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CHINA'S NATIONAL CARBON MARKET[‡]

Carbon Pricing Induces Innovation: Evidence from China's Regional Carbon Market Pilots[†]

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China is facing the dual challenges of curbing its ever-increasing carbon emissions and maintaining high-speed economic growth. On the one hand, China has set an ambitious growth target to reach high-income status by 2035 and become a mid-level, high-income economy by 2050. On the other hand, China has pledged to peak its carbon emissions around 2030 under the Paris Agreement.[1] To achieve the emission target with minimum costs, the Chinese government has resorted to emission trading scheme (ETS) for regulating carbon emissions. It is hoped that this market-based instrument can not only achieve cost-effective emission reductions but also improve the quality of economic growth by inducing innovation.

The regional ETS pilots in China were announced in 2011 by the National Development and Reform Commission (NDRC). The pilots include all 4 direct-controlled municipalities, 2 provinces, 1 special economic zone, and cover a variety of sectors across regions. These pilot regions are granted with flexibility in designing their own carbon market rules following some general national guidelines, while the NDRC oversees the planning and development of ETS (Zhang, Wang, and Du 2017).[2]

The ETS pilots provide a unique quasi-natural experiment for teasing out the causal relationship between ETS and innovation. First, we observe firm's patent applications before and after the ETS pilots, which offers a pre- and post-policy comparison.[3] Second, the pilots are implemented in different regions with significant heterogeneity, allowing us to compare firm-level low-carbon innovation between pilot and non-pilot regions. Third, the pilots cover different manufacturing sectors in different regions, further comparing firm-level low-carbon innovation between these covered and non-covered sectors.[4]

Taking advantage of the variations in the ETS pilots over time, across sectors and regions, we employ a difference-in-difference-in-differences (DDD) approach to identify the effect of ETS in inducing low-carbon innovation. Based on the allowance trading data such as carbon prices and trading volumes from the secondary carbon market, this paper further analyzes the effect of carbon market activity on firms' low-carbon innovation. With this objective, we

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1 In the 2009 Copenhagen Accord, China pledged to reduce its carbon intensity—measured by carbon emissions per unit of GDP—by 40 to 45 percent from 2005 levels by 2020.

2 Each pilot has discretion to determine covered sectors, emissions targets, allowance allocation, monitoring, reporting and verification (MRV), and compliance.

3 The first pilot to launch the carbon ETS was Shenzhen in June 2013, and then followed by Shanghai, Beijing, Guangdong, and Tianjin in the same year. The remaining pilots, Hubei and Chongqing, launched the ETS in April and June of 2014, respectively.

4 The seven pilots cover a range of manufacturing sectors with different thresholds, including power and heating, chemical, iron and steel, and cement.

have assembled a unique dataset pertaining to the publicly-listed firms in China between 2003 and 2015, which integrates detailed firm information about patent applications and financial and accounting reports.

We find that ETS accelerates innovation in low-carbon technologies, comparing the regulated sectors in the pilot regions with the unregulated sectors in the non-pilot regions. Based upon the observed information about carbon market performance, we also find that the pilots with higher carbon prices or higher turnover rates of allowance trading tend to have more active low-carbon innovation activities. In addition, market turnover rate has a stronger effect in spurring innovation than carbon price. These findings are consistent and robust against a series of alternative checks regarding the classification of low-carbon technologies, proxies of innovation, and placebo tests.

I. Data Sources and Variables

A. *Data Sources*

We have created a unique dataset for the empirical analysis. The data pertain to the Chinese publicly-listed firms of both Shanghai and Shenzhen stock exchanges in the manufacturing sectors and utilities during 2003–2015. We compile the data from two sources: the China Stock Market and Accounting Research (CSMAR) Solution supplies the firm-level financial statement, balance sheet data, and structure of corporate tree; China's State Intellectual Patent Office (SIPO) provides firm's patent application information.[5] We match and merge Chinese listed companies and their subsidiaries with those that have filed patent applications based on the archives of the SIPO.

B. *Variables*

Following the related literature (Newell, Jaffe, and Stavins 1999; Johnstone, Haščič, and Popp 2010; Calel and Dechezleprêtre 2016), we use the number of patent applications as a proxy for firms' innovation. To classify low-carbon technologies, we match each patent's main International Patent Classification (IPC) code with the IPC Green Inventory code developed by the IPC Committee of Experts in the World Intellectual Property Organization. The IPC Green Inventory classifies the so-called environmentally sound technologies in the IPC categories, as listed by the United Nations Framework Convention on Climate Change (UNFCCC). We define low-carbon technologies as those associated with alternative energy production, energy conservation, and waste management.

Let $EnvPat_{it}$ denote the number of low-carbon patent applications. Under the regulation of carbon emissions, a firm may divert R&D resources to develop carbon-saving technologies, which in turn could have a crowding-out effect on innovation in other areas. We use $NonEnvPat_{it}$ to represent the number of patents of other technologies. In addition, we use the ratio of low-carbon patents relative to total patents as an alternative measure of the firm-level environmental innovation, denoted by $EnvPatRatio_{it}$. This proxy measures whether ETS shifts the direction of innovation toward low-carbon technologies. Moreover, besides carbon emission regulation, unobservable policies, such as innovation subsidy, may become confounding variables for a firm's decision of patent applications. Thus, using $EnvPatRatio_{it}$ could further mitigate this concern of omitted variables because $EnvPat_{it}$ and $NonEnvPat_{it}$ are subject to the same shocks.

The policy variable of central interest is whether firm i at year t is regulated by a regional ETS pilot. We define ETS_r as a binary indicator, equaling 1 if region r is a carbon market pilot, and zero otherwise.[6] Define $Sector_j$ as a dummy for a covered sector, being 1 if sector j is subject to the regulation in any pilot regions, and zero otherwise. Although the regional carbon market pilots have been launched since 2013, the NDRC formally approved these seven pilots in late October 2011. Thus, we define the post-policy dummy, captured by $Post_t$, using the announcement year instead of the launching year. This dummy variable equals 1 for year 2011 and after, and zero otherwise.

[5] The CSMAR solution performs a similar role as the Compustat database accessed from Wharton Research Data Services.

[6] Shenzhen regional pilot is excluded in this study, because all sectors in the manufacturing industry are subject to carbon ETS in this pilot. This peculiar ETS requirements leave us limited choice of constructing control sectors, which are not enrolled in the ETS.

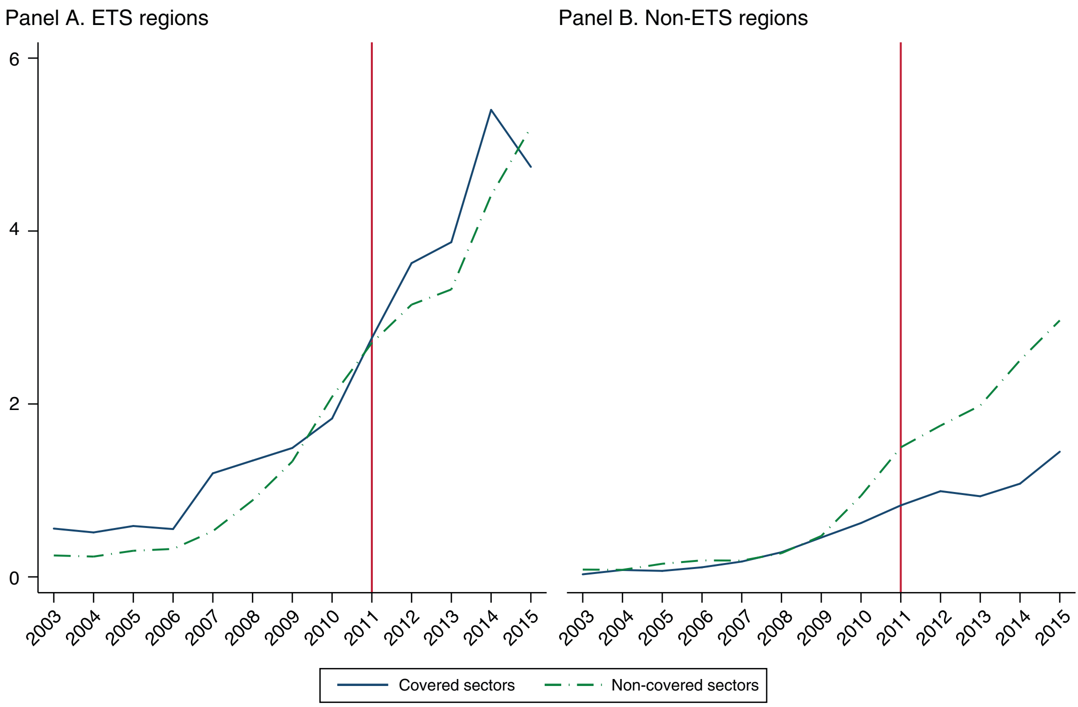

FIGURE 1. LOW-CARBON INNOVATION PER FIRM BY ETS REGIONS AND COVERED SECTORS

The variations in market rules across pilot regions result in substantial differences in carbon market performance, which in turn creates various incentives for innovation. We construct two indicators to measure the performance of carbon market: carbon price and allowance trading activeness. Let $Price_{rt}$ be the carbon price in pilot region r at year t. Similar to the turnover rate in the stock market, we construct an indicator of $Turnover_{rt}$ defined as the ratio of trading volume to the total allowance issued.[7] These two proxies serve as different carbon signals for emission regulatory pressures that may induce firms to engage in low-carbon innovation activities. The former captures real transaction prices for carbon allowance, while the latter reflects the activeness of market trading participation.

C. *Data Description*

We have a sample of 18,937 firm-year observations associated with 1,956 unique listed firms during 2003–2015. On average, a firm files 27 patent applications, among which 1.4 patents are associated with low-carbon technologies.[8] Figure 1 illustrates the trend of low-carbon patent application per firm by covered sectors and by ETS pilot zones over time. We observe a clear-cut pattern between ETS zones and non-ETS zones. In the pilot regions, firms in the covered and non-covered sectors have a similar upward trend of patent applications in low-carbon technologies. In the non-pilot regions, both sectors had a similar trend in patent innovation prior to the ETS policy, while the trend diverged dramatically after the ETS was announced.

[7] For those non-ETS regions, carbon price and turnover rate are coded as zeros.

[8] In the online Appendix, we report the summary statistics on the selected key variables.

II. Empirical Strategy

A. *Empirical Model*

To establish the causal link between ETS and firms' low-carbon innovation, we propose to use the triple-difference (DDD) approach, by comparing low-carbon patent applications between the pre- and post-announcement of ETS, between pilot and non-pilot regions, and between covered and non-covered sectors. For firm i at year t, the baseline model specification is

$$(1) \quad \ln y_{it} = \alpha_1 \times ETS_r \times Sector_j \times Post_t + \beta X_{it} + \gamma_i + \delta_{jt} + \eta_{rt} + \varepsilon_{ijt}.$$

In this form, y_{it} is a set of measures for firm's patent applications, including low-carbon patents $EnvPat_{it}$, other patents $NonEnvPat_{it}$, and share of low-carbon patents $EnvPatRatio_{it}$.[9] Three policy variables of central interest, denoted by ETS_r, $Sector_j$, and $Post_t$, refer to the binary indicators for pilot regions, covered sectors, and post-announcement of ETS, respectively. The corresponding parameter α_1 captures the induced innovation effect of ETS on low-carbon technologies. We control for time-varying firm attributes X_{it} such as firm age, revenue, capital intensity (ratio of capital to labor), and return on assets (ROA). Moreover, the sector linear trend and province linear trend, absorbed by δ_{jt} and η_{rt} respectively, could further help filter out unobserved factors that may be confounding with firm's decisions of innovation. The firm fixed effect, captured by γ_i, is included to control for firm-level unobservable heterogeneity. Finally, ε_{ijt} is an unobserved error term.

B. *Results*

Table 1 presents the estimation results for the baseline model. In column 1, the coefficient for the triple interaction term is positive and statistically significant at the 1 percent confidence level, suggesting the ETS pilots induce innovation. The ETS incentivizes more low-carbon patent innovation for the firms in the covered sectors and in the pilot regions relative to those in the non-covered sectors and non-pilot regions. A statistically insignificant coefficient in column 2 suggests little evidence of the crowding-out effect of ETS on patent applications in other fields. In the last column, we use the share of low-carbon patents as a dependent variable. The estimated coefficient for the interaction term is positive and statistically significant at the 1 percent confidence level, providing further evidence on the induced effects of ETS on innovation.

Table 1—Baseline Results

Variables	ln(EnvPat) (1)	ln(NonEnvPat) (2)	EnvPatRatio (3)
ETS × Sector × Post	0.177	0.172	0.026
	(0.091)	(0.131)	(0.009)
Observations	14,378	14,378	14,378
R^2	0.297	0.583	0.088

Notes: All columns include the firm-level control variables, firm-level fixed effect, year fixed effect, province linear year trend, and sector linear year trend. Standard errors presented in the parentheses are clustered at sector level.

Table 2 reports the estimation results for the heterogeneous effects of carbon market across pilots, using carbon price and turnover rate as proxies for the carbon market performance. In columns 1–3, we find positive and statistically significant coefficients for the two-way interaction terms between covered sectors and carbon prices across pilots. On the one hand, higher carbon price accelerates patent innovation in low-carbon technologies, confirming the induced innovation effect of ETS. On the other hand, it delivers a positive spillover effect on innovation in the areas other than low-carbon technologies. This finding is consistent with the estimation results presented in columns 4–6, which use allowance trading turnover rate as an alternative measure.

C. *Robustness Checks*

We conduct a series of robustness checks. First, we narrow the definition of low-carbon patents to the technologies only related to alternative energy production and energy conservation. Second, we use the count of low-carbon patents per R&D expenditure as an alternative measure for innovation. Lastly, we implement a number of placebo tests by generating pseudo

[9] We use $\log(1 + x)$ to avoid the problem of zeros, where x is the number of patents.

TABLE 2—EFFECTS OF CARBON PRICE AND TURNOVER RATE

Variables	ln(EnvPat) (1)	ln(NonEnvPat) (2)	EnvPatRatio (3)	ln(EnvPat) (4)	ln(NonEnvPat) (5)	EnvPatRatio (6)
Sector × ln(Price)	0.006	0.006	0.001			
	(0.003)	(0.003)	(0.000)			
ln(Price)	−0.002	−0.002	0.000			
	(0.001)	(0.001)	(0.000)			
Sector × Turnover				9.023	14.822	1.183
				(4.439)	(5.380)	(0.303)
Turnover				−3.683	−7.851	−0.255
				(1.308)	(2.697)	(0.179)
Observations	14,378	14,378	14,378	14,378	14,378	14,378
R^2	0.297	0.583	0.088	0.297	0.584	0.088

Notes: Price and Turnover are zeros prior to the launch of carbon market pilots. All columns include the firm-level control variables, firm-level fixed effect, year fixed effect, province linear year trend, and sector linear year trend. Standard errors presented in the parentheses are clustered at sector level.

covered sectors and pseudo pilot regions. The baseline DDD specification from 500 randomized assignments of pseudo covered sectors and pseudo pilots is re-estimated. The main conclusions remain unchanged.[10]

III. Discussion

In this paper, we investigate whether China's regional carbon market pilots can induce low-carbon innovation. The identification strategy relies on a comparison of patent applications between the pre- and post-announcement of ETS, between pilots and non-pilots, and between covered sectors and non-covered sectors. Using Chinese listed firms' patent data, we find consistent and robust evidence supporting the induced innovation effect of ETS. We also find that the pilots with higher carbon price or higher turnover rate tend to have more active innovation activities in the area of low-carbon technologies.

As suggested by Costantini et al. (2017), a 1 percentage point increase in the stock of eco-innovation is associated with a reduction in carbon emission intensity of 0.081 percent. Provided that China's regional ETS pilots increase around 19 percent of low-carbon patent innovations, our back-of-the-envelope calculation indicates that this ETS policy could decrease carbon intensity by more than 1.54 percent. Since the national carbon market was launched in late December, 2017, ETS is expected to play a more significant role in inducing low-carbon innovation, which contributes to China's compliance with the carbon emissions target while reducing the impact of carbon emission regulation on the economy.

[10] Please refer to the online Appendix for the results.

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