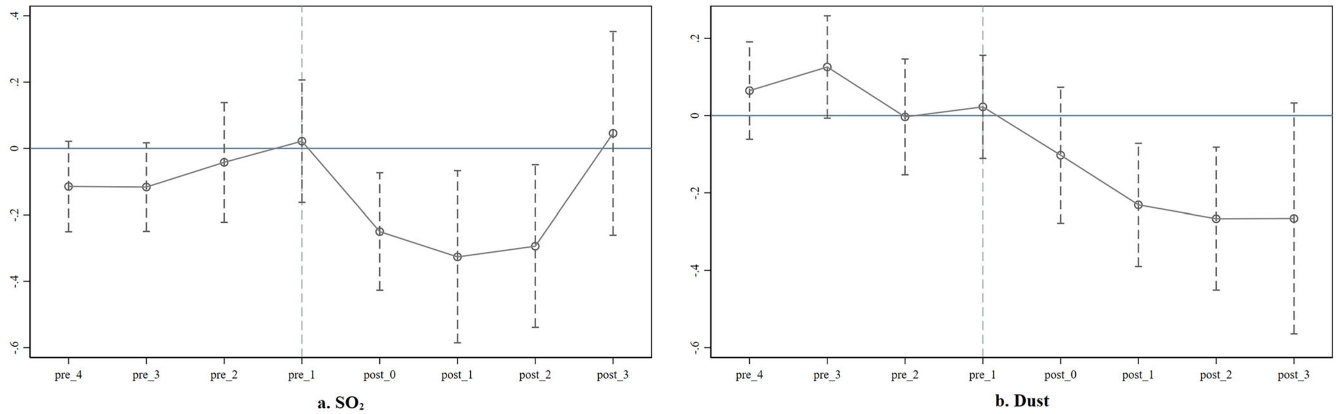

Fig. 5 Parallel trend test. Figure 5 presents the results of the parallel trend tests according to the dynamic DID model. The variable current equals 1 for the year when the city is in the treatment group and 0 otherwise. The dependent variables in (**a**) and (**b**) of Fig. 5 are industrial sulfur dioxide and dust emissions, respectively. The circles represent the estimated values of β_t, and the dashed lines indicate the 95% confidence intervals.

reduction in dust emissions, respectively, relative to the control group following policy implementation. These results reveal the program's environmental benefits and confirm its effectiveness as a pollution-reduction intervention.

Parallel trend test. The DID model relies on the validity of the parallel trends assumption, which posits that the treatment and control groups would have followed similar pre-treatment trends over time (Xu, 2023). To assess the plausibility of this assumption, this study employs an event study framework to examine the dynamic effects of the green patent pre-examination program on local environmental pollution. Specifically, we estimate the following model to evaluate the pollution trends before and after policy implementation:

$$Pollution_{ct} = \beta_0 + \sum_{t=-4}^{3} \beta_t Period_{c,t} + \theta X_{ct} + \delta_c + \omega_t + \varepsilon_{ct} \quad (2)$$

In model (2), $Period_{c,t}$ denotes a set of dummy variables indicating the number of years relative to the implementation of the green patent pre-examination program in city c. For example, $Period_{c,-4}$ equals one if year t is four years prior to the approval of an IPPC in city c, and zero otherwise. The definitions of the remaining variables are consistent with those in model (1).

Figure 5 presents the dynamic treatment effects estimated from the model (2), illustrating the coefficient estimates over an eight-year window centered around the IPPC approval year. Panels (a) and (b) display the results for industrial sulfur dioxide and dust emissions, respectively, with 95% confidence intervals represented by dashed lines. The figure indicates that the pre-treatment coefficients are statistically indistinguishable from zero for both dependent variables, supporting the validity of the parallel trend assumption. Moreover, statistically significant reductions in emissions are observed in the post-treatment period, indicating that the green patent pre-examination program mitigates local industrial pollution.

Robustness test

Propensity score matching. While the baseline staggered DID model provides preliminary evidence of the green patent pre-examination program's environmental effects and helps mitigate endogeneity concerns, potential selection bias remains a threat to causal identification. Specifically, regional heterogeneity across Chinese cities may lead to systematic differences between treated and control groups, potentially confounding the estimated policy effects. To address this concern, this study implements a PSM-DID model, following the methodological frameworks of Heckman (1976). This strategy first matches treatment and control cities based on pre-treatment observable characteristics and then applies the DID model to the matched sample, thereby improving the comparability of treatment and control groups.

Using the control variables from the baseline specification as covariates, this study estimates propensity scores through a logit model. Following established practices (Truex, 2014), this study employs pre-policy city-level characteristics to minimize differences between treated and control cities before program implementation. Given the relatively large control group, this study implements nearest-neighbor matching with a 1:5 ratio based on the estimated propensity scores. To validate the quality of matching, this study conducts balance tests. As shown in Table 4, balancing tests reveal no statistical differences in covariates between the matched treatment and control groups. Additionally, Fig. 6 illustrates a reduction in standardized mean differences after matching, indicating improved covariate balance and supporting the validity of the matching.

To further verify the robustness of the findings, this study re-estimates the effect of the green patent pre-examination program on environmental pollution using the model (1) within the PSM sample. The regression results are presented in Table 5. Columns (1) and (2) show estimates that are consistent with those from the baseline regression, reinforcing the conclusion that the green patent pre-examination program reduces local environmental pollution.

Table 4 Balance test.

Variable	*Treated*	*Control*	*Diff.*	*t-test*	*P-value*
GDP	11.133	11.107	0.026	0.14	0.889
Gov	0.174	0.164	0.010	0.56	0.580
Local	0.622	0.613	0.009	0.24	0.814
Infra	0.817	0.874	−0.057	−0.69	0.493
Indu2	0.436	0.451	−0.015	−0.71	0.484

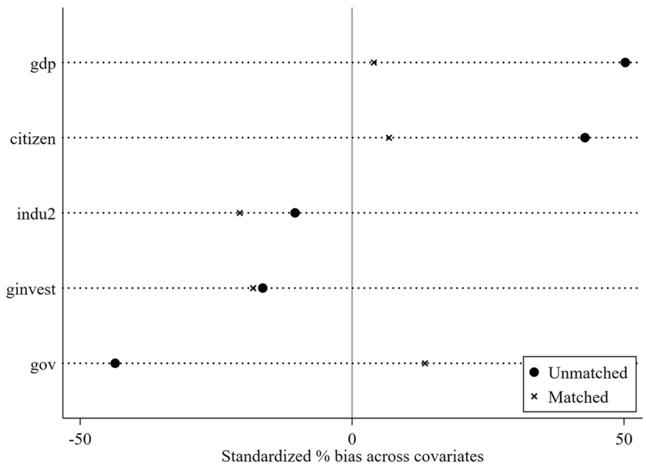

Fig. 6 Balance test. This figure is the balance test of covariates after matching using the PSM method. The black circles represent the standardized mean deviation of covariates before matching, while the black crosses indicate the standardized mean deviation of covariates after matching. The gray solid line indicates a standardized mean deviation of zero.

Replace the dependent variable. To address potential scale effects arising from population differences, this study conducts additional analyses using per capita industrial emissions as alternative dependent variables. The regression results are shown in columns (3) and (4) of Table 5, where the regression coefficients of the dummy variables are significantly negative at the 1% level, consistent with the baseline results. To further evaluate the program's broader environmental impact, the study also examines its effects on other pollution indicators, specifically per capita PM2.5 concentrations (*PM*) and carbon emissions (*Carbon*). As shown in columns (5) and (6), the estimated coefficients remain negative, suggesting that the green patent pre-examination program yields environmental benefits. The robustness of these results across multiple specifications underscores the program's effectiveness in reducing various forms of local pollution.

Placebo test. To assess the potential bias from unobserved variables, this study conducts a placebo test using randomized sampling, following the approach of La Ferrara et al. (2012). The methodology involves randomly selecting a pseudo-treated group matching the same number of actual pilot cities and then re-estimating the model (1) through 500 iterations. Figure 7 displays the distribution of the estimated coefficients and corresponding p-values from these simulations. The figure demonstrates two key findings: first, the estimated coefficients are centered around zero, and second, the majority of p-values are statistically insignificant. These results suggest that the baseline estimates are unlikely to be driven by omitted variable bias, thereby reinforcing the validity of the study's identification strategy.

Exclude other policy interferences. To effectively address potential confounding factors arising from concurrent environmental policies, this study employs two robust strategies: (1) incorporating indicators of policy implementation as control variables, and (2) excluding cities impacted by these policies. The first set of analyses accounts for the carbon emissions trading policy. Specifically, columns (1) and (2) of Table 6 control for its implementation using a dummy variable, while columns (3)-(4) exclude pilot cities entirely. In both cases, the treatment effect remains negative and statistically significant. Similar robustness is observed when controlling for three additional environmental initiatives: low-carbon city policies (columns 5–8), new energy city programs (columns 9–12), and innovative city initiatives (columns 13–16). The consistency of results across all specifications confirms that the observed environmental effects of the green patent pre-examination program are not confounded by other policies.

Table 5 PSM-DID and replace the dependent variable.

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
	***SO*$_2$**	***Dust***	***SO*$_2$*_2***	***Dust_2***	***PM***	***Carbon***
DID	−0.2431*** (−3.6924)	−0.1818** (−2.3540)	−0.2826*** (−5.1102)	−0.2395*** (−3.6304)	−0.1250*** (−9.4072)	−0.0410*** (−3.8171)
Constant	15.1949* (7.7778)	13.4003* (6.5026)	1.2698 (1.1755)	2.6974** (2.2407)	6.7272*** (19.3041)	0.2644 (0.7710)
Observations	1030	1030	2550	2550	2550	2520
R-squared	0.8902	0.8465	0.8992	0.8570	0.9890	0.9821
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes

The t-statistics are reported in parentheses based on standard errors. *, **, and * indicate significant at the 1%, 5%, and 10% levels, respectively.

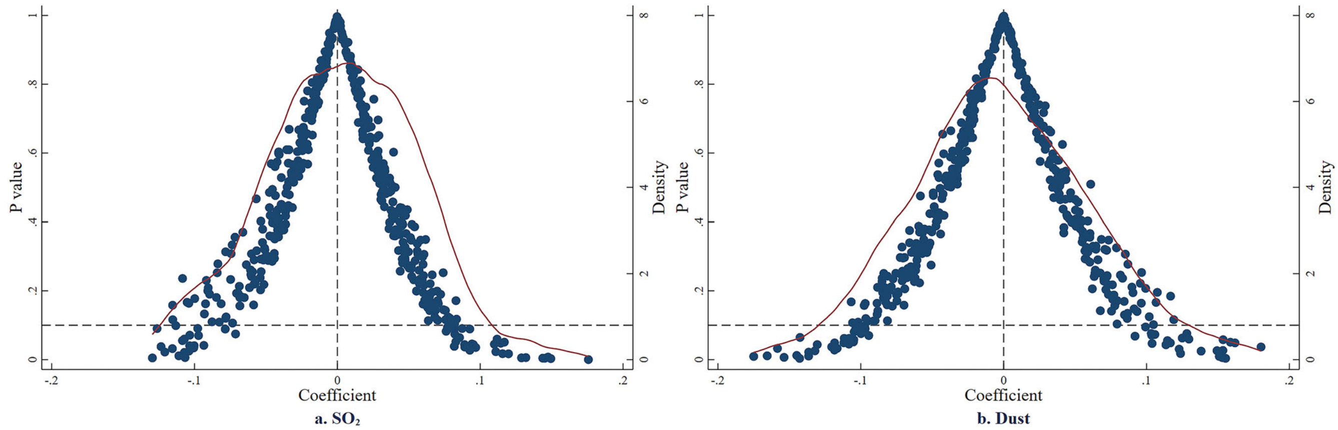

Fig. 7 Placebo test. The figure shows the distribution of coefficients and P-values obtained from 500 estimations, where we randomly select pilot cities and re-estimate Model (1). The dependent variables in (**a**) and (**b**) are industrial sulfur dioxide and dust emissions, respectively.

Table 6 Exclude other policy interferences.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	SO_2	**Dust**	**SO_2**	**Dust**	**SO_2**	**Dust**	**SO_2**	**Dust**
DID	−0.2492***	−0.2011***	−0.2828***	−0.2534***	−0.2550***	−0.2049***	−0.1957**	−0.2959***
	(−4.5949)	(−2.9471)	(−5.0467)	(−3.8389)	(−4.7344)	(−3.0004)	(−2.5550)	(−3.2421)
DID_T	−0.1841**	0.0202						
	(−2.5057)	(0.1715)						
DID_C					0.2070***	0.0666		
					(4.8529)	(1.0255)		
Constant	8.7709***	10.2325***	8.4138***	9.8842***	8.8743***	10.2526***	10.8594***	12.7988***
	(8.4515)	(8.3363)	(8.1219)	(7.9078)	(8.5350)	(8.3454)	(7.7515)	(7.8241)
Observations	2550	2550	2190	2190	2550	2550	1380	1380
R-squared	0.8941	0.8328	0.8928	0.8298	0.8945	0.8329	0.8907	0.8282
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	(9)	**(10)**	**(11)**	**(12)**	**(13)**	**(14)**	**(15)**	**(16)**
	SO_2	**Dust**	**SO_2**	**Dust**	**SO_2**	**Dust**	**SO_2**	**Dust**
DID	−0.2376*	−0.1990*	−0.2850*	−0.3312*	−0.2416*	−0.1991*	−0.2843*	−0.1248
	(−4.3981)	(−2.9235)	(−4.1678)	(−5.1129)	(−4.4650)	(−2.9196)	(−3.8852)	(−1.4213)
DID_N	−0.1450*	−0.0536						
	(−2.8895)	(−0.8360)						
DID_Z					0.1089*	0.0904		
					(1.7571)	(1.1821)		
Constant	8.7976*	10.2277*	8.1047*	8.7376*	8.8594*	10.2771*	7.1545*	9.1099*
	(8.5168)	(8.3220)	(6.7989)	(6.6811)	(8.5488)	(8.3504)	(5.5190)	(6.2558)
Observations	2550	2550	1990	1990	2550	2550	1660	1660
R-squared	0.8942	0.8329	0.8922	0.8429	0.8941	0.8330	0.8888	0.8454
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

The t-statistics are reported in parentheses based on standard errors. *, **, and * indicate significant at the 1%, 5%, and 10% levels, respectively.

Change the research sample. To extend the baseline analysis, which includes only cities approved for IPPC construction in 2018 and 2019, this section incorporates cities approved in 2020. Columns (1)-(2) of Table 7 present the regression results with these additional cities included, showing consistently negative and statistically significant coefficients that align with the baseline findings. To further explore potential heterogeneity, columns (3)-(8) report separate estimates by approval years. The results reveal a clear temporal pattern: cities approved in 2018 and 2019 exhibit significant reductions in pollution (columns (3)-(6)), whereas those approved in 2020 show no statistically significant effects (columns (7)-(8)). This lack of significance likely reflects the limited time for policy implementation and the realization of environmental outcomes during the sample period for the 2020 cohort.

Heterogeneous treatment effects. Recent developments in applied econometrics have raised important concerns about heterogeneous treatment effects in TWFE models, particularly in the staggered DID model (Xu, 2023). In such models, earlier-treated units may serve as controls for later-treated ones, potentially violating the parallel trends assumption and leading to biased estimates (Sun and

Table 7 Change the research sample.

	(1) SO_2	(2) Dust	(3) SO_2	(4) Dust	(5) SO_2	(6) Dust	(7) SO_2	(8) Dust
DID	−0.1808***	−0.1328*	−0.2635***	0.0429	−0.2254***	−0.5133***	−0.0893	−0.0456
	(−3.2681)	(−1.8795)	(−3.8476)	(0.5133)	(−2.8149)	(−5.5825)	(−0.8882)	(−0.3515)
Constant	8.6873***	10.3882***	8.3487***	10.2014***	8.5383***	9.5057***	7.9531***	9.5402***
	(8.5598)	(8.3676)	(7.8259)	(8.1537)	(8.0670)	(7.8236)	(7.4480)	(7.5336)
Observations	2790	2790	2440	2440	2430	2430	2560	2560
R-squared	0.8899	0.8234	0.8911	0.8246	0.8916	0.8310	0.8848	0.8124
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

The t-statistics are reported in parentheses based on standard errors. *, **, and * indicate significant at the 1%, 5%, and 10% levels, respectively.

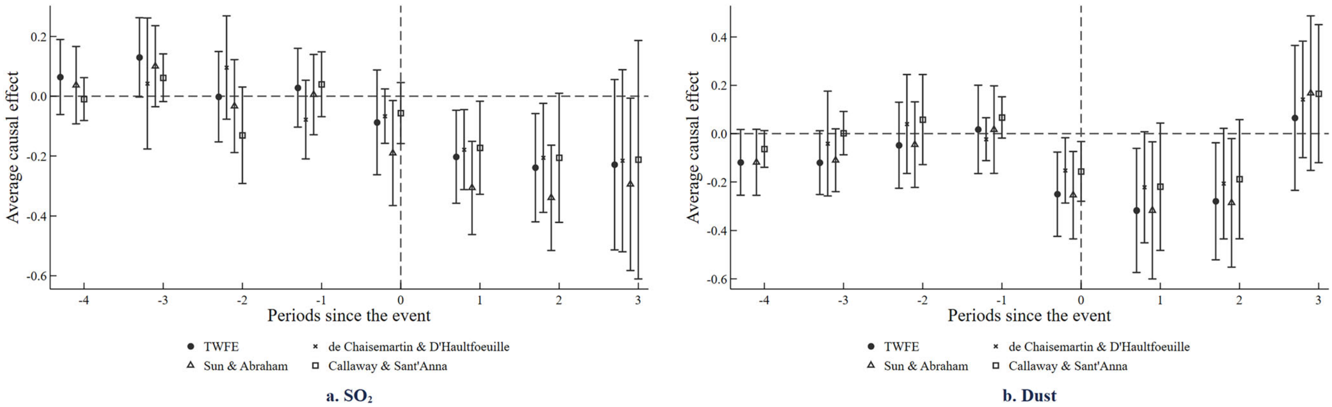

Fig. 8 Heterogeneous treatment effects. Fig. 8 displays the event study results using the heterogeneity robust estimation approach, referring to previous literature (De Chaisemartin & D'Haultfoeuille, 2024; Sun and Abraham, 2021; Callaway and Sant'Anna, 2021). The dependent variables in (**a**) and (**b**) are industrial sulfur dioxide and dust emissions, respectively. The dashed lines indicate the 90% confidence intervals.

Abraham, 2021). To address this issue, this study adopts a heterogeneity-robust estimation framework following recent methodological advances (De Chaisemartin and D'Haultfœuille, 2024; Sun and Abraham, 2021; Callaway and Sant'Anna, 2021). Specifically, we estimate group-time average treatment effects, which account for variation in treatment timing and effect heterogeneity across cohorts and periods. Figure 8 presents the event study estimates derived from this robust approach. The results confirm the presence of parallel pre-treatment trends and demonstrate consistent post-treatment effects, thereby reinforcing the robustness of our baseline findings.

Mechanism test. Having established the effectiveness of the green patent pre-examination program in reducing pollution, this study proceeds to investigate the underlying mechanisms. Theoretical frameworks suggest that the program may improve environmental quality through three primary channels: (1) the promotion of green innovation, (2) the acceleration of green technology transfer, and (3) the reduction of entry by pollution-intensive firms. To empirically examine these hypothesized pathways, the study adopts the following model specification:

$$M_{ct} = \beta_0 + \beta_1 DID_{ct} + \theta X_{ct} + \delta_c + \omega_t + \varepsilon_{ct} \tag{3}$$

Where, M_{ct} is the mechanism variable, including the number of green patent, the number of green technology transfer, and pollution-intensive firm entry numbers and rates. The remaining variables are consistent with model (1).

Stimulating green innovation. The green patent pre-examination program facilitates the accelerated protection of green technologies, potentially stimulating green innovation. To assess this mechanism, this study investigates the program's impact on green innovation by using the number of green patents as the key explanatory variable, following Wagner (2007). Green patents are identified using three complementary approaches. First, patents are classified according to the WIPO *International Green Patent Classifications* using IPC codes obtained from the CNRDS database. Second, a sector-based classification is applied to identify patents related to clean energy and cleaner production industries, based on the *Industrial Classification for National Economic Activities in China*, using data from the incoPat database. This study focuses on invention patent applications and grants, which reflect more original and sophisticated innovations (Tian and Xu, 2022). The mechanism variable is constructed by taking the natural logarithm of one plus the annual count of city-level patent applications in year t.

The innovation effects of the green patent pre-examination program are presented in Table 8. The results show that the program significantly increases the number of green invention patent applications across all classification methods, namely, the WIPO's IPC Green Inventory and sector-based definitions for clean energy and cleaner production industries (columns (1)-(3)). Although the absolute number of granted green invention patents does not exhibit a statistically significant change (columns (4)-(6)), the program notably enhances the quality composition of green patents, as evidenced by a significant increase in the proportion of green invention patents among total patent grants (columns (7)-(9)). Collectively, these findings suggest that the

Table 8 Stimulating green innovation.

	(1) *Apply_WIPO*	(2) *Apply_energy*	(3) *Apply_product*	(4) *Grant_WIPO*	(5) *Grant_energy*
DID	0.2834*** (6.6635)	0.1708*** (4.4127)	0.0861** (2.1565)	0.4153*** (8.0819)	−0.0106 (−0.2702)
Constant	0.6716 (0.7339)	0.6296 (0.7461)	0.0540 (0.0558)	0.1923 (0.1767)	0.8332 (0.9295)
Observations	2550	2550	2550	2550	2550
R-squared	0.9431	0.9556	0.9479	0.9313	0.9607
Controls	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes

	(6) *Grant_product*	(7) *Grantp_WIPO*	(8) *Grantp_energe*	(9) *Grantp_product*
DID	−0.0170 (−0.4358)	0.0518* (6.2289)	0.0192* (3.5203)	0.0344* (3.2892)
Constant	0.5531 (0.5631)	0.1011 (0.5216)	0.1295 (0.9915)	0.5615** (2.0608)
Observations	2550	2548	2550	2549
R-squared	0.9536	0.4577	0.7077	0.6621
Controls	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

The t-statistics are reported in parentheses based on standard errors. *, **, and * indicate significant at the 1%, 5%, and 10% levels, respectively.

pre-examination program promotes the development of green technologies and improves the quality of innovative outputs, offering empirical support for Hypothesis H1.

Promoting green technology transfer. Patent transfers are a central component of technology commercialization (Liu et al. 2022). When a granted patent exhibits commercial potential, it is often acquired by another entity from the original inventor or owner (Maurseth and Svensson, 2020). The green patent pre-examination program may facilitate this commercialization process by expediting the transfer of green technologies through shortened examination periods. To empirically assess this mechanism, this study utilizes green patent transfer data identified through three complementary classification approaches: the WIPO International Green Patent Classification, patents associated with the clean energy sector, and patents linked to cleaner production industries.

Model (3) examines technology transfer effects by using the natural logarithm of one plus the number of city-level green patent transfers as the dependent variable. Column (1) examines transfers of green patent grants identified based on the WIPO Green Patent Classification, while columns (2) and (3) focus on patents related to the clean energy and cleaner production sectors, respectively. The regression results in Table 9 demonstrate positive coefficients for the DID dummy variable across all specifications, revealing that program implementation increased green technology transfers in treatment cities relative to control cities. This enhanced commercialization of green innovations facilitates the practical application of environmental technologies and contributes to the observed reductions in pollution levels. These consistent findings provide empirical support for Hypothesis H2, which posits that the program improves environmental quality through the green technology transfer channel.

Table 9 Promoting green technology transfer.

	(1) *Grant_WIPO_zr*	(2) *Grant_energy_zr*	(3) *Grant_product_zr*
DID	0.3724* (5.2426)	0.2263*** (3.5907)	0.2585*** (3.9116)
Constant	−2.1285 (−1.4946)	−5.4727*** (−3.6451)	−1.4973 (−1.0177)
Observations	2550	2550	2540
R-squared	0.8875	0.9074	0.8914
Controls	Yes	Yes	Yes
City FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes

The t-statistics are reported in parentheses based on standard errors. *, **, and * indicate significant at the 1%, 5%, and 10% levels, respectively.

Restricting pollution-intensive firm entry. The theoretical framework posits that the green patent pre-examination program may support the development of green firms while simultaneously deterring the entry of pollution-intensive firms. This mechanism is empirically tested using data on the registration of polluting firms. First, medium- and heavy-polluting industries are identified based on the *Classification Guidelines for Environmentally Friendly Verification of Listed Companies* issued by China's Ministry of Environmental Protection. Second, firm registration records are screened according to this classification to identify firms operating within these polluting sectors. Third, the number of registered medium- and heavy-polluting firms is aggregated at the city level. Model (3) is re-estimated using two alternative dependent variables: the number and the proportion of pollution-intensive firms. The corresponding regression results are presented in Table 10.

Columns (1)-(3) of Table 10 regression results using the natural logarithm of one plus the number of registered medium-polluting, heavy-polluting, and all pollution-intensive firms at the city level as dependent variables. Columns (4)-(6) present corresponding results based on the proportion of these firms relative to total firm registrations. Across all specifications, the estimated coefficients for the treatment variable are significant and negative, indicating that pilot cities experienced reductions in both the absolute number and relative share of newly registered pollution-intensive firms following program implementation, compared to non-pilot cities. These findings provide support for Hypothesis H3.

Table 10 Restricting pollution-intensive firm entry.

	(1) *Pollu_firm1*	(2) *Pollu_firm2*	(3) *Pollu_firm3*	(4) *Pollu_firm4*	(5) *Pollu_firm5*	(6) *Pollu_firm6*
DID	−0.1653*** (−2.7973)	−0.1817*** (−4.4347)	−0.1813*** (−4.4293)	−0.0061*** (−5.8783)	−0.0149*** (−6.9098)	−0.0210*** (−7.4548)
Constant	2.8464* (3.3059)	4.9337* (7.5072)	4.7917* (7.6841)	−0.0326* (−2.8046)	0.0382 (1.3779)	0.0056 (0.1591)
Observations	2520	2520	2520	2520	2520	2520
R-squared	0.9380	0.9278	0.9393	0.9096	0.8161	0.8520
Controls	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes

The t-statistics are reported in parentheses based on standard errors. *, **, and * indicate significant at the 1%, 5%, and 10% levels, respectively.

Heterogeneity analysis

Heterogeneity of technology exchange market. The development of green technology through either internal R&D or external technology transfer constitutes distinct mechanisms for achieving pollution reduction. The effectiveness of the green patent pre-examination program may thus be conditioned by the maturity of the local technology exchange market. On the one hand, the program's pollution reduction effects may be amplified in developed technology markets through enhanced technology exchange. Well-developed exchange platforms facilitate green technology transfers following patent grants, making the program's environmental benefits more immediately observable. On the other hand, in regions with less developed technology markets, firms may face constraints in acquiring external technologies. In such contexts, the expedited examination process may encourage firms to engage in green innovation as a substitute for external acquisition.

The analysis examines whether the effectiveness of the green patent pre-examination program varies with the development level of regional technology exchange markets. Regions are classified into developed and developing market categories based on regional technology transaction volumes. Panel A of Table 11 reveals that the program demonstrates more substantial pollution reduction effects in regions with developing technology markets, suggesting it substitutes for underdeveloped markets by stimulating direct R&D investment. Additionally, the between-group difference confirms heterogeneity in treatment effects across market types. The findings indicate that the program's design proves particularly valuable for environmental improvement in regions lacking robust technology exchange infrastructure. These results support a substitution mechanism in which expedited patent examination lowers the costs and risks of innovation appropriation, thereby incentivizing firms to internalize green technology development.

Heterogeneity of intellectual property protection. The green patent pre-examination program represents a significant and innovative exploration in the intellectual property protection policy. In addition to patents, inventors may utilize other intellectual property protection ways to protect their technology. Therefore, the effectiveness of a green patent pre-examination program may depend on the broader institutional environment, particularly the strength of local IP protection systems. Regions with stronger intellectual property regimes signal more effective governmental enforcement against technological misappropriation. To examine this potential moderating effect, this study classifies cities into high and low intellectual property protection groups based on the Intellectual Property Protection Index reported in the *National Report on the Status of Intellectual Property Development*.

Table 11 Heterogeneity analysis.

	(1) SO_2 high	(2) SO_2 low	(3) *Dust* high	(4) *Dust* low
Panel A: Heterogeneity of technology market development				
DID	0.0422 (0.1295)	−0.3079*** (−3.7314)	1.2662*** (2.6748)	−0.5508*** (−5.5340)
Constant	10.0860*** (4.4318)	8.9340*** (6.9489)	4.2333* (1.8067)	12.2123*** (7.2661)
Observations	896	1637	896	1637
R-squared	0.9103	0.8949	0.8536	0.8315
Controls	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
	(5) SO_2 high	(6) SO_2 low	(7) *Dust* high	(8) *Dust* low
Panel B: Heterogeneity of intellectual property protection				
DID	−0.1345* (−1.8692)	−0.4059* (−4.0976)	0.1322 (1.4611)	−0.7699* (−6.3371)
Constant	8.2741* (4.6405)	6.0410* (4.8548)	14.3685* (8.4067)	6.5839* (3.8688)
Observations	1228	1311	1228	1311
R-squared	0.9133	0.9011	0.8738	0.8286
Controls	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
	(9) SO_2 high	(10) SO_2 low	(11) *Dust* high	(12) *Dust* low
Panel C: Heterogeneity of institutional environment				
DID	−0.1694** (−2.4314)	−0.2735* (−3.1793)	0.1520* (1.6612)	−0.6025* (−5.6510)
Constant	8.5384* (5.8450)	12.3915* (7.7980)	12.6270* (7.1550)	11.3141* (5.2140)
Observations	1237	1300	1237	1300
R-squared	0.9158	0.8868	0.8794	0.8171
Controls	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

The t-statistics are reported in parentheses based on standard errors. *, **, and * indicate significant at the 1%, 5%, and 10% levels, respectively.

The results in Panel B of Table 11 show that the green patent pre-examination program significantly impacts regions with a lower intensity of intellectual property protection. Furthermore, tests for coefficient differences between the high and low intellectual property protection groups, show that the differences between groups are 0.271 (columns (5)-(6)) and 0.902 (columns (7)-(8)), both statistically significant at the 1% level. These findings suggest that the program's expedited examination process and institutional enforcement mechanisms serve as substitutes for underdeveloped intellectual property systems. By lowering the risks of infringement and providing quicker resolution regarding technology ownership, the program enhances the appropriability of innovation returns.

Heterogeneity of institutional environment. The green patent pre-examination program constitutes an important institutional innovation within the realm of intellectual property protection. Strengthening local institutional frameworks enhances intellectual property enforcement and facilitates the growth of market intermediary organizations. Given the principle of diminishing marginal returns to policy interventions, the program's environmental benefits may be more pronounced in regions with comparatively weaker institutional environments. Accordingly, this study investigates how regional institutional quality moderates the program's pollution reduction effects, shedding light on the interplay between intellectual property policy reforms and local institutional conditions.

Specifically, this study utilizes the marketization index from the *Marketization Index of China's Provinces: NERI Report* to evaluate regional institutional environments. Based on the annual mean values of this index, regions are categorized into high- and low-marketization groups to explore heterogeneous policy effects across differing institutional contexts. The regression results, reported in Panel C of Table 11, indicate that the green patent pre-examination program exerts a more pronounced pollution reduction effect in cities with lower levels of marketization. Tests comparing the coefficient differences between high and low marketization groups indicate that the differences between these groups are 0.104 (columns (9)-(10)) and 0.754 (columns (11)-(12)). Both results are statistically significant at the 5% level. The results imply that targeted intellectual property policy reforms can function as institutional substitutes in less developed market environments, offering dual benefits of environmental improvement and market framework enhancement.

Discussion

This study provides empirical evidence that the green patent pre-examination program reduces environmental pollution in pilot cities, supporting a causal relationship. The findings are consistent with prior literature (Dechezleprêtre, 2013; Lu, 2013; Kuhn and Teodorescu, 2021; Liu et al. 2023). Notably, Xu et al. (2024) show that a one-percentage-point increase in fast-track program intensity leads to reductions in carbon dioxide and sulfur dioxide emissions by 1.15% and 0.12%, respectively. In comparison, the current analysis reveals even greater environmental improvements, with pilot cities showing significant declines in industrial sulfur dioxide and dust emissions compared to control cities. These amplified effects may be attributed to the program's distinctive institutional design, which decentralizes patent examination authority and empowers local governments. This structure also strengthens incentives for promoting green innovation and accelerating industrial upgrading. Overall, the findings suggest that the green patent pre-examination program constitutes a more effective policy instrument for simultaneously advancing environmental protection and high-quality economic development through the patent system.

This study contributes to the debate regarding the effectiveness and optimal design of patent policy, particularly its role in promoting green innovation. The literature remains divided on whether patent protection fosters or hinders innovation. On the one hand, patent policy may incentivize the development of renewable energy technologies, thereby driving progress in clean energy (Qiu and Wang, 2018). On the other hand, it may impose barriers to innovation and impede technology diffusion by restricting follow-on inventions (Bessen and Meurer, 2008). Works by Arrow (1962) and Galasso and Schankerman (2015) highlight the patent policy's potential to stimulate innovative activity. More recently, Zhang et al. (2024) provide empirical evidence that fast-tracking patent applications enhances firm innovation. The positive impacts of the green patent pre-examination program on green innovation and technology transfer support this view. However, these findings stand in contrast to recent claims that stronger intellectual property rights may suppress renewable energy consumption (Alexiou, 2023), underscoring the complexity of the relationship between patent policy and green technological progress.

The findings reveal a positive relationship between green innovation and sustainable development. Specifically, the green patent pre-examination program enhances environmental outcomes through three main channels: fostering green innovation, accelerating the transfer of green technologies, and deterring the entry of pollution-intensive firms. These empirical results lend support to the theory advanced by Romer (1990), Rennings (2000), and Brock and Taylor (2010), which argues that appropriately designed patent policies can advance economic growth and environmental sustainability. Moreover, this study aligns with a growing body of technological research that underscores the emission reduction potential of various green technologies (Sarkar et al. 2019; Habib et al. 2021; Sarkar et al. 2022b; Guchhait et al. 2024; Sarkar et al. 2025a). By investigating the program's effects through multiple mechanisms, this research offers new insights into how intellectual property policy can serve as a powerful instrument for driving green technological innovation and achieving environmental improvement goals.

Conclusion

Main findings. This study focused on China's green patent pre-examination program and its impact on local environmental pollution. Based on city-level data from 2012 to 2021, the staggered DID model was constructed for empirical analysis. This study yielded three key findings: First, the program significantly reduced industrial pollution, as evidenced by declines in sulfur dioxide and dust emissions in treated cities relative to control cities, confirming its effectiveness in achieving environmental goals. To ensure the robustness of these results, the analysis incorporates several complementary strategies. The PSM-DID approach addressed potential sample selection bias; heterogeneity-robust models accounted for variation in treatment timing and effect; and placebo tests alongside alternative specifications validated the credibility of the results. The consistent findings across these robustness checks affirmed both the credibility of the estimated effects and the reliability of the empirical strategy.

Second, the mechanism test revealed that the program could increase the number of green patent applications, enhance the number of green patent transfers, and reduce the registration numbers of pollution-intensive firms. These mechanisms collectively contributed to the observed reduction in environmental pollution. Given the importance of technological progress and industry updates on economic growth, the findings suggest that the program also supports broader goals of sustainable development. Finally, the effects exhibited meaningful heterogeneity across cities, with more significant impacts observed in regions characterized by developing technology markets, weaker intellectual property protection, and undeveloped market institutions. This pattern suggested that the program's accelerated examination process can serve as an effective institutional substitute in contexts where traditional innovation incentives are insufficient.

Managerial insights. This study demonstrates that the green patent pre-examination program contributes to environmental protection and sustainable development. The findings may offer valuable practical guidance for policymakers and firm managers.

First, governments should accelerate patent policy reforms aimed at establishing efficient examination systems for green technologies, including pre-examination mechanisms and accelerated review channels. Concurrently, strengthening intellectual property enforcement through enhanced coordination among protection agencies, specialized legal provisions for green technologies, and deterrent-level penalties for infringement would improve returns on green innovation investments. Given the program's dual function of promoting environmental protection and institutional development, policymakers should prioritize the implementation of such measures in regions with underdeveloped innovation ecosystems to maximize environmental gains and foster broader institutional progress.

Second, establishing an effective green technology exchange market is critical to facilitate the commercialization and diffusion of innovations. Simultaneously, improving the evaluation mechanisms for green technologies is crucial to ensure a comprehensive and accurate assessment of their value and actual contributions to economic and social development. Strengthening both market infrastructure and evaluation standards will accelerate the practical application of green technologies and support the transition toward a more sustainable economy.

Third, policymakers should provide targeted support for firms engaged in R&D within key environmental sectors, such as renewable energy, energy efficiency, and pollution-control technologies. Concurrently, firms are encouraged to actively leverage the green patent pre-examination program's accelerated protection mechanisms to secure early-stage intellectual property rights and enhance their competitive positioning. Coordinated policy incentives and proactive firm participation can foster a virtuous cycle that advances environmental sustainability and generates economic value.

Limitations. There are three main limitations in this study. First, the recent implementation of the green patent pre-examination program may obscure its long-term effects, potentially introducing temporal bias in the estimated effects. In particular, the shorter post-treatment observation window for later-adopting cities may constrain the generalizability of the findings. Second, while the analysis demonstrates the program's environmental benefits through green innovation and industrial composition changes, it does not account for heterogeneity across specific green technology categories or firm-level behavioral responses to the policy. These micro-level mechanisms remain underexplored. Third, due to data limitations, the analysis does not incorporate the significant resource inputs required for IPPC establishment, thereby precluding a full cost-benefit assessment. As a result, the study cannot offer a comprehensive evaluation of the program's net social welfare.

Future scope. Understanding the effects of the green patent pre-examination program is critical for aligning innovation incentives with environmental protection and economic development goals. Given the limitations of this study, future research can expand its contributions in several key areas. First, extended longitudinal analyses are needed to capture the program's long-term effects and assess whether observed benefits persist or evolve. Second, future work should investigate the broader economic implications of this institutional innovation, particularly its influence on entrepreneurial activity and the commercialization of green technologies. Third, comprehensive cost-benefit analyses that incorporate the substantial infrastructure and operational costs of program implementation and its environmental and economic benefits would provide policymakers with more valuable information for decision-making. Additionally, comparative studies examining similar fast-track examination systems in other countries could identify best practices and provide valuable lessons for optimizing policy design.

Data availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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Notes

1 In the U.S., patent grants typically require 3–4 years (Lemley & Sampat, 2012; Shu et al., 2022).
2 https://www.stats.gov.cn.
3 https://www.gsxt.gov.cn.
4 https://www.incopat.com.

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Competing interests

The authors declare no competing interests.

Ethical approval

The study does not involve human participants or their data.

Informed consent

The study does not involve human participants or their data.

Additional information

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