Management Practices and Climate Policy in China*

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Abstract

Cap-and-trade program for CO_2 emissions are being considered by governments worldwide to address the climate change challenge. The success of such a market-based climate policy at minimizing overall abatement cost and fostering low-carbon investment and innovation depends on participants fully understanding the trade-offs between using, selling or banking a permit. We provide the first empirical evidence on how management quality moderates responses to carbon pricing, by analyzing on firms that participated in two of China's regional pilot emissions trading schemes (ETS), located in the city of Beijing and Hubei province. We collect new data by interviewing plant managers or lead engineers at 216 randomly selected firms, and combine them with financial, patent and energy consumption data for each firm. We show that well-managed firms have on average higher productivity, , which has been documented in previous research. In addition, low-carbon innovation measures elicited from managers are strongly positively associated with "green" patenting.

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These results strengthen the credibility of our interview data. We also investigate whether carbon trading affects energy use of regulated firms. We estimate that the launch of the pilot ETS in Beijing has reduced consumption of coal and electricity by treated firms relative to control firms, but this effect is statistically significant only for well-managed firms. Our estimates imply that the overall reduction in coal use following the introduction of the pilot ETS would have been four times smaller if firms with above-median managers had been managed by below-median managers.

Keywords: climate policy; firm behavior; management practices; emissions trading scheme; policy evaluation

JEL classification: D22, O31, Q48, Q54

1 Introduction

China's role as the world's manufacturing powerhouse and its strong dependence on fossil fuels have made it the world's largest emitter of CO_2, with a share of 28% in global emissions. Consequently, international efforts to avoid dangerous climate change critically depend on China taking drastic action to slow down and revert the rapid growth in its emissions over the past decades. Recently, the country has pledged to achieve carbon neutrality by the year 2060. As one of the first steps towards achieving this ambitious goal, China is about to launch the first stage of a nation-wide cap-and-trade program for CO_2 emissions.

Market-based instruments of climate change mitigation, like cap-and-trade, unfold their full potential only if market participants fully understand the trade-offs between using, selling or banking a pollution permit. This decision is not trivial for any manager, and it cannot easily be outsourced to a professional broker, either. Making an optimal abatement choice requires a manager to have profound knowledge of all available options to curb emissions and to identify those with least cost. Taking an optimal banking decision additionally necessitates forecasting which abatement technologies might become available in the future, and at what cost. Whether to procure this technology from another firm or to conduct R&D within the firm is another strategic business decision that managers can hardly delegate. Therefore, a firm's fortune in the carbon market depends on the attitude and aptitude of its management. As a consequence, the success of China's national carbon market at minimizing overall abatement costs and fostering low-carbon investment and innovation, will depend to no minor degree on the quality of its management resources. Despite its policy relevance, this topic has received little attention in the literature thus far.

This paper provides the first empirical evidence on how management quality moderates responses to carbon pricing by firms that participated in two of China's regional pilot emissions trading schemes (ETS), located in the city of Beijing and Hubei province. Introduced in 2013 and 2014, respectively, these schemes are arguably the most important ones among the seven pilot ETS when it comes to foreshadowing the essential features of the nationwide ETS. Beijing, the spearhead of China's rapid economic development, has earned a dubious reputation as one of the world's most polluted capital cities (Hu et al., 2013). Hence, climate policies in Beijing have been designed in part with an eye to reaping air pollution co-benefits, and this is likely to leave its mark on the regulation that will be rolled-out nationwide (Qian et al., 2021). Hubei province has the largest carbon market, both in terms of total value and market volume (Welfens et al., 2017). Given its heavy industrial structure and high GDP growth, the province is representative of the Chinese economy on the whole and hence provides an ideal test bed for predicting the impacts of a national carbon pricing scheme.

Since data on management practices are not provided by official sources, we collect new data by interviewing plant managers or lead engineers at 216 randomly selected firms. Interviews were conducted over the phone and followed the now well-established, double-blind approach by Bloom van Reenen (2007) for measuring management quality. Building on Martin et al. (2012, 2014a), our data collection effort focused on measuring management practices broadly related to climate change – carbon trading, energy consumption, innovation, pollution and emissions control for greenhouse gases (GHG) – but also on more general aspects of management.

The first part of our empirical analysis documents how management correlates with key indicators of firm performance. We find that well-managed firms have on average higher turnover, even after controlling for capital, materials and labor inputs. A one-standard-deviation increase in management quality is associated with a 7.4% improvement in revenue productivity. With respect to low-carbon investment, we correlate the information provided by managers with data on "green" patents filed by the firm. Both variables are strongly positively associated, which underlines the credibility of the information elicited in the survey.

Equipped with a valid measure of climate change related management practices, we then investigate whether carbon trading affects energy use of regulated firms, giving particular attention to treatment heterogeneity across different tiers of management quality. Our estimation results indicate that the launch of the pilot ETS in Beijing has reduced consumption of coal and electricity by treated firms relative to control firms, but this effect is statistically significant only for well-managed firms. Our estimates imply that the overall reduction in coal use following the introduction of the pilot ETS would have been four times smaller if firms with above-median managers had been managed by below-median managers. Based on additional survey questions, we identify anticipation of future regulation under a national carbon market as a strong predictor of managers adopting management practices that may have facilitated emissions reductions under the pilot ETS.

Our paper provides first evidence that better management can leverage the effect of market-based instruments for climate change regulation in China. This finding is policy relevant and timely, given that the country is preparing for the roll-out of a nation-wide ETS poised to become the world's largest carbon market. While China is the world's largest emerging economy, our analysis is also relevant for more than half-a-dozen other emerging economies that are considering the adoption of cap-and-trade policies for GHG emissions. In respect to the academic literature, our paper breaks new ground by connecting the new empirical management literature with an emerging program evaluation literature estimating causal impacts of climate change regulation on business in other parts of the world. Only by linking these two strands of the literature can we gain a better understanding of how a managers' awareness of and ability to identify and implement innovative approaches to mitigate GHG emissions translates into socially desirable outcomes of climate policy.

The paper is structured as follows. The next section describes the policy background and discusses the related literature in detail. Section 3 describes the interview process and additional data collection. Section 4 explores the relationship between management and firm performance. Section 5 presents the results on the pilot ETS and counterfactual analysis. Section 6 concludes.

2 Policy Background and Related Literature

2.1 Carbon Trading in China

In 2011, China announced it would use cap-and-trade as a policy instrument to mitigate GHG emissions, with plans to eventually roll out a nation-wide market for pollution rights encompassing 3.5 billion metric tons of CO_2 emissions per year (Deng et al., 2018, Liu Fan, 2018). This amounts to about twice the current amount of verified emissions in the EU ETS and would establish China's ETS as the world's largest carbon market. The first phase of this nation-wide ETS is about to start and includes 2,267 power generation companies that jointly emitted almost 40% of China's total emissions in 2020.

To support the development of the national ETS, the Chinese government launched between 2013 and 2014 separate pilot schemes in seven different locations: five cities – Shenzhen, Shanghai, Beijing, Tianjin, and Chongqing – and two provinces – Hubei and Guangdong. For simplicity, we will henceforth refer to cities and provinces alike as "regions". In total, the seven pilot ETS covered annual CO_2 emissions of approximately 1.2 billion tons, roughly accounting for 16% of CO_2 emissions and 20% of total energy use in China (Jotzo Löschel, 2014, Stoerk et al., 2019). The bulk of the ETS-regulated firms belong to energy-intensive industries such as power and heating, cement, chemicals, iron and steel, as well as several non-industrial sectors such as hospitals, hotels and buildings (Qi et al., 2014, and Munnings et al., 2016). Since the design of the schemes was not uniform across provinces, there is some variation in the inclusion criteria for firms to be regulated. Participation thresholds for firms, when included, are based on annual CO_2 emissions or energy consumption in a reference period (for example, 2009-2011) and range between three thousand and 20 thousand tons of CO_2 (Zhu et al., 2019). In regards to the analysis below, the initial participation thresholds for firms located in Beijing and Hubei provinces were ten thousand tons of CO_2 and 60 thousand tons of coal equivalent (tce), respectively.

2.2 Related Literature

Recent studies of China's carbon market pilots have revealed two stylized facts about their performance. First, carbon prices vary substantially across the pilot schemes, though average prices have generally been low. Fan Todorova (2017) and Zhang et al. (2017) have documented that the average market price across seven pilots fluctuated between 0 and 125 RMB (i.e., 0-16.3 Euros). While much lower than EPA's social cost of carbon estimate of 35 Euros, carbon prices in the Beijing and Hubei ETS, depicted in Figure B.2 in the appendix, were comparable though to those observed in the European carbon market up until 2018.

Second, market liquidity has been low. The most active market was in Shenzhen, where the cumulative trading volume accounted for only 5.57% of its cap over the period from June 2013 to November 2014. Zhao et al. (2016) report that there are no transactions in nearly one-third of the trading days in the pilot markets, with trading volumes spiking near the compliance deadline. This can be seen also in Appendix Figure B.2 that displays the trading volumes in Beijing and Hubei. It suggests that many of the transactions are made for compliance purposes, and regulated firms failed to capitalize on the allowance surplus to associate carbon trading with their energy conservation management. Both stylized facts are consistent with the assessment by Zhang et al. (2017)

that compliance in the pilot schemes imposed only "soft constraints" on the regulated firms.

An emerging empirical evaluation literature has produced suggestive evidence that the pilot schemes have induced low-carbon innovation and energy conservation among regulated firms. Using firm-level patent data, Cui et al. (2018) find that there is faster development of low-carbon technologies among stock-market listed firms located in the pilot ETS regions compared to those in other regions. Based on industry-level data, Hu et al. (2020) estimate that energy consumption in the pilot ETS regions has been reduced by 22.8% and carbon emissions by 15.5% compared to non-regulated regions. Within the regulated locations, Zhu et al. (2019) find that firms under a fixed, output-based permit allocation conducted significantly more low-carbon innovation than those receiving free permits according to an output-based updating rule.

Our paper contributes to this literature by bringing, for the first time, information on management quality to bear on this. Since this information is not available from existing data sources, we have collected new data by conducting in-depth interviews with firm managers, using a well-established telephonic survey tool (Bloom van Reenen, 2007). The data allow us to disentangle managerial decisions and attitudes from the firm's ex-post response to regulation. Compared to the literature cited above, our dataset has the further advantages that it is not limited to listed firms and that ETS-regulated firms are identified directly rather than using proxies such as location or industry.

Much of the empirical research on carbon trading so far has been conducted in the context of the EU carbon market (see Martin et al., 2016, for a survey), and focused on identifying causal impacts (Calel Dechezleprêtre, 2016, Colmer et al., 2020, Fowlie et al., 2012). Our analysis of the pilot ETS in China not only adds to that body of literature but also connects it to the new empirical management literature. This new link allows us to understand how management practices interact with cap-and-trade policies.

Our interest in the Chinese pilot ETS fits in with a rich emerging literature on the costs and benefits of regulating China's challenging environmental problems (Chang et al., 2018, 2019, Graff-Zivin et al., 2020, Ito Zhang, 2020, Jin et al., 2017, Kahn et al., 2015). Recent research in this strand of literature has established the strong impact of pollution regulation on firm-level total factor productivity (He et al., 2020). Our paper sheds light on how management quality, a fundamental yet so-far unmeasured component of the productivity residual, interacts with regulation in the context of China's war on pollution.

Beyond this particular policy context, our paper contributes to the new empirical management literature which seeks to measure the contribution of management inputs to firm productivity (e.g., Ichniowski et al., 1997, Bertrand Schoar, 2003, Bloom van Reenen, 2007). Recent research in this area has focused on understanding this relationship for the particular case of developing countries (Bloom et al., 2013, McKenzie Woodruff, 2017, Bloom et al., 2016). At a general level, we contribute novel data on management practices at Chinese firms. More specifically, our data speak to management practices that relate to energy use and climate change mitigation. Our questionnaire is based –in large parts, but with appropriate modifications– on a Chinese translation of the one previously used in nearly one thousand interviews with firm managers in Belgium, France, Germany, Hungary, Poland, and the United Kingdom (Martin et al., 2012, 2014a, 2015). Similar to Martin et al. (2012), we find a positive association between management practices relating to climate change and TFP.

Finally, an emerging literature in management has analyzed the role of environmental management with respect to corporate social responsibility and to the financial performance of firms (e.g., Klassen McLaughlin, 1996, Dowell et al., 2000, King Lenox, 2002, Chava, 2014, Earnhart, 2018). This area of research is bound to grow as the environmental stewardship of firms is subject to increasing levels of scrutiny by agents on the financial markets. Our paper contributes not only novel, detailed data to this literature but it also demonstrates that state-of-the-art survey methodology can be employed to measure this important aspect in China, where data collection is challenging.

3 Data and Summary Statistics

Our final sample consists of 216 firms that were interviewed about their management practices in 2016 and 2017. Firms in Beijing and Hubei were selected from the ORBIS database of Bureau Van Dijk, from which we obtain financial data for each of them. We over-sampled firms participating in the pilot ETS system. These were identified from official lists and matched to ORBIS based on their names. We then randomly selected non-ETS companies located in Beijing and Hubei and operating in the same industries as the ETS firms. The response rate was 7.5% for ETS firms and 5.8% for the others, as reported in the Appendix Table A.1. We obtained additional information on all interviewed firms from two further datasets, the China National Intellectual Property Administration database (CNIPA) that details their patent filings, and the Chinese State Administration of Tax (CSAT) dataset that details their energy consumption.

3.1 Data Collection

The environmental performance of a firm is reflected in a range of measurable outcomes, including pollution emissions, energy usage or ISO 14001 certification (Earnhart, 2018). However, these variables do not allows us to directly infer environmental management practices. We therefore ran a survey to elicit information on management practices related to climate change, as well as firms' behavior towards the pilot ETS regulation. Building on previous work by Martin et al. (2012, 2014b), we interviewed managers based on a questionnaire successfully used in Europe.[1] The interview includes questions about carbon trading, energy consumption, innovation, pollution and GHG emissions control, as well as some general management practices.

The survey is targeted at plant managers or leading engineers with knowledge about environmental issues in the firm. Through a telephone survey methodology pioneered by Bloom van Reenen (2007) in the World Management Survey, we minimize the sources of cognitive bias often present in conventional surveys. Managers' responses may be biased by interviewees' tendency to report socially desirable rather than actual practices. To avoid this, the use of open-ended questions followed by more detailed questions allows specially-trained interviewers to better gauge management practices. Each question was evaluated on an ordinal scale from 1 to 5 with a higher score representing better performance. Potential cognitive bias on the part of interviewers and their way of inquiring are addressed first by providing interviewers with benchmark examples for giving low, medium, and high scores, and second by double-scoring a sub-sample of interviews.[2] Any remaining systematic bias is then controlled for by using interviewer fixed effects in the regression analysis.

Table 1 summarizes the variables in our sample. The first panel shows that, on average, managers of firms located in Beijing were older and more likely to have a degree in business management (55% vs. 31%). Other manager characteristics are not significantly different between the two regions. Managers have been on average about 10 years at the firm, are about 40 years old and 20% of them are female. About 40% of the firms in the sample are state-owned and 13% engage in export activities.

3.2 The Climate Change Management Index

Based on the answers to the core set of interview questions, we construct a summary measure that we refer to as the Climate Change Management Index (CCM index for

[1] See in Appendix A.2 the survey questions in Chinese, with an English translation

[2] See the results of the double-scoring in Appendix A.1

Table 1: Summary Statistics and Sample Characteristics

	Beijing	Hubei		All Firms			
	Mean	Mean	*p*-value	Mean	S.D.	Obs.	N
Interview characteristics data							
Manager's tenure in company in years	9.95	9.48	0.736	9.88	7.15	206	206
Manager's education in business management	0.55	0.31	0.013	0.51	0.50	210	210
Manager is female	0.19	0.18	0.957	0.19	0.39	216	216
Manager's age in years	38.74	40.94	0.167	39.10	8.33	201	201
firm's age in years	20.86	14.82	0.000	19.94	7.73	216	216
Firm is state-owned	0.42	0.30	0.227	0.40	0.49	216	216
Firm engages in export	12.84	12.48	0.947	12.79	23.15	149	149
Management index							
CCM index	-0.04	0.20	0.012	0.00	0.50	216	216
Carbon market indices							
Participant in pilot ETS market	0.44	0.58	0.143	0.46	0.50	216	216
Rationality of current trading score	1.79	1.64	0.609	1.77	0.99	83	83
Stringency of current pilot ETS index	-0.16	0.25	0.037	-0.10	0.80	119	119
Anticipated stringency of future ETS index	-0.18	0.16	0.009	-0.13	0.68	216	216
Green Innovation							
Process innovation score	1.68	1.81	0.471	1.70	0.96	216	216
Product innovation score	1.92	2.12	0.357	1.95	1.16	216	216
Innovation index	1.80	1.96	0.320	1.82	0.89	216	216
Firm has green patents	0.47	0.71	0.091	0.51	0.50	89	89
Share of green patents	0.10	0.14	0.491	0.10	0.18	89	89
ORBIS data							
Turnover in 000's USD	183,849.96	84,535.50	0.088	172,249.83	747230.9	1601	216
Employment	1,407.63	724.64	0.066	1,317.00	3630.85	829	206
Capital in 000's USD	41,956.94	27,611.27	0.161	40,318.73	129660.7	1585	216
Cost of goods sold in 000's USD	124.59	66.24	0.173	117.82	533.93	1516	216
Firm energy and water usage							
Oil usage in 000's tons	2.37	12.47	0.023	3.47	46.04	1103	182
Coal usage in 000's tons of oil equivalent	15.98	162.69	0.000	31.94	208.42	1103	182
Electricity usage in megawatts	20.47	85.48	0.004	27.55	232.3	1103	182
Water usage in million of litres	305.13	3,018.71	0.000	600.35	6952.95	1103	182
Oil intensity in tons of oil per million USD	50.04	159.71	0.039	61.98	549.75	1103	182
Coal intensity in tons of coal per million USD	302.51	1,073.75	0.000	386.41	1966.41	1103	182
Electricity intensity in megawatts per million USD	0.82	0.93	0.944	0.83	16.96	1103	182
Water intensity in millions of litres per million USD	4.09	21.82	0.000	6.02	45.41	1103	182

Notes: The *p*-value refers to equality of means between firms in Beijing city and Hubei province. *p*-value tests the difference between the means of the two regions. S.D. stands for standard deviation, and Obs. for observations. ORBIS data is available annually between 2007 and 2016.

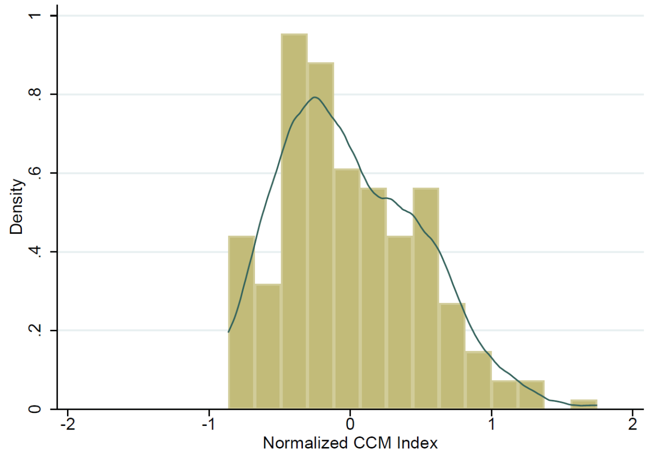


Figure 1: Distribution of the Climate Change Management Index

short). It is computed as the average of 21 normalized scores[3] that measure different aspects of management related to climate change: awareness of issues of climate change and pollution; energy and GHG emissions monitoring, targets and enforcement; competitive and customer pressure on climate change issues. The components of the index are described in full detail in Appendix A.3. By construction, the CCM index has an overall average of zero, but it is higher for the average firm in Hubei (0.20) than in Beijing (-0.04). The difference is significant at the 5% confidence interval. Figure 1 displays the distribution of the CCM index. The distribution is skewed to the right because a few firms scored high on all of the management practices that were discussed in the interviews.

3.3 Firm Behavior on the Carbon Market

As a result of our sampling approach, 46% of the firms in our sample participate in a pilot ETS (44% in Beijing, 58% in Hubei). In order to understand the firms' trading behavior in the pilot ETS carbon markets, the questionnaire included specific questions that allow us to construct three different indicators of carbon market behaviors. First, the *rationality-of-trading score* is based on the interviewee's responses to questions about how firms decide to sell and buy permits, whether they base their decision on forecasts about prices and/or energy usage, and whether they trade off permit revenue against emission reductions costs (see question VII of the survey in Appendix A.2). A low score

[3]The z-scores are computed by subtracting from the raw score the average score and dividing by the standard deviation

is assigned if the firm does not take into account the price of permits or the cost of abatement, while a high score is given if the firm has a thorough understanding of its CO_2 abatement cost curve. Firms in Beijing and Hubei did not significantly differ in their market behavior. The average score of 1.77 suggests a relatively passive attitude towards the management of permits. This is consistent with very low trading volumes on the markets discussed in the literature.

Second, the *market stringency score* measures how difficult it is, in the interviewee's view, for the firm to comply with the emissions cap implied by the permit allocation to the production site, how strict the enforcement by the authorities has been, and how large their estimation of the cost burden of being part of the pilot ETS as a share of annual operating cost is (see question VIII of the survey in Appendix A.2). The difference between Beijing and Hubei ETS participants is again insignificant. The average score of 2.59 suggests that targets are more stringent than business-as-usual, but that no fundamental adjustments were needed to comply. This is consistent with the relatively low prevailing price on the markets.

Third, the *anticipated stringency of future ETS score* captures, for firms expecting to be part of the nation-wide ETS, how stringent they expect the next phase to be, whether sanctions will be imposed for non-compliance, whether auctioning will be included for the distribution of allowances, and whether they deem it likely that the nation-wide carbon market will actually be launched (see question IX of the survey in Appendix A.2). Expected stringency of the next phase is higher than current stringency, with an average score of 3.27. Interviewers gave a score of 3 or above when firms anticipated some necessary adjustments and more regular audits.

3.4 Innovation

Green innovation is captured by both an index relying on the management questionnaire and actual patent data. Our survey data focused on the innovative effort (rather than outcome) distinguishing between process and product innovation. Process innovation is the use of new methods or new technologies to reduce energy use or GHG emissions in the production of existing products (see question X of the survey in Appendix A.2). Product innovation refers to the invention of products that allow users to reduce their emissions footprint (see question XI of the survey in Appendix A.2). To measure how firms perform in terms of their innovative efforts we included questions such as whether their company dedicates staff time and financial resources to finding innovative ways to reduce GHG emissions at their production facility to produce greener products, and prompted them for examples. Process and product innovation scores are not significantly different between the two regions. The average process and product innovation score are respectively 1.70 and 1.95, meaning that the amount of R&D resources committed to these purposes was not large. We combine process and product innovation scores into an overall *innovation index*.

Further information on innovation is obtained from the CNIPA database, which covers all the published patent applications from 1985 in China and contains detailed information on each patent. We use the number of approved patents as an objective measure of a firm's innovation efforts. Moreover, we classify a patent as green if its International Patent Classification code (IPC code) conincides with the IPC Green Inventory code that was developed by the IPC Committee of Experts in the World Intellectual Property Organization. We use the number of approved green patents to measure firms' innovation in green technologies and compute the share of green patents as a percentage of the total number of patents. 70% of firms that innovate in Hubei vs. 47% of firms that innovate in Beijing have at least one green patent, and this difference is significant at the 10% significance level. However, both regions have about 10% of their patents classified as green innovation.

3.5 Financial Data

The ORBIS data provides firm level financial data. We extract the firms' annual turnover, capital and cost of goods sold in US dollars.[4] These measures allow us to account for difference in sizes and inputs and to assess the annual changes in energy intensity per turnover. Turnover and employment are twice as large in Beijing firms as in Hubei firms, significant at the 10% significance level. Capital and cost of goods are also larger in Beijing but the differences are not significant.

3.6 Energy Consumption

Chinese State Administration of Tax (CSAT) data was obtained when available for the firms we interviewed. It provides firm-level energy consumption data, more specifically the usage of oil, coal, electricity and water among firms located in Beijing city and Hubei province.[5] For each fuel, we compute energy intensity by taking the ratio of oil

[4] We use the "Historic ORBIS" version of the data.

[5] Natural gas is not included which could be the case because natural gas consumption only accounted for less than 6 percent of the total energy consumption (less than 5 percent of the energy consumption in manufacturing) before 2015 as reported in Chinese Statistical Yearbooks http://www.stats.gov.cn/tjsj/ndsj/2019/indexeh.htm.

(in tons of oil equivalent), coal (in tons of coal equivalent) and electricity consumption (in megawatt hours), divided by the firm's turnover (in million USD).

Oil, coal, electricity and water usages are much larger in Hubei with average differences as large as ten times average usage in Beijing. Apart from reflecting differences in the industry structure, this could be due to the higher pilot ETS participation thresholds that prevail and affected our sample. Adjusted for turnover, energy intensities remain much larger in Hubei, except for electricity intensity where the difference is not significant between the two regions.

4 Climate Change Management and Firm Performance

4.1 Productivity

To begin our empirical analysis, we examine how climate change related management practices vary with firm performance. To this end, we regress the log turnover of firm i in year t on firm i's CCM index ($CCMI_i$) and further controls. The OLS regression is given by

$$y_{it} = \alpha_0 + \beta_M CCMI_i + \mu' c_{it} + x'_{it}\gamma + z'_i\delta + u_{it}. \tag{1}$$

where the vector c_{it} contains (the log of) employment, capital, and cost of goods sold which includes all material costs associated with the production of the goods or services sold by a firm, measured annually between 2007 and 2016. Controlling for c_{it} allows us to interpret the coefficient on $CCMI_i$ as the effect on the productivity residual. The vectors x_i and z_i control for firm and interview characteristics, respectively. Firm-level controls include age, as well as dummies for exporter status, state ownership, region and industry at the two-digit NACE level.[6] Interview 'noise' controls include the day-of-week on which the interview took place, interviewer fixed effects as well as characteristics of the manager interviewed such as tenure, educational background and gender. The stochastic error term u_{it} is clustered at the firm level.

Table 2 reports the OLS parameter estimates of eq. (1). In all specifications, the CCM index is positively and significantly associated with (log) turnover. The coefficient estimate drops from 0.919 in column (1) to 0.695 when firm characteristics are included in column (2). This suggests that better managed firms also have higher returns to production and sales. In column (3), the association remains positive and statistically significant, but the coefficient further drops to 0.144. The coefficient implies that a one-

[6]NACE is the acronym for "Nomenclature statistique des activites economiques dans la Communaute europeenne".

Table 2: Climate Change Management Index and Productivity

	(1)	(2)	(3)
		Log Turnover	
CCM index	0.919***	0.695***	0.144**
	(0.201)	(0.174)	(0.061)
Hubei firm		-0.056	-0.001
		(0.224)	(0.079)
State-owned		0.483***	0.071
		(0.158)	(0.061)
Log(Employment)		0.492***	0.065
		(0.090)	(0.050)
Log(Capital)			0.151***
			(0.038)
Log(Cost of Goods Sold)			0.733***
			(0.071)
Year and industry controls	Yes	Yes	Yes
Noise controls	Yes	Yes	Yes
Age controls	Yes	Yes	Yes
Number of observations	1601	1601	1601
Number of firms	216	216	216
R-squared	0.478	0.613	0.901

Notes: Results obtained in OLS regressions of the log turnover between 2007 and 2016 on the CCM index, including year, industry, interview, interviewee and interviewer controls. Controls for the region (Hubei vs Beijing) of the firm, state-ownership, log of employment as well as exporter status, age and age squared of the firm are included in columns (2) and (3). In column (3) cost of goods sold and capital, both in logs, are added. Robust standard errors given in parenthesis are clustered at the firm level. Significance levels are indicated as * 0.10, ** 0.05, *** 0.01.

standard-deviation increase (0.50) in the CCM index is associated with a 7.4% increase in revenue productivity.

This result is consistent with the earlier finding that higher productivity is associated with better general management practices[7] and closely mirrors a result obtained for UK manufacturing firms (Martin et al., 2012). Given the similarity of our research design to the one used in that study, , it is possible to meaningfully compare the effect magnitudes implied by the parameter estimates in both studies, i.e. the conditional correlation in our sample (0.144) and the one estimated by Martin et al. (2012, cf. Table 2 column 2) (0.119). A one-standard deviation increase in the CCM index is associated with a 5% increase in revenue productivity among UK firms vs. 7.4% at Chinese firms.[8]

4.2 Fuel Intensity

One channel for management practices to enhance productivity is by improving the efficiency of energy use. In line with this, a negative correlation between the World Management Index and energy intensity was documented for manufacturing firms in the U.K. (Bloom et al., 2010) and in the U.S. (Boyd Curtis, 2014). Martin et al. (2012) show that a close analogue to our CCM index is negatively correlated with a cost-based measure of energy intensity. For lack of information on energy costs, we estimate eq. (1) using the ratio of fuel use and turnover as the dependent variable. The results are reported in Appendix Table B.2 and show no systematic correlation with the CCM index. In Section 5 we shall revisit energy consumption as an outcome variable when analyzing how management practices interacts with climate policy.

4.3 Green Innovation

Since 2006, the Chinese government has incorporated increasingly ambitious and wide-ranging environmental policies in successive Five Year Plans, hoping to spur the development of green technologies. This has led to the rise of patenting in green technologies during the last decade (Linster Yang, 2018). Several studies mentioned in the literature review have investigated the impact of the ETS on innovation. To assess how the firms in our sample perform in this important aspect, we look at the correlation between

[7] Bloom et al. (2013) estimate the causal impact of adopting good management practices on productivity in the textile industry in India, an emerging economy sometimes compared to China. They find that increasing the general management score by one standard deviation causes a 17% increase in productivity.

[8] One standard deviation of the CCM index is 0.41 in (Martin et al., 2012) in the same specification as our column (3). A two-sample t-test does not allow us to reject the null hypothesis that the difference of 0.025 between the coefficients is statistically not different from zero.

Table 3: Green Patents and Innovation Practices

	(1)	(2)
	Green Patents	
	Share of patents	[Yes/no]
Climate Change Management index	6.146	0.294
	(4.154)	(0.353)
Innovation index	3.912*	0.668***
	(2.331)	(0.257)
Process innovation score	4.813*	0.452*
	(2.470)	(0.253)
Product innovation score	1.847	0.572***
	(1.847)	(0.207)
Interview controls	Yes	Yes
Firm-level controls	Yes	Yes
Estimation	OLS	Probit
Number of firms	89	89

Notes: Each cell represents a separate OLS regression in column (1) and Probit in column (2). The dependent variable is defined as the share of green patents in total patents (in %) in column (1) and as a dummy equal to 1 if the firm has green patents in column (2). Each line reports the result of a different estimation with the explanatory variable of that column and in addition controls for location (Hubei vs Beijing), state-ownership, industry (one-digit), exporter status, age and age squared of the firm, the logarithm of average employment (between 2001 and 2016) and interview noise. Robust standard errors in parenthesis. Significance levels are indicated as * 0.10, ** 0.05, *** 0.01.

green patents filed by a firm and the innovation measures gathered in the survey. This is done by regressing patents on innovation scores while controlling for a range of firm characteristics and interview noise.

Table 3 displays the results obtained in the sample of 89 firms for which patenting information is available. Each cell refers to a separate regression. The dependent variable for results in column (1) is the percentage share of green patents over the total patents, whereas in column (2) it is a dummy variable indicating whether a firm engages in green patenting. Two patterns are emerge from these regressions. First, climate change related management practices as measured by the overall CCM index are not associated with higher levels of green patenting - at least not in a statistically significant sense. Second, firms that reported higher values for process and product innovation in the interview also have significantly higher levels of green patenting. We take this as evidence that the green innovation variables measured through the survey are valid representations of the firm's innovative activity.

5 Management Practices and Carbon Trading

Equipped with the CCM index as a reasonably accurate measure of management quality, this section analyzes how management practices interact with firm-level responses to climate change policies. As a case-in-point, we resort to carbon pricing under the Chinese pilot emissions trading scheme. Our analysis focuses on firm-level adjustments to energy usage following the introduction of the ETS. In particular, we are interested in how these adjustments differ between well-managed firms and the rest of the pack.

5.1 Data

Due to data constraints, our empirical analysis focuses on firms in Beijing, where emissions trading was launched in 2013.[9] We keep only those firms that have at least one observation before and after 2013 to allow for before-and-after comparisons. Only firm-year observations with at least one non-zero fuel consumption are included. Following those cleaning steps, our dataset consists of 128 firms, 56 of which are regulated by the ETS. According to the CCM index, 64 firms are well managed, i.e., above the median. Table A.3 in the Appendix reports descriptive statistics for the CCM index and resource consumption before the introduction of the ETS in 2013. In addition to energy usage (electricity, coal and gas) we include water consumption for comparison. Note that ETS regulated firms and big energy consumers tend to be better managed (only 20 of the well-managed firms are non-ETS firms and the average well-managed firm consumes more coal and electricity by an order of magnitude).

5.2 Changes in Fuel Use in Response to Carbon Trading

To estimate the impact of the ETS on energy use, we adopt a strategy akin to a Differences-in-Differences (DiD) estimator. That is, we measure how regulated firms change their energy use following the introduction of the ETS and compare it to unregulated firms. To accommodate the fact that some firms never use certain fuels, we assume that firm i's fuel demand $e_{i,t}$ is given by

$$e_{i,t} = \theta_i f(x_{i,t}, \epsilon_{i,t}) \geq 0 \qquad (2)$$

where θ_i is a fixed effect and f a non-negative function of observable covariates x_{it} and a random disturbance ϵ_{it}. A simple DiD estimator for this model is obtained by averaging

[9] The ETS in Hubei was introduced in 2014 and the energy usage data is only available until 2015.

Figure 2: Fuel Consumption by Regulatory Status and Tier of CCM Index

energy use in pre- (e_i^{pre}) and post-treatment periods (e_i^{post}) and calculating the growth rate as

$$\gamma_i = \frac{e_i^{post} - e_i^{pre}}{0.5 \times (e_i^{post} + e_i^{pre})}. \tag{3}$$

This statistic is well-suited to our application because it accommodates zero energy consumption and because unobserved heterogeneity θ_i drops out.[10]

Figure 2 shows kernel density plots of the growth in energy and water use (calculated in eq. (2) across firms in our sample from Beijing). For each outcome variable, we provide separate distribution plots after partitioning the sample by ETS regulatory status and by tier of the CCM index. This provides first insights into how management practices shape firms' responses to carbon pricing. The top left panel shows the plot for coal. The graph uncovers a striking difference between well-managed and not-so-well managed firms. Among firms with above-median values of the CCM index, growth in coal usage of unregulated firms first-order stochastically dominates that of regulated firms. This means that, at each percentile of the distribution for well-managed firms, the change in coal use following the introduction of the ETS is less positive or more negative among

[10]Below we also explore the robustness to using a Poisson specification which is an alternative way to deal with zero values and unobserved heterogeneity.

Table 4: ETS Impact on Growth of Energy Use

Dependent Variables:	ΔCoal		ΔOil		ΔElectricity		ΔWater	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ETS firm	-0.3454	0.6675	0.1890	-0.3206	-0.3387*	-0.1424	0.0049	-0.0739
	(0.2965)	(0.5245)	(0.2439)	(0.4386)	(0.1848)	(0.3845)	(0.1653)	(0.3074)
Above-median CCM index		0.4677		-0.2037		-0.0968		-0.2705
		(0.4497)		(0.2749)		(0.2572)		(0.2311)
ETS firm×		-1.541**		0.7893		-0.1887		0.2751
above-median CCM index		(0.6811)		(0.5410)		(0.4637)		(0.3848)
Observations	110	110	125	125	127	127	128	128
R^2	0.01221	0.05412	0.00522	0.02334	0.02630	0.03293	6.88×10^{-6}	0.00966
Adjusted R^2	0.00306	0.02735	-0.00287	-0.00087	0.01852	0.00934	-0.00793	-0.01430

Notes: OLS regressions include a constant (omitted). The dependent variables are the arc growth rates, as defined in eq. (3), for tons of coal (columns (1) and (2)), tons of oil (columns (3) and (4)), electricity (in 10,000 Watts) (columns (5) and (6)), and water consumption in litres (columns (7) and (8)). Robust standard-errors in parentheses. Significance levels are indicated as * 0.10, ** 0.05, *** 0.01.

regulated firms than among unregulated firms. While not necessarily causal, this finding is consistent with a negative treatment effect over the entire distribution of treated, well-managed firms. In contrast, among firms with below-median values of the CCM index, ETS firms do not exhibit slower growth in coal use than non-ETS firms. This underlines the importance of management quality when firms to respond to market-based instruments of climate policy.

The panel for electricity (on the bottom left) shows that usage among ETS firms tends to grow more slowly after the introduction of the policy than among non-ETS firms. While this pattern holds true for all firms, it is somewhat more pronounced among well-managed firms.

The density plot for oil (top-right) shows little difference in growth rates across management tiers. If anything, badly-managed ETS firms are somewhat less likely to increase their usage of oil than well-managed ETS firms, which hints at different fuel-substitution strategies across both groups. Growth rates for water use, which we include for comparison in the bottom-right panel, exhibit no discernible differences in the distributions between groups with different management quality.

For statistical inference, we complement the graphical analysis with regressions of the form

$$\gamma_i = \mathbf{D}_i \beta + \varepsilon_i \tag{4}$$

where γ_i is the above-defined growth rate and $\mathbf{D}_i$ is a vector of dummy variables that partitions the sample into different groups of firms. Table 4 reports a set of results where firms are distinguished only by ETS status, i.e. $\mathbf{D}_i = ETSFirm_i$. The estimated coefficients are displayed in the odd-numbered columns and reveal little in

Table 5: ETS Impact on Growth of Energy Use with Management and Size

Dependent variables:	ΔCoal (1)	ΔOil (2)	ΔElectricity (3)	ΔWater (4)
ETS firm	0.9163**	0.3792	0.3265	-0.0314
	(0.4015)	(0.4511)	(0.5972)	(0.5528)
Above-median CCM index	0.4805*	-0.0829	-0.0398	-0.1883
	(0.2447)	(0.2607)	(0.2457)	(0.2359)
Above-median coal consumer	-2.341***			
	(0.2818)			
ETS Firm × above-median CCM index	-1.071**	0.9708**	-0.1783	0.1900
	(0.4326)	(0.4456)	(0.4278)	(0.3912)
ETS Firm × above-median coal consumer	-0.0667			
	(0.4455)			
Above-median oil consumer		-0.9810***		
		(0.2652)		
ETS Firm × above-median oil consumer		-0.7685*		
		(0.4329)		
Above-median electricity consumer			-0.4780**	
			(0.2271)	
ETS Firm × above-median electricity consumer			-0.2942	
			(0.5594)	
Above-median water consumer				-0.5930**
				(0.2348)
ETS Firm × above-median water consumer				0.3914
				(0.5173)
Observations	110	125	127	128
R^2	0.57375	0.25253	0.09165	0.05520
Adjusted R^2	0.55325	0.22112	0.05412	0.01648

Notes: OLS regressions include a constant (omitted). The dependent variables are the arc growth rates as defined in eq. 3 for tons of coal (column (1)), tons of oil (column (2)), electricity (in 10,000 Watts) (column (3)), and water consumption in litres (columns (4)). Above-median are dummies indicating the firm is above the sample's median for the CCM Index, or for their pre-2013 average water or energy consumption for each fuel. Robust standard-errors in parentheses. Significance levels are indicated as * 0.10, ** 0.05, *** 0.01.

the way of a statistically significant relationship between ETS participation and average growth in energy consumption. While point estimates are sizable, only the coefficient for electricity is significant at the 10% level. To account for heterogeneity in management practices, we additionally include a dummy for firms that rank above the median of the CCM index and its interaction with the ETS dummy, i.e., hence $\mathbf{D}_i = [ETSFirm_i, AboveMedianCCM, ETSFirm_i \times AboveMedianCCM_i]$. In line with our findings in Figure 2, the coefficient on this interaction is negative and statistically significant for coal, but there are no significant coefficients for any of the other fuels (cf. even-numbered columns of Table 4).

Our results lend support to the hypothesis that well-managed firms respond more strongly to carbon pricing than not-so-well managed firms. The fact that the former are substantially larger than the latter - in particular in terms of coal consumption - raises concerns that we might be picking up the effect of size rather than a causal effect from management. If large firms are better managed than small firms, they might also be in a better position to reduce energy consumption in response to regulation for reasons unrelated to management. To address this concern, we split our sample into groups based on their pre-ETS energy consumption levels. For each fuel type, we define firms with consumption below or above the median. For example, ETS firms with above-median levels of coal consumption use coal in amounts similar to the average well-managed ETS firm (cf. Appendix Table A.3. In regressions reported in Table 5, we additionally control for the initial fuel consumption and its interactions with regulatory status and management. The results show, indeed, that above-median users of coal reduce their consumption by more than firms below the median, all else equal. However, this has only a moderate impact on the $ETSFirm \times AboveMedianCCM$ interaction, which remains highly significant and large.[11] The corresponding coefficient in column (2) indicates a statistically significant increase in the growth of oil consumption of similar magnitude, which could point to a substitution between those fuels among the well-managed firms. However, this result is not robust to further analysis presented below and in Appendix Figures B.3 and B.4.

5.3 Panel-Data Regressions

We exploit the panel structure of the energy data to check the robustness of the results in the previous section with respect to functional form assumptions, the treatment of unobserved heterogeneity, and the possible influence of pre-trends. Instead of averaging energy consumption values across years before and after the policy change, we now analyze year-to-year variation in energy use and check for trends in pre-treatment differences between treated and untreated firms. What is more, we use a fixed-effects approach instead of differencing, so as to control for unobserved heterogeneity at the firm level and for common shocks. To deal with zero values, and as an alternative to computing growth rates based on eq. (3), we estimate a Poisson model as in Silva Tenreyro (2006).

$$e_{it} = \exp(\beta \mathbf{D_{it}} + \alpha_i + \alpha_t + \epsilon_{it}) \tag{5}$$

where e_{it} is the energy or water consumption of firm i in year t and α_i, and α_t are firm and year fixed effects, respectively.

Table 6 shows results for a specification where $\mathbf{D}_i = [ETSFirm_i \times Post2012_t, ETSFirm_i \times$

[11] Note that a reduction of 100% in "arc" growth terms corresponds to a 60% reduction for the normal growth rate.

Table 6: ETS Impact - Poisson Specification (2007-2015)

Dependent Variables:	Coal	Oil	Electricity	Water
Model:	(1)	(2)	(3)	(4)
Variables				
ETS firm x After 2012	0.5818	-2.553**	1.338	0.1564
	(0.5181)	(1.161)	(1.006)	(0.2593)
ETS firm x Above Median CCMI x After 2012	-1.697*	2.509*	-2.818***	-0.3459
	(0.9832)	(1.410)	(1.058)	(0.6192)
Fixed-effects				
Year	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes
Fit statistics				
Observations	781	862	880	880
Squared Correlation	0.94102	0.58844	0.99495	0.71346
Pseudo R^2	0.92722	0.72998	0.94755	0.84335
BIC	9,037,626.2	5,625,891.9	14,258,427.1	305,864,833.5

Notes: Poisson fixed-effect regressions. The dependent variables are consumption of energy by the firm in each year between 2007 and 2015, i.e. tons of coal (column 1), tons of oil (column 2), electricity (in 10,000 Watts) (column 3), and water consumption in liters (columns 4). Above-median CCMI is a dummy indicating the firm is above the sample's median for the CCM index that is interacted with two dummies, one indicating participation in the ETS (ETS firm) and the other the time period (post 2012, i.e. years in which the ETS is in place). Robust standard-errors (clustered at the firm level) in parentheses. Significance levels are indicated as * 0.10, ** 0.05, *** 0.01.

$AboveMedianCCM_i \times Post2012_t]$.[12] We find a strong negative effect of the pilot ETS on the consumption of coal and electricity for firms with an above-median CCM index. We also find a positive effect on oil consumption. The effects implied by the coefficients are of a similar order of magnitude as the results above and statistically significant at 10% or better.

We also estimate a version of eq. (5) that includes interactions between $(ETSFirm_i, ETSFirm_i \times AboveMedianCCM_i)$ with a full set of year dummies for 2007 to 2015. We plot the coefficient estimates from those interactions in Figure 3. The effect size is relative to the year 2010 which was the last year before plans for the ETS were announced by the Chinese government. Hence, we can distinguish between a baseline period (2007 to 2010), an announcement period (2011-2012) and an implementation period (2013 onward). For coal, we observe that trends for non-ETS firms and ETS firms of any management type are closely aligned both in the baseline period and the announcement period. It is only with the start of the implementation period in 2013 that well-managed ETS firms diverge, showing a sharp decline in coal consumption relative to other firms. For electricity, we find a similar picture with the exception that well managed firms show a sharp decline of consumption in 2012, the last year of the announcement period. We also see a rather sharp drop in 2015. This is most likely the consequence of a reporting problem, as

[12] Note that $ETSFirm_i$ and $AboveMedianCCM$ are absorbed in the firm fixed effect.

only five firms in the sample reported non-zero amounts of electricity consumption in the year 2015 (cf. Appendix Table A.4). A similar reporting problem is evident for water consumption in 2015. As a robustness check, we re-estimate the Poisson model after dropping all observations for 2015 from the sample. Appendix Table B.3 confirm that our results are robust to any reporting issues in 2015. We also repeat the trend diagrams for electricity and water in Appendix Figure B.1 without 2015 which allows a better scaling.

In regards to oil consumption, results in Table 6 are suggestive of a decline for worse managed firms only. This would be consistent with the idea that well managed firms might have substituted some of their fuel usage from coal and/or electricity to oil. However, this result is not robust to dropping 2015 observations in Appendix Table B.3. Moreover we see from Figure 3 that oil consumption is more noisy with big differential trends emerging even in the pre-policy and announcement periods. In sum, the results for oil consumption might be too unreliable to support strong conclusions.

5.4 How Much Does Management Matter?

The statistical significance of the above findings does not automatically imply that they are economically significant. We therefore assess the above results with regards to the following question: How much higher would emissions be if no firm was well managed? We assess this counterfactual scenario using our most conservative estimate of the effect on coal consumption, $\beta_{CCM \times ETS}$, reported in column (1) of Table 5. For each firm i, we compute the counterfactual growth rate of coal consumption as

$$\gamma_i^{CF} = \gamma_i - \beta_{CCM \times ETS} \times ETSFirm_i \times AboveMedianCCM_i \tag{6}$$

This adjusts the growth rate of well-managed ETS firms by the average difference to not-so-well managed ETS firms, and leaves growth rates at all other firms unaffected. Using eq. (3), we then back out the counterfactual level of consumption for firm i as

$$e_{post}^{CF} = \gamma^{CF} \times \bar{e} + e_{pre}$$

where $\bar{e} = 0.5(e_{post} + e_{pre})$.

Figure 4 illustrates the outcome of the counterfactual exercise. On aggregate, coal use decreased by around 80% in our sample when comparing the periods before and after 2013. If ETS firms with above-median management quality would have had below-median management quality, coal use would have decreased only by about 20%. We

Figure 3: Trends in Energy Consumption (2007-2015)

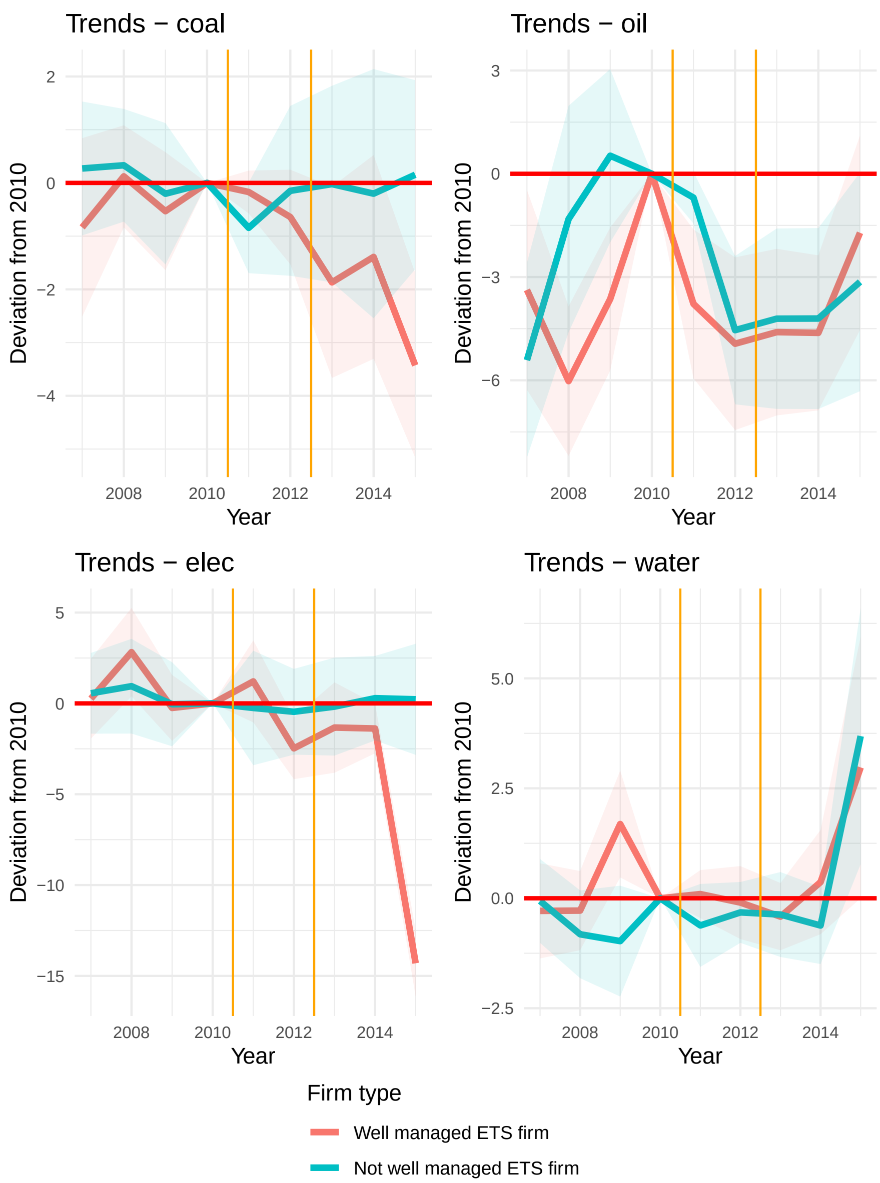
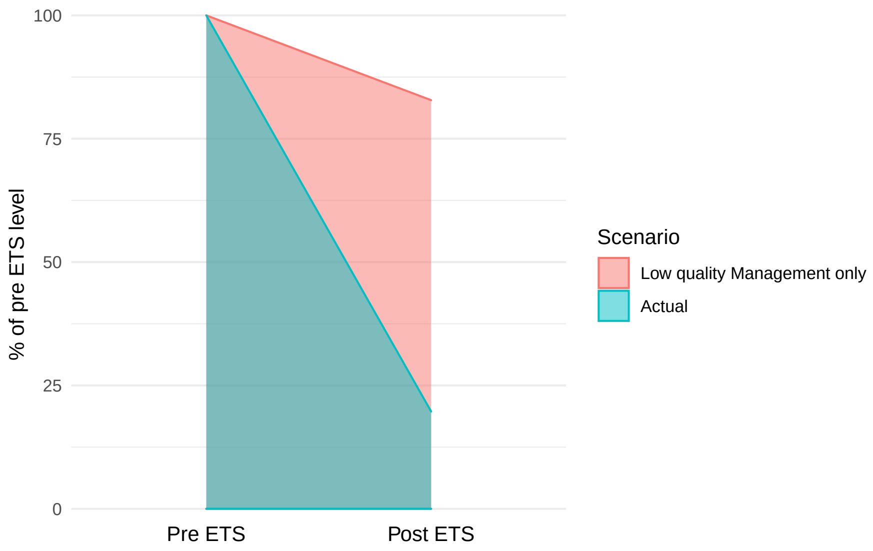


Figure 4: Counterfactual Reduction in Coal Consumption



thus conclude that management quality has an economically significant impact on the extent to which businesses in China respond to carbon pricing.

5.5 Exploring Mechanisms

Firms ranking higher on our CCM index respond more strongly to carbon pricing. Which aspects of those management practices explain this finding? The answer to this question matters because it could inform the design of complementary policies that would make China's national ETS more effective. To break ground on this, we explore which ones of the interview scores relating to the pilot ETS, described in Section 3.3, are good predictors of the CCM index after controlling for firm characteristics and interview noise. We implement this in the OLS regression equation

$$CCM_i = \alpha + \beta s_i + x_i'\gamma + z_i'\delta + u_i \tag{7}$$

where s_i is an ETS-related survey score or policy participation dummy not included in the CCM index.

Table 7 reports the estimation results from four different regressions. The first column shows a positive and significant association between the CCM index and ETS

Table 7: CCM Index and Trading Behavior

	(1)	(2)	(3)	(4)
Explanatory variable:	ETS participation	Rationality of current trading	Stringency of current ETS	Anticipated stringency of future ETS
Dependent variable: CCM index	0.326***	0.135*	0.176*	0.285***
	(0.101)	(0.074)	(0.091)	(0.054)
Interview controls	Yes	Yes	Yes	Yes
Number of firms	216	99	99	216

Notes: OLS regressions of CCM index on four different explanatory variables. All columns include controls for industry, exporter status, city, state-ownership, age and age squared of the firm as well as interview, interviewee and interviewer controls. Pilot ETS participation is a dummy indicating the firm is part of the ETS. The three other explanatory variables are averages of scores taking a value 1 to 5 that have been normalised. Rationality takes the average of the scores on how firms decide to sell and buy permits, inclusion of forecasts about prices and/or energy usage, and trade off of permit revenue against emission reductions costs. Stringency is average z-scores of how tough the cap is, how strict the enforcement by the authorities has been and the estimation of the cost burden in percentage of annual operating cost. Rationality of future ETS averages expectation to be part of the national ETS in the future, of next phase stringency, auctioning and toughness of target, anticipation of future sanctions for non-compliance and whether it is likely that a nation wide carbon market will be developed. When a z-score is missing it is set to zero and controls for missing variables are included too. Robust standard errors in parenthesis. Significance levels are indicated as * 0.10, ** 0.05, *** 0.01.

participation. The following three columns exploit the variation of the index within ETS firms. We estimate that firms that score higher in terms of the rationality of their trading behavior on the carbon market are more likely to score higher also on the CCM index (column 2). The correlation is significant only at 10%, but it is consistent with the notion that a manager who is capable of optimizing her carbon trades is more prepared to reduce the firm's energy consumption if this makes economic sense. Columns three and four of Table 7 show that the perceived stringency of the ETS - in particular the expected stringency a future national ETS - is a strong predictor of the CCM index. This provides suggestive evidence that in particular those managers who are more convinced that the nation-wide ETS will materialize are prepared to adopt climate friendly management practices, and this might also lead them to be more pro-active about reducing consumption of high-carbon fuels like coal on site.

6 Conclusions

China – currently the world's largest emitter of greenhouse gases – has pledged to become carbon neutral by 2060 and has been embracing market-based approaches for achieving this goal. In this study, we have analyzed how management quality affects the effectiveness of such policies in the context of pilot carbon trading schemes in two regions. This allows us to learn about the effects of a future nation-wide market. A key ingredient of our study is a new index of management practices related to climate change which we constructed based on interviews with Chinese managers. Our study breaks new ground by combining this kind of information with a quasi-experimental evaluation of a cap-and-trade program.

Our main finding is that firms regulated under the ETS reduced their consumption of fuels with a high carbon content more strongly than unregulated firms, and that this is statistically significant only for firms that ranked above the median value of our index, i.e. well-managed firms. Our econometric estimates imply that, in a counterfactual experiment where good managers are replaced by bad ones, the reduction in coal consumption would have been much lower. We attribute this result to the fact that understanding the trade-off between using, selling or banking a pollution permit is more demanding than simply complying with a quota or standard. An implication of this result is that complementary policies are needed to enhance the effectiveness of the nation-wide ETS that will be rolled out later this year.

Caveats arise mainly from data limitations. We found hesitation to participate in an interview to be more wide-spread among Chinese managers than in other countries. This is reflected in lower-than-usual response rates. Further limitations concern the energy data, which exhibit reporting problems at the end of the sample period and which did not give us a time series long enough to analyze the Hubei ETS. These imperfections have prevented us from employing some of the more sophisticated techniques from the toolbox of program evaluation, but the novelty of the data allows us to make valuable recommendations for the development of carbon markets.

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Appendices

A Data

A.1 Survey

This appendix provides more details on the data collection made through the survey. From the summer of 2016 to the end of 2017, a team of 22 post-graduate students at ShanghaiTech University conducted the survey through telephone interviews with industrial firms located in Beijing and Hubei.[13] Firms were randomly selected from the ORBIS database that also contains contact details. When contacting firms, interviewers requested to speak to the managers or engineers in charge of environmental issues at the operation facilities. Following the BVR methodology, the interviewers asked open-ended questions starting with those that are more general and broad (e.g., How is pollution discussed within your business?) followed by more specific queries (Did you commission reports or studies on how pollution/climate change will affect your business?). Interviewers will ask for examples so that they can form a reasonable assessment of the interviewee's responses. Based on a response assessment grid described relative to the questionnaire, the interviewers will provide a score between 1 and 5 with a higher score representing better performance.

Out of 1218 contacted firms, 323 firms refused to participate and 670 firms ceased operation or declined our requests to talk to their managers. In total, we interviewed managers from 219 firms successfully. Among these firms, 185 out of the 219 firms were located in Beijing city, and 35 firms were located in Hubei province. Compared to Beijing, firms in Hubei province appear more averse to accepting interviews which could be due to the culture, business sentiment, and the lack of exposure to survey interview experience. Hence, it was particularly challenging to obtain interviews with firms in Hubei especially after the province was affected by a major flood in 2017. On average, an interview lasted 35 minutes. Out of the 219 interviews, three firms have no financial data available and we therefore drop them from our analysis, such that the final sample has 216 firms.

In total, 90 of the 219 firms interviewed were double-scored, i.e. a second interviewer listened to the interview silently and scored the interviewee's answers. Figure A.1 plots the distributions of the climate change management index for firms with and

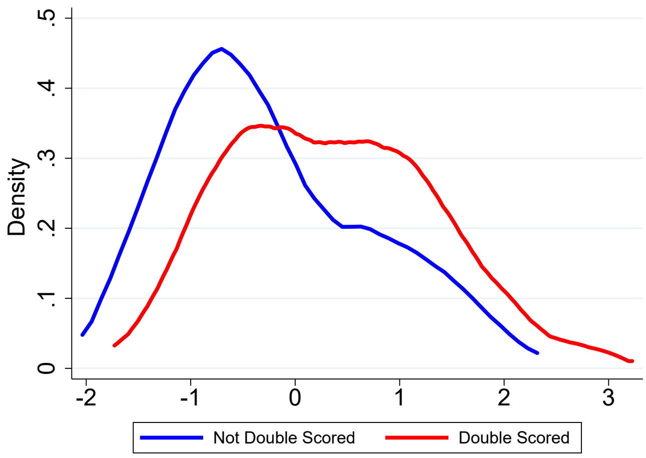
[13] Some of the interviews were conducted by Chinese graduate students at Imperial College Business School and the London School of Economics.

Table A.1: Survey Response Rates by ETS Location

	Total firms contacted	No. of firms interviewed	No. of ETS firms successfully interviewed	No. of non-ETS firms successfully interviewed	Refused/non-contactable	No.of firms successful interviews	Response rate
Beijing	752	250	104	81	502	185	33.50%
Hubei	895	37	20	14	1273	34	4.10%
Total	1647	287	124	95	1775	219	17.40%

Notes: The non-contactable firms include those firms which ceased operation and failed attempts to engage contact despite multiple call-backs. It also includes those firms that refused to allow contact with their staff if interviewers could not provide the exact name and title of the person they wished to speak to.

Figure A.1: Double Scoring



Notes: This figure compares the Kernel density distributions of the CCM index of firms that were double scored and were not double scored.

without double-scoring. It can be seen that the mean value of the environmental management index for firms that had been double-scored is higher than firms that had not been double-scored. This could reflect that interviewers are indeed subjective in their assessment of each question despite the provision of benchmark examples. Nevertheless, regressing the environmental management index on the double-score assignment while controlling for the interviewer fixed effect, the effect of double-score is not statistically significant anymore. This suggests that the interviewer bias can be controlled by using the interviewer fixed effect in regression estimates.

A.2 Survey questionnaire

Questionnaire
A scoring guide was provided for the scores of 1, 3, and 5. Interviewers could award any integer score between 1 to 5.

Measuring Climate Change Management Practices
The objective was to capture climate change related management practices within firms. To summarize the vast amount of information from the survey and to mitigate the potential collinearity in responses, we compute scores for each topic I,II,III,… as simple averages of the scored answers to the specific sub-questions (a),(b),(c),… addressing this particular topic. We compute topical z-scores of those averages by subtracting the mean and dividing by the standard deviation. Broader indices such as the CCM Index are computed as unweighted averages of a subset of z-scores.

I. Awareness of pollution and climate change			
(a) How is pollution discussed within your business? Can you give examples? (b) Can you give examples of occurrences where pollution is formally discussed in management meetings? (c) Do your strategic objectives mention pollution? (d) Did you commission reports or studies on how pollution will affect your business? (e) Can you tell me how the discussion of management and strategic decisions about climate change differs from that about pollution? Can you give some examples?			
	Score 1	**Score 3**	**Score 5**
Scoring grid:	Don't know if threat or opportunity. No awareness.	Some awareness backed up by evidence that this is being formally discussed by management.	Evidence that climate change is an important part of the business strategy.
II. Energy control management			
(a) How detailed is your monitoring of energy usage? (b) How often do you monitor your energy usage? Since when? (c) Describe the system you have in place.			
	Score 1	**Score 3**	**Score 5**
Scoring grid:	No monitoring apart from looking at the energy bill	Evidence of energy monitoring as opposed to looking at the energy bill, i.e. there is some consciousness about the amount of energy being used as a business objective. However, discussions are irregular and not part of a structured process and are more frequent with price rises. Not more than quarterly monitoring of energy.	Energy use is measured and monitored constantly and is on the agenda in regular production meetings. Energy use in the plant is divided up in space (by production line, machine or similar) and monitored over time (daily, hourly or continuously). The amount of energy rather than the cost is focused on.
(a) Do you have any targets on energy consumption which management has to observe? (e.g. kWh of electricity) (b) Do you have an energy intensity (conservation) target? (c) Can you describe some of the challenges you face in meeting these targets? How often do you meet these targets? Do you think they are tough?			
	Score 1	**Score 3**	**Score 5**
Scoring grid:	No targets	Targets exist but seem easy to achieve	Evidence that targets are hard to achieve

III. GHG emissions and pollution management			
(a) Do you explicitly monitor your carbon emissions? Since when? (b) How do you estimate your carbon emissions? (c) Are your carbon estimates externally validated?			
	Score 1	**Score 3**	**Score 5**
Scoring grid:	No specific carbon monitoring.	Detailed energy monitoring with clear evidence for carbon accounting (at least firm level). Manager is aware that energy figures need to be scaled by carbon intensity.	Carbon accounting of both direct and indirect emissions (supply chain emissions). External validation of carbon figures.
(a) Do you have any absolute targets on carbon emissions which management has to observe? (b) How about any carbon emissions targets relative to your company's production of output? (c) Can you describe some of the challenges you face in meeting the targets? (d) How often do you meet these targets? Do you think they are tough? Note: If the manager replies they have pilot ETS targets, ask: Have these been translated into internal targets for management?			

	Score 1	Score 3	Score 5
Scoring grid:	No targets for carbon emissions.	There is some awareness of the contribution of different energy sources and production processes to carbon emissions, but this is a secondary consideration to cost focused energy targets. There is some degree of difficulty in the targets.	There are separate targets for carbon emissions, distinct from energy use. GHG emissions are a KPI (Key Performance Indicator) for the firm. The contribution of each energy source and the production process to GHG emissions is known and suggested improvement projects for the production are assessed on their potential impact on carbon as well as energy efficiency.

IV. Target enforcement

(a) What happens if energy consumption or GHG emission targets are not met?
(b) Do you publicize targets and target achievement within the firm or to the public? Can you give examples? Are there financial consequences in case of non-achievement?
(c) Are there non-financial consequences in case of non-achievement?
(d) Is there a bonus for target achievement?

	Score 1	Score 3	Score 5
Scoring grid:	No targets or missing targets do not trigger any response.	Both target achievement and non-achievement are internally and externally communicated.	Target non--achievement leads to financial consequences internally and/or externally; including penalties, e.g. staff does not get bonus.

V. Pressure from customers

(a) Are your customers concerned about your GHG emissions?
(b) How do they voice this concern?
(c) Do your customers require hard data on your carbon emissions?
(d) Are your customers concerned about the standard of "green" management or production of your company? If so, to what extent?

	Score 1	Score 3	Score 5
Scoring grid:	"B2C" - Not aware that emissions performance is of significant concern to consumers of their product. "B2B" - Not aware that businesses they supply to are concerned about the emissions of the plant; quality and price are the only considerations.	"B2C" - The business is aware of the importance of climate--change issues in general and so are conscious that their customers may consider GHG performance to be important, although they do not expect or require data as proof. "B2B" - Customers set ISO 14001 as a precondition to suppliers. Evidence of environmental compliance is requested, but details of emissions figures are not required.	"B2C" - Being seen to reduce GHG emissions is thought to be important in the purchasing decisions of the firm's consumers. This has been determined by market research or consumers have voiced their concern through other means. Customers also ask for certified data on emissions during production or usage. A customer--friendly system to recognize the best products in terms of energy efficiency is often available in the market (e.g. EU energy efficiency grade for home appliances). "B2B" - Customers ask for evidence of external validation of GHG figures. Customers request information on carbon emissions as part of their own supply chain carbon auditing. Customers conform to PAS 2050 or other national standard in carbon foot--printing and so require detailed information on a regular basis.

Carbon Market Behavior

The questions below focused on capturing the firm's understanding of and behavior in the pilot ETS. Questions under VIII refer to the nation-wide ETS (referred to as CCETS) which, at the time of the survey, was scheduled to begin in 2017.

VI. Rationality of market behavior

(a) How do you decide how many permits to buy or sell or trade at all?
(b) Did you base this decision on any forecast about prices and/or energy usage?
(c) Did you trade permit revenue off against emission reduction costs in your planning on this issue?

	Score 1	Score 3	Score 5
Scoring grid:	Take their permit allocation as a target to be met as such and do not take into account the price of permits or the cost of abatement. Just sell if there is a surplus or buy if there is a deficit.	Are in the process of learning how the market works and now have someone in charge of managing the ETS so as to minimize compliance cost. This person has experience in financial markets and sometimes interacts with the production manager.	Company has a thorough understanding of the site-specific CO_2 abatement cost curve. Trading is used as a tool to reduce compliance cost and to generate extra revenues from excess abatement. Moreover, company forms expectations about permit price and re-optimizes abatement choice if necessary. Trader resorts to futures and derivatives.
VII. Stringency of pilot ETS			
(a) How tough is the emissions cap/quota currently imposed by the CCETS on your production site? (b) Can you describe some of the measures you put in place to comply with the cap? (c) How stringent has the enforcement been? (d) What is the overall annual cost burden of being part of the pilot ETS?			
	Score 1	**Score 3**	**Score 5**
Scoring grid:	Cap is at business as usual. No enforcement of cap.	Some adjustments seem to have taken place, however nothing which led to fundamental changes in practices; e.g. insulation, etc. The firm might be audited but this is rare / possibility to discuss with the auditor.	Measures which led to fundamental changes in production processes; e.g. fuel switching; replacement of essential plant and machinery. The firm's CO_2 emissions are regularly audited (every year at least) by an independent third-party auditor.
VIII. Anticipated stringency of next ETS phase			
(a) Do you expect to be part of the CCETS from 2017 onwards? (b) How stringent do you expect the next phase of the ETS (from 2017 to 2020) to be? (c) Will it be tough for your firm to reach such a target? Can you describe some of the measures you would have to put in place? (d) Do you believe the allowances will be distributed through an auctioning mechanism? (e) Is it likely that sanctions for non-compliance will become more stringent? (f) Do you expect that the CCETS will be extended to a national trading market in the future?			
	Score 1	**Score 3**	**Score 5**
Scoring grid:	Cap for next phase is anticipated to be comparable to business as usual. The manager believes there will be no additional sanctions and that they will receive the permits for free.	Phase II is likely to trigger some adjustments, however nothing that will lead to fundamental changes in practices. Only a small part of permits will be auctioned and sanctions are not expected to be very high.	The presence of strong sanctions, extensive use of auctioning and more stringent targets in Phase III is anticipated. It is likely to imply the adoption of measures which will lead to fundamental changes in production processes. It might also imply the closure of the plant, or redundancy of more than 20% of employment.

Measuring Green Innovation

The questions below refer to a firm's long-run strategy for environmental management. They gathered information about innovation efforts undertaken by the firm with the objective (i) to reduce emissions at their production facilities and (ii) to produce products that help customers to reduce their emissions.

IX. Process innovation			
(a) Do you dedicate staff time and/or financial resources to finding new ways of reducing the GHG emissions at your facility? Did you commission any studies for that purpose? (b) Can you give examples? (c) What fraction of your firm's global Research & Development funds is used for that? (less than 10%, more than 10%?)			
	Score 1	**Score 3**	**Score 5**
Scoring grid:	No R&D resources committed to reducing GHG emissions.	Evidence of R&D projects to reduce emissions	Evidence that this kind of R&D is an important component in the company's R&D portfolio
X. Product innovation			
(a) Globally, is your company currently trying to develop new products that help your customers to reduce GHG emissions? (Note: If the firm is not a multi-national company, then just asked about their entire firm's R&D plan) (b) Can you give examples? (c) What fraction of your Research & Development funds are used for that? (Less than 10%, more than 10%?)			

	Score 1	Score 3	Score 5
Scoring grid:	No efforts to develop climate change related products	Some efforts but it is not the main objective of the firms R&D efforts	The firm is focusing all product R&D efforts on climate change

Questionnaire in Chinese

以下为采访问卷以及为采访员提供 1，3 和 5 得分的评分指南。采访员可以授予 1 到 5 之间的任何整数分数

I. 环境污染和气候变化的意识			
(a) 贵公司的员工是否会对环境污染进行讨论吗？能不能举出一些例子？ (b) 环境污染相关问题是否会在正式管理层会议讨论？能不能举出一些例子？ (c) 您公司是否有聘请专家顾问以便策划环境污染相关的战略目标？ (d) 关于环境污染的报告和学习将如何影响您的业务？			
	1 分	**3 分**	**5 分**
评分的指导标准:	不明白是威胁还是机会。	有证据说明在管理层被正式讨论过这个问题	有证据表明气候变化是商业策略中的重要的一部分。
II. 能源监管			
(a) 你们对于能源使用的监测能具体到什么程度? (b) 你们多久监测一次能量的使用？从什么时候开始？ (c) 描述下你们现有的系统。			
	1 分	**3 分**	**5 分**
评分的指导标准:	除了能源消费账单没有其它监控	不仅仅关注与能源账单，而是存在对能源使用量的监测，比如：存在作为经营目标能源的使用的意识。 然而，讨论是没有规律的，没有组织的，当价格上涨的时候会更加频繁。不超过一季一次的能源监控。	能源的使用会被不断地测量和监控，这也是定期会议的日常事项。空间上，能源的使用被分成在生产线上的，机器或者类似上的使用，能源使用每天，每小时或者连续地被监控）。关注能源使用量而不是费用。
(a) 你们在能源消耗上有什么目标（例如：多少千瓦时的）电量） (b) 你们公司是否有能源使用强度（保存）目标？ (c) 您能描述下为了达到这些目标前会有哪些挑战吗？多久一次能达到这些目标？您认为他们艰难吗？			
	1 分	**3 分**	**5 分**
评分的指导标准:	没有目标	目标存在但是很容易就能实现	证据表明目标很难实现。详细说明。
III. 温室气体排放与污染的监管			
(a) 你们有没有明确地监管你们碳排放量？从什么时候开始？ (b) 你们怎么估计碳排放量？ (c) 碳排放量的估计有没有经过外部的审核认证？			
	1 分	**3 分**	**5 分**
评分的指导标准:	没有特定的碳计量监控	详细的有明显证据的碳计量（至少在公司层面）的能源监控。经理意识到能源数据需要被碳强度衡量	直接和间接的排放（排放供应链）都需要计量碳的排放量。碳计量数据需要得到外部的验证
(a) 你们公司在碳排放上是否有什么绝对性的目标？ (b) 你们公司在碳排放上是否有什么相对于生产的排放目标？ (c)能不能描述下达到这些目标前会有哪些挑战 (d) 多久一次达到这些目标？你认为达到这些目标艰难吗？ 注：如果经理回答他们有碳排放交易这类型目标，问他们“这些目标是否已经变成管理层的内部目标了？”			
	1 分	**3 分**	**5 分**

评分的指导标准:	对于碳排放量没有目标	意识到不同的能源和生产过程会产生不同量的碳排放，但是相对于能源的成本来说这是个次要因素。实现目标有一定的难度	碳排放根据不同能源的使用具有不同的目标。温室气体碳排放量是公司的关键绩效指标。每种能源以及生产过程对碳排放量的影响是共识的，对碳以及能源效率的影响是用来评价生产项目的改善程度的。

IV.	**目标的实施与严格性**		
(a) 如果能源消耗或者温室气体排放量的目标没有达到会发生什么 (b) 有没有在公司内部或者对公众宣传目标和目标的完成度？能给出例子吗？如果目标没有达成，会有财务上的后果吗？ (c) 如果没有达到目标, 是否会造成除了经济损失之外的其他后果? (d) 完成目标会有奖金吗？			
	Score 1	**Score 3**	**Score 5**
评分的指导标准:	没有目标或者没达标也不会导致任何后果	目标的完成和没有完成都会在公司的内部和外部得到宣传	没有完成目标会在公司内部或者外部导致财政上的后果；包括惩罚，例如，员工没有奖金

V.	**公司面临顾客针对环境要求的压力**		
(a) 顾客关心你们温室气体排放量吗 (b) 他们是怎样表达这种关心的？ (c) 顾客需要你们公布二氧化碳排放量的数据吗？ (d) 你们的客户关心贵公司的绿色环保管理和产品吗？ 如果是的话，在何种程度上？			
	1 分	**3 分**	**5 分**
评分的指导标准:	B2C (面向终端顾客)顾客不认为排放量对于产品十分重要 B2B（面向其他商家），他们提供的交易没有考虑到产生的排放量；他们考虑的只有质量和价格	B2C（面对终端客户），企业意识到气候变化的重要性，他们的顾客也有可能认为温室气体排放量是很重要的，虽然他们并没有要求企业提供数据作为证据。 B2B（客户是其他商家） 客户对他们的供应商设置 ISO14001 作为前提. 环保达标的证据是需要的，但是具体的排放量数据不需要。	B2C（客户是终端用户） 降低 GHG 排放是公司的顾客做出购买决定的一个重要因素。市场的研究肯定了这个或者顾客通过其他途径表达了他们对于环境的关心。顾客也要求厂商提供在生产和使用当中排放量的有证数据。一个以客为尊的系统经常能在市场中识别出能源有效的产品。 B2B（客户是其他商家） 顾客要求 GHG 数据的外部检测结果。顾客需要碳排放的信息作为他们自己碳审计的供应链。顾客在碳排放量上遵守 PAS2050 或者其他国家标准，所以需要定期的具体信息。

碳排放交易的市场行为

VI.	**公司企业在碳排放交易的市场行为与理智性**		
(a) 您如何决定购买，出售，或交易多少许可证？ (b) 在做出决定前，您是否有参考市场的能量价格以及/或者参考能量使用需求以便预测公司以后所需的碳排放的许可证？ （注：能源价格如石油，煤炭，天然气等的价格会影响能源的需求从而影响到碳排放额度的需求） (c) 您公司是否有利用买卖碳排放的许可证以便抵销公司的减排成本？			
	1 分	**3 分**	**5 分**
评分的指导标准:	公司只以许可证的分配数量为目标，在碳排放上尽量不超过限额。在公司的营运操作不考虑排放许可证的价格或成本的减少。如果有盈余卖掉剩余的许可证。如果不够，则购买多些许可证。	公司现在正学习碳排放交易市场的过程中，现在已经有人在负责管理碳排放交易，以尽量减少排放成本。此人对金融市场的运作有经验，有时也会同生产经理进行合与作配合的探讨。	公司目前已经对整个二氧化碳减排成本有着透彻的了解。交易已经成为公司的一种工具来降低成本以达到官方的限额。此外，公司也会对碳排放市 场交易的价格进行预测。如果必要的话，公司也会对公司业务的需求而对 许可证的需求与价格重新评估，以达到对公司的最佳效益。我们的交易员也会利用期货及衍生工具来管理碳排放交易体系所分配的碳排放证限额。
VII.	**碳排放交易试点的相关条例对公司企业的管制**		

(a) 目前碳排放交易所施加的排放上限/配额，对您公司生产活动的限制有多严格? (b) 请问您是否可以描述一些所采取的应对措施？ (c) 碳排放交易的强制施行有多严格？ (d) 请问您预计公司每年会因为碳排放交易体系所施加的政策而增加多少成本？			
	1 分	**3 分**	**5 分**
评分的指导标准:	配额对公司没有任何影响. 没有任何强制性	对公司有些影响，也采取了一些应对的调整与措施，但是没有导致根本性的变化，例如：更换隔离器，等。 公司可能会被监察审计，但是这很少见，或者； 公司管理人员可以和监察部门讨论其表现，或者； 公司经常性的被监察，但是重点不在 CO_2 排放	对公司有很大影响，导致根本性的变化。例如：转用燃料，更换重要的厂房及机器，等。 公司的 CO_2 排放指标经常性的被第三方监察机构监察（每年至少一次）
VIII. 公司对碳排放交易下一个阶段的展望与严格性			
(a) 你们预计会在 2017 年参与碳排放的交易吗？ (b) 你估计碳排放交易在下一个阶段（2017 至 2020）会有多严格的要求？ (c) 您的公司达到这样一个目标会是艰难的吗？你能描述一下你将采取的哪些措施？ (d) 你认为配额能通过拍卖机制分配吗？ (e) 您认为以后政府对不遵守条例的公司的惩罚会更加严厉吗? (f) 您认为碳排放交易会扩张到全国性的交易市场吗？			
	1 分	**3 分**	**5 分**
评分的指导标准:	和平常一样没有更严格的要求。经理认为不会有附加的制裁而且他们会免费收到许可证。	第二阶段有可能引发一些调整，但是不会导致根本上的改变。只有一小部分许可证将被拍卖，制裁也不会非常严格。	第三阶段预测会有严格的制裁，广泛地使用拍卖，这些方法都会在生产过程中导致根本意义上变化。这也有可能意味着工厂的关闭或者大于百分之二十的裁员。

衡量绿色创新与科研发展

IX. 生产流程的创新与科研			
(a) 你们有没有使用员工时间和/或财政资源来寻找降低温室气体排放量的新办法？为了这个目的有没有展开研究？ (b) 能不能举一些出例子? (c) 你们公司全球研究发展资金的多少比例是用来达成这些目标的（少于 10%，多于 10%）？ (注：这不包括员工训练费用或者能源监控费用，应当是关于真正的创新的投入 。如果该家公司不是跨国企业，那就问他关于整个公司的研究发展计划)			
	1 分	**3 分**	**5 分**
评分的指导标准:	没有资源投入针对减少温室气体排放的研发	证据表明有 R&D 项目来减少排放	这种类型的研发是公司 R&D 投资组合的重要组成部分
X. 产品的创新与科研			
(a) 在国际上，贵公司现在是否在研发帮助顾客减少温室气体排放量的新产品？ （注：如果该家公司不是跨国企业，那就问他关于整个公司的研究发展计划） (b) 能给出一些例子吗？ (c) 你们的研究和发展资金中的多少比例是用来研发这种新产品？（少于或者大于百分之十）			
	1 分	**3 分**	**5 分**
评分的指导标准:	没有发展和环境变化有关的产品	有作出努力但是不是公司研究发展的主要目标	公司把所有研究发展产品的努力都放在了应付气候变化上

A.3 Constructing the CCM Index and Sub-Indices

Table A.2 lists descriptive statistics of the 21 components that are averaged to generate the CCM index.

In Figure A.2, it appears that the distribution of the CCM index is different in the two regions under study. The distribution in Hubei, where the CCM index is on average higher, displays less dispersion, and appears bimodal with not as many badly managed firms as in Beijing but also more well managed firms.

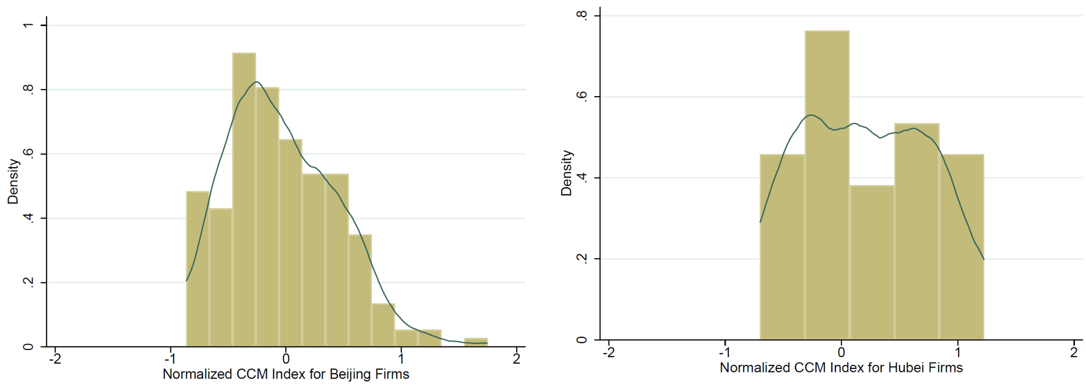


Figure A.2: Distribution of the Climate Change Management Index

Table A.2: Climate Change Management Index Components

			Mean	S.D.
Awareness	How is pollution discussed within your business? Can you give examples?	5-points scale	3.13	1.29
	Can you give examples of occurrences where pollution is formally discussed in management meetings?	5-points scale	3.10	1.38
	Can you tell me how different the discussions or management and strategic decisions around climate change are different to those on pollution? Can you give some examples?	0-1 dummy	0.15	0.36
Energy monitoring	How detailed is your monitoring of energy usage?	5-points scale	2.75	1.71
Energy consumption targets	Do you have any targets on energy consumption which management has to observe? (e.g. kWh of electricity)	0-1 dummy	0.76	0.43
	Can you describe some of the challenges you face in meeting these targets?How often do you meet these targets? Do you think they are tough?	5-points scale	2.46	1.29
GHG emissions monitoring	Do you explicitly monitor your carbon emissions? Since when?	5-points scale	1.97	1.38
	How do you estimate your carbon emissions?	5-points scale	2.17	1.48
	Are your carbon estimates externally validated?	5-points scale	2.43	1.76
GHG emissions targets	Do you have any absolute targets on carbon emissions which management has to observe?	0-1 dummy	0.22	0.42
	How about any carbon emissions targets relative to your company production of output?	5-points scale	1.61	1.03
	Can you describe some of the challenges you face in meeting the targets?	5-points scale	1.27	0.75
	How often do you meet these targets? Do you think they are tough? Note: If the manager replies they have CCETS targets, ask: Have these been translated into internal targets for management? Recode this as evidence for degree of difficulty in meeting targets.	5-points scale	1.32	0.89
Target enforcement	What happens if energy consumption or GHG emission targets are not met?	5-points scale	2.46	1.49
	Do you publicize targets and target achievement within the firm or to the public? Can you give examples? Are there financial consequences in case of non-achievement?	0-1 dummy	0.62	0.49
	Are there non-financial consequences in case of non-achievement?	0-1 dummy	0.45	0.50
	Is there a bonus for target achievement?	0-1 dummy	0.39	0.49
Customer pressure	Are your customers concerned about your GHG emissions?	5-points scale	1.30	0.80
	How do they voice this concern?	5-points scale	1.31	0.84
	Do your customers require hard data on your carbon emissions?	0-1 dummy	0.09	0.29
	Are your customers concerned about the standard of 'green' management or production of your company? If so, to what extent?	0-1 dummy	0.41	0.49

A.4 Energy use by type of firms

Table A.3: Energy consumption by Management Quality and ETS

			Coal		Oil		Electricity		Water	
ETS firm	CCMI	N	mean	sd	mean	sd	mean	sd	mean	sd
Non-ETS	below-median	52	307.4	929.8	120.7	250.5	229.5	544.8	19154	40498
	above-median	20	595.4	1792.7	557.0	1472.6	232.5	415.7	63378	97783
ETS	below-median	12	698.7	1239.2	10079.3	19415.5	1113.2	1931.1	189900	227542
	above-median	44	69994.8	337595.7	5498.3	27014.6	98428.9	603023.0	1124853	4108234
	All	128	24344.2	199222.9	2971.1	17068.3	34068.8	353989.4	422155	2446216

Notes: Descriptive statistics for the energy consumption variables before the introduction of the ETS in 2013. We report separate figures for well managed (above-median) and not so well managed (below-median), as well as ETS and non ETS regulated firms.

Table A.4: Non-Zero Observations by Year

Year	All	Coal	Oil	Electricity	Water
2007	34	34	29	34	34
2008	43	43	38	42	40
2009	45	45	40	45	42
2010	44	44	39	16	41
2011	54	54	50	12	50
2012	55	55	47	55	55
2013	78	78	72	64	78
2014	29	29	27	29	29
2015	59	59	23	5	5

Notes: Number of firms consuming a positive amount of energy by type in the panel dataset used for the analysis in section 5.3.

B Additional Results

B.1 Correlation with Management Scores and Sub-Indices

To shed light on which particular management practices might be driving the results on the CCM index, we decompose the index into scores and sub-indices, also computed using the z-scores of raw scores. The CCM index is decomposed into seven components as described in Table A.2: awareness, energy and GHG emissions monitoring and targeting, target enforcement and customer pressure. For instance, the climate change awareness index includes awareness scores that indicates how thoroughly climate change and pollution is being discussed among employees of the firm and to what extent this discussion takes place at the management level. The monitoring scores reflect how detailed the monitoring of energy consumption, or GHG emissions is within the firm. The energy consumption and GHG emissions targets measure whether the firm has targets that management has to observe and how challenging it is to meet these targets. The target enforcement index seeks to indicate how consequential it is to meet or not the target. Finally, the customer pressure index combines information about how demanding customers are about GHG emissions and the standards of green management. On the basis of these components, we estimate eq. (1) using only particular management practices instead of the overall CCM index. The results are presented in Table B.1, where each cell corresponds to one regression. Both column (1) and (2) have the logarithm of turnover as dependent variable. As column (1) includes employment as a control variable, the coefficients can be interpreted as a correlation between the management measure and labor productivity. In column (2), we also control for capital and materials, such as to be estimating a measure or total factor productivity. Columns (3) to (6) take the energy intensity measures of Appendix Table (B.2).

After controlling for firm's size and resources, we find that the positive association of the CCM index with turnover is mainly driven by energy and GHG monitoring as well as the target enforcement score, which measures the stringency of the enforcement of targets on energy consumption and emissions targets.

B.2 Correlation of the CCM Index and Energy Intensity

Table B.1 also examines how specific climate change management practices are correlated with energy intensity of production. Column (3) shows that management practices that control energy usage and set targets GHG emissions are associated with lower oil intensity. This is consistent with efforts spent on monitoring energy consumption,

Table B.1: Management Score Components

	(1) Turnover (Lab. prod.)	(2) Turnover (TFP)	(3) Oil Intensity	(4) Coal Intensity	(5) Electricity Intensity	(6) Water Intensity
Awareness	0.329**	0.070	-11.567	-91.919	0.499	3.433
	(0.132)	(0.049)	(21.883)	(106.350)	(0.632)	(3.857)
Energy monitoring	0.355***	0.068*	-53.948***	62.606	-0.033	-0.515
	(0.092)	(0.039)	(19.122)	(51.180)	(0.363)	(1.801)
Energy target	0.178*	0.020	-13.773	83.790	0.379	3.633
	(0.101)	(0.029)	(13.727)	(75.563)	(0.382)	(2.216)
GHG monitoring	0.511***	0.083**	-1.370	83.951	1.277	1.394
	(0.108)	(0.042)	(20.608)	(123.432)	(1.101)	(2.143)
GHG targets	0.199**	0.031	-49.730**	-92.622	0.814	10.924
	(0.097)	(0.028)	(24.144)	(134.329)	(0.722)	(8.137)
Target enforcement	0.211**	0.062*	-31.641	267.442**	0.387	-2.108
	(0.104)	(0.037)	(20.412)	(114.997)	(0.495)	(3.332)
Customer pressure	0.177*	0.038	-28.627	-29.037	-0.838	1.484
	(0.105)	(0.027)	(21.699)	(61.118)	(0.969)	(1.463)
Year and industry controls	Yes	Yes	Yes	Yes	Yes	Yes
Interview controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes
Number of observations	1601	1601	1103	1103	1103	1103
Number of firms	210	210	182	182	182	182

Notes: Each cell represents the result of a separate OLS regression using different indices as dependent variables. The dependent variable is defined as logarithm of turnover in columns (1) and (2), oil intensity in column (3) [tons of oil per million USD], coal intensity in column (4) [tons of coal per million USD], electricity intensity in column (5) [MegaWatts per million USD], and water consumption in columns (6) [litre per USD]. All columns include controls for log of employment, location (Hubei vs Beijing), state-ownership, industry, exporter status, age and age squared of the firm as well as interview, interviewee and interviewer controls. In column (2), logarithm of cost of goods sold and logarithm of fixed assets obtained from the ORBIS database are included. Lab.prod. stands for labor productivity and TFP for total factor productivity. Significance levels are indicated as * 0.10, ** 0.05, *** 0.01.

setting consumption targets and controlling GHG emissions being effective at reducing fuel use (the usual caveat about causality applies). Finally, columns (3) to (6) shows that none of the various measures of climate change management practices display any significant correlation with coal, electricity or water usage intensity, except for the target enforcement score for coal but with a counter-intuitive sign. This might be due to the substitution between oil and coal usage among firms in China.

Table B.2: Climate Change Management and Energy Intensity

	Oil Intensity (1)	Coal Intensity (2)	Electricity Intensity (3)	Water Intensity (4)
CCM index	0.660	-0.032	0.083	0.717***
	(0.457)	(0.250)	(0.197)	(0.264)
Hubei firm	2.569***	0.274	2.964***	0.617
	(0.715)	(0.410)	(0.382)	(0.558)
State-owned	-0.015	0.738***	0.204	0.201
	(0.405)	(0.250)	(0.215)	(0.310)
Log(Employment)	-0.117	-0.308***	0.006	-0.129
	(0.139)	(0.101)	(0.140)	(0.178)
Year and industry controls	Yes	Yes	Yes	Yes
Interview noise controls	Yes	Yes	Yes	Yes
Age controls	Yes	Yes	Yes	Yes
Number of observations	479	764	722	862
Number of firms	133	157	165	166
Adjusted R-squared	0.593	0.345	0.438	0.259

Notes: OLS regressions. The dependent variables are the logarithms of tons of coal per million turnover in USD (columns (1)), tons of oil per million USD of turnover (columns (2)), , MegaWatts electricity per million turnover in USD (columns (3)), and water consumption in litres per turnover in USD (column (4)). All columns include controls for location (Hubei vs Beijing), state-ownership, log of employment, industry, exporter status, age and age squared of the firm as well as interview, interviewee and interviewer controls. Robust standard errors given in parenthesis are clustered at the firm level. Significance levels are indicated as * 0.10, **0.05, *** 0.01.

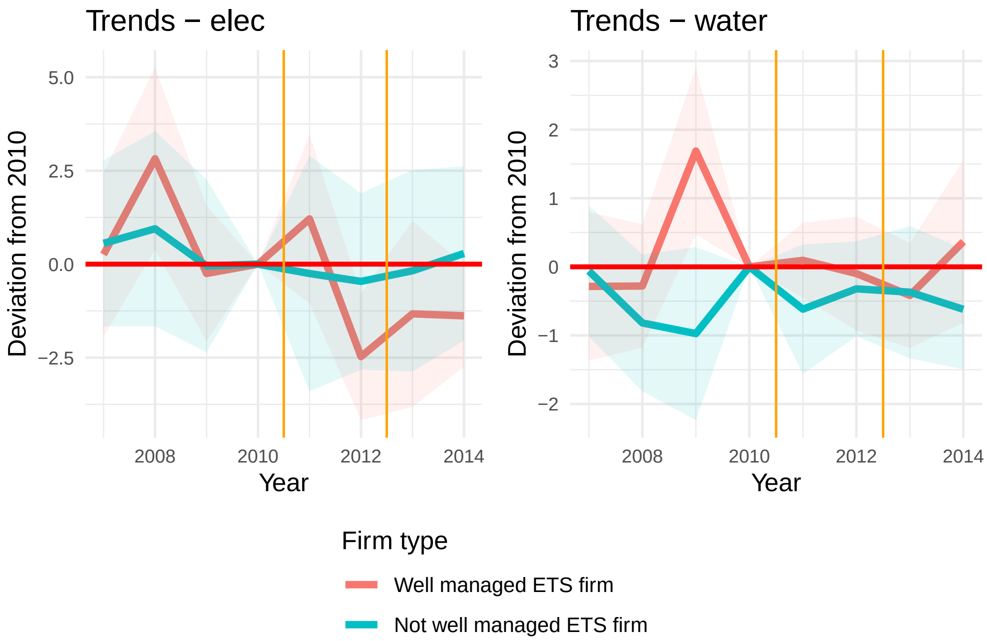
B.3 Robustness Analysis of Management Practices and Carbon Trading

Table B.3: ETS Impact - Poisson Specification (2007-2014)

Dependent Variables:	Coal	Oil	Electricity	Water
Model:	(1)	(2)	(3)	(4)
Variables				
ETS firm x After 2012	0.5826	-3.165***	1.467	0.1564
	(0.5213)	(1.108)	(0.9503)	(0.2592)
ETS firm x Above Median CCMI x After 2012	-1.696*	1.065	-2.679**	-0.3459
	(0.9870)	(1.361)	(1.048)	(0.6191)
Fixed-effects				
Year	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes
Fit statistics				
Observations	618	803	819	819
Squared Correlation	0.94078	0.77639	0.99495	0.71328
Pseudo R^2	0.92207	0.79487	0.94704	0.83922
BIC	9,024,875.8	3,757,861.6	14,229,479.1	305,860,786.4

Notes: Poisson fixed effect regressions. The dependent variables are consumption of energy by the firm in each year between 2007 and 2007, i.e. tons of coal (column (1)), tons of oil (column (2)), electricity (in 10,000 Watts) (column (3)), and water consumption in litres (columns (4)). Above-median CCMI is a dummy indicating the firm is above the sample's median for the CCM index that is iteracted with two dummies, one indicating participation in the ETS (ETS firm) and the other the time period (post 2012, i.e. years in which the ETS is in place).

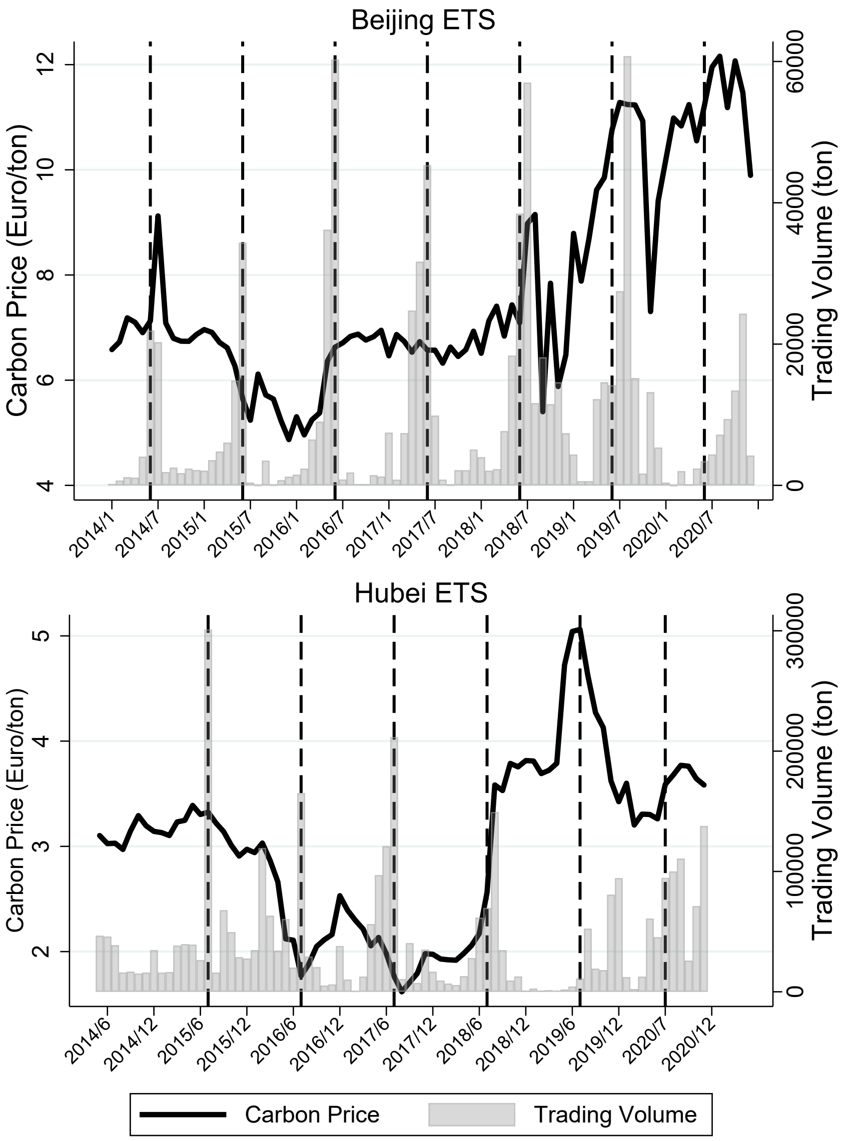
Figure B.1: Trends of Energy Consumption (2007-2014)



Notes: The figures report the result from fitting eq. 5 with a full set of year dummy interactions between management quality and ETS firm status using the pre-announcement period year 2010 as the reference year. Data for the year 2015 is not included in the regression. The data points indicate how the different types of firms deviate from their differences in 2010, in years other than 2010.

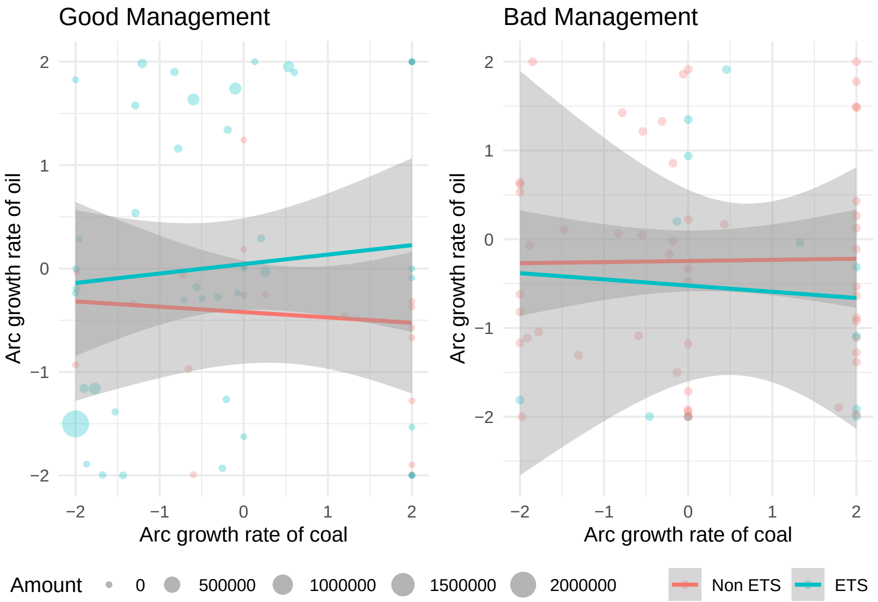
B.4 Additional Tables and Figures

Figure B.2: Historical prices and trading volumes in Beijing and Hubei



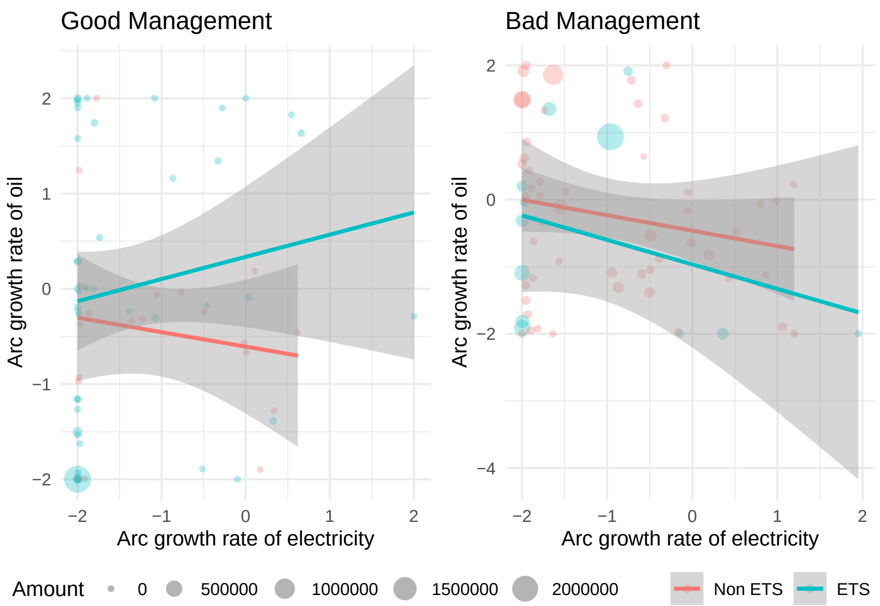
Notes: The graphs show monthly average prices and trading volumes based on data from Wind Economic Database, which covers over 1.3 million macroeconomic and industry time series data, such as financial markets, foreign trade, emissions trading markets, etc., in China. Prices were converted at a fixed currency exchange rate of 1 CNY = 0.13 Euro. The dashed lines indicate compliance cycles, which in Beijing end in June and in Hubei in July of each year.

Figure B.3: Fuel Substitution: Oil vs. Coal



Notes: Scatter plot of arc growth rates γ_i for oil use (vertical axis) and coal use (horizontal axis) across firms. Arc growth rates are computed as $\gamma_i = (e_i^{post} - e_i^{pre})/[0.5 \times (e_i^{post} + e_i^{pre})]$ where e_i^t is the average consumption of a particular fuel at firm i in either the pre- or the post-ETS period. Each circle represents a firms that is either regulated (in green) or unregulated (in red). Fitted regression lines are from a linear projection of y on x and a constant. The grey zone indicates a 95-% confidence interval. Separate graphs are plotted for firms ranked above the median of the CCM index (LHS) and for those below the median (RHS).

Figure B.4: Fuel Substitution: Oil vs. Electricity



Notes: Scatter plot of arc growth rates γ_i for oil use (vertical axis) and electricity use (horizontal axis) across firms. Arc growth rates are computed as $\gamma_i = (e_i^{post} - e_i^{pre})/[0.5 \times (e_i^{post} + e_i^{pre})]$ where e_i^t is the average consumption of a particular fuel at firm i in either the pre- or the post-ETS period. Each circle represents a firms that is either regulated (in green) or unregulated (in red). Fitted regression lines are from a linear projection of y on x and a constant. The grey zone indicates a 95-% confidence interval. Separate graphs are plotted for firms ranked above the median of the CCM index (LHS) and for those below the median (RHS).