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Green Technology Innovation under China's New Development Concept: The Effects of Policy-Push and Demand-Pull on Renewable Energy Innovation*

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Abstract

Green technology innovation meets the dual expectation of innovative development and green development perspectives. Under the canonical demand-pull and policy-push theories, a long-term mechanism for green technology innovation could be formed through upstream policy push and downstream demand-pull. Leveraging China's regional carbon emission trading scheme pilots as a quasi-natural experiment, this paper examines the policy-push and demand-pull effects on innovation in renewable energy patents. The data pertain to the city-level renewable energy patents from 2000 to 2020. Based upon the triple difference-in-difference method, results suggest that both policy-push and demand-pull factors exert positive effects on innovation. This paper further explores the practical and theoretical implications of green technology innovation under the new development perspective.

Keywords: new development perspective, green technology innovation, demand pull, policy push, carbon emission trading

I. Introduction

Since economic reform and opening, China has created a miracle of long-term rapid economic growth, providing a solid foundation for achieving the target of building a moderately

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prosperous society in all respects. Looking back, China's traditional economic development model raises a controversial issue, the long-standing "GDP cult." Economic development goals focus heavily on economic output but turn a blind eye to environmental degradation and natural resource depletion, leading to a long-term contradiction between economic growth and green development. Taking CO_2 emissions as an example, the latest report by the World Resources Institute (WRI) suggests that China's carbon emissions have increased dramatically from 2.89 billion tons in 1990 to 12.06 billion tons in 2019. Such a drastic increase poses a daunting challenge to meeting the carbon peak and neutrality goals while achieving green economic development.

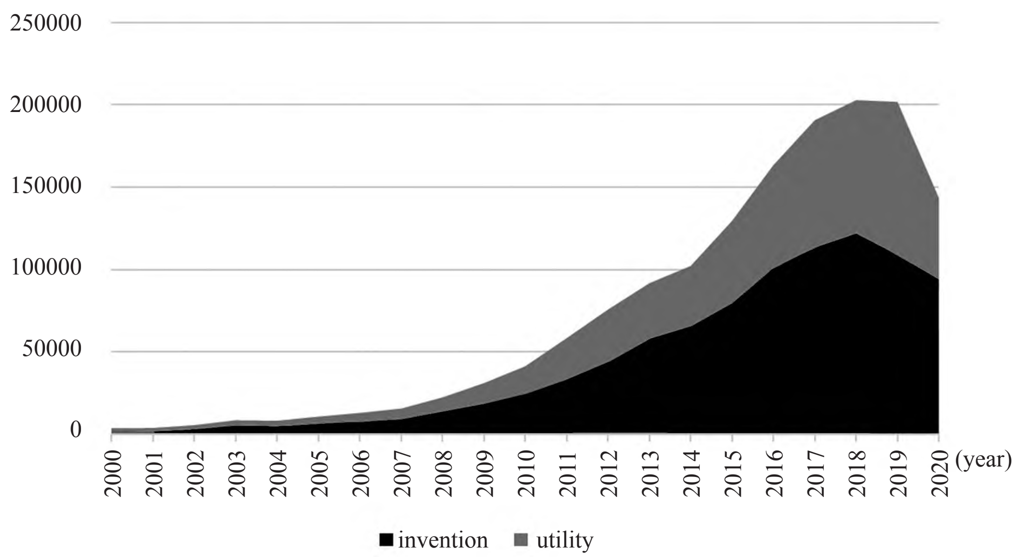
Faced with the increasingly severe problem of green development, China then started promoting green transformation. In the 18th National Congress of the Communist Party of China, the country incorporated "ecological civilization" into the overall layout of the construction of socialism with Chinese characteristics and proposed the "Beautiful China Initiative." The 20th National Congress of the Communist Party of China in 2022 further proposed promoting the great rejuvenation of the Chinese nation in all respects through Chinese-style modernization, in which the harmonious coexistence of man and nature is one of the five characteristics of Chinese-style modernization. Starting from the 13th Five-Year Plan, China has proposed to lead overall development with the new development concept of innovation, coordination, greenness, openness, and sharing. Since then, green development has been treated as the key to solving the problem of harmonious coexistence between man and nature. It further promotes green transformation in the prevention and control of environmental pollution, the improvement of ecosystem diversity, stability and sustainability, and the promotion of carbon peak and carbon neutrality. With the improvement of living standards, the public's demand for a green environment, green products, and green consumption has increased significantly, further strengthening the endogenous power of green development.

Looking ahead, China still encounters some challenges in promoting green development in the new journey of building a modern country in all respects. First, in relation to the goal of reaching the level of moderately developed countries in terms of per capita GDP by 2035, China still needs to maintain medium-to-high-speed economic growth, putting tremendous pressure on energy consumption as well as carbon reduction. Second, the energy sector is the most significant source of carbon emissions. The nation's endowment structure determines that coal consumption accounts for a relatively high proportion of the energy supply. To promote green development, an "energy revolution" must be promoted. Third, the cleanup of the industrial sector is the key to carbon mitigation and pollution reduction. The development of the real economy still rests on the manufacturing industry's keeping up a good pace in its growth. It is necessary to coordinate industry's green transformation and its competitiveness. Fourth, in the new stage of promoting common prosperity, narrowing the gap between urban and rural areas means that the income and consumption of rural residents in areas with relatively poor economic development will increase rapidly, posing another new challenge to green development.

The only way to deal with these challenges is to implement the new development perspective. Promoting the innovative application of green technology is in line with the requirements of the two concepts of innovative development and green development. It provides new solutions for the realization of the multiple development goals mentioned above. Understanding the driving factors behind the development and diffusion of green innovation is of the greatest significance to promoting the nation's green development.

In recent years, China has been promoting green technology innovation. On the supply side, it has strengthened environmental controls, initiated the carbon emission trading system, and implemented various policies such as green subsidies and environmental taxes to encourage green technology innovation. On the demand side, it emphasizes a market-oriented green technology innovation system by strengthening the dominant position of enterprises in green technology innovation, promoting the marketization of the transfer and transformation of innovation achievements, and expanding market demand. These practices have successfully facilitated the rapid growth of wind energy and photovoltaics. From 2010 to 2020, the growth rate of the nation's wind energy installed capacity and power generation was 26.5 percent and 24.3 percent respectively. The growth of photovoltaic installed capacity and power generation was even faster. In the meanwhile, as illustrated in Figure 1, China witnessed the sky-rocketing development of new energy patents.

Figure 1 Renewable Energy Patents Granted in China



In light of the classic policy-push and demand-pull theories in the innovation literature, this paper seeks to understand the recent rapid development of China's renewable energy innovation. Innovation is measured by aggregated city-level patent innovation in relevant technological fields. Taking advantage of China's regional ETS pilots as a policy shock, we utilize the triple Difference-in-Difference (DID) empirical strategy. Empirical results suggest that both upstream policy promotion and downstream demand pull have positive effects on new energy technology innovation. This paper provides a new analytical perspective and empirical evidence for green technology innovation.

II. Relevant Literature and Hypothesis Development

1. Relevant literature

China's green technology innovation research has a long history.[1] Due to its developmental stage, governance system, environmental governance, and government functions, China's policy and market environment for green technology innovation are different from those of developed countries. The growing literature gives attention to the effects of environmental regulation and other related policies on green innovation.[2]

The existing theoretical literature discusses the incentive mechanisms of corporate green technology innovation and diffusion. He Xiaogang proposes that the dual interaction of environmental policies and R&D subsidy policies constitutes an inducement for green technology innovation.[3] Jia and Zhang study the impact of knowledge stock and spillovers on green technology innovation within and across regions,[4] and further explore the impact of environmental regulation on green technology and non-green technology R&D path dependence. Cao and Zhang construct a tripartite evolutionary game model of corporate green technology innovation, government environmental rules, and consumer environmental oversight.[5] They analyze the effect of publicity on public environmental protection, innovation incentives, and pollution taxes on corporate green technology innovation.

Empirical research literature focuses on evaluating the impact of environmental regulation on the efficiency of green technology innovation in the spirit of the Porter hypothesis.[6]

One strand examines the effectiveness of specific environmental regulatory measures on corporate green technology innovation. Xu, He and Long compare three environmental

1 See, for example, Xu Qingrui, Wang Weiqiang and Lyu Yan, "Research on Environmental Technology Innovation of Chinese Enterprises."

2 Xu Shichun, He Zheng and Long Ruyin, "The Effects of Environmental Regulations on Enterprise Green Technology Innovation," pp. 67-74.

3 He Xiaogang, "Research on Optimal Regulation Structure of Green Technology Innovation: Based on the Dual Interactive Effect of R&D Support and Environmental Regulation," pp. 144-153.

4 Jia Jun and Zhang Wei, "The Path Dependency of Green Technology Innovation and Environmental Regulation Analysis," pp. 44-52.

5 Cao Xia and Zhang Lupeng, "Evolutionary Game Analysis of the Diffusion of Green Technological Innovation of Enterprises," pp. 68-76.

6 Michael Porter, "American Green Strategy," pp. 95-117; Adam B. Jaffe and Karen Palmer, "Environmental Regulation and Innovation: A Panel Data Study," pp. 610-619.

regulatory measures: the pollutant discharge tax, auctioned pollutant discharge permits, and tradable pollutant discharge permits, and examine the differential effects of these policies on corporate green technology innovation.[7] Using a geographically weighted regression model, Li finds a spatial autocorrelation between the pollution discharge fee system and green technology innovation.[8] In addition, the Porter hypothesis has been well documented in developed provinces. Guo's findings indicate that the collection of sewage charges induces firms to increase R&D intensity. Its impact is more effective than environmental administrative penalties and the issuance of local laws.[9] Recent literature focuses on the impact on corporate green innovation[10] of non-traditional measures, e.g. low-carbon cities, green credit policies, and environmental protection target responsibility systems.

Another strand seeks to study the impact of different types of environmental regulation on green technology innovation. Li and other two scholars divide environmental regulation into the command-and-control type, incentive type, and voluntary type,[11] exploring how environmental regulation affects corporate R&D investment and the accumulation of green technology capabilities. Using the panel data of thirty provinces and municipalities in China from 2006 to 2016, Fan and Sun test the effect of market incentives and command-and-control environmental regulations on the development of green technology.[12] Wang and Zhang introduce green technology innovation willingness as an intermediary variable,[13] and further study the impact of different types of environmental regulations on green innovation. Based on the green patent data of listed companies from 1990 to 2010, Qi, Lin and Cui find that the pilot policy of emission rights trading induced green innovation enterprise activities in polluting industries in the pilot areas.[14] Along these lines, Cui, Zhang and Zheng used the patent application data of listed companies from 2003 to 2015. Their findings indicate

7 Xu Shichun, He Zheng and Long Ruyin, "The Effects of Environmental Regulations on Enterprise Green Technology Innovation," pp. 67-74.

8 Li Wanhong, "Spatial Econometrics Test of Pollutant Discharge System's Impetus to Green Technological Innovation: Taking 29 Provinces and Regions' Manufacturing Industries as Examples," pp. 1-9.

9 Guo Jin, "The Effects of Environmental Regulation on Green Technology Innovation: Evidence of the Porter Effect in China," pp. 147-160.

10 Xu Jia and Cui Jingbo, "Low-Carbon Cities and Firms' Green Technological Innovation," pp. 178-196; Wang Xin and Wang Ying, "Research on the Green Innovation Promoted by Green Credit Policies," pp. 173-188; Tao Feng, Zhao Jinyu and Zhou Hao, "Does Environmental Regulation Improve the Quantity and Quality of Green Innovation? Evidence from the Target Responsibility System of Environmental Protection," pp. 136-154.

11 Li Guangpei, Li Yange and Quan Jiamin, "Environmental Regulation, R&D Investment and Enterprises' Green Technological Innovation Capability," pp. 61-73.

12 Fan Dan and Sun Xiaoting, "Environmental Regulation, Green Technological Innovation and Green Economic Growth," pp. 105-115

13 Wang Juanru and Zhang Yu, "Environmental Regulation, Green Technologically Innovative Intention and Green Technological Innovative Behavior," pp. 352-359.

14 Qi Shaozhou, Lin Shen and Cui Jingbo, "Do Environmental Rights Trading Schemes Induce Green Innovation? Evidence from Listed Firms in China," pp. 129-143.

that China's high carbon price and frequent turnover of carbon allowances are conducive to corporate green innovation.[15] The findings of Cui, Wang and Xu suggest that China's participation in the Clean Development Mechanism under the Kyoto Protocol significantly improves firms' patent innovation in renewable energy technologies.[16]

One of the key challenges in empirical research is the measurement of green technology innovation. Existing studies mainly use efficiency measurement methods such as DEA to calculate the efficiency of green technology innovation,[17] with some analyzing efficiency differences among regions and regional green growth performance[18] and others using microdata as a measure of green technology innovation. Li, Bi and Sun use green product innovation and green process innovation,[19] while Guo uses green patents granted and projects awarded.[20] The most widely used proxy is the number of green patents filed in China and the construction of the corresponding patent quality indicators.[21]

We contribute to the existing literature in the following ways. First, we expand the theoretical horizon. The existing literature focuses on the direct or indirect impact of environmental regulations and policies on green technology innovation, particularly the upstream of innovation. However, green technology innovation is also affected by market demand, which needs to be analyzed from the theoretical perspective of the interaction between innovation policy and demand expansion. Second, we utilize the causal identification method. Existing

15 Jingbo Cui, Junjie Zhang and Yang Zheng, "Carbon Pricing Induces Innovation: Evidence from China's Regional Carbon Market Pilots," pp. 453-457.

16 Jingbo Cui, Zhenxuan Wang and Haishan Yu, "Can International Climate Cooperation Encourage Knowledge Spillovers to Developing Countries? Evidence from CDM," pp. 923-951.

17 Klaus Conrad and Dieter Wastl, "The Impact of Environmental Regulation on Productivity in German Industries," pp. 615-633.

18 Qian Li, Xiao Renqiao and Cheng Zhongwei, "Research on Industrial Enterprises' Technology Innovation Efficiency and Regional Disparities in China: Based on the Theory of Meta-frontier and the DEA Model," pp. 26-43; Wang Hailong, Lian Xiaoyu and Lin Deming, "Effects of Green Technological Innovation Efficiency on Regional Green Growth Performance: An Empirical Analysis," pp. 80-87; Zhang Juan *et al*., "Research on the Influence of Environmental Regulation on Green Technology Innovation," pp. 168-176; Fan Dan and Sun Xiaoting, "Environmental Regulation, Green Technological Innovation and Green Economic Growth, China Population," pp. 105-115.

19 Li Wanhong, Bi Kexin and Sun Bing, "Research on the Effect of Environmental Regulation Intensity on the Green Technological Innovation of Pollution Intensive Industries: An Empirical Test Based on Panel Data for 2003-2010," pp. 72-81.

20 Guo Jin, "The Effects of Environmental Regulation on Green Technology Innovation: Evidence of the Porter Effect in China," pp. 147-160.

21 Jingbo Cui, Junjie Zhang and Yang Zheng, "Carbon Pricing Induces Innovation: Evidence from China's Regional Carbon Market Pilots," pp. 453-457. Qi Shaozhou, Lin Shen and Cui Jingbo, "Do Environmental Rights Trading Schemes Induce Green Innovation? Evidence from Listed Firms in China," pp. 129-143; Tao Feng, Zhao Jinyu and Zhou Hao, "Does Environmental Regulation Improve the Quantity and Quality of Green Innovation: Evidence from the Target Responsibility System of Environmental Protection," pp. 136-154; Jingbo Cui, Zhenxuan Wang and Haishan Yu, "Can International Climate Cooperation Induce Knowledge Spillover to Developing Countries? Evidence from CDM," pp. 923-951.

literature mainly uses such methods as efficiency accounting, index construction, and regression estimation, focusing on describing the basic facts of green technology innovation and verifying correlations. Recent studies have used specific policy shocks to analyze the mechanisms but lack an overall evaluation of green development strategies. Third, we focus on renewable energy innovation. Carbon reduction and pollution reduction in the energy production sector is a key area of green development in China and a major sector of green technology innovation.

2. Hypothesis development

The two major driving forces of technological progress arise from policy-push and demand-pull. Vannevar Bush proposed the germinal idea of the policy-push force,[22] i.e., a supply-side linear diffusion trend from R&D to innovation. Schmookler's argument, originating from the demand side perspective, that expectations of market demand are the determinants of technological progress since they form market traction and guide and stimulate new directions for R&D innovation.[23] Burgeoning empirical studies have shown that policy-push and demand-pull are the two driving forces that affect the direction of technological innovation and the speed of technology diffusion.[24]

Policy-push and demand-pull determinants are crucial in the field of green technology innovation. First, on the one hand, green technology requires a large amount of R&D funds, as the positive effect of knowledge spillovers from R&D innovation gradually accumulates and forms industrialized promotion. At the same time, huge R&D investment faces uncertain and complex market returns. In terms of policy promotion, public sector R&D investment can help alleviate the shortage of R&D investment, and the installed capacity of new energy can provide a positive knowledge spillover effect for the advancement of new energy technology. When it comes to the demand-pull force, market-based or command-and-control environmental policies can reduce the uncertainty of the return on R&D investment by creating market demand for environmental technologies. This further compensates for the competitive disadvantages faced by environmental technologies in the early stages and provides support for market promotion.

This paper takes the establishment of China's regional carbon market as a quasi-natural experiment policy to identify the policy-push and demand-pull effects on green technology innovation. Since 2000, the Chinese government has adopted the Clean Development Mechanism (CDM) under the framework of the Kyoto Protocol. On the one hand, China

22 Vannevar Bush, "Science, the Endless Frontier," pp. 32-35.

23 Jacob Schmookler, *Invention and Economic Growth*.

24 Pablo del Río González, "The Empirical Analysis of the Determinants for Environmental Technological Change: A Research Agenda," pp. 861-878; Jens Horbach, "Determinants of Environmental Innovation: New Evidence from German Panel Data Sources," pp. 163-173; Michael Peters *et al*., "The Impact of Technology-push and Demand-pull Policies on Technical Change: Does the Locus of Policies Matter?", pp. 1296-1308; Valeria Costantini *et al*., "Demand-pull and Technology-push Public Support for Eco-innovation: The Case of the Biofuels Sector," pp. 577-595.

introduces new energy technologies from developed countries through CDM projects, laying the foundation for energy transformation and development. On the other hand, the Certified Emission Reduction (CER) generated through CDM projects is transferred to developed countries through market-oriented means, that is, it is used to fulfill carbon emission reduction commitments and starts a journey to the carbon market. At the 2009 Copenhagen Climate Change Conference, the Chinese government publicly committed for the first time to reduce carbon dioxide emissions per unit of GDP by 40-45 percent by 2020 compared with 2005 levels. Since then, China has begun to consider a market-oriented climate change policy, i.e., an emissions trading system, to balance economic growth and climate change governance. In 2011, the National Development and Reform Commission (NDRC) approved seven regional carbon pilots. At the 2016 Paris Climate Change Conference, the Chinese government further announced its commitment to having carbon reach its peak by 2030. On September 22, 2020, Chinese President Xi Jinping announced at the General Debate of the United Nations General Assembly that China would strive to reach its carbon peak by 2030 and achieve carbon neutrality by 2060, demonstrating China's responsible role with regard to the governance of climate change in the global community.

We explore the characteristics of new energy technological innovation from the perspective of China's regional carbon market. Firstly, the carbon market is a market-oriented policy tool for achieving dual carbon goals and fulfilling international climate change commitments. The carbon market provides dual incentives for firms to carry out green innovation through explicit carbon prices and implicit competition mechanisms, thus boosting firms' clean energy transformation, improving energy consumption efficiency and reducing the cost of carbon emissions reduction for the whole society. This is an important tool for boosting technological development in renewable energy. Secondly, as a market-oriented policy, the carbon market continues to play a leading role on the demand side, reducing the uncertainty of market returns for technological innovation in new energy. It is also a long-term policy path to achieve coordinated governance of economic development and climate change. Finally, the regional carbon market policy has the nature of a quasi-natural experiment policy. Its spatial and intertemporal variations could help us gauge causal relations, further effectively identifying the role of demand-pull and policy push in renewable energy innovation.

III. Data and Empirical Model

1. Data sources

The key variable of interest is prefecture-level renewable energy patents from 2000 to 2020, the data on which was supplied by the China Intellectual Property Office. The NDRC provided detailed information for each of the first seven regional ETS pilots. We further retrieved provincial renewable energy data, including photovoltaic power generation, wind power generation, newly added photovoltaic generator equipment capacity, and newly added wind power generation equipment capacity data. The relevant information was provided by the Statistical Database of DRCNET. China Electricity Council reported the average utilization hour data of power generation equipment, and the China Research Data Service Platform supplied total energy consumption and energy industry investment data at the provincial level. The China Price Statistical Yearbook reported the fuel power purchase price. Other indicators such as energy consumption, price, and R&D investment were constructed by the Office for National Statistics.

(1) China ETS indicators

China's regional carbon pilots comprise eight provinces and municipalities and were rolled out into two phases. In October 2011, the NDRC issued the Notice on Launching Carbon Emissions Trading Pilot Work, approving seven regions (Beijing, Shanghai, Tianjin, Chongqing, Hubei, Guangdong, and Shenzhen) for the launch of carbon trading programs. In 2016, Fujian became the eighth pilot in China. These eight pilots vary in terms of the industrial sectors they cover, as shown in Table 1. In this paper, we account for all the eight pilots in two batches and execute the causal inference by comparing the outcome of the interests of ETS pilots and non-ETS pilots during the pre-and-post periods.

Table 1 China's Region ETS Pilots

Pilots	Launching time	Sectors covered
Shenzhen	Jun. 2013	Industrial sector: electric power, natural gas, water supply, manufacturing Non-industrial sector: large public buildings, public transportation
Beijing	Nov. 2013	Industrial sector: electric power, thermal energy, cement, petrochemicals Non-industrial sector: public institutions, services, transportation
Shanghai	Nov. 2013	Industrial sector: electric power, steel, petrochemicals, chemical industry, nonferrous metals, building materials, textiles, paper, rubber, chemical fiber Non-industrial sector: aviation, airport, water transportation, ports, malls, hotels, commercial office buildings, railway stations
Guangdong	Dec. 2013	Electric power, cement, steel, petrochemical, paper, civil aviation
Tianjin	Dec. 2013	Electric power, thermal energy, steel, chemical industry, petrochemicals, oil and gas extraction, paper, aviation, building materials
Hubei	Feb. 2014	Electric power, thermal energy, nonferrous metals, steel, chemical industry, cement, petrochemicals, automotive manufacturing, glass, pottery, water supply, chemical fiber, paper, pharmaceuticals, food and beverages
Chongqing	Jun. 2014	Electric power, electrolytic aluminum, ferroalloy, acetylene, caustic soda, cement, steel
Fujian	Sep. 2016	Electric power, petrochemicals, chemical industry, building materials, steel, nonferrous metals, paper, aviation, pottery

(2) Green technology indicator

Green technology innovation is proxied by renewable energy patents at the prefectural level. The Green Inventory List, promulgated by the World Intellectual Property Organization (WIPO) reports seven categories of environmental technology: transportation, waste management, energy conservation, alternative energy production, administrative regulation or design, agriculture or forestry, and nuclear power generation. The Green Inventory List is a widely used indicator for green patent innovation.[25] From the main categories of energy conservation and alternative energy production, we retrieve a further 25 subcategories of renewable energy and energy efficiency, including wind, solar, biomass, geothermal, and energy storage facility technologies, etc.[26] To further capture the heterogeneity of patent value, we divide patents into invention patents and utility model patents. Lastly, renewable energy patents are aggregated into the prefectural level to better control inter-provincial differences in renewable energy innovation.

(3) Demand-pull and policy-push indicators

The demand-pull and policy-push factors are in line with existing literature.[27] Provincial-level renewable energy is mainly made up of production and equipment capacity indicators for wind and photovoltaics. Given the power grid structure, green power consumption cannot be accurately measured. We thus selected wind power and photovoltaic power generation as the industrial demand-driven indicators. Since the scale of wind power and photovoltaic installed capacity is greatly affected by policy shocks, we designated the capacity of wind power and photovoltaic equipment (i.e., installed capacity) as the policy-push indicator. It is noticeable that various aspects of renewable energy projects are regulated by the government. The investment funds in the central budget are used as front-end promotion indicators and are arranged and dispatched by the central government in a unified manner. The installed capacity represents policymakers' policy intention to develop renewable energy. Wind power projects, starting with site selection, demonstration, approval, etc., are all regulated by provincial governments, reflecting the strength of each province's policy promotion. Renewable energy power generation is integrated into the grid for unified allocation and distribution, coupled with a unified electricity price subsidy policy. Demand indicators such as power generation are relatively stable.

(4) Fossil fuel energy price; fossil energy price data

Conventional wisdom suggests that the rising price of fossil fuel energy would lead to a demand for renewable energy. We selected the fuel power purchase price index as provincial-level fossil energy price data. Commodity prices are determined by supply and demand. An increase in the purchase price index of fuel and power may be related to an increase in demand for fossil energy or a decrease in supply. Hence, it is affected both by policy-driven

25 Jingbo Cui, Junjie Zhang and Yang Zheng, "Carbon Pricing Induces Innovation: Evidence from China's Regional Carbon Market Pilots," pp. 453-457; Qi Shaozhou, Lin Shen and Cui Jingbo, "Do Environmental Rights Trading Schemes Induce Green Innovation? Evidence from Listed Firms in China," pp. 129-143.

26 Jingbo Cui, Zhenxuan Wang and Haishan Yu, "Can International Climate Cooperation Induce Knowledge Spillover to Developing Countries? Evidence from CDM," pp. 923-951.

27 Michael Peters *et al*., "The Impact of Technology-push and Demand-pull Policies on Technical Change: Does the Locus of Policies Matter?", pp. 1296-1308; Valeria Costantini *et al*., "Demand-pull and Technology-push Public Support for Eco-innovation: The Case of the Biofuels Sector," pp. 577-595.

and demand-driven factors. To this end, this paper treats the fossil energy price index as another type of explanatory variable and examines its shifting and substitution effects on renewable energy sources.

We also cover energy and R&D data at the provincial level, mainly including investment and consumption. Investment refers to energy industry investment, research and experimental development expenditures, while consumption refers to the average utilization hours of power generation equipment and total energy consumption.

2. Variable construction

The dependent variables include the total number of renewable energy patents, renewable energy invention patents, and renewable energy utility model patents, indexed by $NEpat_{rt}$, $NEpatI_{rt}$, and $NEpatU_{rt}$, respectively. All proxies are in the logarithm fashion.

The key explanatory variable is the China ETS indicator. Let ETS_r, as a dummy for the ETS regional pilots, equal one if region r is one of the eight pilots, and zero otherwise. Since most of regional pilots were launched in 2013, we set $Post_t$ as the year dummy for the launch of ETS. It takes a value of one if the year was 2013 or later, and zero otherwise.[28] To further distinguish between the announcement effects and launching effects of the ETS,[29] the dynamic effect model used in this paper reports the year-specific effect of the ETS on city-level renewable energy innovation.

Provincial renewable energy indicators include wind power generation ($WindGen_{rt}$) as the demand-pull factor, and wind power capacity ($WindCap_{rt}$), summed up in newly added wind power generation capacity, as the policy-push factor. In addition, we add the fuel power purchase price index ($FuelPower_{rt}$) to measure the energy substitution effect. In the robustness check, we cover photovoltaic power generation ($SolarGen_{rt}$) and photovoltaic installed capacity ($SolarCap_{rt}$). All variables are in the logarithm fashion except dummy indicators.

We also control for provincial characteristics, including investment in energy industry ($EnIndInvst_{rt}$), research and development expenditure (RD_{rt}), average utilization hours of power generation equipment ($AHUPGE_{rt}$) and energy consumption (TEC_{rt}). Our empirical exercise is carried out at the city-level. Table 2 provides descriptive statistics for selected interest variables.

Table 2 Descriptive Statistics

Vars	Definition	Obs	Mean	Std	Min	Max
NEpat	Renewable energy patent	6,173	3.377	1.877	0.693	10.040
NEpatI	Renewable energy invention patent	6,173	2.655	1.936	0	9.763
NEpatU	Renewable energy utility patent	6,173	2.761	1.747	0	8.939
ETS	ETS dummy	6,173	0.153	0.360	0	1

28 Jingbo Cui, Junjie Zhang and Yang Zheng, "Carbon Pricing Induces Innovation: Evidence from China's Regional Carbon Market Pilots," pp. 453-457.

29 Jingbo Cui *et al.*, "The Effectiveness of China's Regional Carbon Market Pilots in Reducing Firm Emissions," pp. 1-6.

Post	Post period dummy	6,173	0.377	0.485	0	1
WindGen	Wind power generation	6,173	2.256	2.034	0	6.589
WindCap	Wind power capacity	6,173	4.820	3.782	0	10.563
FulePower	Fossil fuel purchase price	6,173	46.340	49.720	0	123
SolarGen	Solar power generation	6,173	1.189	1.727	0	5.357
SolarCap	Solar power capacity	6,173	3.122	3.677	0	10.435
EnIndInvst	Energy sector investment	6,173	5.176	2.493	0	8.127
RD	R&D expenditure	6,173	4.282	2.226	0	8.155
AHUPGE	Avg hours of power generation	6,173	7.869	2.003	0	8.892
TEC	Energy consumption	6,173	8.720	2.489	0	10.631

3. Empirical model

Following the empirical strategies proposed in the existing literature,[30] our identification method relies on a variant of the triple DID models. By comparing the outcome of interests between ETS pilots and non-ETS pilots during the pre-and-post ETS periods, we further interact with the demand-pull and policy-push factors. The model proposed is as follows:

$$NEpat_{rt} = \beta_0 + \beta_1\, ETS_r \times Post_t \times DemandPull_{rt} + \beta_2\, ETS_r \times Post_t \times PriceTransition_{rt} + \rho X_{rt} + \gamma_r + \delta_t + \varepsilon_{rt}, \tag{1.1}$$

$$NEpat_{rt} = \beta_0 + \beta_1\, ETS_r \times Post_t \times PolicyPush_{rt} + \beta_2\, ETS_r \times Post_t \times PriceTransition_{rt} + \rho X_{rt} + \gamma_r + \delta_t + \varepsilon_{rt}, \tag{1.2}$$

where ETS_r denotes the regional ETS dummy, equaling one if region r is one of the eight pilots and zero otherwise. $Post_t$ captures the post dummy, equaling one if the year t is 2013 and later and zero otherwise. $DemandPull_{rt}$ indicates demand-pull factors, including wind power generation $WindGen_{rt}$. It captures the actual effective local demand for wind power technology; the greater the power generation, the stronger the demand-pull effect is. $PriceTransition_{rt}$ captures the price-induced energy substitution, while $FuelPower_{rt}$ denotes the fuel power purchase price index. The higher the price index, the greater the induced technology shift towards renewable energy. $PolicyPush_{rt}$ represents policy-push factors, such as wind power installed generation $WindCap_{rt}$. The higher the value, the stronger the policy-push factor. X_{rt} controls for the provincial variable, including investment in energy sectors, R&D expenditures, average utilization hours of power generation equipment, and energy consumption. In addition, the baseline model also includes the city-level and year fixed effects to absorb time-invariant city unobservable and year-specific trends respectively. Lastly, ε_{rt} is the error term.

The key parameter of interest, denoted by β_1, is the coefficient for the triple interaction terms of $ETS_r \times Post_t \times DemandPull_{rt}$ and $ETS_r \times Post_t \times PolicyPush_{rt}$ in Eq (1.1) and (1.2)

30 Michael Peters *et al*., "The Impact of Technology-push and Demand-pull Policies on Technical Change: Does the Locus of Policies Matter?", pp. 1296-1308; Valeria Costantini *et al.*, "Demand-pull and Technology-push Public Support for Eco-innovation: The Case of the Biofuels Sector," pp. 577-595.

respectively. Comparing renewable energy patent innovation between the ETS pilots and non-ETS pilots during the pre- and post-ETS periods enables one to capture the effects of demand-pull and policy-push factors on city innovation in the renewable energy field. If β_1 is positive in Eq (1.1), the demand-pull indicator facilitates renewable energy innovation. If it is positive in Eq (1.2), the policy-push factor boosts relevant innovation under the ETS framework.

IV. Empirical Results

1. Baseline results

Table 3 reports the regression results based on the baseline triple DID model Eq (1). Columns (1)-(2) examine wind power generation and fuel power producer purchase prices, while columns (3)-(4) focus on wind capacity and fuel power producer purchase prices. The odd columns add the prefectural-level and year fixed effects, while the even columns further control for relevant provincial characteristics. All regression models consider standard errors clustered at the city level.

Table 3 Baseline Effects on City Renewable Energy Patent Innovation

Vars	Nepat			
	(1)	(2)	(3)	(4)
$ETS_r \times Post_t \times$	0.131**	0.102*		
$WindGen_{rt}$	(0.057)	(0.056)		
$ETS_r \times Post_t \times$	0.007*	0.006*	0.007*	0.006*
$FuelPower_{rt}$	(0.003)	(0.003)	(0.004)	(0.003)
$ETS_r \times Post_t \times$			0.127***	0.113***
$WindGap_{rt}$			(0.034)	(0.033)
$EnIndInvst_{rt}$		-0.035		-0.034
		(0.029)		(0.030)
RD_{rt}		0.170***		0.175***
		(0.023)		(0.023)
$AHUPGE_{rt}$		0.040		0.064
		(0.058)		(0.061)
TEC_{rt}		0.034*		0.033*
		(0.018)		(0.018)
Constant	3.000***	1.937***	2.972***	1.718***
	(0.182)	(0.411)	(0.190)	(0.421)
Observation	6,173	6,173	6,173	6,173
R2	0.924	0.926	0.924	0.925
City fixed effect	Y	Y	Y	Y
Year fixed effect	Y	Y	Y	Y

Note: standard errors reported in the parenthesis are clustered at the city level. *,**, and *** indicate statistical significance at the 10 percent, 5 percent, and 1 percent level respectively.

In column (1), the estimated coefficient of the triple interaction term $ETS_r \times Post_t \times WindGen_{rt}$ is 0.131, which is statistically significant at the 5 percent level. This positive estimate indicates that power generation exerts a demand-pull effect that facilitates renewable energy patent innovation through ETS pressure. Column (2) adds investment and consumption control variables. Whereas the value drops to 0.102, the estimated coefficient remains positive and statistically significant at the 10 percent level. This finding indicates that the added control variables help explain changes in renewable energy patents. The main result still holds, i.e., that the ETS promotes renewable energy innovation in pilot regions through demand-pull effects. Similarly, the estimated coefficient for $ETS_r \times Post_t \times FuelPower_{rt}$ is 0.007, reported in column (1). The estimate is statistically significant at the 10 percent level, indicating that ETS facilitates renewable energy innovation through induced energy substitution due to the rising price of fossil fuel. This positive estimate remains at the 10 percent level after the inclusion of provincial control variables in column (2). This finding lends further strong support to the demand-pull effect of fossil fuel prices on renewable energy innovation.

Columns (3) and (4) show the results for wind power capacity and fossil fuel purchase price. The estimated coefficients for $ETS_r \times Post_t \times WindGap_{rt}$ are positive and statistically significant at the 1 percent level. These findings suggest the strong policy-push effect of wind power capacity. The results for the $ETS_r \times Post_t \times FuelPower_{rt}$ are consistent with those reported in the first two columns.

The fixed effects and related control variables in the above model help absorb some explanatory power in renewable energy innovation. Thus, our preferred models are reported in columns (2) and (4), which control for a rich set of fixed effects and provincial control variables. Driven by the demand for wind power generation, the shift to and substitution by renewable energy induced by the purchase price of fuel power producers, as well as the promotion of wind power installation policies, China's regional ETS policy facilitates renewable energy innovation patents. The average treatment effects of wind generation, fossil fuel price, and wind capacity are 10.74 percent, 0.6 percent, and 11.96 percent respectively.[31] This paper also examines the impact of provincial-level control variables on renewable energy innovation. Here, R&D expenditures and energy consumption have a significant role in fostering innovation in renewable energy.

2. Dynamic effects

The DID model rests on the pre-trend assumption that both treated and control groups do not exhibit any statistically significant outcome variables before the treatment. To further test this assumption and illustrate the year-specific treatment effects, we rely on the event study model. Thus, a variant of the baseline triple DID model is proposed as follows,

$$NEpat_{rt} = \beta_0 + \sum_{n=1}^{10} \beta_n\, ETS_r \times Post2011_t \times WindGen_{rt} + \sum_{m=0}^{11} \beta_m\, ETS_r \times Post2011_t \times WindGen_{rt} + \beta_1\, ETS_r \times Post2011_t \times FuelPower_{rt} + \beta_2\, ETS_r \times Post2011_t$$

31 The estimated impact is transformed by $100 \times [\exp\text{^}(\beta_1)\text{-}1]$.

$$\times WindCap_{rt} + \rho X_{rt} + \gamma_r + \delta_t + \varepsilon_{rt}, \quad (2.1)$$

$$NEpat_{rt} = \beta_0 + \sum_{n=1}^{10} \beta_n\, ETS_r \times Post2011_t \times WindCap_{rt} + \sum_{m=0}^{11} \beta_m\, ETS_r \times Post2011_t \times WindCap_{rt} + \beta_1\, ETS_r \times Post2011_t \times FuelPower_{rt} + \beta_2\, ETS_r \times Post2011_t \times WindGen_{rt} + \rho X_{rt} + \gamma_r + \delta_t + \varepsilon_{rt}, \quad (2.2)$$

In the above form, we set 2010 as the benchmark. $Post2011_t$ is the ETS policy dummy, which equals one if the year is 2011 and later, and zero otherwise. Other variables are defined in model Eq (1.1) and (1.2). β_n denotes the year-specific effect during the pre-ETS period of 2000 to 2010, while β_m represent the estimate for the post-ETS period from 2011 to 2020. The former captures the pre-trend effect, while the latter indicates the long-term dynamic effect.

Figure 2 Dynamic Effects of Wind Power

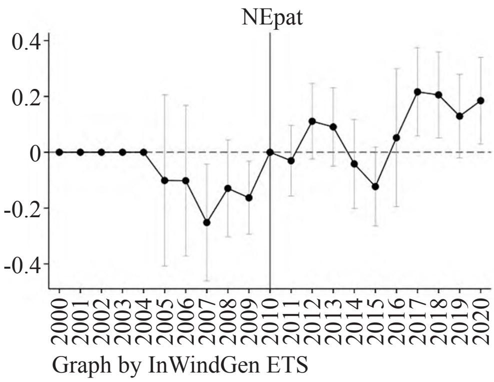
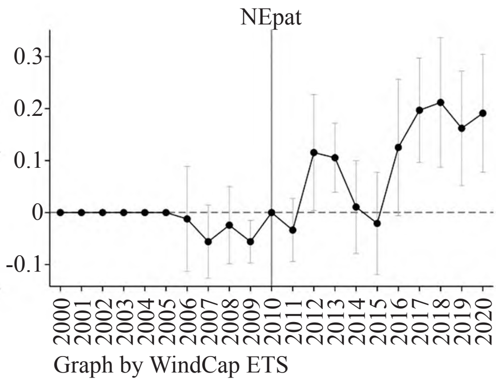


Figure 3 Dynamics Effects of Wind Capacity



Figures 2 and 3 plot the estimated β_s and the 95 percent confidence interval. The former illustrates the estimated dynamic effects for wind power generation ($ETS_r \times Post_t \times WindGen_{rt}$), while the latter shows that for wind power capacity ($ETS_r \times Post_t \times WindCap_{rt}$). The estimated coefficients for β_n during the pre-ETS period of 2000 to 2010 are not statistically significant, indicating that treated and control groups do not preserve any statistically significant differences in innovation outcome before the ETS. This satisfies the pre-trend assumption. The estimated coefficient for the post-ETS year-specific dummies, denoted by β_m, are statistically significant in some years during the 2011-2013 period, indicating the announcement effect. The magnitude of this estimate rises after 2016 and then becomes stable. Such post-ETS effects suggest some lagged ETS effects on renewable energy innovation, further demonstrating the announcement and trading effects as shown in Cui *et al*.[32] Moreover, both figures exhibit some consistency, lending further support to the induced innovation of China's ETS.

3. Heterogeneity

Patents differ by type, i.e., the invention and utility model types. To further examine this

32 Jingbo Cui *et al.*, "The Effectiveness of China's Regional Carbon Market Pilots in Reducing Firm Emissions," pp. 1-6.

heterogeneity, we split the renewable energy patent by patent type. Let *NepatI* and *NepatU* be invention and utility model patents respectively.

Table 4 Heterogenous Effects by Patent Type

Vars	*NepatI*		*NepatU*	
	(1)	(2)	(3)	(4)
$ETS_r \times Post_t \times WindGen_{rt}$	0.128**		0.045	
	(0.064)		(0.062)	
$ETS_r \times Post_t \times FuelPower_{rt}$	0.011**	0.011**	0.003	0.003
	(0.004)	(0.005)	(0.003)	(0.003)
$ETS_r \times Post_t \times WindCap_{rt}$		0.147***		0.055*
		(0.039)		(0.032)
$EnIndInvst_{rt}$	-0.060*	-0.055	-0.066**	-0.068**
	(0.036)	(0.036)	(0.026)	(0.027)
RD_{rt}	0.188***	0.195***	0.168***	0.171***
	(0.026)	(0.027)	(0.025)	(0.025)
$AHUPGE_{rt}$	-0.037	-0.008	0.134*	0.149*
	(0.043)	(0.046)	(0.078)	(0.080)
TEC_{rt}	0.001	-0.000	0.067***	0.066***
	(0.020)	(0.020)	(0.024)	(0.024)
Constant	2.159***	1.896***	0.510	0.402
	(0.376)	(0.383)	(0.528)	(0.531)
Observation	6,173	6,173	6,173	6,173
R2	0.890	0.889	0.906	0.906
City fixed effect	Y	Y	Y	Y
Year fixed effect	Y	Y	Y	Y

Note: standard errors reported in the parenthesis are clustered at the city level. *,**, and *** indicates the statistical significant at the 10 percent, 5 percent, and 1 percent level, respectively.

In Table 4, Columns (1) and (2) show the results for invention patents. The estimated coefficient for $ETS_r \times Post_t \times WindGen_{rt}$ is 0.128, while the coefficient for $ETS_r \times Post_t \times FuelPower_{rt}$ is 0.110. Both estimates are statistically significant at the 5 percent level. The coefficient for the wind capacity interaction term $ETS_r \times Post_t \times WindCap_{rt}$ reports a value of 0.146, statistically significant at the 1 percent level and with a similar magnitude to the wind power generation in column (1), but a higher significance level. The remaining columns of Table 4 show the results for utility model patents. The estimated coefficients for wind power generation and fuel price are positive but not statistically significant at any conventional level. The coefficient for wind power capacity remains significant at the 10 percent level. These findings together suggest that the policy-push and demand-pull factors only facilitate valuable invention patents in renewable energy fields.

4. Robustness checks

To test the stability of the baseline results, we conduct a rich set of robustness checks, including alternative measures for policy-push and demand-pull factors, alternative DID model specification, and alternative ETS measures.

(1) Iterative policy-push and demand-pull factors

We first consider alternative renewable energy *r* policy-push and demand-pull factors. We replace wind power in the baseline by solar energy. Thus, solar power generation is the alternative demand-pull determinant, while solar power capacity is the proxy for the policy-push factor. Table 5 reports the results for renewable energy patents, invention patents, and utility model patents.

Table 5 Robustness Checks by Solar Generation

Vars	*Nepat*		*NepatI*		*NepatU*	
	(1)	(2)	(3)	(4)	(5)	(6)
$ETS_r \times Post_t \times SolarGen_{rt}$	2.462***		3.454***		1.824**	
	(0.630)		(0.893)		(0.774)	
$ETS_r \times Post_t \times FuelPower_{rt}$	0.004	0.005*	0.006	0.009**	0.001	0.003
	(0.003)	(0.003)	(0.004)	(0.004)	(0.003)	(0.003)
$ETS_r \times Post_t \times SolarCap_{rt}$		0.021		0.064*		-0.022
		(0.032)		(0.038)		(0.034)
$EnIndInvst_{rt}$	-0.008	-0.007	-0.024	-0.022	-0.045*	-0.047*
	(0.029)	(0.029)	(0.034)	(0.034)	(0.027)	(0.026)
RD_{rt}	0.179***	0.171***	0.201***	0.191***	0.171***	0.162***
	(0.023)	(0.023)	(0.027)	(0.027)	(0.024)	(0.024)
$AHUPGE_{rt}$	0.080	0.077	0.005	0.009	0.170*	0.158*
	(0.074)	(0.073)	(0.060)	(0.062)	(0.092)	(0.090)
TEC_{rt}	0.039**	0.039**	0.007	0.008	0.071***	0.071***
	(0.018)	(0.018)	(0.020)	(0.020)	(0.025)	(0.025)
Constant	1.336**	1.370***	1.472***	1.431***	0.023	0.134
	(0.529)	(0.521)	(0.475)	(0.478)	(0.631)	(0.613)
Observation	6,173	6,173	6,173	6,173	6,173	6,173
R2	0.924	0.924	0.887	0.887	0.905	0.905
City fixed effect	Y	Y	Y	Y	Y	Y
Year fixed effect	Y	Y	Y	Y	Y	Y

Note: standard errors reported in the parenthesis are clustered at the city level. *,**, and *** indicates the statistical significant at the 10 percent, 5 percent, and 1 percent level, respectively.

Columns (1) and (2) present the results for renewable energy patents. The estimated coefficient for solar power generation, $ETS_r \times Post_t \times SolarGen_{rt}$, is positive and statistically significant at the 1 percent level, while the coefficient for solar power capacity $ETS_r \times Post_t \times SolarCap_{rt}$ is positive but not significant at any conventional level. When it comes to examining patent type, columns (3) and (4) shows the positive estimates on invention patents for both solar power generation and solar power capacity. Both estimates are statistically significant at the conventional level. The remaining columns indicate significant results for solar power generation but a muted result for solar power capacity in utility model patents. Taken together, the demand-pull factor proxied by solar power generation has a stronger impact both on valuable invention patents and utility model patents, while the policy-push factor measured by solar capacity only exhibits a positive impact in relation to the invention patents.

(2) Alternative DID model specification

Next, we revisit the induced innovation effect of China's ETS by turning to the conventional DID model. In line with existing literature studying China's ETS,[33] the DID model is proposed as follows,

$$NEpat_{rt} = \beta_0 + \beta_1\, ETS_r \times Post2011_t + \rho X_{rt} + \gamma_r + \delta_t + \varepsilon_{rt}, \tag{3}$$

where $Post2011_t$ is the ETS policy dummy, equaling one if the year is 2011 and later and zero otherwise. Other variables are defined in model Eq (1.1) and (1.2). The parameter of interest β_1 captures the effect of ETS on city renewable energy innovation by comparing the innovation outcome between the ETS and non-ETS pilots during the pre-and post-ETS periods. If β_1 is positive, ETS facilitates innovation in relevant renewable energy fields.

Table 6 reports the results. Columns (1) and (2) show the results for total patents in renewable energy. The estimated coefficients for the interaction term $ETS_r \times Post2011_t$ are positive and statistically significant at the 1 percent level in both columns. These findings suggest the strong impact of ETS on the facilitation of patent innovation. Columns (3) and (4) further report the results for invention patents, while the remaining columns show the results for the utility model patents. In all columns, the estimates are consistently positive and significant at the 1 percent level. These findings lend strong support to the induced innovation of ETS on renewable energy patent regardless of patent type.

Table 6 Robustness Check with DID Model

Vars	*Nepat*	*Nepat*	*NepatI*	*NepatI*	*NepatU*	*NepatU*
	(1)	(2)	(3)	(4)	(5)	(6)
$ETS_r \times Post2011_t$	0.274***	0.228***	0.284***	0.232**	0.333***	0.275***
	(0.076)	(0.074)	(0.093)	(0.093)	(0.080)	(0.079)
$EnIndInvst_{rt}$		-0.007		-0.015		-0.055*
		(0.030)		(0.035)		(0.028)
RD_{rt}		0.168***		0.187***		0.168***
		(0.026)		(0.029)		(0.025)

33 Liu Ye and Zhang Xunchang, "Carbon Emissions Trading System and Enterprise R&D Innovation: Empirical Research Based on the Triple Difference Model," pp. 102-114; Jingbo Cui, Junjie Zhang and Yang Zheng, "Carbon Pricing Induces Innovation: Evidence from China's Regional Carbon Market Pilots," pp. 453-457; Huang Xianglan, Zhang Xunchang and Liu Ye, "Does China's Carbon Emissions Trading Policy Fulfill the Environmental Dividend?", pp. 86-99; Guo Lei and Xiao Youzhi, "Research on the Innovation Incentive Effect of the Carbon Emission Trading Pilot," pp. 147-161; Jingbo Cui *et al.*, "The Effectiveness of China's Regional Carbon Market Pilots in Reducing Firm Emissions," pp. 1-6.

$AHUPGE_{rt}$		0.135**		0.070		0.201***
		(0.058)		(0.051)		(0.068)
TEC_{rt}		0.040**		0.007		0.070***
		(0.019)		(0.020)		(0.025)
Constant	3.356***	1.271**	2.633***	1.297***	2.736***	0.114
	(0.006)	(0.519)	(0.007)	(0.460)	(0.006)	(0.602)
Observation	6,173	6,173	6,173	6,173	6,173	6,173
R2	0.922	0.924	0.884	0.886	0.902	0.905
City fixed effect	Y	Y	Y	Y	Y	Y
Year fixed effect	Y	Y	Y	Y	Y	Y

Note: standard errors reported in the parenthesis are clustered at the city level. *,**, and *** indicates the statistical significant at the 10 percent, 5 percent, and 1 percent level, respectively.

(3) Alternative ETS measures

Lastly, we remove Fujian province, i.e., the last region to launch an ETS pilot. For robustness, we only take account of seven regional ETS pilots by replacing the ETS dummy into those among the seven regions. Table 7 reports the relevant results based upon the DID model listed above. The estimated interaction terms are still consistently positive and statistically significant at conventional levels, confirming the induced innovation effects of the China ETS on renewable energy patents.

Table 7 Robustness Check without the Fujian Pilot

Vars	*Nepat*	*NepatI*	*NepatU*
	(1)	(2)	(3)
$ETS7_r \times Post2011_t$	0.144*	0.174*	0.172**
	(0.076)	(0.102)	(0.078)
$EnIndInvst_{rt}$	-0.015	-0.022	-0.064**
	(0.030)	(0.036)	(0.028)
RD_{rt}	0.166***	0.186***	0.166***
	(0.026)	(0.029)	(0.025)
$AHUPGE_{rt}$	0.123**	0.061	0.187***
	(0.055)	(0.048)	(0.065)
TEC_{rt}	0.039**	0.007	0.069***
	(0.018)	(0.020)	(0.025)
Constant	1.409***	1.406***	0.281
	(0.499)	(0.441)	(0.585)
Observation	5,990	5,990	5,990
R2	0.923	0.885	0.904
City fixed effect	Y	Y	Y
Year fixed effect	Y	Y	Y

Note: standard errors reported in the parenthesis are clustered at the city level. *,**, and *** indicates the statistical significant at the 10 percent, 5 percent, and 1 percent level, respectively.

V. Conclusion and Discussion

Green technology innovation is an important path for implementing new development perspectives, innovation-driven development, and the building of an ecological civilization. This paper argues that the promotion of green technology innovation needs to be coordinated in terms of the policy-push and demand-pull factors. Using China's regional carbon ETS as a policy shock, this paper adopts the triple DID method to test the impact of policy-push and demand-pull factors on renewable energy patents. The baseline finding suggests that policy-push and demand-pull factors increase facilitation of renewable energy patent innovation by 11 percent through ETS pressure. The effect is more pronounced on invention patents under the solar demand-pull and wind power policy-push factors.

Our findings have profound implications. As a large developing country, China firmly holds to harmonious coexistence between humans and nature in the comprehensive construction of a modern country. There is an urgent need to improve long-term mechanisms to support green technology innovation. The empirical findings in this paper indicate that policy-push and demand-pull factors not only play a significant role in promoting renewable energy innovation but also have an equal contribution. Green technology not only encounters a high risk of innovation failure but also faces market failure. China's recent focus on promoting green innovation has been from the supply side through environmental regulations and industrial policies. Attention should also be paid to the demand side by utilizing market forces and self-realization mechanisms that can effectively drive green technology innovation. In this regard, China's ultra-large-scale market's strategic demand advantage still has great potential for promoting green technology innovation.

Our findings on renewable energy innovation indicate that the demand side of green technology is concentrated at the industry level, rather than directly dealing with the consumer market of households and individuals. The simultaneous promotion of nationwide ecological civilization construction and the construction of a modern industrial system means that the demand for green technology innovation will be effectively expanded. We should focus on the green technology innovation demand contained in the adjustment and upgrading of industrial structure as a policy focus and lay stress on amplifying the impact of industrial structure upgrading policies on green technology innovation. Moreover, this paper shows that the rise in fossil fuel prices also promotes green technology demand. To encourage green innovation, we should strengthen the coordination of a variety of policies, including environmental, energy, industrial, and science and technology policies. Put differently, we would be able to systematically improve the governance system if we follow the new development perspective.

Lastly, one research topic worth further investigation is the study green technology innovation under China's new development perspective with a focus on the interaction of demand-pull and policy-push factors. This is a characteristic of China as a developing country promoting the construction of ecological civilization and is also a characteristic of China's green development research.

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