When the Cat is Away the Mice Will not Play:

The Political Economy of the Carbon Emission Trading System

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Abstract

This study examines how the Carbon Emission Trading System (ETS) mitigates the emission instability caused by political shocks. We document a phenomenon in Chinese cities where carbon emissions increase during political leaders' turnovers ("the cat is away"), contrasting sharply with the typical emission reductions observed during regulatory inspections ("the cat is around"). This emissions volatility, driven by political shocks, highlights an unexpected form of government failure. However, the introduction of an ETS effectively moderates this response. The stabilizing effect of the ETS operates through two mechanisms: it reinforces consistent government regulation and curbs firms' opportunistic behavior. Additionally, we find that a higher carbon price enhances the ETS's ability to control emissions while simultaneously cushioning the impact of political shocks.

Keywords: Carbon emissions control; Pilot ETS in China; Political uncertainty; Climate policy; Government failure and market failure

JEL: D78; H70; Q50; R11; P28

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1. Introduction

Carbon emissions control is an ongoing cat-and-mouse game between regulators and polluters. Governments all over the world have employed various methods such as emission standards, feebates, the carbon tax, and the carbon Emission Trading System (ETS), etc. to fix the market failure of firms' pollution (Goulder and Schein, 2013; Adamou, Clerides, and Zachariadis, 2014; Rozenberg et al. 2020). Among these approaches, the carbon ETS stands out for its ability to price emission costs via permit trading, thereby enhancing game efficiency and effectiveness (Parry 2012). By aligning economic incentives with environmental goals, the ETS has become a key instrument in climate policy in developed countries.

However, the landscape of climate policy has grown more complex in recent years. Mounting political uncertainty has led to persistent discontinuities in climate initiatives..[1] Unexpected events, such as military conflicts and unpredictable election outcomes, have introduced further complexity, raising doubts about the credibility and stability of emissions reduction commitments (Sousanis, 2015; Yu et al., 2021). At the same time, fragile global agreements and wavering political resolve exacerbate challenges in limiting global warming. This context underscores the urgent need to understand how political uncertainty affects carbon emissions and to identify strategies to safeguard climate policies from these disruptions.

[1] https://www.chicagobooth.edu/review/confronting-uncertainty-climate-policy

China, the world's largest carbon emitter, offers critical lessons in navigating these challenges. To meet its ambitious target of achieving carbon neutrality by 2060, China has implemented the world's largest carbon ETS. Since 2012, pilot programs across Chinese cities have provided unique insights into the effects of carbon markets under diverse geographic, demographic, and industrial conditions. These experiences not only help China refine its domestic policies but also serve as valuable political economy knowledge for other nations grappling with political uncertainty.

This study investigates how carbon emissions in Chinese cities respond to two symmetric natural experiments that induce changes in regulatory intensity: turnovers of senior local government officials and unannounced inspections by the central government. Using daily data from 2013 to 2019 across 270 cities in 31 provinces, we document a 2.2% increase in emissions during local government leader turnovers. Regression Discontinuity Design (RDD) estimates further confirm the discontinuity in turnovers' effects on air quality. Our empirical findings also show that air quality improved during inspections which is consistent with existing literature (Zheng and Na 2020). While existing literature has examined the impact of inspections on air quality——"the cat is around" (Zheng and Na 2020), we provide the first analysis of a symmetric situation, "the cat is away".

Importantly, we identify a significant moderating effect of the carbon ETS on both scenarios. Specifically, the ETS reduces emission increases by 5% during "the cat is away" periods and enhances emission reductions by 5.5% during "the cat is around" periods in regions covered by the system. Using Propensity Score Matching (PSM)

analysis and alternative subsampling strategies, we confirm that this moderating effect is not driven by city selection. Even when excluding cities without the ETS, those integrated into the system exhibit lower susceptibility to political shocks after its introduction.

To explore how the ETS stabilizes emissions during turnovers, we examine two channels: government regulatory intensity and firms' opportunistic behavior. Our analysis reveals reduced fines for environmental violations during turnovers, indicating weakened regulatory enforcement. Simultaneously, listed firms in polluting industries increase mergers and acquisitions, signaling opportunistic behavior in operations and production. After the ETS is established, both fines and M&A activity normalize during turnovers, suggesting that the ETS stabilizes regulatory intensity and curbs firms' opportunistic behavior, thereby stabilizing carbon emissions during political shocks. Further evidence shows that the inspection effect stems from the enforcement of penalties during central government inspections.

Thus, the presence of a carbon market mitigates the impact of regulatory policy uncertainty on emissions control efforts. These results remain robust under alternative event windows and estimation methods. Furthermore, our theoretical model, detailed in the online appendix, predicts that cities with the ETS are less responsive to political events than those without, as the ETS regulates firms' behavior and reduces incentives and opportunities for gaming the system. The model also highlights the importance of a sufficiently high carbon price—a condition we define as the Efficient Carbon Market Condition. We find that a higher carbon price amplifies the moderating effect on

regulatory intensity and improves air quality. Since price reflects market operation efficiency, our analysis reinforces the conclusion that the ETS stabilizes emissions control efforts amid political uncertainty.

Our research unveils the systematic opportunistic emissions induced by political uncertainty, underscoring the imperative for a nuanced understanding of the interplay between political economy factors and climate policy (Fredriksson and Svensson 2002). Also, our study offers one of the first resolutions for mitigating the political uncertainty effect on climate policy by carbon ETS. Futhermore, our study provides some of the first evidence of how the ETS addresses both government and market failures in carbon emission control (Stern, 2022; Stern and Stiglitz, 2021). The findings suggest that, even when the cat is away, the mice will not play because the ETS is in place to discourage opportunistic behavior. This has significant implications for the development of the ETS, as well as other market-based instruments initiated by governments, particularly in China and other developing countries, where political factors can profoundly influence the effectiveness of environmental policies (Yu et al. 2021; Tang and Bao 2024). Finally, our study emphasizes the essentiality of adequate carbon price which grants the efficiency of the carbon market (Rozenberg 2020). By addressing these issues, our study comprehensively evaluate the importance of carbon ETS on both emission reduction and moderating effect on government failures. It contributes to the ongoing debate on the optimal design and implementation of the climate policy, ultimately informing the global effort to mitigate climate change.

2. Literature Review and Hypothesis

2.1.Political Economy in Climate Change Mitigation

The political economy of climate change mitigation is largely driven by the need to balance global cooperation with national interests (Goldthau and Sovacool, 2012; Keohane and Victor, 2011). International agreements such as the Paris Agreement require countries to commit to reducing greenhouse gas emissions, but domestic politics and economic factors often influence the ambition and implementation of these commitments. Countries face trade-offs between environmental goals, economic growth, and social equity, which influence the choice and effectiveness of policy instruments such as carbon pricing and renewable energy subsidies (Meckling, 2011). Moreover, the geopolitical context can have a significant impact on carbon reduction efforts, as demonstrated by the net increase of greenhouse gas, equivalent to the annual output of a country such as Belgium, triggered by the first 12 month of the Ukraine war [2].

Moreover, geopolitical events, such as the Ukrainian war and the Israeli–Palestinian conflict, can significantly alter countries' attitudes towards climate change and sustainable development goals. For instance, Russia's invasion of Ukraine hastened the EU's plan for renewable energy supply but also reminded EU countries of "energy independence"[3]. These events highlight the intricate interconnections between global politics, economics, and environmental challenges.

[2] https://www.reuters.com/world/accounting-war-ukraines-climate-fallout-2023-06-06/

[3] https://www.chathamhouse.org/2023/09/consequences-russias-war-ukraine-climate-action-food-supply-and-energy-security/04-upended

Besides, Several studies have highlighted the influence of national political events on environmental outcomes. For example, Zheng and Na (2020) examine the effects of unannounced inspections by the central government on air pollution levels, concluding that cities significantly reduced their emissions during these inspections. Persistent tensions between decentralized and centralized imperatives generate cycles in environmental and energy systems governance in China (Alkon and Wong 2020). These studies suggest that political events can shape the enforcement and effectiveness of environmental policies.

Another stream of research has focused on the role of political turnover in environmental policy enforcement. For instance, Patnaik (2019) shows how the ideology of government actors and the electoral cycle and the type of prevalent bureaucratic regulatory system can shape environmental policies in the EU. Tian and Tian (2021) find a significant relationship exists between the political incentives of city officials and environmental pollution during the Provincial Communist Party Congresses, when new leadership for the party committee is determined. There is an environmental political business cycle in which pollution increases in years leading to the year of leader turnover when local leaders lessen the enforcement of environmental regulations to reduce local industries' production costs and/or to attract firms from other jurisdictions (Cao et al., 2019). Similarly, Wu et al. (2013) discover that political turnover in Chinese provinces led to increased energy consumption and CO2 emissions, indicating a potential trade-off between political stability and environmental outcomes.

2.2.Efficacy of Carbon Emission Systems

The flexibility, adaptability, and innovation-driven nature of the ETS, coupled with its potential to foster international cooperation, make it a powerful tool for achieving emission reduction goals in an efficient and equitable manner. By putting a price on carbon, the ETS encourages firms to reduce their emissions in the most cost-efficient manner (Munnings et al., 2016), fostering innovation and investments in low-carbon technologies (Chen et al., 2021; Ren et al., 2020; Zhu et al., 2019).

Moreover, the ETS can be adapted over time to reflect changing policy goals, market conditions, or scientific knowledge, ensuring that the policy remains relevant and effective in addressing the evolving challenge of climate change (Ellerman et al., 2016). The ETS has the potential to facilitate international cooperation and policy harmonisation, helping to address the global nature of climate change. The EU ETS, for example, has inspired the development of carbon markets in other regions and provided a model for international policy coordination (Tuerk et al., 2009). By linking carbon markets across different jurisdictions, the ETS can help to achieve global emission reduction targets in a more cost-effective and equitable manner (Hintermann et al., 2016).

The EU ETS, as the world's largest and longest-running carbon market, has attracted substantial research attention. For instance, Ellerman et al. (2016) provide an in-depth analysis of the EU ETS, assessing its performance in terms of environmental effectiveness, cost efficiency, and distributional equity. They found that the EU ETS led to a 10% reduction in emissions within regulated sectors during the 2008-2016 period. Calel and Dechezlepretre (2016) analyse the impact of the EU ETS on technological

innovation, demonstrating that the policy stimulated patenting activity in low-carbon technologies. Martin et al. (2016) examine the role of the EU ETS in shaping corporate investment behavior, finding evidence of increased investments in energy efficiency and low-carbon technologies.

Several studies have offered a global outlook on the ETS design and implementation, comparing different carbon markets and drawing lessons for future policy development (Hintermann et al., 2016; Narassimhan et al., 2018; Tuerk et al., 2009; Xiong et al., 2017). The Regional Greenhouse Gas Initiative (RGGI), a cap-and-trade program in the Northeastern United States, has been successful in reducing emissions (Murray and Maniloff, 2015). The California Cap-and-Trade Program has played a significant role in reducing the state's greenhouse gas emissions (Cushing et al., 2018; Woo et al., 2017; Woo et al., 2018).

As new carbon markets emerge in other regions, researchers have increasingly focused on these developing ETS. For example, Duan et al. (2014) reviewe the design and implementation of China's pilot ETS, highlighting the challenges in ensuring equitable distribution of permits and improving market efficiency. China's seven pilot ETS have demonstrated potential for reducing emissions. A study by Qi et al. (2018) in Applied Energy find that the pilot schemes led to a 3-5% reduction in CO2 emissions in regulated industries between 2013 and 2015.

2.3.Carbon Market: Market Failure and Government Failures

The perennial debate on the balance between government intervention and free markets lies at the heart of economic growth considerations. Over the years, evidence

has emerged highlighting the intricacies of market and government failures. Early discussion on market failure (Stiglitz, 1989;Datta-Chaudhuri, 1990) and government failure (Datta-Chaudhuri, 1990; Krueger (1990)urged to identify the source of failure and striking a delicate balance between market and government interventions (Stiglitz, 1989). In the pursuit of balance, scholars have explored innovative approaches like systems competition (Sinn 1997) and social norms (Agell 1999).

Specifically, market failure and government failure have always been a key issue in discussing optimal climate policy. In the early stages of the carbon ETS development, Atkinson and Tietenberg (1991) scrutinized the Environmental Protection Agency (EPA)'s emissions trading program, revealing significant market failures. These included the program's inability to execute some cost-effective trades violating air quality standards, a rigid constant emissions rule, and suboptimal early trades. Building on this, Andrew (2008) highlights failure within the EU ETS, citing generous emissions allocations by states undermining the carbon price, exclusions of certain industries and gases, and instances of fraud due to information gaps, which exemplifies a system prone to both market and government failures. Newell (2012) specifically scrutinizes the Clean Development Mechanism (CDM) under the Kyoto Protocol, identifyng problems such as fraud, gaming, and a lack of additionality of emissions reductions, emphasizing that these were rooted in deeper political economy issues.

Since the 2010s, the global development of carbon ETS has accelerated, guided by both government and market efforts (Paterson 2012). Governments, tasked with drawing agreements on carbon emission plans, grapple with developing models of the

social cost of carbon under controversy. Pindyck (2013) criticizes Integrated Assessment Models (IAMs) for their unreliability in estimating the social cost of carbon, suggesting a focus on plausible catastrophic outcome scenarios and their welfare impacts to inform stringent emission abatement policies. Stern and Stiglitz (2021) critique the assumption in IAMs that governments can perfectly correct market failures and redistribute income.

In summary, climate policy serves as a compelling and optimal case for understanding the intricate interplay of government and market failures. Since the concepts of "market failure" and "government failure" are inherently intertwined (Nedergaard 2006; Furton and Martin 2019), policymakers must adeptly recognize the inevitable systemic changes associated with decarbonization, involving disruption, disequilibria, and policy coordination challenges (Stern, 2022; Stern and Stiglitz, 2021).

2.4.Gaps in the literature & Development of Hypotheses

Existing research on the carbon ETS has made significant contributions to our understanding of their design, implementation, and effectiveness. While many studies have assessed the technical aspects of the ETS design and their impact on emissions reduction (e.g., Ellerman et al., 2016; Qi et al., 2018), this paper, which focuses on the impact of political uncertainty on carbon emission trading systems in China, can contribute to filling this gap.

Moreover, although there are several studies on individual ETS (e.g., California Air Resources Board, 2019; Zhang et al., 2014), comparative analyses across different jurisdictions and systems are relatively limited (e.g., Egenhofer et al., 2011). Such

research could provide valuable insights into the factors that determine the success or failure of the ETS and inform policy design and implementation. By examining the Chinese ETS market as a whole and also investigating trading activities within the ETS in China, this paper could contribute to the development of a more comprehensive understanding of the ETS in different contexts.

Based on the above discussions, we derive two hypotheses as follows.

Hypothesis 1: Cities reduce/increase carbon emissions during inspections/turnovers

Hypothesis 2: Carbon emissions in Cities with the ETS are less responsive to inspections and turnovers.

3. Data and Methods

3.1.Data Sources and Sample

The dependent variable of this study, air quality, is measured by a wide range of indicators in the literature, such as air quality index, PM2.5, CO2, etc (Chen and Whalley, 2012; Davis, 2008; Fu and Gu, 2017; Viard and Fu, 2015; Zhang et al., 2017; Zhong et al., 2017).

In 2012, China updated its air quality index (AQI) to include six pollutants, namely SO2, NO2, PM10, PM2.5, O3, and CO, in order to better evaluate the air pollution level according to Technical Regulation on Ambient Air Quality Index. This new AQI is a more comprehensive indicator than the previous air pollution index (API) as it incorporates three additional pollutants (PM2.5, O3, and CO) and reflects a higher value when the air pollution is more severe(Greenstone et al., 2022). Consequently, recent

studies have adopted AQI as the core indicator of air pollution levels (Li et al., 2021; Xue et al., 2021; Wang et al., 2021). Therefore, we focus on daily AQI in our research and also cover alternative measures in the robustness check.

Besides, weather conditions play a crucial role in determining the level of air pollution and emission. For example, precipitation and wind can reduce the concentration of pollutants such as PM10 (Rost et al., 2009; Jones et al., 2010), while humidity, temperature, and sunshine are related to other pollutants such as ozone (Fu and Gu, 2017). Therefore, we included the main weather condition variables as controls in our analysis, such as time of sunshine, average wind speed, 24-hour precipitation, average humidity, and average temperature.

[Insert Figure 1 about here]

The sample periods started from October 28th 2013, to December 31st 2019, covering 270 cities from 31 provinces in China. The variables are the AQI (higher index implies lower air quality), pollutants' density (μg/m3), time of sunshine (0.1 hours), precipitation in 24 hours (0.1 mm), average wind speed(0.1m/s), average humidity(1%), average temperature(0.1℃), turnover of municipal leaders(1 for days in the week before the announcement of turnover), holiday dummy, inspection(1 during inspection). Air quality data are collected from China National Environment Monitoring Center. Weather data is collected from National Meteorological Information Center. Turnover, inspection and holiday data are collected from official websites manually.

3.2.Unannounced Inspections

Travelling inspection represents a highly efficient and well-known approach for

the Ministry of Ecology and Environment (MEE) to fulfil its mission in daily work. In fact, since 2012, the inspection teams have played a vital role in the anti-corruption campaign under the leadership of Chairman Xi. Typically, these inspection teams are led by powerful government officials who previously held provincial leadership roles, and they conduct unannounced visits to provinces or state-owned enterprises (SOEs) to assess compliance with regulations and rules. As addressing climate change is a top priority for MEE, carbon emissions have always been a critical area of inspection.

Local government takes the visits by inspection teams exceptionally seriously due to the political status of the team leader and the severe consequences that could result from any wrongdoing detected. According to the MEE website, the travelling inspection teams report their arrival in the provincial capital on the website and typically spend one month in the province. Table 2 shows the schedule of MEE inspections from 2016 to 2019, covering all 31 regions in our sample. Most provinces and cities experienced two inspections, while several areas, including Tibet, Xinjiang, and Tianjin, only experienced one inspection. To identify the impact of travelling inspections on the environment, we constructed dummies for travelling inspections based on the information provided on the MEE website. Specifically, the dummy variable takes a value of 1 when the inspection team is currently inspecting the province or city, which is consistent with existing literature(Zheng and Na 2020).

[Insert Table 1 about here]

3.3.Turnovers of Senior Local Government Officials

We focus our attention on high-ranking officials in a given city, specifically the

mayor and head secretary. We manually collected information on their turnover from official websites, such as ce.cn and local government websites. While some turnovers may be unpredictable prior to their announcement, most turnovers have information leakage beforehand. Consequently, political uncertainty in the short period before the announcement of turnover is extremely high for firms and other agents in the city. To maximize the turnover effect during this short period, we exclude turnovers that occurred 14 days before the next turnover shock. These methods also help us to keep the consistency of data in event study research and the RD model in section 5.5. Our sample consists of 1282 turnovers for 270 cities during the sampling period, while one city had no turnovers during the sampling period. Table 3 shows the distribution of turnovers among different regions. Most regions had over 40 turnovers during the period, while minority autonomous regions like Tibet, Guangxi, and Xinjiang had fewer turnovers. To capture the effect of officials' turnover, we constructed dummies that take a value of 1 for days within one week before the turnover and 0 for other dates. We also applied alternative windows as a robustness check in section 5.3.

[Insert Table 2 about here]

3.4.Other Control Variables

To account for the holiday effect which caused the possible traffic condition change (Fu and Gu 2017), we introduce a holiday dummy variable that takes a value of 1 on official holidays, such as New Year, Spring Festival, Tomb-Sweeping Day, Labor Day, Dragon Boat Festival, Mid-Autumn Festival, and National Day. By incorporating this variable, we aim to account for any variations in traffic patterns that may be

attributed to the occurrence of holidays.

[Insert Table 3 about here]

3.5.Empirical Model and Estimation Techniques

Our main model based on panel data and city level fix effects.

$$LnAQI_{it} = \alpha_i + \gamma_t + \beta_1 Turnover_{it} + \beta_2 Inspection_{it} + \theta Holiday_t + \delta W_{it} + \varepsilon_{it} \quad (1)$$

The benchmark model examines the relationship between air quality and political uncertainty and central travelling inspection. The dependent variable, $LnAQI_{it}$, is the natural logarithm of the AQI in the city i on day t. We also consider other air pollutant measures, including PM2.5, PM10, SO2, NO2, CO, and O3, in the logarithmic form. The model includes city and monthly fixed effects, denoted by α_i and γ_t, respectively, to control for unobserved, time-invariant city-specific characteristics and time effects within a month. $Turnover_{it}$ is 1 for days in a week before the turnover of senior officials in the city i. β_1 is the coefficient describing the effect of political uncertainty on local air quality. $Inspection_{it}$ is 1 if the central travelling inspection is inspecting the province of the city i. β_2 describe the inspection effect on air quality. $Holiday_t$ is 1 for official holidays. And W_{it} includes weather controls, namely the level of sunshine, wind speed, precipitation, humidity and temperature for the city I on day t. ε_{it} is the error term.

To further test for the structural break caused by the turnover, we also adopt a regression discontinuity(RD) design which identifies potential breaks in two parametric series before and after turnovers (Greenstone et al. 2022).The RD model can be written

as follows:

$$LnAQI_{it} = \alpha_i + \gamma_t + \beta_1 AfterTurnover_{it} + \beta_2 f(t - TurnDate_{it}) + \beta_3 AfterTurnover_{it} * f(t - TurnDate_{it}) + \beta_4 Inspection_{it} + \theta Holiday_t + \delta W_{it} + \varepsilon_{it} \quad (2)$$

where $LnAQI_{it}$ also indicates the log form pollution levels reported by in the city i on day t. $AfterTurnover_{it}$ is an indicator variable that equals one if city i at time t is in 7 days after a local leader's turnover. $t - TurnDate_{it}$ represents the number of days from the turnover and is the running variable. We include a "control function," $f(t - TurnDate_{it})$, and allow it to differ pre and post turnovers. We also controls similar variables as equation 1 including inspection, holiday, weather indicators and fixed effects.

The parameter of Interest, $\beta 1$, estimates whether there is a discontinuity in air pollution levels immediately post the turnover, after flexible adjustment for the days before/after automation and the covariates. We estimate the RD by firstly get residual in regression which is similar to equation 1 but without turnover indicators and then conduct RD analysis on the residual. This procedure provides a consistent estimate of the same RD parameter of interest (Lee and Lemieux 2010).

4. Empirical Findings and Discussions

4.1.Political Uncertainty Effect of Anannounced Turnovers and Inspections

Table 4 presents the empirical findings of our first hypothesis, using the Difference-in-Differences (DID) model and panel data. We examine seven different measures of air pollution in this table, controlling for city fixed effects, monthly fixed

effects, holiday effects, and weather conditions. The first column of Table 4 presents our main result, revealing that both turnovers and inspections significantly affect local air quality, albeit in opposite directions. Specifically, during the turnover window, the air quality deteriorates by 2.2% with a 1% level of significance. In contrast, during the inspection period, air quality improves by 5%, which aligns with our hypothesis and prior research. Importantly, turnover effects remain significant in Columns 2, 3, and 5, while inspection effects remain significant across all seven columns. Furthermore, turnover has a higher impact on PM10 and PM2.5, exceeding 2.5%, while it does not significantly influence the concentration of SO2, CO, and O3. In contrast, inspection has the highest impact on SO2, with a 9.9% decrease.

Table 4 also provides additional insights by revealing that wind speed, precipitation, and humidity are negatively associated with air pollutants such as PM2.5,PM10 and SO2, consistent with existing literature(Fu and Gu 2017;Deryugina et al., 2019; Brodeur et al.2021).

On RD estimate, we start by visualizing the patterns in the data. In Figure A1(A), we plot the raw daily reported AQI concentration data. Figure A1(B) plots the residualized concentrations after adjustment for all controls in equation 1 without turnover. In both panels, we observe a striking decrease in reported AQI immediately after turnovers.

We then present RD estimates from equation (2) in Table A1(A). To comply with the baseline DID model ,the bandwidths are 7 days in all columns. Columns (1) to (3) report the results with linear polynomial function and columns (4) to (6) report the

results with quadratic polynomial functions. We use three different kernel weighting strategies in Table A1 including Triangle, epanechnikov, and uniform. The RD estimate have similar results in different columns. Turnovers result in a 2.5% to 3.2% air quality deterioration in table 1 which is closed to the DID estimate in table 4. Therefore, the date of turnover announcement induce a clear discontinuity in air quality. When political uncertainty suddenly settled with the announcement, polluters stop pollution as they believe the regular regulation and monitoring system is back.

[Insert Table 4 about here]

[Insert Table 5 about here]

4.2. The Moderating Effect of ETS

Chinese cities vary dramatically in many respects. Therefore, to further explore the turnover effect and inspection effect based on the heterogeneity among cities, we decompose the city sample according to my Hypothesis 2. By deriving the effect in different groups, we show how cities react to turnover and inspections differently. Table 5 shows the difference and mechanism of the effect.

Column 1 uses the subsample of regions covered by the provincial carbon ETS. There are seven regional carbon ETS supported by the Development and Reform Commission since 2013: Beijing, Shanghai, Shenzhen, Guangdong, Hubei, Chongqing and Tianjin. Moreover, on December 22, 2016, Fujian opened a new provincial carbon ETS, the only trading carbon allowance besides the above 7 ETS. These eight carbon ETS mainly focused on firms in the province and were the core of carbon emission transactions before 2021, when the national carbon ETS opened. With the systematic

regulation and management of carbon emissions, firms and governments in those provinces and cities were operating the game of cat and mouse differently compared to regions without the carbon ETS. Therefore, we found that the turnover and inspection effect patterns are much different in column 1. The coefficient of Turnover is insignificant, while the coefficient of Inspection is significantly positive. This result is entirely different from the pattern in column 2, using the subsample of regions without the carbon ETS. Such a divergence is likely the result of the carbon ETS, which changes the behavior of firms.

Moreover, we use an interaction term to derive the influence of the carbon ETS on the turnover and inspection effect. In column 3, we use a dummy for the carbon ETS and its interaction term with turnover and inspection dummies. Carbon ETS (covered) is 1 for cities that start to be covered by a provincial carbon ETS. Since all eight carbon ETS opened on different dates, we chose the market opening date as the start of the dummy for the carbon ETS. The turnover and inspection effects become significant with the carbon ETS and interaction terms. Air quality deteriorates by 2.94% during the turnover window and improves by 5.9% during inspections. The magnitude of the effect is larger than that in Table 2. More importantly, the coefficient of the interaction term of Carbon ETS (covered) * Turnover is significantly negative, and that for Carbon ETS (covered) * Inspection is significantly positive. Establishing a carbon ETS seems to form self-regulation that limits the emission during the turnover period by 5.04% and induces the emission during inspections by 5.51%. Therefore, the ETS effect hedges abnormal air quality turbulence during turnovers and inspections.

Establishing carbon emissions trading schemes (ETS) in provincial capitals is more likely to impact cities that are already their respective provinces' economic and political centres. To test the effect of carbon ETS, we analyze subsamples consisting only of cities with established carbon ETS in column 4. The results indicate that turnover and inspection effects are insignificant, contrasting those obtained from other cities in column 5. To further assess the influence of the carbon ETS, I utilize a set of interaction terms similar to column 3 in column 6. Here, the coefficient of Carbon ETS(location) remains insignificant, but the coefficient of Carbon ETS(Location)*Turnover is -9.34%, higher than the effect observed in column 3. This implies that the self-regulation of firms in capital cities is more significant than firms in other cities. Conversely, the coefficient of Carbon ETS(Location)*Inspection is insignificant.

4.3. Will the Moderating Effect a Result of City Selection

While Tables 4 and 5 investigate the impact of the carbon ETS on turnover and inspection effects, differences between cities with and without the carbon ETS may stem from endogeneity. Specifically, pilot cities for Chinese reforms may not have been randomly selected. A key concern is that cities with an ETS might perform better simply because they inherently experience lower political uncertainty, even before the ETS was established.

To address potential selection bias, we employ two strategies: (1) limiting the subsample to cities covered by the carbon ETS and (2) using propensity score matching (PSM) to match these cities with comparable ones. Although pilot regions may face

selection bias, focusing on them helps mitigate this concern. Since all regions eventually established an ETS but at different times, the staggered openings allow regions without an ETS to serve as a control group..

Therefore, in Table 6, Columns 1 to 4, we first compare the turnover effect between different groups. Since there is no inspection before the opening of the last ETS, we drop the inspection variable and its interaction term in Columns 1 to 5 for clearer expression. In Columns 1 and 2, we divide the sample of regions never covered by ETS by December 2016, when the last ETS in the sample finally opened. For these columns, we find that the turnover effect increased slightly over time. However, in Columns 3 and 4, we find that the turnover effect for regions with ETS dropped significantly after the opening of ETS.

In Column 5, the interaction term is significant, suggesting that even without concerns about city selection, the moderating effect still applies in these cities. In Column 4, we analyze subsamples of cities with carbon ETS coverage, finding that the turnover effect reaches 14.61%, even higher than in Column 1. Moreover, the interaction term exhibits a stronger hedge effect, with Carbon ETS(Location)*Turnover having a coefficient of 18.2%, surpassing the turnover effect. Conversely, the coefficient for the inspection effect is insignificant and negative. Since all inspections occurred after ETS establishment, there is no interaction term between Carbon ETS and Inspection. Table 7 also demonstrates the impact of the establishment of the ETS on cities using other subsamples. In column 3, we utilize the subsample of cities covered by the carbon ETS. The results indicate that the turnover effect is significant for cities

covered by the carbon ETS, with a coefficient of 10.25%, considerably higher than that observed in Table 5-Table 5-4, column 3. However, this substantial effect is tempered by the interaction term, which has a coefficient of -11.18% after the ETS establishment. Furthermore, inspection effects for these cities are significantly positive.

We also apply PSM to draw the concern of city selection in Column 6 and 7.In the first stage of PSM matching, we estimate a logit model with an ETS-covered dummy variable as the dependent variable and determinants such as average local pollution levels, demographic, economic, and environmental protection indicators from the five years preceding the pilot scheme announcement in 2011 as independent variables. We then use this regression to calculate the predicted probabilities of being an ETS-covered city for each observation. Employing a nearest-neighbourhood matching strategy within calliper radius of 0.1 in column 1 and 0.05 in column 2 without replacement, we identify comparable cities for each ETS-covered city based on their propensity scores.

Results in columns 6 and 7 demonstrate that employing PSM-DID strengthens the moderating effect of carbon ETS compared to Table 4Table 5. The moderation effect on Turnover increases from approximately 5% to 6%, and the moderation effect on Inspection increases from 5% to 7%. Therefore, cities covered by carbon ETS benefit from this moderation effect compared to untreated cities eligible for ETS coverage.

Finally, while air quality in cities with the carbon ETS does not change significantly during inspections, other regions experience worse air quality. One possible explanation is that when inspection teams arrive in provincial capitals, other cities are informed about the inspection but not its schedule. The traveling inspection

team does not inspect every city daily but moves around the province. As a result, cities outside the capitals have time to prepare. To perform well during inspections, firms in these cities may accelerate short-term emissions before the team arrives or over-emit afterward to compensate for their "good performance" during inspections. Such behavior is highly risky for cities without an ETS, as they face penalties if caught. However, cities covered by the carbon ETS can purchase additional allowances if caught, with the only cost being future allowance purchases. This risky behavior leads to increased emissions in non-inspected cities, consistent with the insignificant coefficient in Column 4.

4.4.Channels for The Moderating Effect of ETS

To examine the mechanism behind the moderating effect, we explore two key channels: the regulatory intensity of local governments and the opportunistic behaviors of firms. The moderating effect reflects a shift in equilibrium following the establishment of an emissions trading system (ETS), driven by changes in firm and government behaviors that existed prior to the ETS. Controlling for weather conditions, changes in air quality or carbon emissions largely depend on two factors: the regulatory intensity of governments and the strength of emissions by firms.

Government regulatory intensity varies over time, influenced by political factors such as economic growth goals or fiscal planning, often aligned with the political business cycle. As shown in the baseline analysis, the turnover and inspection effects suggest two distinct states of emissions or regulatory intensity. To verify whether these effects are related to regulatory intensity, we use environmental protection fine data. By

analyzing the daily fine counts in each city over the period studied, we demonstrate how regulatory intensity changes under different circumstances.

Table 7 presents the results. Columns 1 to 4 examine how regulatory intensity evolves and contributes to the ETS's moderating effect. To maintain consistency in comparison, we exclude inspection indicators since inspections were absent in regions prior to the establishment of their ETS. Column 1 indicates that before the ETS's implementation, pilot regions had fewer fines during periods of local government turnover. In contrast, Column 2 shows an insignificant coefficient for fine counts. Column 3 reveals that the introduction of the ETS leads to an increase in fines during turnovers, suggesting that turnover effects previously weakened regulatory intensity due to heightened political uncertainty. However, after the ETS's establishment, automated monitoring systems reduced regulatory costs and enhanced regulatory intensity. Although the effect becomes insignificant in Column 4 when all regions are included, the mitigating impact of inspections is clear. This suggests that while traveling inspections enhance regulatory intensity, the ETS reduces fines by integrating market operations and lowering punishment frequency.

On the firm side, political uncertainty encourages opportunistic behaviors. Contrast with their US peers, Chinese firms tends to opportunistically operate M&A during periods with high political uncertainty. High-polluting industries typically face stringent regulation, but during times of uncertainty, firms exploit the situation to adjust their operations. To capture this, we analyze the number of mergers and acquisitions (M&A) by local listed firms, which are often associated with high-pollution industries.

Columns 4 to 8 in Table 7 present these results. Before the ETS's implementation, firms exhibited increased M&A activity during local government turnovers, as shown in Column 4. Columns 5 and 6 demonstrate that the ETS significantly mitigates this opportunistic effect, which remains significant in Column 7. These findings suggest that while political uncertainty amplifies firms' opportunistic behaviors, the ETS reduces such behaviors by enforcing consistent monitoring and reporting systems. The concentration of M&A activity during turnovers implies opportunistic operations and production practices by firms, which are curtailed by the ETS and its automated monitoring mechanisms.

In summary, the ETS moderates the impact of political uncertainty through two key channels. First, it stabilizes regulatory intensity, reducing the time-varying patterns of local government regulators. Second, it curtails firms' opportunistic behaviors by providing a consistent monitoring and reporting framework. These effects collectively contribute to a more predictable and stable regulatory environment, enhancing the effectiveness of environmental governance.

5. Conclusions and Policy Implications

The findings of this paper provide empirical support for the effectiveness of the Emission Trading System (ETS) in addressing both market and government failures in carbon emission control. By analyzing two natural experiments—unannounced inspections by the central government and turnovers of senior local government officials—we show that cities with an ETS are less responsive to these political events. This suggests that the ETS helps mitigate the impact of political uncertainty on emission

control efforts. The ETS effectively addresses both market and government failures by combining market incentives with policy targets. Its flexibility, adaptability, and innovation-driven nature, along with its potential to foster international cooperation, make it a powerful tool for achieving emission reduction goals in an efficient and equitable manner.

Overall, the ETS addresses market and government failures in carbon emission control by harnessing market incentives and aligning them with policy objectives. It overcomes market failures by creating a price signal for carbon emissions, internalizing the environmental costs of greenhouse gases, and stimulating technological innovation and the development of low-carbon solutions. At the same time, the ETS provides firms with the flexibility to choose how to reduce emissions, enabling them to respond to market conditions and technological advancements. This flexibility helps bridge the information and knowledge gaps often associated with government interventions, ensuring that emission reductions are achieved in the most economically efficient way. Furthermore, the ETS can be adapted over time to reflect evolving policy goals, market conditions, and scientific knowledge, ensuring its continued relevance and effectiveness in addressing the dynamic challenge of climate change.

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Figure 1. Sample Cities, Pilot Carbon ETS Cities and Pilot Carbon ETS Regions

The Figure shows the distribution of 270 cities in our sample. Cities covered by dark green are cities with Pilot Carbon ETS. Regions coloured by light green are cities covered by provincial Carbon ETS. Gray regions are other cities in our sample.

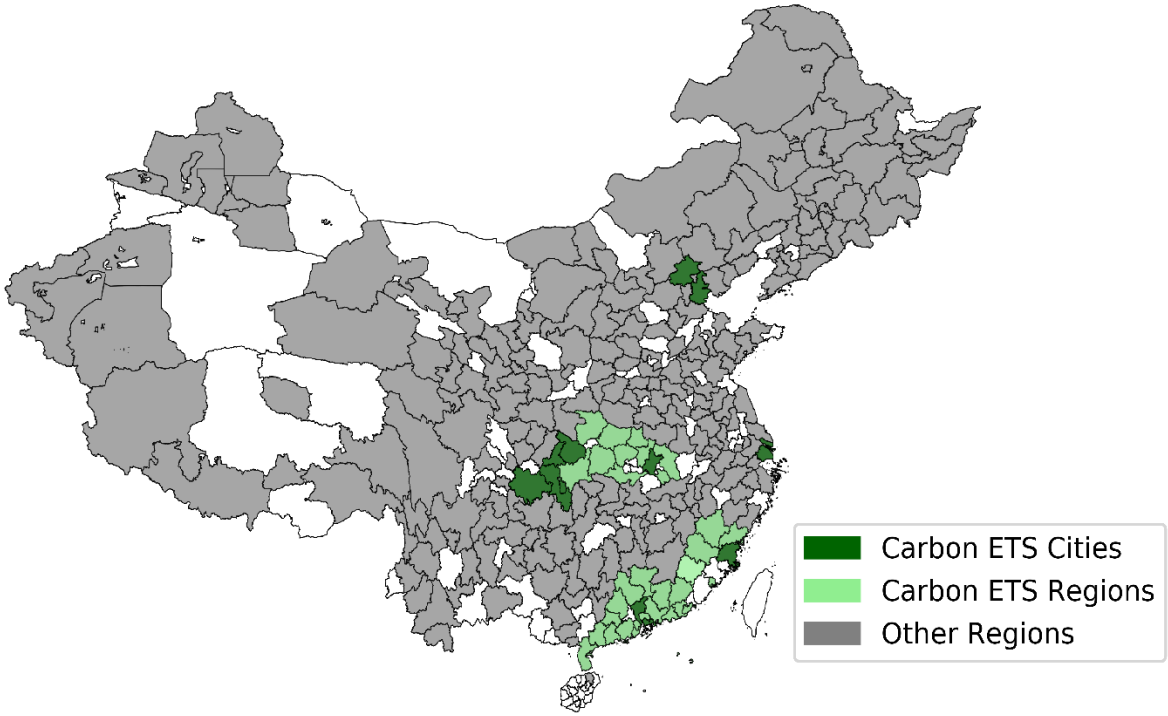


Table 1: Unannounced inspections

Date	Province	Date	Province	Date	Province
2016/1/4	Hebei	2017/4/27	Anhui	2018/6/6	Jiangsu
2016/7/12	Ningxia	2017/4/28	Tianjin	2018/6/6	Yunnan
2016/7/14	Guangxi	2017/4/29	Shanxi	2018/6/7	Guangxi
2016/7/14	Inner Mongolia	2017/7/19	Heilongjiang	2018/10/30	Hunan
2016/7/14	Jiangxi	2017/8/7	Sichuan	2018/10/31	Anhui
2016/7/15	Yunnan	2017/8/8	Qinghai	2018/10/31	Hubei
2016/7/16	Henan	2017/8/10	Shandong	2018/11/1	Shandong
2016/11/24	Chongqing	2017/8/11	Hainan	2018/11/3	Shaanxi
2016/11/26	Hubei	2017/8/11	Jilin	2018/11/3	Sichuan
2016/11/28	Guangdong	2017/8/11	Xinjiang	2018/11/4	Guizhou
2016/11/28	Shaanxi	2017/8/12	Zhejiang	2018/11/4	Liaoning
2016/11/28	Shanghai	2017/8/15	Tibet	2018/11/5	Jilin
2016/11/29	Beijing	2018/5/30	Heilongjiang	2019/7/8	Beijing
2016/11/30	Gansu	2018/5/31	Hebei	2019/7/9	Shanghai
2017/4/24	Fujian	2018/6/1	Henan	2019/7/12	Chongqing
2017/4/25	Hunan	2018/6/2	Ningxia	2019/7/12	Gansu
2017/4/25	Liaoning	2018/6/3	Jiangxi	2019/7/14	Hainan
2017/4/26	Guizhou	2018/6/5	Guangdong	2019/7/14	Qinghai
		2018/6/6	Inner Mongolia	2019/7/15	Fujian

Table 2: Turnovers

Table 2 shows how many city-level leaders' turnovers were in a province during the from October 28th 2013 to December 31th 2019.

Province	Turnovers	Province	Turnovers
Anhui	44	Jiangsu	44
Beijing	4	Jiangxi	43
Chongqing	5	Jilin	59
Fujian	30	Liaoning	88
Gansu	41	Ningxia	15
Guangdong	100	Qinghai	16
Guangxi	36	Shaanxi	30
Guizhou	43	Shandong	65
Hainan	4	Shanghai	2
Hebei	42	Shanxi	58
Heilongjiang	73	Sichuan	56
Henan	61	Tianjin	3
Hubei	54	Tibet	16
Hunan	57	Xinjiang	35
Inner Mongolia	51	Yunnan	51
		Zhejiang	56

Table 3. Summary Statistics

Variable	Obs	Mean	Std. dev.	Min	Max
AQI(Air Quality Index)	511,772	74.22	47.50	0	500
PM2.5(μg/m3)	511,772	44.29	39.57	0	1787
PM10(μg/m3)	511,772	79.89	77.54	0	8818
SO2(μg/m3)	511,772	19.32	23.12	0	800
NO2(μg/m3)	511,772	29.10	17.37	0	471
O3(μg/m3)	511,772	58.77	29.60	0	435
CO(μg/m3)	511,772	0.98	0.57	0	25.69
Sunshine(0.1 hour)	511,772	56.45	41.57	0	155
Precipitation(0.1mm)	511,772	27.79	96.90	0	4552
Wind Speed(0.1m/s)	511,772	21.72	12.24	0	205
Humidity(1%)	511,772	67.38	19.05	3	100
Temperature(0.1℃)	511,772	139.55	112.33	-388	423
Turnover	511,772	0.02	0.12	0	1
Holiday	511,772	0.07	0.25	0	1
Inspection	511,772	0.03	0.16	0	1

Table 4. Political Uncertainty and Local Air Quality

The table reports the results of DID regressing log air quality indicators against a dummy for political uncertainty(*Turnover*) and a series of controls. *Turnover* is 1 for days in the week before local leaders' turnover. *Inspection* is 1 for days in the period of MEE travelling inspections. City fixed effects, monthly fixed effects and holiday dummy are included. Standard errors are clustered at the city level. Robust t-statistics are in parenthesis. ***, **, and * correspond to statistical significance at 1%,5% and 10% levels respectively.

	(1) log(AQI)	(2) log(PM2.5)	(3) log(PM10)	(4) log(SO2)	(5) log(NO2)	(6) log(CO)	(7) log(O3)
Turnover	0.0220***	0.0241**	0.0250***	0.0154	0.0155**	-0.0057	-0.0099
	(2.94)	(2.31)	(2.64)	(1.28)	(2.19)	(-0.76)	(-1.07)
Inspection	-0.0504***	-0.0781***	-0.0707***	-0.0993***	-0.0319***	-0.0221**	-0.0397***
	(-6.69)	(-7.41)	(-7.12)	(-6.02)	(-3.04)	(-2.32)	(-3.27)
Sunshine	-0.0002*	-0.0007***	-0.0005***	0.0005***	0.0001	-0.0001*	0.0020***
	(-1.86)	(-5.13)	(-3.85)	(4.27)	(0.62)	(-1.70)	(18.66)
Precipitation	-0.0006***	-0.0010***	-0.0009***	-0.0004***	-0.0002***	-0.0001***	-0.0001***
	(-21.65)	(-25.89)	(-23.93)	(-12.70)	(-7.60)	(-7.64)	(-5.71)
Wind Speed	-0.0057***	-0.0109***	-0.0081***	-0.0112***	-0.0161***	-0.0070***	0.0052***
	(-12.37)	(-17.66)	(-12.78)	(-17.97)	(-20.72)	(-19.15)	(11.47)
Humidity	-0.0024***	0.0010	-0.0060***	-0.0084***	-0.0020***	0.0033***	-0.0058***
	(-5.30)	(1.53)	(-10.87)	(-16.76)	(-5.75)	(11.56)	(-10.64)
Temperature	0.0015***	0.0017***	0.0018***	-0.0017***	0.0006***	0.0004***	0.0017***
	(12.76)	(10.25)	(12.40)	(-10.12)	(5.79)	(4.02)	(9.10)
City FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Holiday	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	511,760	511,704	511,602	511,725	511,710	511,690	511,689
R2	0.4891	0.5228	0.5363	0.6203	0.6484	0.5285	0.5085

Table 5. Political Uncertainty, air pollution and Carbon ETS

The table reports the results of DID regressing log air quality indicators against a dummy for political uncertainty(*Turnover*), an interaction term between *Turnover* and *Carbon ETS*. *Turnover* is 1 for days in the week before local leaders' turnover. *Inspection* is 1 for days in the period of MEE travelling inspections. Carbon ETS*(Covered)* is one if the city has been covered by one of the eight provincial Carbon ETS. *Carbon ETS(location)* is one if the city has a provincial Carbon ETS. Column 1 uses the subsample of only regions finally covered by eight provincial carbon ETS. Column 4 uses the subsample of cities with Carbon ETS finally. Standard errors are clustered at the city level. Robust t-statistics are in parenthesis. ***, **, and * correspond to statistical significance at 1%,5% and 10% levels respectively.

	(1) Regions Covered by Carbon ETS	(2) Other	(3) All	(4) Cities with Carbon ETS	(5) Other	(6) All
Turnover	-0.0030	0.0248***	0.0294***	-0.0206	0.0237***	0.0246***
	(-0.19)	(3.06)	(3.60)	(-0.88)	(3.12)	(3.23)
Inspection	0.03**	-0.0562***	-0.0590***	-0.01	-0.0510***	-0.0518***
	(2.05)	(-7.04)	(-7.37)	(-0.20)	(-6.68)	(-6.79)
Carbon ETS(Covered)			0.0020			
			(0.10)			
*Carbon ETS(Covered)*Turnover*			-0.0504**			
			(-2.20)			
*Carbon ETS(Covered)*Inspection*			0.0551***			
			(3.56)			
Carbon ETS(location)						-0.0181
						(-0.44)
*Carbon ETS(Location)*Turnover*						-0.0934***
						(-2.92)
*Carbon ETS(Location)*Inspection*						0.0460
						(1.09)
Control	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Holiday	Yes	Yes	Yes	Yes	Yes	Yes
N	78,817	432,943	511,760	16,794	494,966	511,760
R2	0.4849	0.491	0.4892	0.4367	0.4926	0.4891

Table 6. Moderating Effect is Not The Result of City Selection

To address concerns regarding city selection in the adoption of carbon ETS, the table presents results using propensity score matching (PSM) and other subsamples. Columns 1 to 2 presents results using only regions without ETS while columns 3 to 5 uses only regions with ETS. Columns 6 and 7 present results from PSM sample matching. Column 6 utilizes a nearest neighbourhood matching strategy within a 0.1 calliper radius without replacement, while Column 7 employs a similar strategy within a 0.05 calliper radius without replacement. *Turnover* is 1 for days in the week before local leaders' turnover. *Inspection* is 1 for days in the period of MEE travelling inspections. *Carbon ETS(Covered)* is one if the city has been covered by one of the eight provincial Carbon ETS. *Carbon ETS(location)* is one if the city has a provincial Carbon ETS. Standard errors are clustered at the city level. Robust t-statistics are in parenthesis. ***, **, and * correspond to statistical significance at 1%,5% and 10% levels respectively.

	Regions Without ETS		Regions With ETS			PSM	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Before the Last ETS	After the Last ETS	Before Opening	After Opening	All	Without Replacement Radius=0.1	Without Replacement Radius=0.1
Turnover	0.021*	0.033***	0.109***	-0.010	0.103*	0.0636***	0.0628***
	(1.80)	(2.63)	(2.83)	(-0.63)	(2.01)	(4.10)	(3.86)
Carbon ETS(Covered)					-0.024	-0.0146	-0.0145
					(-1.04)	(-0.47)	(-0.46)
Carbon ETS(Covered)*Turnover					-0.113**	-0.0624**	-0.0597**
					(-2.14)	(-2.28)	(-2.15)
Inspection						0.0570***	0.0618***
						(-3.33)	(-3.53)
Carbon ETS(location)*Inspection						0.0718***	0.0768***
						(3.74)	(3.88)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Holiday	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	190,863	242,080	6,016	72,801	78.817	120,140	114,510
R2	0.4868	0.4999	0.6320	0.4769	0.4850	0.5139	0.5098

Table 7. Mechanism

The table reports the results of DID regressing log air quality indicators against a dummy for political uncertainty(*Turnover*), an interaction term between *Turnover* and *Carbon ETS*. *Turnover* is 1 for days in the week before local leaders' turnover. *Inspection* is 1 for days in the period of MEE travelling inspections. Carbon ETS*(Covered)* is one if the city has been covered by one of the eight provincial Carbon ETS. *Carbon ETS(location)* is one if the city has a provincial Carbon ETS. Column 1 uses the subsample of only regions finally covered by eight provincial carbon ETS. Column 4 uses the subsample of cities with Carbon ETS finally. Standard errors are clustered at the city level. Robust t-statistics are in parenthesis. ***, **, and * correspond to statistical significance at 1%,5% and 10% levels respectively.

	Environmental Regulation				Merge and Acquisition			
	Regions Covered by Carbon ETS			All	Regions Covered by Carbon ETS			All
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Before Opening	After Opening	All	All	Before Opening	After Opening	All	All
Turnover	-0.428**	0.128	-0.980***	-0.0241	0.565**	-0.066	0.498***	0.260**
	(-2.00)	(0.76)	(-3.09)	(-0.43)	(2.50)	(-0.52)	(3.18)	(2.24)
Inspection		0.274**	0.305**	0.783***		-0.163	-0.132	-0.185**
		(2.34)	(2.56)	(8.42)		(-1.18)	(-0.88)	(-2.12)
Carbon ETS(Covered)			0.002	-0.263			0.155	0.084
			(0.00)	(-1.05)			(0.90)	(0.58)
*Carbon ETS(Covered)*Turnover*			1.115***	0.188			-0.561**	-0.299*
			(3.14)	(0.80)			(-2.57)	(-1.75)
*Carbon ETS(Covered)*Inspection*				-0.483***				0.275
				(-3.11)				(1.49)
Control	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Holiday	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	6,016	72,801	78,817	511,772	6,016	72,801	78,817	511,772
R2	0.3537	0.4108	0.4008	0.3359	0.2004	0.3039	0.2995	0.2611

Online Appendix

A1. Additional Materials for Chapter 5

A1.1 The Model

A1.1.1 Firms and Regulations

A small economy has a polluting sector that produces a good x This economy consists of consumers and polluting firms, with the population normalized to 1. Consumers experience disutility due to pollution associated with local firms' production. A representative consumer's utility function is given by:

$$U = u(c^x) - \theta(H)(X) \quad (1)$$

where c^x is consumption of the good x and unregulated production g(x), with domestic prices equal to p. $u(c^x)$ is a strictly concave and differentiable sub-utility function. Production of x by each of the n identical firms is given by x_i, where $nx_i = X$. θ is per-unit damage, which depends on the $H = nh_i$ spent by the firms on pollution control, where $\theta_h < 0$ and $\theta_{hh} > 0$. 0. Thus, $\theta(H)$represents aggregate emissions damage level. Besides, the consumer surplus for consuming good x is $\omega(x)$.

Good "x" is produced with a constant marginal cost equal to one. The cost of producing good "x" is given by $v(x, h)$, with the assumptions $v_x > 0, v_h > 0$. In addition to production costs, firms are regulated based on a carbon emission reduction plan. The regulation cost Δ incurred on observing the carbon emission reduction plan is:

$$\Delta(\theta_t, x_t, x_{t-1}, \varepsilon_t, \zeta_t) = \zeta_t(\theta_t x_t - \varepsilon_t x_{t-1})$$

Here, ζ_t represents the punishment on extra emissions based on the plan, which is the difference between the current emissions $\theta_t x_t$and an emission limit $\varepsilon_t x_{t-1}$, based on the carbon emissions of the last period.

The cost of the carbon emission plan is a regular daily regulation cost. However, firms have a proportion of production plans that are spontaneously applied. Such a production is more intensive than a normal plan in a short period of time and is usually applied when the overall production plan is overloaded. I define this part of production as g(x). Accordingly, they have a probability $0 \leq P_1 \leq 1$ to face a strict regulation period when they will be punished by $\zeta_t \theta_t g(x)$ if they have high pollution during that period. Such a strict regulation is normally presented by Central MEE Inspection teams. They also have the opportunity to benefit from polluting, with a bonus of $\mu_t \theta_t g(x)$ when regulation is absent, with a probability $0 \leq P_2 \leq 1$ and $\mu_t > 0$. For example, firms can turn off environmental protection cost during the period. Given all the costs, the profit function of each firm is given by:

$$\pi = P(x_t) - v(x_t, h_t) - \zeta_t(\theta_t x_t - \varepsilon_t x_{t-1}) - P_1\zeta_t\theta_t g(x) + P_2\mu_t\theta_t g(x) \quad (2)$$

The local government is responsible for daily regulation and the well-being of the population. They also care about the punishment by the central government which may influence their promotions. Their utility function is based on the weighted sum of consumers' utility and firms' utility, including punishments during strict regulation periods when the central government penalizes them for high pollution during inspections. The government's utility function is given by:

$$\Omega = \omega(x) - \theta(H)(X) + P(x_t) - v(x_t, h_t) - \zeta_t(\theta_t x_t - \varepsilon_t x_{t-1}) - P_1\zeta_t\theta_t g(x) + P_2\mu_t\theta_t g(x) + \alpha(\zeta_t(\theta_t x_t - \varepsilon_t x_{t-1}) - P_1\kappa_t\theta_t g(x)) \quad (3)$$

This utility function incorporates weights α for governments' own welfare including the fine income on firms for extra emission and punishment $P_1\kappa_t\theta_t g(x)$ from the central government. Here, $\kappa_t$represents the magnitude of the central government's punishment.

To simplify, I use $g(x) = \beta x_t^2$. Based on equation (2), I can derive the optimal production value using the first-order condition on x_t:

$$x_t = \frac{P - v_{x_t} - \zeta_t\theta_t}{2\beta\theta_t(\zeta_t P_1 - \mu_t P_2)} \quad (4)$$

From equation (4), I find the factors influencing firms' decisions if I simplify the cost function by $v_{x_t} = v$: $\frac{\partial x_t}{\partial \zeta_t} \leq 0, \frac{\partial x_t}{\partial P_1} \leq 0, \frac{\partial x_t}{\partial P_2} \geq 0$. In other words, higher punishment for carbon emissions reduces firms' production and emissions. A higher probability of strict regulation also reduces production, while a higher probability of absent regulation increases production and emissions.

For the government, I can derive their optimal regulation method based on equation (3):

$$(\alpha - 1)(\theta_t x_t - \varepsilon_t\theta_{t-1}x_{t-1}) = P_1\theta_t x_t^2 \quad (5)$$

This equation indicates that the current method poses a risk for local government officials. Successfully achieving carbon emission reduction plans is beneficial, but this gain can be offset by firms over emission during inspections, which are caught and punished by the central government.

A1.1.2 Firms and the Carbon Market

However, the game has changed with the carbon ETS. For firms, participation in the carbon ETS means not only transactions in the carbon market but also a comprehensive daily emission monitoring system. Therefore, the profit function of each firm is given by:

$$\pi_i = P(x_t) - v(x_t, h_t) - \zeta_t\big(1 - \epsilon_t(\delta_t)\big)(\theta_t x_t - \varepsilon_t x_{t-1}) - \epsilon_t(\delta_t)\lambda_t(\theta_t x_t - \varepsilon_t x_{t-1}) - P_1\zeta_t\theta_t g(x, \delta) + P_2\mu_t\theta_t g(x, \delta) \quad (6)$$

Where λ_t represents the stochastic market price of carbon in the local market, which firms must pay for excess emissions $\theta_t x_t - \varepsilon_t x_{t-1}$ by buying carbon. This formation of the carbon market is consistent with the current method of determining carbon allowance in China. δ_t is the level of the carbon ETS development. $\epsilon_t(\delta_t)$ is the probability that a firm is subject to the carbon market. In a

more developed market, firms have more opportunities to participate which means $\frac{\partial \epsilon}{\partial \delta} \geq 0$. For firms, spontaneous production is a function of overall production and the carbon ETS development. $\frac{\partial g}{\partial \delta} \leq 0$ because a more developed carbon market with better daily monitoring reduces firms' willingness to evade pollution silently. ξ_t is the probability that the central government will penalize the local government for pollution during inspections. Given that the carbon ETS was introduced by MME (responsible for inspections), inspection teams consider market development as an alternative to emission regulation only when players adhere to the market's rules rather than the government's punishments. Therefore, $\xi_t(\delta_t)$ is lower when the development level δ is higher, implying better local carbon ETS development will be welcomed by inspection teams. Additionally, $\rho_t(\delta_t)$ is the probability for a firm to evade undetected pollution. $\rho_t(\delta_t)$ is lower when δ is higher, indicating that a more developed market entails more firms being monitored and regulated by the local carbon ETS. Therefore, firms have difficulty engaging in silent pollution in situation 2.

For governments, the Pilot carbon ETS is promoted by local government as an important political achievement, resulting in political competition among leading regions. Since the united carbon ETS for the entire country is the eventual goal of the pilot scheme, the winner of the local pilot carbon ETS development has the opportunity to become a leader in national carbon ETS. The government's utility function is recalibrated as:

$$\begin{aligned}\Omega = \omega(x) - \theta(H)(X) + P(x_t) - v(x_t, h_t) - \zeta_t\big(1-\epsilon_t(\delta_t)\big)(\theta_t x_t - \varepsilon_t x_{t-1}) \\ - \epsilon_t(\delta_t)\lambda_t(\theta_t x_t - \varepsilon_t x_{t-1}) - P_1\zeta_t\theta_t g(x,\delta) + P_2\mu_t\theta_t g(x,\delta) \\ + \alpha(\zeta_t\big(1-\epsilon_t(\delta_t)\big)(\theta_t x_t - \varepsilon_t x_{t-1}) - P_1\kappa_t\theta_t g(x,\delta) + S_t(\delta_t)) \qquad (7)\end{aligned}$$

Where $S_t(\delta_t)$represents the net benefits of a more developed carbon market, including political power, industrial synergy, and economic growth, excluding the cost of market development. To simplify, I use $g(x) = \beta(1-\epsilon_t)x_t^2$ .Therefore, I can update equation (4) as follows:

$$x_t = \frac{P - v_{x_t} - \lambda_t\epsilon_t\theta_t - \zeta_t(1-\epsilon_t)\theta_t}{2\beta\theta_t(1-\epsilon_t)(\zeta_t P_1 - \mu_t P_2)} \qquad (8)$$

As $0 < \zeta_t < 1; 0 < \mu_t < 1$, changes of P_1, P_2result in negligible changes in x_t if δ_t is high enough and $\zeta_t \to 0, \mu_t \to 0$. For the government, I can derive the first-order condition on the regulation method ζ^* based on equation (7), yielding:

$$P_1\beta\theta_t x_t^2 = (1-\alpha)\big(1-\epsilon_t(\delta_t)\big)(\theta_t x_t - \varepsilon_t x_{t-1}) \qquad (9)$$

This indicates that the expected penalties on firms' excess emissions during inspections are reduced by $\epsilon_t(\delta_t)$ compared to an economy without a carbon market. Now, the local government has an additional essential tool for emission reduction—carbon market development. Deriving the first-order condition on (7) and (6), I obtain the condition of equilibrium market development:|

$$S_\delta = -P_1\kappa_t\epsilon_\delta\theta_t x_t^2 + \epsilon_\delta\zeta_t(\theta_t x_t - \varepsilon_t x_{t-1}) \qquad (10)$$

Since $\epsilon_\delta \leq 0, S_\delta \geq 0$, the above equation (10) implies that the optimal market development strategy for the government is when the government's benefit from an improved carbon market is equivalent to the benefit change for firms.

When will the carbon ETS contribute to improvement in carbon emission reduction and political uncertainty amelioration? For the resolution of market failure, I expect the carbon ETS to induce lower emission and emission intensity. According to (4) and (8). To simplify the model, I use $\xi_t = \rho_t = (1 - \epsilon_t)$, which aligns with the assumption that a better carbon market reduces the penalties for inspections and the bonuses for silent emissions. So I need:

$$x_c < x_{nc} \tag{11}$$

$$\theta_c < \theta_{nc} \tag{12}$$

To fix the government failure, the carbon ETS should have a moderating effect on political uncertainty effect. Comparing the different $\frac{\partial x_t}{\partial P}$ for equation (4) and (8) helps explain the change in the political uncertainty effect caused by the carbon market. Consequently, I get:

$$\frac{\partial x_{t,nc}}{\partial P_{1,nc}} < \frac{\partial x_{t,c}}{\partial P_{1,c}} \tag{13}$$

$$\frac{\partial x_{t,nc}}{\partial P_{2,nc}} > \frac{\partial x_{t,c}}{\partial P_{2,c}} \tag{14}$$

With (11),(12),(13), (14), I get the Efficient Carbon Market condition:

$$P - v_{x_t} - \lambda_t \theta_t < 0 \tag{15}$$

As existing literature has scrutinized the current low carbon price, (15) is an intuitive condition when the carbon price is high enough for firms to change their mind about pollution. Firms will get free allowance according to the carbon emission reduction plan. They will change their production plan if their marginal profit is lower than the current carbon price which means if they have extra emissions their total profit decline. Accordingly, Therefore, a high carbon price changes the game. As the cost of emissions becomes expensive, firms release less carbon and retreat from polluting industries.

This model implies that to reduce the political uncertainty effect, a developed market should maintain a high carbon price, making the cost of purchasing every unit of carbon they produce unaffordable. An efficient carbon market smoothing their emission by neglecting the special period with or without regulations. Conclusively, the adequate carbon price will not only achieve the goal of carbon emission reduction but also reduce the political uncertainty effect

A1.2 Robustness Check

A1.1.1 RDD Estimate of the Turnover Effect

On RD estimate, I start by visualizing the patterns in the data. In Figure 1(A), I plot the raw daily reported AQI concentration data. Figure 1(B) plots the residualized concentrations after adjustment for all controls in equation 1 without turnover. In both panels, I observe a striking decrease in reported AQI immediately after turnovers.

I then present RD estimates from equation (2) in Table 1(A). To comply with the baseline DID

model ,the bandwidths are 7 days in all columns. Columns (1) to (3) report the results with linear polynomial function and columns (4) to (6) report the results with quadratic polynomial functions. I use three different kernel weighting strategies in Table 1 including Triangle, epanechnikov, and uniform. The RD estimate have similar results in different columns. Turnovers result in a 2.5% to 3.2% air quality deterioration in table 1 which is closed to the DID estimate in table 1. Therefore, the date of turnover announcement induce a clear discontinuity in air quality. When political uncertainty suddenly settled with the announcement, polluters stop pollution as they believe the regular regulation and monitoring system is back.

Table A1-1 RDD Estimates of Air Pollution After Turnovers

The table reports the results of non-parametric RD estimate of residualized log air quality indicators against turnover. *AfterTurnover* is 1 for days in a week after the turnovers of local leaders. The bandwidths are 7 days in all columns. Columns (1) to (3) report the results with linear polynomial function and columns (4) to (6) report the results with quadratic polynomial functions. I use three different kernel weighting strategies in Table 1 including Triangle, epanechnikov and uniform. City fixed effects, monthly fixed effects and holiday dummy are included. Standard errors are clustered at the city level. Robust t-statistics are in parenthesis. ***, **, and * correspond to statistical significance at 1%,5% and 10% levels respectively.

	(1)	(2)	(3)	(4)	(5)	(6)
AfterTurnover	-0.025*	-0.025*	-0.032**	-0.025*	-0.025*	-0.032**
	(-1.84)	(-1.85)	(-2.56)	(-1.84)	(-1.85)	(-2.56)
Local Polynomial	Linear	Linear	Linear	Quadratic	Quadratic	Quadratic
Kernel	Tri.	Epa.	Uni.	Tri.	Epa.	Uni.
Controls	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Holiday	Yes	Yes	Yes	Yes	Yes	Yes
N	17,096	17,096	17,096	17,096	17,096	17,096

Figure A1.1 RD Plots for AQI and Residual of AQI Estimate

The Figure shows the decrease of pollution immediately after local leaders' turnovers. To be consistent with DID estimate, bandwidth is 7 in both Panel (A) and (B). Panel (A) uses the raw AQI value and Panel (B) uses the residual of equation 1 estimate without Turnover. The fitted line allows for a quadratic time trend.

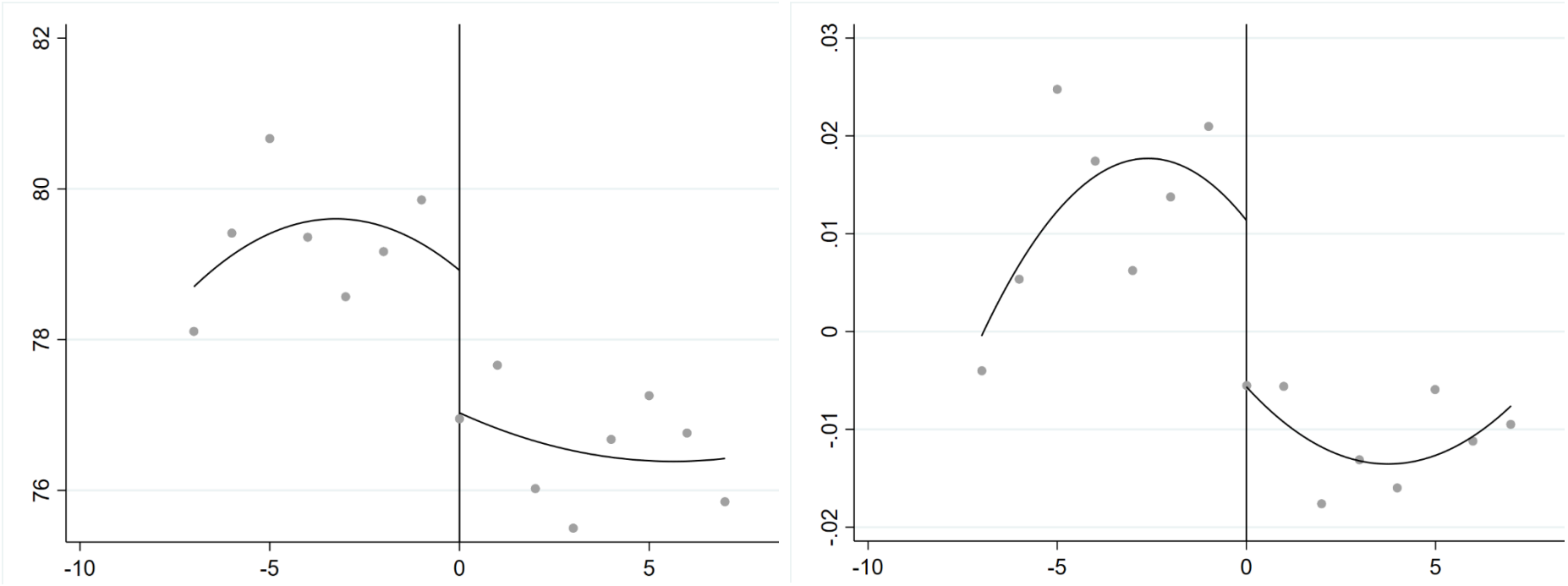


Table A1-2 Efficient Carbon Market Condition and Carbon Price

The table reports the results of regressing log air quality indicators against a local carbon price, political uncertainty indicators, an interaction term between carbon price and political uncertainty indicators using subsamples. *Turnover* is 1 for days in the week before local leaders' turnover. *Inspection* is 1 for days in the period of MEE travelling inspections. *Carbon Price* is the daily close price of local carbon market's core index in RMB/ton of carbon emission. Column 1 uses the subsample of only regions which eight provincial carbon ETS finally covers and days which have carbon trading. Column 2 uses the subsample of cities with Carbon ETS finally and days which have carbon trading. Standard errors are clustered at the city level. Robust t-statistics are in parenthesis. ***, **, and * correspond to statistical significance at 1%,5% and 10% levels respectively.

	(1)	(2)
	Regions Covered by Carbon ETS	Cities with Carbon ETS
Turnover	0.0961**	0.1772**
	(2.40)	(2.01)
Inspection	-0.0077	-0.0296
	(-0.29)	(-0.37)
Carbon Price	-0.0028***	-0.0025**
	(-5.57)	(-2.34)
*Carbon Price*Turnover*	-0.0041**	-0.004**
	(-2.52)	(-2.43)
*Carbon Price*Inspection*	0.0031***	0.0016
	(2.80)	(1.11)
Controls	Yes	Yes
City FE	Yes	Yes
Month FE	Yes	Yes
Holiday	Yes	Yes
N	38,463	6,482
R2	0.5022	0.4616

A1.5.3 The Efficient Carbon Market Condition and ETS Moderating Effect

Though 6.2 confirm the moderating effect of ETS which helps to reduce the political uncertainty effect on carbon emission, the mechanism of the effect remain unclear. Specially, as early research has mentioned, the carbon ETS is not always efficient in carbon emission reduction. Therefore, an inefficient carbon market may not always have further moderating effect on political uncertainty. How could the carbon ETS works efficiently? And What is the condition for the carbon ETS to moderate political uncertainty?

In section 4, I apply the equation (15), the Efficient Carbon Market Condition of ETS, which to reach the Efficient Carbon Market situation. Such a condition requires the carbon price is high enough for firms to reduce their pollution. In reality, heterogenous firms have various marginal profit and react to carbon price differently. But as the carbon price gets higher, more firms have to shut down their pollution. Therefore, carbon price should have a positive effect on carbon emission reduction and political uncertainty effect. As for the Chinese carbon ETS pilot scheme, the provincial ETS aims to firstly cover local firms, local carbon price represents the constraint for local firms. Accordingly, I apply the local carbon price and its interaction term with inspection and turnover in this section to see if higher carbon price reduce carbon emission and political uncertainty effect.

Table 8 represents the effect of carbon price on carbon emission and political uncertainty effect using only regions and cities covered by the carbon ETS and periods with carbon trading. Carbon Price is the close price of the core index in the local the carbon ETS, in Yuan per ton of carbon emission. In Column 1 , the coefficient of Carbon Price and Carbon Price*Turnover are significantly negative and coefficient for Carbon Price*Inspection is significantly positive. Therefore, for regions covered by the carbon ETS, 1 Yuan of carbon price increase reduce local carbon emission by 0.28%. It also reduce the effect of turnovers by 0.41% and reduce the effect of inspections by 0.31%. Column 2 shows the estimate for cities with the carbon ETS. While carbon price has a similar reduction on carbon emission and turnover effect, it has no significant effect on inspections. It is consistent with the result in Table 7, which indicates that turnovers is highly exogenous for all cities while inspections only have effect on non-capital cities.

Table 8 is also interesting for the carbon price effect on inspections. Table 7 reveals the puzzle of the inspection effect on regions covered by the ETS that have higher pollution during inspections. Table 8 explains the phenomenon by the interaction term. Higher carbon price during inspections raises the carbon emission during inspections for cities covered by but without the carbon ETS. That is to say, cities around provincial capitals, which are always the first station of inspections, increase their emission when the demand for carbon allowance is high.

The high demand for carbon prices during inspections has implications for firms' behavior. Inspection teams, as the analysis in section 5 mentions, will punish air pollution but are aware of the carbon ETS. Better carbon ETS will satisfy their aims as they are supported by MEE. Therefore,

the best strategy for firms is to have less pollution during inspections. And the sub-optimal strategy is to have enough carbon allowance which will cover their pollution during inspections.

However, traveling inspections never arrive at a non-capital city at the first station which means all other cities, covered by the carbon ETS, will do their best to prepare for the inspections. Cities and firms do not always have pollution before and after the arrival of inspection at risk. As column 1 has shown, only when the carbon price is high which means firms already have a high pollution plan during the period will they have over-emission at risk. When the carbon price and demand are low, firms will not have pollution during the inspections as they will not be punished without a high pollution plan. The over-pollution related to carbon demand and inspection is a new government failure produced by the carbon ETS.

9.5.4 Robustness Checks

For the robustness check, I rerun the models presented in Table 3, columns 3 and 6, using alternative windows for turnovers ranging from 3 to 30 days. The results are presented in Tables 9 and 10. Table 9 focuses on cities covered by the carbon ETS and shows that the turnover effect remains robust for windows ranging from 3 to 15 days. This effect leads to a reduction in the air quality of up to 2.94% with a significance level of 1%. However, the turnover effect disappears for longer windows of 30 days. The coefficient for Carbon ETS (Covered) * Turnover is significant for windows of 7, 9, and 30 days. Its influence ranges from 5.04% for seven days to 3% for 30 days. Furthermore, the inspection effect and its interaction term with Carbon ETS remain robust under alternative windows for turnovers.

Table 10 shows that, with Carbon ETS (Location), the turnover effect is similarly robust and remains significant even for windows up to 30 days. However, the carbon ETS appears to affect air quality during turnovers with more extended periods positively. The coefficient of Carbon ETS (Covered) * Turnover is significant even for windows of 30 days, and it leads to an 10% improvement in air quality. This finding is consistent with the reality in political centres where agents are more cautious and patient under uncertainty. Moreover, the inspection effect remains similarly robust to that in Table 8.

Secondly, I use alternative measures for the tests in Tables 3 and 5. Specifically, I use PM2.5, which was newly included in the 2012 standard of AQI. Table 11 presents the test results for Table 3 with the independent variable of the logarithm of PM2.5. The results are very similar to those shown in Table 3. Cities covered by or located with the carbon ETS differ regarding their PM2.5 concentration during turnover windows. However, when controlling for the interaction between Turnover and Carbon ETS, the results indicate that the carbon ETS significantly reduces the PM2.5 concentration during turnover windows. This effect ranges from 13.44%, stronger for cities where ETS is located, to cities covered by ETS. The carbon ETS also changes the PM2.5 concentration during inspections, as cities emit more during inspections when ETS is present. The only difference

between Table 3 and Table 11 is that Carbon ETS (Location) * Inspection is significantly positive in Column 6 of Table 11. Therefore, compared with AQI, PM2.5 is more influenced by the carbon ETS for cities where ETS is located during inspections. Table 12 shows that the RD model has similar results to those presented using AQI for PM2.5.

In table 8, I apply carbon price to prove the essentiality of Efficient Carbon Market condition. However, the endogenous problem remains a concern for the carbon price. Much evidence has shown that carbon price may be influenced by weather and air quality. I draw the concern by following analysis. Firstly, the causality from air quality to carbon price is mostly longer period. Most research on how air quality influence carbon price relies on the government intervention for pollution which requires a period for policy execution(Han et al. 2019). Also, existing literature indicates that government intervention induce a positive relation between carbon price and AQI (Zhou and li, 2019; In et al. 2022; Zhu et al. 2022). But it is not reasonable when the causality reverses. Since Table 8 reveals a negative relation between carbon price and AQI instead. Firms reduce production and emission when the carbon is not affordable. But good air quality will not drive up their demand on carbon.

Finally, I conduct further empirical works to draw the concern. In Table 13, I applies three strategies to eliminate the reverse causality problems. In column 1 and 2, I use lag 1 term carbon price and In column 3 and 4, I use lag 1 to 3 terms average carbon price which are unlikely to be influenced by future air quality. In column 5 and 6, I use the residual of lag 1 to 3 carbon price which is the regression residual of carbon price on weather conditions and air quality. Interestingly, I find the carbon price remain a significantly negative effect on carbon emission in nearly all columns which means higher carbon price indeed reduce carbon emission. And it can also reduce political uncertainty effect induced by inspections and turnovers.

Table A1-3 Robustness Check with Alternative Windows-Focusing on Carbon ETS(Covered)

The table reports the results of DID regressing log air quality indicators against a dummy for political uncertainty(*Turnover*), an interaction term between *Turnover* and *Carbon ETS*. *Turnover* is 1 for days in the 3,7,9,15 and 30 days before local leaders' turnover for column 1 to 5. *Carbon ETS(Covered)* is one if the city has been covered by one of the eight provincial Carbon ETS. Standard errors are clustered at the city level. Robust t-statistics are in parenthesis. ***, **, and * correspond to statistical significance at 1%,5% and 10% levels respectively.

	(1) [-3,0)	(2) [-7,0)	(3) [-9,0)	(4) [-15,0)	(5) [-30,0)
Turnover	0.0265*** (2.69)	0.0294*** (3.60)	0.0240*** (3.12)	0.0188*** (2.62)	0.0107 (1.60)
Inspection	-0.0591*** (-7.38)	-0.0590*** (-7.37)	-0.0590*** (-7.37)	-0.0590*** (-7.36)	-0.0591*** (-7.37)
Sunshine	-0.0002* (-1.87)	-0.0002* (-1.88)	-0.0002* (-1.88)	-0.0002* (-1.88)	-0.0002* (-1.88)
Precipitation	-0.0006*** (-21.68)	-0.0006*** (-21.68)	-0.0006*** (-21.68)	-0.0006*** (-21.68)	-0.0006*** (-21.68)
Wind Speed	-0.0057*** (-12.37)	-0.0057*** (-12.37)	-0.0057*** (-12.37)	-0.0057*** (-12.37)	-0.0057*** (-12.37)
Humidity	-0.0024*** (-5.30)	-0.0024*** (-5.30)	-0.0024*** (-5.30)	-0.0024*** (-5.30)	-0.0024*** (-5.30)
Temperature	0.0015*** (12.77)	0.0015*** (12.78)	0.0015*** (12.78)	0.0015*** (12.79)	0.0015*** (12.79)
Carbon ETS(Covered)	0.0015 (0.07)	0.0020 (0.10)	0.0022 (0.11)	0.0022 (0.10)	0.0031 (0.15)
Carbon ETS(Covered)*Turnover	-0.0239 (-1.01)	-0.0504** (-2.20)	-0.0487** (-2.18)	-0.0292 (-1.43)	-0.0300* (-1.72)
Carbon ETS(Covered)*Inspection	0.0552*** (3.56)	0.0551*** (3.56)	0.0552*** (3.56)	0.0553*** (3.57)	0.0557*** (3.61)
City FE	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes
Holiday	Yes	Yes	Yes	Yes	Yes
N	511760	511760	511760	511760	511760
R2	0.4891	0.4892	0.4892	0.4892	0.4892

Table A1-4 Robustness Check with Alternative Windows -Focusing on Carbon ETS(Location)

The table reports the results of DID regressing log air quality indicators against a dummy for political uncertainty(*Turnover*), an interaction term between *Turnover* and *Carbon ETS*. *Turnover* is 1 for days in the 3,7,9,15 and 30 days before local leaders' turnover for column 1 to 5. *Carbon ETS(location)* is one if the city has a provincial Carbon ETS. Standard errors are clustered at the city level. Robust t-statistics are in parenthesis. ***, **, and * correspond to statistical significance at 1%,5% and 10% levels respectively.

	(1) [-3,0)	(2) [-7,0)	(3) [-9,0)	(4) [-15,0)	(5) [-30,0)
Turnover	0.0230** (2.58)	0.0246*** (3.23)	0.0197*** (2.73)	0.0172** (2.55)	0.0088 (1.43)
Inspection	-0.0518*** (-6.80)	-0.0518*** (-6.79)	-0.0518*** (-6.79)	-0.0518*** (-6.79)	-0.0518*** (-6.78)
Sunshine	-0.0002* (-1.86)	-0.0002* (-1.87)	-0.0002* (-1.87)	-0.0002* (-1.87)	-0.0002* (-1.86)
Precipitation	-0.0006*** (-21.65)	-0.0006*** (-21.65)	-0.0006*** (-21.65)	-0.0006*** (-21.65)	-0.0006*** (-21.64)
Wind Speed	-0.0057*** (-12.37)	-0.0057*** (-12.37)	-0.0057*** (-12.37)	-0.0057*** (-12.37)	-0.0057*** (-12.37)
Humidity	-0.0024*** (-5.30)	-0.0024*** (-5.30)	-0.0024*** (-5.30)	-0.0024*** (-5.30)	-0.0024*** (-5.30)
Temperature	0.0015*** (12.76)	0.0015*** (12.76)	0.0015*** (12.76)	0.0015*** (12.77)	0.0015*** (12.78)
Carbon ETS(Location)	-0.0197 (-0.48)	-0.0181 (-0.44)	-0.0174 (-0.43)	-0.0161 (-0.40)	-0.0131 (-0.32)
Carbon ETS(Location)*Turnover	-0.0035 (-0.08)	-0.0934*** (-2.92)	-0.1048*** (-3.49)	-0.0985*** (-2.92)	-0.0976*** (-3.39)
Carbon ETS(Location)*Inspection	0.0465 (1.10)	0.0460 (1.09)	0.0465 (1.10)	0.0492 (1.16)	0.0628 (1.53)
City FE	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes
Holiday	Yes	Yes	Yes	Yes	Yes
N	511760	513422	511760	511760	511760
R2	0.4891	0.489	0.4891	0.4891	0.4892

Table A1-5 Robustness Check with PM2.5 as the Alternative Measurement

The table reports the results of DID regressing log PM2.5 concentration against a dummy for political uncertainty(*Turnover*), an interaction term between *Turnover* and *Carbon ETS*. *Turnover* is 1 for days in the week before local leaders' turnover. *Carbon ETS(Covered)* is one if the city has been covered by one of the eight provincial Carbon ETS. *Carbon ETS(location)* is one if the city has a provincial Carbon ETS. Column 1 uses the subsample of only regions finally covered by eight provincial carbon ETS. Column 4 uses the subsample of cities with Carbon ETS finally. Standard errors are clustered at the city level. Robust t-statistics are in parenthesis. ***, **, and * correspond to statistical significance at 1%,5% and 10% levels respectively.

	(1) Regions Covered by Carbon EST	(2) Other	(3) All	(4) Cities with Carbon EST	(5) Other	(6) All
Turnover	-0.0046	0.0270**	0.0335***	-0.0377	0.0266**	0.0278***
	(-0.21)	(2.40)	(2.95)	(-1.29)	(2.51)	(2.62)
Inspection	0.0586***	-0.0880***	-0.0949***	0.0459	-0.0804***	-0.0816***
	(2.88)	(-7.64)	(-8.23)	(0.84)	(-7.52)	(-7.64)
Sunshine	-0.0001	-0.0009***	-0.0007***	0.0005	-0.0007***	-0.0007***
	(-0.43)	(-6.38)	(-5.16)	(0.85)	(-5.41)	(-5.13)
Precipitation	-0.0006***	-0.0011***	-0.0010***	-0.0008***	-0.0010***	-0.0010***
	(-7.69)	(-27.43)	(-25.96)	(-3.93)	(-25.83)	(-25.90)
Wind Speed	-0.0166***	-0.0102***	-0.0109***	-0.0188***	-0.0107***	-0.0109***
	(-13.17)	(-16.02)	(-17.66)	(-10.62)	(-17.32)	(-17.66)
Humidity	-0.0037	0.0018***	0.0010	0.0075	0.0008	0.0010
	(-1.32)	(2.72)	(1.53)	(1.15)	(1.24)	(1.53)
Temperature	0.0023***	0.0018***	0.0017***	0.0028***	0.0017***	0.0017***
	(6.52)	(9.88)	(10.26)	(4.90)	(10.08)	(10.25)
Carbon ETS(Covered)			0.0277			
			(1.11)			
*Carbon ETS(Covered)*Turnover*			-0.0639**			
			(-2.02)			
*Carbon ETS(Covered)*Inspection*			0.1074***			
			(5.24)			
Carbon ETS(location)						0.0082
						(0.17)
*Carbon ETS(Location)*Turnover*						-0.1344***
						(-3.31)
*Carbon ETS(Location)*Inspection*						0.1228**
						(2.48)
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Holiday	Yes	Yes	Yes	Yes	Yes	Yes
N	78,816	432,888	511,704	16,794	496,572	511,704
R2	0.5038	0.5327	0.5229	0.4628	0.5258	0.5228

Table A1-6 Robustness Check with PM2.5 as the Alternative Measurement RD

The table reports the results of non-parametric RD estimate log PM2.5 concentration against a dummy for political uncertainty(*Turnover*) using symmetric windows of 7 days before turnover and seven days after the turnover. *Turnover* is 1 for days in the week before local leaders' turnover. Standard errors are clustered at the city level. Robust t-statistics are in parenthesis. ***, **, and * correspond to statistical significance at 1%,5% and 10% levels respectively.

	(1)	(2)	(3)	(4)	(5)	(6)
AfterTurnover	-0.019	-0.02	-0.03*	-0.019	-0.02	-0.03*
	(-1.06)	(-1.13)	(-1.85)	(-1.07)	(-1.13)	(-1.85)
Local Polynomial	Linear	Linear	Linear	Quadratic	Quadratic	Quadratic
Kernel	Tri.	Epa.	Uni.	Tri.	Epa.	Uni.
Controls	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Holiday	Yes	Yes	Yes	Yes	Yes	Yes
N	17,094	17,094	17,094	17,094	17,094	17,094

Table A1-7 Robustness Check Using Different Forms of Carbon Price

The table reports the results of DID regressing log AQI concentration against a dummy for political uncertainty(*Turnover* and *Inspection*), an interaction term between *Turnover* and different forms of *Carbon Price*, an interaction term between *Inspection* and different forms of *Carbon Price*, weather controls, city, monthly and holiday fixed-effects. *Turnover* is 1 for days in the week before local leaders' turnover. *Inspection* is 1 for days when the region is covered by inspections. *Carbon Price* is the lag 1 close price of local carbon ETS for column 1 and 2, average close price for the last three days for column 3 and 4, and the residual of average close price for the last three days for column 5 and 6. Standard errors are clustered at the city level. Robust t-statistics are in parenthesis. ***, **, and * correspond to statistical significance at 1%,5% and 10% levels respectively.

	Carbon Price t-1		Average Carbon Price of [t-1:t-3]		Average Residual of [t-1:t-3]	
	Regions Covered by Carbon ETS	Cities with Carbon ETS	Regions Covered by Carbon ETS	Cities with Carbon ETS	Regions Covered by Carbon ETS	Cities with Carbon ETS
	(1)	(2)	(3)	(4)	(5)	(6)
Turnover	0.037	0.075	0.054	0.046	-0.009	0.001
	(0.94)	(0.84)	(1.44)	(0.53)	(-0.56)	(0.02)
Inspection	-0.039**	-0.100	-0.54***	-0.111	0.016	-0.038
	(-2.01)	(-1.45)	(-3.15)	(-1.44)	(1.31)	(-0.53)
Carbon Price	-0.003***	-0.003***	-0.003***	-0.002***	-0.001**	-0.002
	(-5.56)	(-2.61)	(-4.73)	(-2.14)	(-2.11)	(-1.47)
Carbon Price*Turnover	-0.003	-0.003	-0.003*	-0.003	-0.004	-0.013
	(-1.46)	(-1.28)	(-1.86)	(-0.86)	(-0.71)	(-1.31)
Carbon Price*Inspection	0.003***	0.002**	0.004***	0.004***	0.006***	0.006*
	(4.27)	(2.06)	(6.19)	(2.83)	(5.78)	(1.70)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Holiday	Yes	Yes	Yes	Yes	Yes	Yes
N	36,580	6,091	57,114	9,914	57,114	9,914
R2	0.50	0.46	0.49	0.45	0.49	0.45

Table A1-8 Political Uncertainty, air pollution and Carbon ETS for Different Months

The table presents the robustness test results of the Difference-in-Differences (DID) regression, where the dependent variable is the log of air quality indicators. The key independent variables include a dummy for political uncertainty (*Turnover*) and an interaction term between *Turnover* and *Carbon ETS*. The variable *Turnover* equals 1 for days within the week prior to local leaders' turnover, while *Inspection* is 1 for days during Ministry of Ecology and Environment (MEE) inspections. *Carbon ETS (Covered)* equals 1 if the city is covered by one of the eight provincial Carbon Emissions Trading Schemes (ETS), and *Carbon ETS (Location)* equals 1 if the city hosts a provincial Carbon ETS. Columns 1 to 3 report results using a subsample restricted to December, January, and February—the months with the highest turnover frequency, as local deputy commissions are typically held during this period. Columns 4 to 6 use data from the remaining months. The robustness checks demonstrate that the effect of political turnover remains consistent across different subsamples. Standard errors are clustered at the city level, and robust t-statistics are reported in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

	December, January and February			Other Months		
	(1)	(2)	(3)	(4)	(5)	(6)
	Regions Covered by Carbon EST	Other	All	Cities with Carbon EST	Other	All
Turnover	0.0067	0.0118	0.0237*	-0.0042	0.0150	0.0194**
	(0.45)	(0.92)	(1.74)	(-0.26)	(1.61)	(2.08)
Inspection	-0.0284*	-0.0340**	-0.0519**	0.0247	-0.0582***	-0.0582***
	(-1.70)	(-2.06)	(-2.49)	(1.40)	(-8.03)	(-8.13)
Sunshine	-0.0004***	-0.0007***	-0.0007***	0.0002	-0.0003***	-0.0002**
	(-2.84)	(-5.25)	(-5.22)	(0.79)	(-3.12)	(-2.11)
Precipitation	-0.0025***	-0.0026***	-0.0026***	-0.0003***	-0.0006***	-0.0005***
	(-15.79)	(-17.51)	(-17.45)	(-5.42)	(-20.92)	(-21.11)
Wind Speed	-0.0103***	-0.0092***	-0.0093***	-0.0103***	-0.0035***	-0.0042***
	(-15.66)	(-13.95)	(-14.35)	(-9.94)	(-7.73)	(-9.30)
Humidity	0.0038***	0.0033***	0.0028***	-0.0079***	-0.0040***	-0.0045***
	(5.16)	(5.30)	(4.30)	(-3.88)	(-9.52)	(-10.58)
Temperature	0.0026***	0.0027***	0.0026***	0.0020***	0.0018***	0.0017***
	(16.61)	(18.97)	(19.03)	(8.10)	(17.00)	(18.26)
Carbon ETS(Covered)			-0.1213***			0.0571***
			(-5.04)			(3.55)
*Carbon ETS(Covered)*Turnover*			-0.0595			-0.0339*
			(-1.60)			(-1.69)
*Carbon ETS(Covered)*Inspection*			0.0707**			0.0463***
			(2.41)			(3.01)
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Holiday	Yes	Yes	Yes	Yes	Yes	Yes
N	95357	123147	129220	58891	323649	382540
R2	0.5284	0.4983	0.4987	0.4679	0.5010	0.4970

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EDUCATION

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Renmin University of China *2017*
B.Sc. Finance, School of Finance

RESEARCH INTERESTS

Alternative Investments, Behavioral Finance and Urban Economics

WORKING PAPERS[6]

[1] Legacy of Treaty Ports: Enduring Influence on Individual Investors' Risk-taking
with Tse-Chun Lin (HKU)
Abstract: Using novel datasets of advertisements, news, and individual mutual fund investment, we investigate the lasting impact of the Treaty Port legacy on individuals' risk-taking behaviors in business and mutual fund investment in China. We find that the Treaty Port system introduced a business boom, creating a lasting legacy of risk-taking that enabled the Treaty Ports cities to adapt to both phases of the closed and open economy. This cultural shift in risk attitudes, originating in 19th-century China, continues to shape the behavior of local residents and investors today. Specifically, these investors allocate a greater proportion of their investments to riskier funds. Importantly, this effect is observed exclusively among local residents, rather than immigrants who share the same institutional and economic environments. This effect has spatial spillovers at the distance up to 700 kilometers from the ports. It operates through three key channels: foreign market access, cultural diversity, and legal systems. These findings collectively indicate an enduring influence of the Treaty Ports on local values and norms in individuals' investment decisions.

[2] Politics and Asset Prices: China's Anti-corruption Campaign and Prices of Luxury Homes in Beijing
with Liang Peng (Pennsylvania State University)
Under Review by Real Estate Economics,
Presented at: 2023 AREUEA International Conference, 2023 AsRES-GCREC Joint International Real Estate Conference*, EFMA 2024
Abstract: While anti-corruption efforts may improve social fairness and economic efficiency, they can have unintended, depressing impacts on asset prices. Using condo sales from 2012 to 2018 in Beijing, we find that luxury condos commanded about 5% higher prices than ordinary condos before the anti-corruption announcement in December 2012. However, this luxury premium became a 10% discount following the announcement and was more significant in the two districts where most government agencies are located. Analyzing the 11 rounds of anti-corruption traveling inspections after the announcement, we find that after each inspection, the luxury premium decreased more in the two districts, and more for condos nearer the inspection targets. Next, we identify subdivisions developed on land lots with unusually low land sale prices, which we assume have a higher likelihood of corruption. Post the announcement, we find that the luxury premium was significantly lower in these subdivisions.

[3] Political Uncertainty and Carbon Emission Trading: Evidence from China

[6] Paper Presented by co-authors at conference or workshop is denoted with *

With Helen Bao (University of Cambridge)
CITIES, 2024
Presented at: University of Cambridge, Land Economy Research Seminar
Abstract: This article explores the impact of political uncertainty on sustainable urban development by examining carbon emission trading systems (ETS) in four major markets in China (Beijing, Shanghai, Guangdong, and Hubei) from 2014 to 2022. As an alternative to carbon taxes, carbon ETS markets have become increasingly popular due to their success in reducing greenhouse gas emissions. However, their effectiveness is often hindered by political instability and uncertainty. Utilizing logistic regression and AR(1)-GARCH estimations, we identify a negative relationship between political uncertainty and carbon trading volume. Our study also reveals significant variations in the responses of these markets to political uncertainty. The paper contributes to the understanding of how ETS markets operate in a complex and constantly changing political environment. We suggest that policymakers need to consider the impact of political uncertainty on carbon trading when designing and implementing urban policies that promote sustainable development. Additionally, our research contributes to the development of urban policies that can be effectively implemented in both developed and developing regions.

[4] Naive Attention and Extrapolative Beliefs: Evidence from Digital Footprints of Mutual Fund Investment
with Lei Huang(HKU), Tse-Chun Lin (HKU) and Fangzhou Lu(HKU)
Presented at: China Fintech Research Conference 2024
Abstract: Using account-level digital footprints on a major Chinese fintech platform, we find that retail investors who pay more attention to their mutual fund investments have lower subsequent performance. The negative correlation can be attributed to trend-chasing behavior induced by the investors' extrapolative beliefs, which is amplified by the "naïve attention" paid to their investment. We also find that younger investors suffer more from this naïve attention effect. Overall, our results suggest that investor attention can be a double-edged sword; its effect on investment performance hinges on how the attention is triggered and allocated.

[5] When the cat is away the mice will not play: The political economy of carbon emission trading systems
with Helen Bao (University of Cambridge)
Presented at: Zhejiang University*, Hangzhou City University*, International Forum on High-Quality Economic Development in the Context of Carbon Neutrality*
Abstract: We explore how the carbon Emission Trading System (ETS) addresses both government failure and market failure in the cat-and-mouse game of controlling emissions. By analyzing the responses of Chinese cities to unannounced inspections and turnovers of local government officials, we observe that cities reduce emissions when inspections occur ("the cat is around") but become lax when political powers shift ("the cat is away"). The emission turbulence induced by political shocks introduces new government failures. However, cities with the ETS exhibit less responsiveness to these events, as the ETS regulates firms and mitigates gaming. A model suggests that the Efficient Carbon Market condition, characterized by a high carbon price, enables the carbon ETS to control emissions and moderate the effects of political shocks simultaneously. Empirical evidence supports the essentiality of this condition.

WORK IN PROGRESS

[1] Global Real Estate Market and Flights to Safety
with Liang Peng(Pennsylvania State University)

[2] Political Premium in Art
with Liang Peng(Pennsylvania State University)

[3] **Pray to God or Pray for Luck: Religion Effect in Risk Taking of Chinese Investors**
with Ke Song (Renmin University) and Xingzi Ren (Capital University of Economics and Business)

OTHER ACADEMIC ACTIVITIES

Profession Membership

American Economic Association
American Real Estate and Urban Economics Association
European Economic Association
The Royal Economic Society

TEACHING EXPERIENCE

Supervisor of Land Economy Tripos, Part IA - Quantitative and legal methods for land economists *Spring 2023*
University of Cambridge, Department of Land Economy

Teaching Assistant of Real Estate Finance, Undergraduate and Master level *Summer 2018*
Renmin University, School of Finance

Financial Econometrics, Undergraduate *Spring 2017*
Renmin University, School of Finance

SEMINARS AND CONFERENCE PRESENTATIONS

2024 China Fintech Research Conference
2023 International Forum on High-Quality Economic Development in the Context of Carbon Neutral
2023 Hangzhou City University Workshop
2023 AREUEA International Conference
2023 AsRES-GCREC Joint International Real Estate Conference
2023 University of Cambridge, Land Economy Research Seminar
2016 Cornell International Real Estate Case Competition