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Keywords Carbon Emissions Trading Scheme, Target responsibility system, Policy evaluation, Triple difference-in-differences

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The Incremental Impact of China's Carbon Trading Pilots

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China has adopted the carbon emissions trading system (ETS) due to its advantages on efficiency and cost grounds. Prior to the national carbon market, China operated seven ETS pilots as experiments for eight years in addition to the existing Energy Conservation and Carbon Abatement Target Responsibility System (ECCA-TRS) in order to accumulate experience with carbon markets. However, the incremental effects of these pilots are unclear so far. Here, we show that the ETS pilots have produced no additional carbon abatement effect or abatement cost-saving effect, while ECCA-TRS contributed primarily to the relative decline in CO_2 emissions and absolute decline in CO_2 intensity of covered industries in pilot regions. A binding target is necessary to permit ETS to act as the backstop emissions constraint. Adjusting local governments' abatement achievement using the buy-in and sell-out of carbon allowances can allow the ECCA-TRS and ETS to act as well-integrated instruments.

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1. Introduction

Energy resource security and carbon abatement are at the heart of China's sustainable

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development. Over the past 40 years since the open policy and economic reforms in 1978, China has adopted a batch of instruments such as energy efficiency investment projects, energy performance standards, and feed-in tariffs for renewable electricity to balance the negative side effects of its economic growth (Price et al., 2011). At the seventy-fifth session of the United Nations General Assembly in September 2020, President Xi Jinping announced that China would aim to achieve net zero by 2060, which will demand a substantial effort by a developing country. In July 2021, China launched the national carbon market to support the climate change mitigation goals. However, the issue of how to coordinate the existing energy-saving governance and carbon trading mechanism still needs to be answered, which may directly affect whether China's national carbon market will be a success. Prior to the national carbon market, seven ETS pilots had been run as experiments for eight years, in order to learn lessons for the future design of the national carbon market. However, the carbon prices in the pilot schemes hovered at low levels (Fig.1a, Fig.1b) and the trading volumes of carbon permits in pilot carbon markets were always concentrated on a short period before the compliance date.

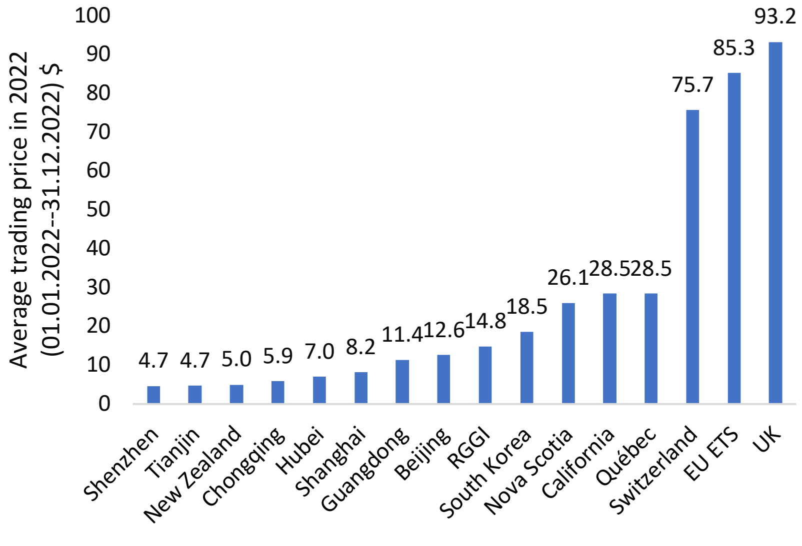


Fig.1a Average carbon prices of main carbon markets in the world in 2022. The data is calculated from the carbon prices of each carbon market, which are collected from the Allowance Price Explorer.

Rather than assuming that carbon markets are binding, we must clarify why the impact of carbon markets needs investigation. In theory, when the carbon price exceeds the marginal abatement cost, firms would implement abatement activities rather than buy permits from the carbon market or use their own allowances. Carbon markets equalize the marginal abatement cost among covered firms to the carbon price under a single regulation without any distortions, the carbon price can be used to assess the cost of the regulation (Leard and McConnell, 2021). However, if the existence of other carbon policies has already raised marginal abatement costs of firms to higher levels than the carbon price, changes in the carbon market price would not be expected to change abatement behaviours. In other words, the low-hanging fruit abatement activities with cheap abatement costs have been deployed under the pressure of other abatement policies. If the carbon price is not higher than the firms' marginal abatement costs, carbon trading can be ineffective, even though the carbon price is a positive value. In this case, carbon prices are not binding on abatement incentives. With the carbon price rising higher and higher, it will exceed the marginal abatement cost of a larger number of firms since the cost varies across firms. Therefore, a higher carbon price is more likely to cause emissions reduction as abatement decisions depend on the comparison of the carbon price and the marginal abatement cost of the firm. Since carbon markets could be non-binding and ineffective, this leads to the question why the carbon price is still positive but not equal to zero. The biggest reason why this positive carbon price might occur is the expectations of market participants about the future tightening of the emissions target. Firms prefer to hold extra allowances before the end of the period for the possible price increase due to uncertainty of future abatement cost, unforeseen business-as-usual emissions variation and cap shrinks (Hintermann et al., 2016). Besides this option value of holding allowances, the hedging purposes by other market participants also contribute to the price bias since carbon allowances can also be held as financial assets (Paolella and Taschini, 2008). The "collapse" of the carbon price of EU ETS in 2006 and 2007 illustrates the effect that expectations have over carbon prices. In April 2006, the aggregate emissions data of covered firms were released. Given the known total cap, market participants realized the actual demand for the allowances, and the carbon price fell dramatically in a few days; it was clear that most likely no extra demand could be created by weather or other factors before the period end, and the EUA (European Union Allowance) price therefore dropped to zero during most of 2007 (Ellerman and Buchner, 2008; Caney and Hepburn, 2011).

In EU ETS's first phase, allowances banking between phases was not allowed; therefore, the carbon price was just a short-term signal (Abrell et al., 2011). The clear recognition that there was a large surplus and allowances would be invalid in the next period led to the collapse of the carbon price. However, this is not the case for China's carbon pilots. Allowances can be banked for future periods, and long-term expectations of increasing prices affect the option value of holding permits. Moreover, market participants do not have a clear knowledge of the aggregate emissions of covered firms since the related data are not released. Even though most pilots have released their annual allowances allocation amounts, the numbers are very approximate. The unawareness of the degree of scarcity combined with the expectations of tightening caps means that market participants would hold more allowances than they need during the current period. In addition to the option value and hedge purposes of holding allowances, transaction costs are another factor hindering market clearance and causing price bias, especially for those small firms without dedicated departments to deal with carbon emissions and trading-related affairs (Hintermann et al., 2016). Thus, positive carbon prices in China do not necessarily imply that the introduction of carbon pricing is binding and leads to any additional abatement.

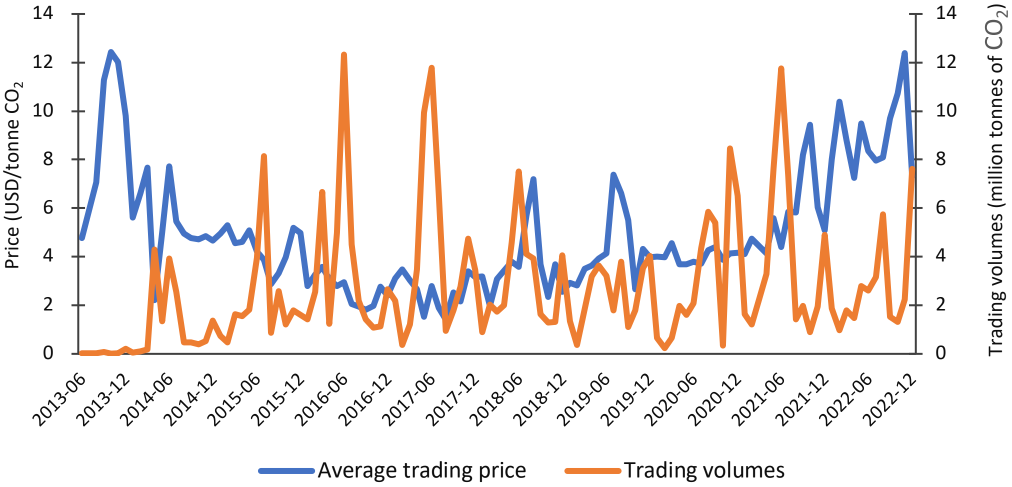
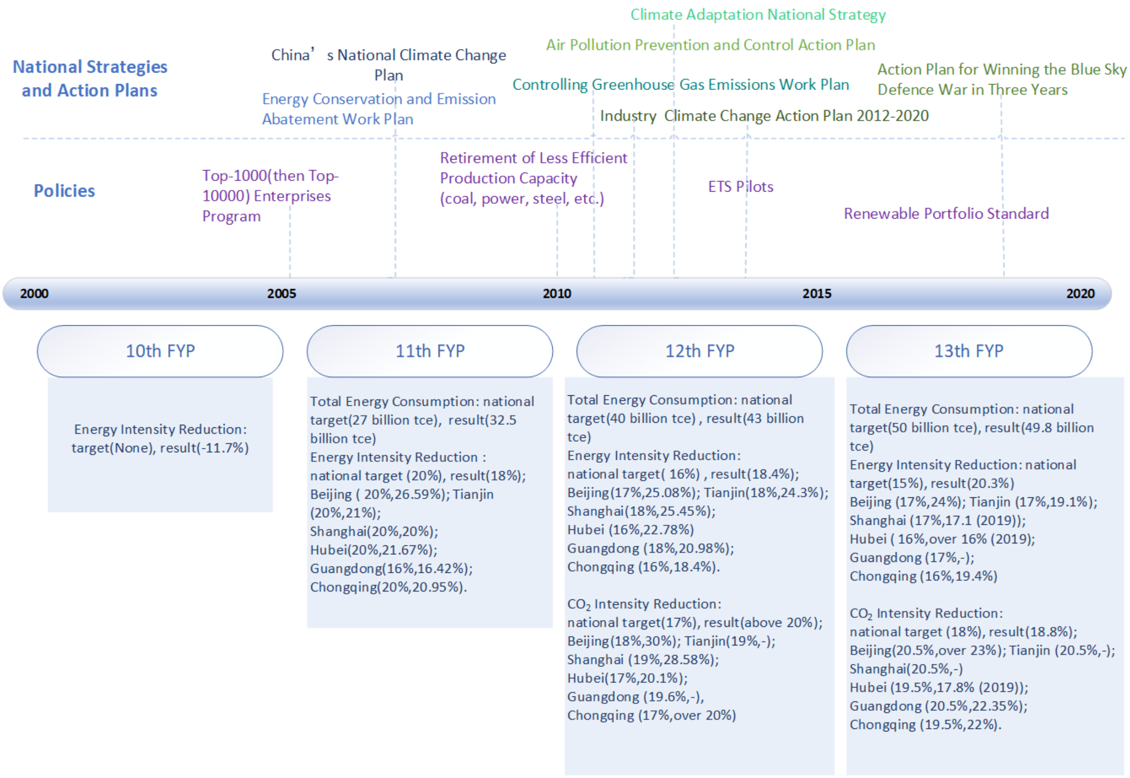


Fig.1b Monthly average carbon prices and monthly trading volumes of seven Chinese pilot carbon markets. The data is calculated from carbon prices and trading volumes of each pilot carbon market in China, which are collected from the iFinD database.

The Energy Conservation and Carbon Abatement Target Responsibility System (ECCA-TRS) is China's pre-existing energy-saving and carbon-abatement governance system based on the performance assessment of local governments. The system was established gradually after China's administrative reorganization in 2000. In this system, local governments coordinate various resources and instruments to achieve the set goals. There is no clear official definition of the relationship between ECCA-TRS and ETS: namely is the ETS a substitute for or a tightening up of the ECCA-TRS? The targets of ECCA-TRS have not been phased down in pilot regions with the participation of ETS, so in this sense, carbon trading is an additional carbon-constraint instrument on top of the existing policies in these regions. The establishment of China's ETS follows the Chinese government's tradition of "crossing the river by feeling the stones" toward a new instrument policy (Duan, 2015: 232). Before proceeding with a nationwide policy, the government tends to experiment with a new instrument policy in several specific regions. It is common practice to choose regions with different features to be the trial areas.

China's ETS pilots therefore span diverse geographical locations, including coastal and inland regions and across a range of heavy-industry and tertiary prominent areas. In this way, policymakers can gather problems that occurred in various complex and changing environments and work out corresponding solutions in order to maximize a successful expansion of the instrument policy. China has decided to transform traditional energy-saving and climate change policies into market-based instruments, as theory and practice in other countries have proven that market-based instruments are superior to command-and-control policies. Therefore, the critical point is not the choice between carbon trading and command-and-control measures but how to design a well-functioning, effective and efficient policy framework. Undoubtedly, the seven ETS pilots have contributed a great deal to the accumulation of knowledge to operate the national carbon market in China. Furthermore, investigating whether ETS pilots act as an effective incremental policy is necessary for a practical, national policy framework.



Energy Intensity Reduction: target(None), result(-11.7%)

Total Energy Consumption: national target(27 billion tce), result(32.5 billion tce)
Energy Intensity Reduction : national target (20%), result(18%);
Beijing (20%,26.59%); Tianjin (20%,21%);
Shanghai(20%,20%);
Hubei(20%,21.67%);
Guangdong(16%,16.42%);
Chongqing(20%,20.95%).

Total Energy Consumption: national target(40 billion tce) , result(43 billion tce)
Energy Intensity Reduction:
national target(16%) , result(18.4%);
Beijing(17%,25.08%); Tianjin(18%,24.3%);
Shanghai(18%,25.45%);
Hubei (16%,22.78%)
Guangdong (18%,20.98%);
Chongqing (16%,18.4%).

CO_2 Intensity Reduction:
national target(17%), result(above 20%);
Beijing(18%,30%); Tianjin(19%,-);
Shanghai (19%,28.58%);
Hubei(17%,20.1%);
Guangdong (19.6%,-),
Chongqing (17%,over 20%)

Total Energy Consumption: national target(50 billion tce), result(49.8 billion tce)
Energy Intensity Reduction: national target(15%), result(20.3%)
Beijing (17%,24%); Tianjin (17%,19.1%);
Shanghai (17%,17.1 (2019));
Hubei (16%,over 16% (2019);
Guangdong (17%,-);
Chongqing (16%,19.4%)

CO_2 Intensity Reduction:
national target (18%), result(18.8%);
Beijing(20.5%,over 23%); Tianjin (20.5%,-);
Shanghai(20.5%,-)
Hubei (19.5%,17.8% (2019));
Guangdong (20.5%,22.35%);
Chongqing (19.5%,22%).

Fig.2 FYP targets, national strategies and action plans about energy conservation and carbon abatement. The upper part depicts the evolution of key energy, national climate strategies and action plans. The lower part depicts energy-saving and carbon abatement Five Year Plan (FYP) targets and results of national and pilot regions. Data and these policies were collected from official government websites by the authors.

When ETS pilots were put into operation, a batch of energy-saving policies under the ECCA-TRS frame had existed for years (Fig.2). The noteworthy point is that we only focus on ETS pilots but pay no attention to China's national carbon market. The features of ETS pilots remained stable in our study period. Given the overlay of ETS pilots on top of the existing policy instruments, our question is: what is the incremental impact of ETS pilots on CO_2 abatement? However, only a small number of studies focused on the additional effects of China's ETS pilots, on top of the existing policies. According to Stern and Green (2015), China’s success in slowing CO_2 emissions growth may be primarily a side-effect of traditional command-and-control policies. Cao et al. (2021) show that the ETS does not affect the coal efficiency of regulated coal-fired power plants, and the output contraction is most likely to be driven by government decisions.

On the other hand, some research shows that the ETS produced positive effects. Cuiet et al. (2021) showed that China's ETS pilots significantly reduced CO_2 emissions. However, the tactic used in this paper to eliminate exogeneity through building the control group for the ETS-regulated firms by matching them to other firms in the same industry, but in potentially different regions, fails to eliminate the contamination of ECCA-TRS which features stringency variation among regions. Given that different jurisdictions are assigned different ECCA-targets during the research period under the ECCA-TRS functioning framework, the results may be misleading. Their paper tries to eliminate the confounding influence of other energy policies by adding a binary policy indicator for Top-10k firms[1]. However, the different regulation stringency of Top-10k firms by region is a more important issue here, as firms regulated by the Top-10k program in ETS pilots may have more ambiguous reduction targets under the ECCA-TRS, and their indicator variable cannot capture the policy-stringency variation. Furthermore, their study would be more convincing if the province-year and industry-year fixed effects were adopted in all specifications rather than for the restricted use as a robustness check.

In this study, we estimate the incremental impact of the seven ETS pilots on carbon abatement in the presence of the existing ECCA-TRS. Specifically, we examine whether China's ETS pilots contributed to carbon abatement when the effect of the ECCA-TRS is considered. We use data on 33 two-digit industrial sectors in 30 provinces in China from 2006 to 2019 and employ a triple difference method, taking advantage of the geography, time, and industry variations that China's ETS pilots have in practice. We apply province-industry, year-by-province, and year-by-industry fixed effects in our estimations to control for time-invariant differences across province-industries and nonparametric trends for each province and industry. Furthermore, we eliminate the contamination of ECCA-TRS inequality among industries by weighting observations using CO_2 emissions and CO_2 intensity in our estimations.

Our study contributes in several ways to the literature on carbon trading and the carbon governance system.

First, to the best of our knowledge, this is the first paper to adjust for the effect of the ECCA-TRS when exploring the incremental effect of China's ETS pilots on CO_2 abatement. Almost all existing studies did not consider the influence of ECCA-TRS, which is a unique but important mechanism for

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[1] The Top-10k program was launched in 2011 for those enterprises whose annual comprehensive energy consumption exceeds 10,000 tonnes of standard coal and some designated enterprises in specific areas with more than 5000 tonnes of standard coal. Based on the data in 2010, there were about 17000 enterprises in China, which satisfied this condition. Their energy consumptions accounted for more than 60% of the total energy consumption of the country. The Top-10k program is the main instrument to achieve the energy and abatement target in China.

China. Our results can expand the empirical literature on the implementation of overlapping policy instruments to address the climate change issue. Some studies have explored the interaction of various kinds of energy-saving and climate change policies. Goulder and Stavins (2011) argue that problems arise from the overlapping of state and federal policies in the US: state-level policies may fail to reduce greenhouse gas emissions nationwide and may weaken the cost-effectiveness of the overall emissions reduction effort in the country. The highlighted issue raised by the overlapping policies is the 'waterbed effect' which means the overlay of policies affects abatement distribution but not the aggregate emissions reduction. Gerarden et al. (2020) showed that the royalty surcharge in the US on top of the Clean Power Plan would reduce emissions by reducing leakage and serve as a backstop for the abatement target, although it would also lead the Clean Power Plan to be nonbinding in some cases. On the other hand, the interaction between national market-based instrument and command-and-control policies can also lead to more emission reduction. As a response to a national tax on nitrogen oxides emissions in Sweden, local regulators set more stringent emissions standards in their jurisdictions to cut the tax payment to the national government, thus this interaction between national emission tax and local emission standards causes more abatement (Coria et al., 2021). Perino, et al. (2020) analyze various overlap types of unilateral policy and wide carbon pricing systems in Europe and North America, pointing out that the degree of the waterbed effect in China's national cap-and-trade system will affect the effectiveness of the province-level additional climate action. However, there is very little research, which deeply investigates the interaction of carbon trading and provincial energy-saving efforts in China.

Second, our results prove the ineffectiveness of the ETS pilots in China, which is quite the opposite conclusion from most other existing research. Specifically, the results show that ETS pilots did not affect the CO_2 emissions or CO_2 intensity of covered industries, and also that the ETS pilots did not substitute command-and-control measures under ECCA-TRS and did not accelerate carbon abatement or reduce the abatement cost. The ETS pilots offer China's national carbon market valuable lessons to deal with the overlay of the ECCA-TRS and the ETS. Carbon markets with loose targets for aggregate emissions reductions are non-binding on top of the ECCA-TRS with strong political incentives. Therefore, a relatively tight abatement target is needed to allow the national carbon market to be a real constraint. Meanwhile, some changes are necessary for ECCA-TRS to support the development of carbon trading. The challenge of net zero will demand such strenuous efforts that various well-integrated policy instruments are needed to guarantee its achievement. A cap-and-trade mechanism can ensure the achievement of the overall quantity target while other existing policies have other complementary benefits; a combination of ETS with other policies would allow the drawbacks of pre-existing policies on their own to be overcome (Pollitt and Dolphin, 2020).

The rest of the paper proceeds as follows. We describe the mechanism of ECCA-TRS and the background of the introduction of China's carbon trading in section 2. In Section 3 the methodology and data are explained. In section 4, we present the empirical results. In section 5, we discuss what the roles of ETS and ECCA-TRS should be.

2. ECCA-TRS and the implementation of China’s ETS pilots

2.1 The mechanism of ECCA-TRS and its effect

Energy intensity reduction was and is one of the most important strategies of China's government since the 1980s, and the original purpose was to eliminate energy shortages. It was achieved through a governance system which mainly relied on ministries (tiao tiao 条条) in charge of different industries in the 1980s and 1990s (Li et al., 2016). After the administrative reorganization in 2000, those specific ministries were abolished, and local governments and the reorganized ministries gradually took over the energy-saving management through the ECCA-TRS. It is necessary here to clarify the conception of ECCA-TRS more precisely.

ECCA-TRS is one of the binding targets in China's target responsibility governance system to limit energy consumption and carbon emissions. In this paper, ECCA-TRS covers the period when energy-saving and cost-abatement targets were in place and when only energy-saving targets were set for local governments. Under the ECCA-TRS, the Chinese central government set national energy-saving and carbon reduction targets in the Five-Year Plans (FYPs). Various measures were then deployed through the vertical and horizontal governance structure (ministries and local governments governance structure named tiao tiao kuai kuai 条条块块) to achieve the mandatory energy intensity reduction and CO_2 abatement targets (Kostka and Hobbs, 2012: 770). Provincial governments receive their energy intensity reduction and CO_2 abatement targets and then disseminate them to municipalities, layer by layer, down to county and township levels (Li and Zhou, 2005). Energy conservation and carbon abatement performance of the jurisdiction is an essential item in the evaluation criteria for government officials' promotion (The State Council, 2007; The State Council, 2016). Career concerns encourage local leaders to take action to fulfill those energy-saving and carbon-conservation targets. Ministries and their branches are weaved into the function net through their specific-field targets and local leaders' coordination to take collective actions (Auffhammer and Gong, 2015).

Local leaders employ the policy-bundling tactic to combine energy-saving policies with other important policies to ensure the implementation of those energy-saving policies. Interest-bundling is another way to motivate different actors to carry out energy-saving policies: local leaders bundle their political interests with local enterprises' economic interests by offering preferential access to government-provided resources. Furthermore, for state-owned enterprises, the denial of promotion and formal censure are similar effective political punishments for managers as for local officials (Kostka and Hobbs, 2012: 768). Accountable department officials negotiate with local enterprise managers to urge them to improve energy efficiency but overlook the cost-effectiveness issue. For private enterprises, political connections can help private enterprises obtain loans and overcome market failures (Li et al., 2008). Assisting local governments to fulfill the ECCA targets is an excellent opportunity to establish a political connection. This interest-bundling, an atypical kind of rent-seeking, may lead to allocation distortion of the central projects, which often needs local governments' co-operation, and credit misallocation of China's state-owned banks (Cull et al., 2015; Habich-Sobiegalla, 2018).

In this target responsibility governance system, a batch of energy-saving actions has been employed. These included the "Top-1000 Enterprises Energy Conservation Program" which started in April 2006, and was then expanded to Top-10k enterprises in the 12th Five-Year-Plan and the Ten-Key Projects. These programs led to the phasing out of small-scale polluting factories and the consolidation of production capacity of large efficient enterprises. They also reduced the proportion of energy-intensive industries through expanding tertiary industry (Zhou et al., 2010; Fisher-Vanden et al., 2016; Borenstein and Kellogg, 2022;). Although Top-1000, Top-10k programs, and Ten-Key Projects were initiated by the National Development Reform Commission (NDRC) and involved enterprises getting financial support from China's Ministry of Finance, the local government still takes full charge of these enterprises to reach the jurisdiction's energy-saving target (Lu et al., 2014). Many of the enterprises covered by these programs tended to overfill their energy-saving target due to the local government's pressure (Karplus et al., 2020). The specific incentivization process of local government on enterprises is often flexible, negotiable and involves many informal incentives (Kostka and Hobbs, 2012: 768).

After the ECCA-TRS was first established in the 11th Five-Year Plan[2], there has been much research focused on the assessment of this system and its separate policy instruments. These

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[2] Although in the 11th Five-Year Plan period, only energy-saving targets were set, but not CO_2 abatement targets, those CO_2 abatement targets were involved from the 12th Five-Year Plan, we still use “ECCA-TRS” here to avoid possible conception confusion. The most important thing is that the mechanism of ECCA-TRS have been set from the 11th Five-Year Plan, no matter whether the CO_2 abatement targets were involved.

assessment studies show the effectiveness of the ECCA-TRS. Price et al. (2011) evaluated the overall fulfillment process of China’s 11th Five-Year Plan energy-saving targets through the assessment of specific deployed instruments and programs, they reached the conclusion that China had achieved substantial energy conservation when compared to the counterfactual baseline. Broadly similar points were made by other studies. Zhang et al. (2022) analyzed the impact of China’s energy intensity constraint imposed by the 12th Five-Year Plan, and they found that the constraint significantly increased the total factor carbon performance index of China's fossil fuel power plants. In their empirical study, Fan et al. (2022) found that Chinese government targets significantly reduced firm energy intensity and were more effective for energy-intensive firms. Fu et al. (2022) have also proved that government fuel-regulation intervention can effectively constrain firms' fuel consumption in China. According to Chen et al. (2021), the Top-1000 enterprises program caused output cuts in regulated enterprises, although with 40% output loss shifted to other unregulated firms in the same conglomerate. China's comprehensive energy-saving policies have been effective in making industries reduce their energy intensity (Zhang et al., 2011; Zhu and Ruth, 2015; Hu, 2016). The energy efficiency improvement was the primary factor slowing down the growth of industrial energy consumption (Ke et al., 2012).

Although ECCA-TRS works as an effective regulatory system, some defects have been highlighted. Experience during the 11th FYP has demonstrated that achieving a 19.1% energy intensity reduction against the target of 20% came at the cost of forcing a number of provinces to switch off large swathes of industrial capacity (Han et al., 2012). The targets assigned are often unscientific and unrealistic, and local governments do not know exactly the true energy conservation potential of the enterprises (Lo, 2014). Under high pressure, local governments tend to use all available instruments to incentivize enterprises to implement energy-saving activities. These instruments include fiscal policies, financial support, and other administrative measures. Basically, county and township governments are the ultimate bearers of the pressure. However, some of these lower levels of government take on too ambitious tasks which are not matched to their institutional capacity which is a function of human capital, institutional arrangements, financial resources, and their authority in policy-making (Li et al., 2016). Therefore, they tend to take "one-size-fits-all" actions as a last resort to achieve their energy-saving targets (Lo, 2020).

Even if local governments could allocate abatement targets more scientifically and enterprises could comply with the command and control-based system completely, the mechanism is costlier compared to an ETS, as it lacks the flexibility ETS can offer to reach a cost-effective situation. The cost minimization of a given abatement target is more likely to be achieved by adopting a market-based instrument (Auffhammer and Gong, 2015).

2.2 The implementation of ETS pilots and their main features

On efficiency and cost grounds, economics tends to emphasize emission pricing policies (implemented via a carbon tax or carbon emissions permit trading system), which can achieve reductions of CO_2 emissions at relatively lower costs (Kaplow, 2010; Borenstein et al., 2019; Stavins, 2020). Carbon pricing approaches are superior to regulatory approaches on cost ground as they can ensure marginal abatement equality for sectors (Metcalf, 2009). Moreover, they can provide the incentive for technology innovation due to the potentially low cost of new technology (Newell, et al. 1999). A carbon ETS has advantages over a carbon tax in that it limits the quantity of total emissions in line with targets arising from climate science; ETS provides an envelope within which all other emissions-reducing policies (such as support for specific low-carbon technologies) can sit (Pollitt, 2019). Based on the advantages of carbon trading, China chose ETS as the cornerstone towards net zero. It is a notable transformation from "command-and-control" policies.

China decided to introduce carbon emission trading system (ETS) pilots to explore a more efficient and cost-effective mechanism to combat global warming, along with trying to set more scientific targets in the 12th Five-Year-plan. On October 29, 2011, the NDRC promulgated the notice to establish seven ETS pilots in China. All four province-level municipalities (Beijing, Shanghai, Tianjin, and Chongqing), two provinces (Guangdong and Hubei), and one special economic zone (Shenzhen) are covered in the ETS pilots of China. The timeline was as follows: Shenzhen introduced its carbon market in August 2013, Beijing and Shanghai in November 2013, Guangdong and Tianjin in December 2013, and Hubei and Chongqing in April and June 2014. All seven pilots had been launched by June 2014. The seven ETS pilots have been independently designed and operated, featuring a variety of differences, but they are similar in essential respects.

In terms of scope and coverage, most covered industries in China's ETS pilots are industries with higher carbon intensity or carbon emissions amount. Although inclusion thresholds, covered industries and numbers of covered industries are different in each pilot, most pilots include petrochemicals, chemicals, construction materials, iron and steel, nonferrous metals, and electricity. Plus, each pilot has its own carbon-intensive sectors based on its unique industrial structure.

In terms of the emission cap, the schemes of China's ETS pilots are different from the normal fashion under which the government sets a cap first and then allocates permits to emitters, but the caps are set in a "bottom-up" fashion from industry-level benchmarks and growth rates, the caps in industry level add up to the total cap of each pilot (Jotzo and Löschel, 2014).

In terms of permit allocation, most pilots' allowances are allocated to firms for free, and a small share of allowances are auctioned in Beijing, Guangdong, and Hubei (ICAP 2020). Allowances are traded between firms within each pilot area, so each pilot has its own carbon price. The carbon price in Beijing is the highest most of the time. As for permit allocation, three main permit allocation approaches are adopted in China's ETS pilots, which are based on historical emissions, historical CO_2 intensity, and benchmark CO_2 intensity of industries (Table 1).

We refer to the allocation approach based on historical emissions as a mass-based allocation approach, which means the cap is determined in advance based on the historical CO_2 emissions amount. The cap equals the historical CO_2 emissions amount multiplied by a discount factor which is decreasing year by year. We refer to approaches based on historical CO_2 intensity and benchmark CO_2 intensity as a rate-based allocation approach, which means there is no certain cap for the industry in advance until the compliance period ends and the output quantity of the period is known. Because only a few industries apply a benchmark-based approach, we do not additionally distinguish the two rate-based allocation approaches.

Table 1: Covered industries, and permit allocation approaches in China's ETS pilots

Specific Permit allocation approach	Permit allocation approach	Covered industries
Beijing		
Mass-based allocation approach	Historical emissions	Cement, petrochemicals, other industrial, service sector, and public transport
Rate-based allocation approach	Historical emissions intensity	Electricity providers, heating sector
	Benchmark	Electricity providers (combined Heat and power generation) from 2017
Tianjin		
Mass-based allocation approach	Historical emissions	Iron and steel, petrochemicals, chemicals, and exploration for oil and gas
Rate-based allocation approach	Historical emissions intensity	Heat and electricity production
Shanghai		
Mass-based allocation approach	Historical emissions	Iron and steel, petrochemicals, chemical fibers, chemicals, nonferrous metals, building materials, paper, nonferrous metals, building materials, paper
Rate-based allocation approach	Benchmark	Power and heat
Hubei		
Mass-based	Historical	Iron and steel, nonferrous metals, petrochemicals, chemicals,

allocation approach	emissions	textile, ceramics, automobile and equipment manufacturing, food, beverage, and medicine producers, and water supply
Rate-based allocation approach	Historical emissions intensity	Glass and other building materials, pulp and paper
	Benchmark	Power and heat supply, cement
Guangdong		
Mass-based allocation approach	Historical emissions	Papermaking, petrochemicals
Rate-based allocation approach	Benchmark	Power, iron and steel, cement
Shenzhen		
Rate-based allocation approach	Benchmark	Textile, chemicals, nonferrous metals, plastic products, electronics
Chongqing		
Mass-based allocation approach	Historical emissions	Power, electrolytic aluminum, ferroalloys, calcium carbide, cement, caustic soda, and iron and steel

The central government's support for carbon trading does not necessarily lead to its adoption by local governments, as local policymakers tend to continue the command-and-control measures to ensure the immediate carbon intensity reduction effect (Zhou et al., 2022). There is a growing appetite for measuring the incremental effects of carbon trading in China.

3. Methodology and Data

3.1 Data

The regressions in this paper use balanced province-industry level data on 33 industrial sectors in 30 provincial regions of China, data on CO_2 are from 2006 to 2019, data on CO_2 intensity and output are from 2006 to 2017, as many provinces did not release the output data in 2018 and 2019. Tibet, Hong Kong, Macao, and Taiwan are not included because of data unavailability. We do not include the mining sector in this paper for two reasons. First, the highly uneven distribution of the mining sector among regions means there is no data in some regions. Second, few mining firms are covered in the ETSs. Excluding the mining sector from the control group has little impact on our estimation results. The data used in this paper come primarily from two sources: The China Emission Accounts and Datasets (CEADs) for the CO_2 emissions data and the statistical yearbooks of China's 30 provinces for the data on gross industrial output and profit. The economic activity data is measured in the constant price level of 2003.

The emissions from electricity and heat account for a significant share of total emissions. However, the price regulation of electricity and heat in China hinders the increased costs being passed down to downstream heat and electricity users. It is crucial to ensure that the electricity and heat users take responsibility for the CO_2 emissions embodied in electricity and heat under the ETS (Zhang et al., 2014). In response, the CO_2 measure method applied for the covered firms counts in both direct and indirect emissions in China. Therefore, it is adequate to include direct and indirect CO_2 emissions in the total CO_2 emission of industries in our analysis. We do this to reflect more precisely the potential variation of CO_2 emissions caused by ETS pilots. The problem of "double counting" does not affect the rationality of our analysis, as we do not shed light on China's overall aggregate CO_2 emissions amount in this paper. We add CO_2 emissions from heat and electricity consumption of each industry to each industry's total CO_2 emissions from CEADs, in which CO_2 emissions from electricity and heat are not included (Shan et al., 2018; Shan et al., 2020). Emissions from heat and electricity are calculated based on the province sectoral energy inventories of CEADs and the heat emission factors provided by IPCC and regional power grids' emission factors provided by NDRC.

We gather annual average coal, oil, gas, and electricity prices at the provincial level from the Wind database. Because changes in fuel prices may affect industries disproportionately according to industries' energy structure, we interact energy prices with each fuel's proportion of each industry to indicate fuel prices of each industry at the provincial level and then log the weighted prices before implementing the regression.

3.2 Estimation strategy

The identification strategy of this paper takes advantage of the geography, time, and industry variations that China's ETS pilots have in practice. The implementation of ETS pilots contains variation along three dimensions: (i) between periods (pre and post), (ii) between provinces or municipalities (treated and control), and (iii) between industries (covered and uncovered). Therefore, we employ a triple-difference method to estimate the impact of ETS pilots. We use data on CO_2 emissions, CO_2 intensity (CO_2 emissions per industrial output value), and indicators of abatement cost such as gross industrial output value (output) of 33 industrial sectors in 30 provinces of China in 2006-2019 (data on CO_2 intensity and output are in 2006-2017 due to missing data for many provinces in 2018 and 2019). The log specification is better for comparisons across industries in different regions with different baseline quantities, all our dependent variables of interest are logged type. We estimate the ETS pilots' average treatment effect using a triple-difference model given by:

$$y_{pit} = \beta_1(post_t \times ETS_p \times ind_{pi}) + \theta_{pi} + \delta_{pt} + \gamma_{it} + \epsilon_{pit} \qquad (Equation\ 1)$$

Theoretically, the impact of ETS on industrial activity under an emissions rate-based allocation approach is different from that under the mass-based allocation approach (Pizer and Zhang, 2018; Goulder et al., 2022). A precise evaluation must distinguish these two allocation approaches to avoid vague results. Therefore, we include assessments of the impacts of ETS pilots on industries applying rate-based allocation and industries applying mass-based allocation separately.

$$\begin{aligned} y_{pit} = \beta_1(post_t \times ETS_p \times massbased_{pi}) + \beta_2(post_t \times ETS_p \times ratebased_{pi}) \\ +\theta_{pi} + \delta_{pt} + \gamma_{it} + \epsilon_{pit} \qquad (Equation\ 2) \end{aligned}$$

In these models, y_{pit} is the outcome variable of interest (the logged CO_2 emissions, CO_2 intensity, and gross industrial output value, respectively) in province p, industry i, and period t. $post_t$ is an indicator variable equal to 1 for 2014 and later years. Most of the pilots began at the end of 2013, two pilots began in early 2014. Thus, it is reasonable for us to regard 2014 as the actual start year.

ETS_p is an indicator variable taking the value of 1 if the province (or municipality) is an ETS pilot—Beijing, Shanghai, Guangdong, Tianjin, Hubei, and Chongqing. Shenzhen is a city in Guangdong province, so we treat Shenzhen and Guangdong as a pilot. For all other provinces, ETS_p equals to 0. ind_{pi} is an indicator variable which equals to 1 if industry i in province p is covered in ETS pilots, and equals to 0 otherwise. $massbased_{pi}$ is an indicator variable which equals to 1 if the industry applies mass-based permit allocation approach, $ratebased_{pi}$ is an indicator variable which equals to 1 if the industry applies rate-based permit allocation approach. Each pilot decides the permit allocation approach for every industry in the jurisdiction. The industries covered by each ETS pilot and their permit allocation approaches are listed in Table 1.

The variables $\theta_{pi} + \delta_{pt} + \gamma_{it}$ represent the full set of province-industry, province-time and industry-time fixed effects to control for unobservable time-invariant differences across province-industries and unique trends for each province and industry. These unobservable differences also include other energy-saving and carbon-reduction policies. China has given much attention to climate and environmental issues for decades. It is very interesting to note that carbon reduction policies and energy-saving policies have boomed in recent years in China. $\delta_{pt}\ and\ \gamma_{it}$ fixed effects absorb effects of these energy conservation and carbon abatement policies in different regions and industries to a large extent, which can eliminate the contamination of other related policies to our estimation. Specifically, δ_{pt} absorbs the effect of time-variant policies specific for each province. ECCA-TRS related policies can be captured by this province-year fixed effect mostly as ECCA-targets feature jurisdiction and time (five-year-plan or yearly targets) variation; γ_{it} absorbs the effect of time-variant policies specific for each industry nationwide.

β_1 in equation (1) captures the treatment effects of ETS pilots on average for all covered industries. β_1, β_2 in equation (2) capture the treatment effects of ETS pilots on subgroups applying mass-based and rate-based permit allocation approaches. When we regress CO_2 emissions and CO_2 intensity, following the literature, observations are weighted by their denominator of the dependent variable in 2012 (Greenstone, 2002; Curtis, 2018). The most important reason for weighting the regressions using CO_2 and CO_2 intensity in our paper is to make uncovered industries in the control group more comparable with ETS-covered industries. Local governments prefer to impose abatement pressure to those key industries with higher CO_2 emissions or CO_2 intensities, and these key industries are always chosen to be covered by ETS pilots. It is plausible that we assess the impact of ETS pilots on the basis that those ETS-covered and uncovered industries suffer same level pressure from local governments under ECCA-TRS. Via weighting observations by CO_2 or CO_2 intensities, we can ensure that those key industries with higher CO_2 or CO_2 intensities drive our regression results. The actual control group industries tend to be those with higher CO_2 emissions or CO_2 intensities but not covered by ETS pilots, both treatment group and control group suffer similar level pressure from ECCA-TRS. In this way, can we derive the net impact of ETS pilots apart from the ECCA-TRS within province since we have controlled province-year fixed effects. We also use the denominator of CO_2 emissions as the weight to regress output to eliminate the influence of the ECCA-TRS. We add x_{pit} to the model, a vector of energy prices, to exclude the impact of energy prices. Coal price, oil price, gas price, and electricity price are included in x_{rit} for robustness checking.

To understand ETS pilot impact and the source of the confounding factor, we performed dynamic estimates using equation 3:

$$y_{pit} = \sum_{t=-s}^{S} \beta_{Tm}^{t}\left[1(year = t) \times ETS_p \times massbased_{pi}\right]$$

$$+ \sum_{t=-s}^{S} \beta_{T}^{t}[1(year = t) \times ETS_p \times ratebased_{pi}] + \theta_{pi} + \delta_{pt} + \gamma_{it} + \epsilon_{pit}$$

(Equation 3)

The coefficients β_{Tm}^{t}capture the treatment effect of ETS pilots on industries applying mass-based permit allocation approach year by year. β_{Tr}^{t} for industries applying rate-based permit allocation approach.

4. Main Results

4.1 Impact on carbon reduction

In this section, we estimate the incremental impact of ETS pilots on the CO_2 emissions and the CO_2 intensity of covered industries. Since we eliminate the influence of industrial structural change by controlling the industry-year fixed effect, we do not need to worry about the general decline of heavy industries causing any bias to our results. Moreover, we also control the province-year fixed effect to exclude the influence of any shocks that happen to the particular regions and control the time-invariant differences across province-industries by the province-industry fixed effect. Based on the fact that the ECCA-TRS assigns abatement targets to local governments in their Five-Year-Plans and yearly developing plans, targets vary from different jurisdictions in different years, the province-year fixed effect has actually absorbed the effects of ECCA-TRS to a large extent. So far, we have considered most of the possible factors that can lead to the contamination of our assessment results, but there is still one crucial factor that bears noting: the ECCA-TRS may vary among different industries within the same province. The difficulty of stripping the effect of ETS from ECCA-TRS in our analysis lies in the fact that when local governments impose abatement pressure and commands, those carbon-intensive industries covered by ETS are always top priorities for local governments due to their more tremendous abatement potential. Fortunately, the clear coverage scope of ETS facilitate us to eliminate the influence this ECCA-TRS inequality among industries by comparing ETS-covered industries to those carbon-intensive industries which are uncovered by ETS but influenced by ECCA-TRS. We do this by using the denominator of CO_2 emissions and CO_2 intensities to weight observations to ensure treatment group and control group are comparable with similar abatement pressure from the ECCA-TRS.

To exclude the case that the ETS could be introduced to maintain the effect that would otherwise weaken under the existing policy of ECCA-TRS, we test further whether the implementation of ETS pilots saves any output loss compared with the situation with ECCA-TRS only in the next section of this paper since it is widely accepted that ETS means less output loss compared to command-and-control measures.

The main results on CO_2 emissions are in Table 2. Panel A of the table reports results for β_1 in the model (1), the coefficients of the overall effect. Panel B of the table reports the results for β_1 β_2 in the model (2) for separate effects on mass- and rate-based industries. Column (1) of Table 2 reports a basic result with no controls. To account for the time-invariant differences across province-industries, we add province-industry fixed effect in column (2). To exclude the influence of industry-specific trends, for example, the shrinking of heavy industries, or any industry-specific shock nationwide in any specific year, we control year-by-industry fixed effect in column (3). To account for any shock for all industries in the specific province each year including the yearly ECCA-target for different provinces, we add a year-by-province fixed effect in column (4). All regressions are weighted by the denominator (2012) of CO_2 emissions to account for the ECCA-TRS inequality among industries. The standard errors are clustered at the province-industry level.

Table 2: Effects of ETS pilots on CO_2 emissions (weighted by the denominator of CO_2) emissions)

Panel A	(1)	(2)	(3)	(4)

Post × ETS × Ind	-0.0384	0.105***	-0.174***	0.0171
	(0.380)	(0.0265)	(0.0399)	(0.0688)
Panel B				
Post × ETS × Rate	0.566	0.125***	-0.141***	0.0516
	(0.377)	(0.0318)	(0.0480)	(0.0698)
Post × ETS × Mass	-1.067***	0.0700	-0.228***	-0.0463
	(0.272)	(0.0443)	(0.0557)	(0.0884)
Observations	13,160	13,160	13,160	13,160
Province-industry FE		Yes	Yes	Yes
Industry-year FE			Yes	Yes
Province-year FE				Yes

Notes: Standard errors in parentheses *p < 0.10, **p < 0.05, ***p < 0.01. Regressions are weighted by the denominator (2012) of CO_2 emissions to account for the ECCA-TRS inequality among industries. The standard errors are clustered at the province-industry level.

Table 3 runs the same specifications for CO_2 intensity, but regressions are weighted by the denominator (2012) of CO_2 intensity. Our estimation results show no evidence of any carbon abatement effect of ETS pilots on average or in the subgroups applying different permit allocation approaches in terms of CO_2 emissions or CO_2 intensity.

Table3: Effects of ETS pilots on CO_2 intensity (weighted by the denominator of CO_2 intensity)

Panel A	(1)	(2)	(3)	(4)
Post × ETS × Ind	-0.640*	-0.421***	-0.160**	0.132
	(0.382)	(0.0665)	(0.0690)	(0.133)
Panel B				
Post × ETS × Rate	-0.135	-0.421***	-0.107	0.160
	(0.402)	(0.102)	(0.0883)	(0.180)
Post × ETS × Mass	-1.061**	-0.421***	-0.203**	0.112
	(0.427)	(0.0876)	(0.0913)	(0.143)
Observations	11,256	11,256	11,256	11,256
Province-industry FE		Yes	Yes	Yes
Industry-year FE			Yes	Yes
Province-year FE				Yes

Notes: Standard errors in parentheses $^*p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. Regressions are weighted by the denominator (2012) of CO_2 intensity. The standard errors are clustered at the province-industry level.

If some industries or provinces rely more on a certain fuel, it is plausible that those industries will suffer more if there is a shock in the fuel price. Thus, we include prices of main fuels (coal, oil, gas, and electricity) consumed by industries in our estimations to control energy prices factors. Results[3] are similar. To avoid the possibility that the choice of research period influences our results, we do a robust check using another time span. The 12th Five-Year Plan starting in 2011, involved the carbon abatement targets for the first time, which represents a new type of mandatory policy being implemented. Hence, we reexamine the impact of ETS pilots using data beginning from 2011. We also involve energy prices simultaneously in our robust check estimations. The results[4] are robust. Tianjin and Chongqing rank lowest among all pilots in the maturity assessment, and in terms of carbon price level and trading volume, these two pilots' performance is the worst (Liu and Zhang, 2019). To avoid the possibility that these pilots with poor performance might drive our results, we drop Tianjin and Chongqing to conduct a robust check. The results[5] are robust.

4.2 Impact on cost-effectiveness

This part tests whether ETS substitutes the ECCA-TRS partly to maintain the abatement that covered industries had due to the existing ECCA-TRS policies. The above section has shown that ETS pilots did not affect CO_2 emissions and CO_2 intensity of covered industries. However, we cannot conclude that China's ETS pilots are ineffective so far. If it was the case that carbon trading replaced ECCA-TRS partly and achieved an equal carbon abatement target compared with the ECCA-TRS-only situation, we could also get the result that ETS pilots did not achieve additional carbon abatement.

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[3] See Supplementary Tables C1 andC2 for details.

[4] See Supplementary Tables B1, B2, D1, D2 for details.

[5] See Supplementary Tables E1, E2 for details.

However, if ETS substitutes the ECCA-TRS partly to achieve the equal abatement target as in the ECCA-TRS-only situation, the abatement cost of the covered industries would decrease since carbon trading is more cost-effective than command-and-control policies.

The emissions trading market offers firms with high marginal abatement costs the opportunity to purchase the right to emit rather than force them to implement abatement activities and is expected to yield cost savings compared to command-and-control policies (Carlson et al., 2000). Some studies indicate that there will be less output loss if an ETS is employed to achieve the equal abatement target compared to the situation via command-and-control measures (Färe et al., 2013; Färe et al., 2014; Wang et al., 2016). Through a firm-level empirical study, Chen et al. (2021) have shown that China's command-and-control policy can lead to output loss in the 11th Five-Year-Plan period. Therefore, we can expect some output increase due to the participation of carbon trading compared to ECCA-TRS only.

We estimate the impact of ETS pilots on the output of covered industries using the same estimation specifications as we assess the impact on CO_2 emissions. We control for a full set of fixed effects, and use the denominator of the CO_2 emissions to weight the estimations to ensure control group is consistent with that when we regress CO_2 emissions. However, we observe no significant positive effects on the output of covered industries induced by ETS pilots in Table 4. The results[6] are similar when we control energy prices. Moreover, when we change the research period using data from 2011 to 2017, the results[7] are robust. Thus, we can draw the conclusion that China's ETS pilots had no carbon reduction effects nor replaced ECCA-TRS partly to narrow the negative effect of ECCA-TRS.

Table 4: Effects of ETS pilots on output (weighted by the denominator of CO_2 emissions)

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[6] See Supplementary Table C3 for details.

[7] See Supplementary Tables B3, D3 for details.

Panel A	(1)	(2)	(3)	(4)
Post × ETS × Ind	0.706***	0.492***	-0.0313	0.0731
	(0.262)	(0.0735)	(0.0612)	(0.0471)
Panel B				
Post × ETS × Rate	0.988***	0.498***	-0.0383	0.0961
	(0.337)	(0.0977)	(0.0800)	(0.0679)
Post × ETS × Mass	0.227	0.481***	-0.0197	0.0309
	(0.220)	(0.110)	(0.0863)	(0.0853)
Observations	11,256	11,256	11,256	11,256
Province-industry FE		Yes	Yes	Yes
Industry-year FE			Yes	Yes
Province-year FE				Yes

Notes: Standard errors in parentheses *p < 0.10, **p < 0.05, ***p < 0.01. Regressions are weighted by the denominator (2012) of CO_2 emissions. The standard errors are clustered at the province-industry level.

4.3 Impact of ECCA-TRS

ETS did not achieve a carbon abatement effect either in terms of CO_2 emissions or CO_2 intensity, but the CO_2 intensity of ETS-covered industries in pilot areas indeed experienced a more significant decrease than their counterparts, and CO_2 emissions experienced a minor increase (Appendix I, Table A1). The impact of ETS pilots on CO_2 emissions is economically large (a 17.4% decrease in CO_2 emissions see Table 1) and statistically significant at the 1% level when we control province-industry and industry-year fixed effect. Similarly, the impact of ETS on CO_2 intensity is economically significant (a 16% decrease in CO_2 intensity see Table 2) and statistically significant at the 5% level when we control province-industry and industry-year fixed effects. However, when we add province-year fixed effect in our estimations, the impacts of ETS on CO_2 emissions and CO_2 intensity become insignificant (Tables 1,2). This transformation implies that when we control for the province-year level confounding factors, ETS pilots have no significant impact on abatement.

Table 5: Relative trend of profitability of covered industries

	ln Profitability
Post × ETS × Ind × Trend	-0.00694 (0.00601)
Observations	11,656
Province-industry FE	Yes
Industry-year FE	Yes
Province-year FE	Yes

Notes: Standard errors in parentheses *p < 0.10, **p < 0.05, ***p < 0.01. The standard errors are clustered at the province-industry level. The coefficient captures the trend of profitability of covered industries in ETS pilots compared to other industries.

We do not observe covered industries having any decreasing profitability trends (profit/output) compared to their counterparts (Table 5). Thus, enterprises of covered industries in ETS regions seem unlikely to reduce CO_2 emissions by suspending production or shutting down spontaneously due to any economic shocks that might weaken the profitability. As for the shrinking secular trends of heavy industries, we have considered this element and added the industry-year fixed effect in our estimations to eliminate the possible influence of structural change. Since we have ruled out the possibility that enterprises spontaneously reduce CO_2 emissions or CO_2 intensity due to economic shocks, the more significant CO_2 emissions and CO_2 intensity reductions of covered industries are almost certainly due to stricter external pressure in these pilot areas. Here, we suppose that the confounding factor is the ECCA-TRS since it was and is the cornerstone of China’s energy and climate change governance. As seen in Fig.2 and Appendix II, Tables A2 and A3, the emission reduction targets under ECCA-TRS in the pilot areas are higher than the national average.

Further, pilot regions always try to achieve more than the central government’s designed task since they take the lead in many aspects, and CO_2 abatement should not be an exception. On the other hand, we expect to see decreasing trends in CO_2 emissions and CO_2 intensity in the absence of

ETS pilots. In order to observe the confounding of ECCA-TRS clearly, we performed dynamic estimates of the impacts of ETS pilots in our whole study period.

In the estimations of Fig.3, we regress the outcome variables with the province-industry and industry-year fixed effects but without the province-year fixed effect. Also, we do not use the denominator of CO_2 emissions and CO_2 intensity as weights when regressing. In this way, we try to show the results without eliminating the confounding of the ECCA-TRS.

The downward slopes prior to the ETS in Fig.3 (Panel A, B and D) suggest that CO_2 emissions of mass and rate-based allocation industries and CO_2 intensity of mass-based allocation industries have been trending downward prior to ETS's implementation. Although the effects of ETS pilots after 2014 are significant, we cannot conclude that they are effective considering the influence of other confounding factors.

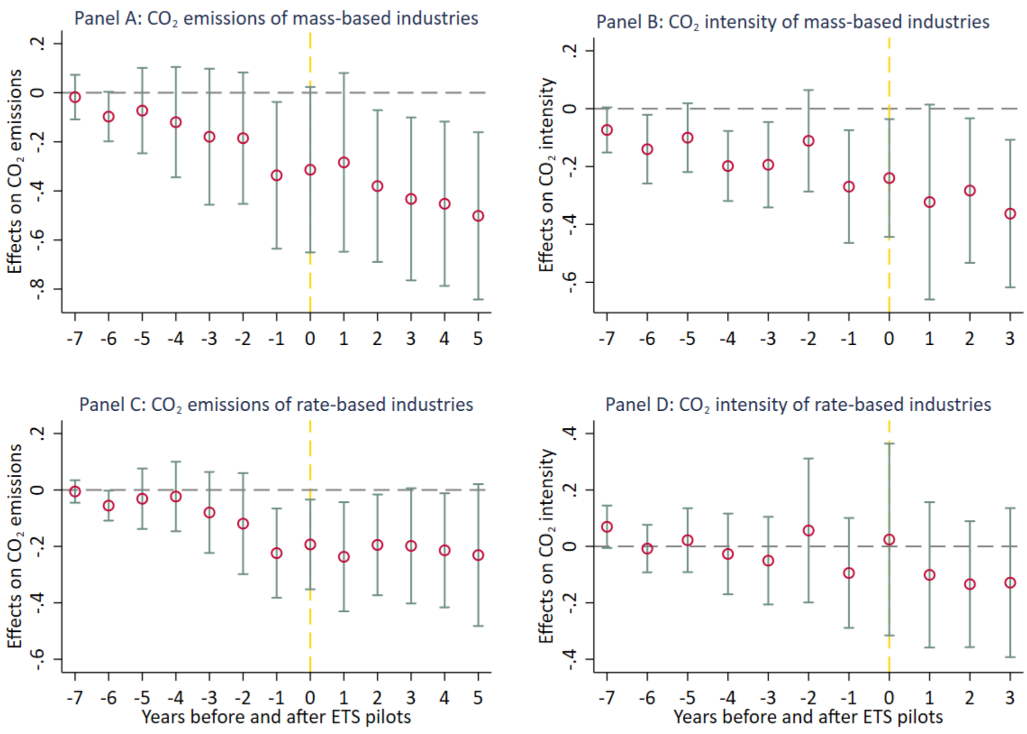

Fig.3 Dynamic estimates of impacts of ETS pilots: without eliminating ECCA-TRS's contamination by weighting or controlling province-year fixed effect. The red hollow cycles represent estimated

coefficients on each year from the dynamic estimates regression not controlling province-year fixed effect or weighting regressions. The grey points present the 95 per cent confidence intervals. Standard errors are robust and clustered at the province-industry level.

And then, in Fig.4, we plot coefficients of dynamic estimates using CO_2 emissions as a weight when we regress CO_2 emissions, using CO_2 intensity as weights when we regress CO_2 intensity, and we control province-year fixed effect in our estimations, to eliminate the effect of the ECCA-TRS. We found that the trends weakened, and the coefficients are insignificant. We plot the event-time coefficients here for a visual inspection of the misleading results we can get if not considering ECCA-TRS pressure on covered industries. We emphasize this to highlight the importance of eliminating ECCA-TRS's contamination when we assess ETS's impact. If we ignore these factors, we may get the misleading result that ETS pilots induce a significant carbon reduction effect.

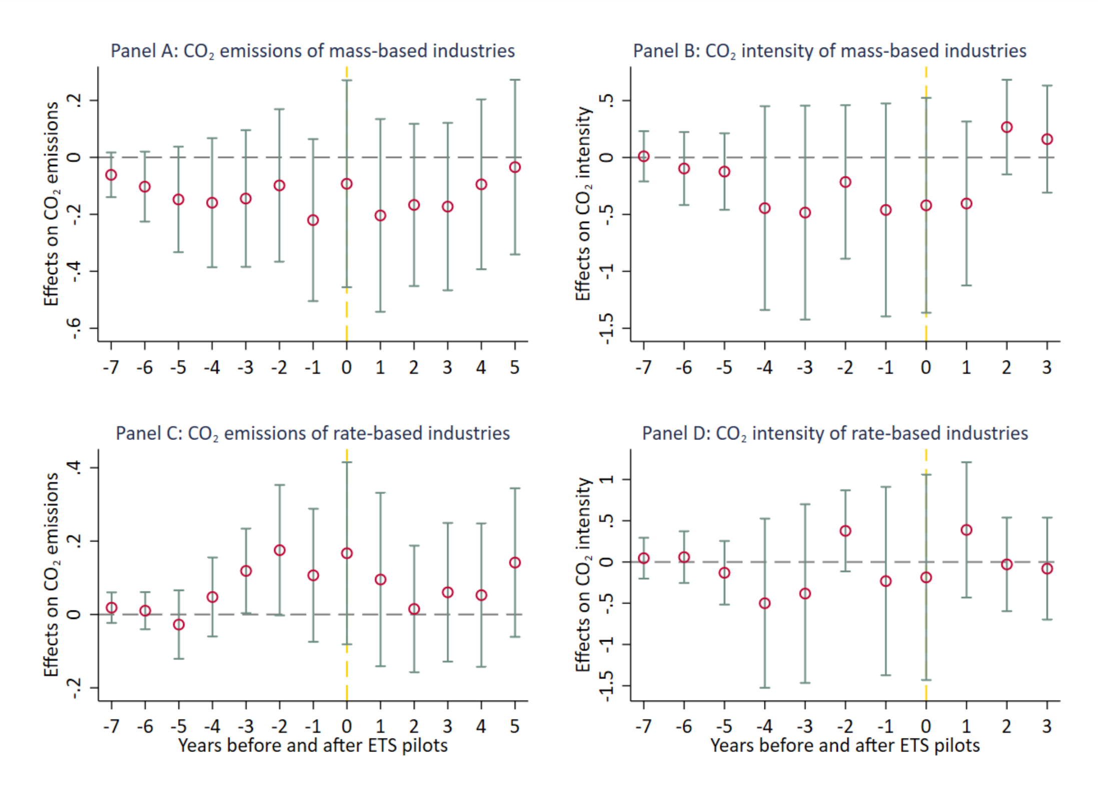

Fig.4 Dynamic estimates of impacts of ETS pilots: eliminating ECCA-TRS's contamination by weighting observations and controlling the province-year fixed effect. The red hollow cycles represent estimated

coefficients on each year from the dynamic estimates' regression when we exclude the contamination of the ECCA-TRS. The grey points present the 95 per cent confidence intervals. Regression of panel A and C is weighted by the denominator (2012) of CO_2 emissions, regression of panel B and D is weighted by the denominator (2012) of CO_2 intensity. Standard errors are robust and clustered at the province-industry level.

5. Conclusions

Our analysis presents evidence that, on the whole, ETS pilots do not act as an effective incremental carbon abatement policy to achieve extra carbon reduction beyond ECCA-TRS, nor work as a complementary instrument to reduce the abatement cost of covered industries. Although perhaps several specific sectors in some pilots have some reduction effect caused by ETS, the overall impact is insignificant. However, apart from being expected to achieve some emissions reduction, these pilots were also introduced to increase learning and awareness of carbon markets in China, their failure to have incremental impacts should not be viewed as a policy failure. Indeed, on the contrary, the pilot markets are working as might be predicted by economic theory given their implementation at low levels of stringency in the presence of a tighter pre-existing policy.

ECCA-TRS contributed to the larger carbon abatement of covered industries in ETS pilots. In order to peak the country's CO_2 emissions at around 2030 and achieve net zero by 2060, China must increase the stringency of its carbon trading mechanism. Getting to net zero requires the discipline that carbon markets bring to the enforcement of overall carbon emissions quantities. As the carbon constraint binds, differences in relative costs of abatement between sectors and firms will become more critical. Using market prices to guide decision-making will become more important, not less important. While command and control are useful when the action to be commanded is easy to identify, it is much less useful when the exact nature of abatement is hard to identify and when the cost of mistakes is rising. Getting to net zero is not merely about energy efficiency or copying best practices; it is about hard choices between which technologies to deploy where (and when) and involves substantial rises in carbon-based energy costs (Caney and Hepburn, 2011: 205-206; Schmalensee and Stavins, 2013: 107;). National decarbonization needs a more fundamental sustainability transition policy mix that promotes innovation and carbon decline, and induces deep system change (Rosenbloom, et al., 2020; Liu, et al., 2022). This suggests a strong role for delegation to the market to guide abatement and, critically, a tight overall cap on emissions as a key part of the policy mix.

Thus, a binding target should be set to let the ETS act as the backstop emissions constraint in the process to net zero. This means the interaction between the ECCA-TRS carbon reduction targets and the carbon market cap needs to be explicitly considered. This will involve allowing certain ECCA-TRS carbon reduction targets to be met by the use of the carbon market, in line with economic incentives and shifting the carbon focus of the ECCA-TRS to non-covered sectors or entities below the size thresholds for inclusion. This will allow the ETS to cost-effectively guarantee the overall abatement constraint, and the ECCA-TRS and ETS to play a complementary (rather than substitute) role in encouraging carbon abatement in China.

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Appendix Ⅰ

Table A1: Summary Statistics

	ETS pilots			Non-ETS pilots			All regions
	Treatment industries	Control industries	Total industries	Treatment industries	Control industries	Total industries	All industries
Panel A. Pre-launch (2006-2013)							
CO_2	24,447	1,255	6,461	50,655	1,554	9,128	8,591
CO_2_intensity	26,265	4,043	9,032	85,257	14,715	25,639	22,286
Output	1,355	598.2	768.0	961.6	357.6	451.1	515.1
Profit	41.25	38.08	38.79	38.58	36.34	36.68	37.11
Panel B. Post-launch (2014-2019 for CO_2 and profit, 2014-2017 for CO_2 intensity and output)							
CO_2	26,904	1,535	7,211	66,568	2,269	12,127	11,140
CO_2_intensity	16,855	2,707	5,883	68,294	13,708	22,146	18,867
Output	2,302	1,060	1,339	1,599	701.4	840.3	940.8
Profit	141.7	73.14	88.48	83.21	40.31	46.92	55.32
Panel C. Difference over time							
CO_2	2457	280	750	15913	715	2999	2549
	(10.1%)	(22.3%)	(11.6%)	(23.9%)	(31.5%)	(32.9%)	(29.7%)
CO_2_intensity	-9410	-1336	-3149	-16963	-1007	-3493	-3419
	(-35.8%)	(-33.0%)	(-34.9%)	(-19.9%)	(-6.8%)	(-13.6%)	(-15.3%)
Output	947	461.8	571	637.4	343.8	389.2	425.7
	(69.9%)	(77.2%)	(74.3%)	(66.3%)	(96.1%)	(86.3%)	(82.6%)
Profit	100.45	35.06	49.69	44.63	3.97	10.24	18.21
	(243.5%)	(92.1%)	(128.1%)	(115.7%)	(10.9%)	(27.9%)	(49.1%)

Notes: The columns contain means of the variables listed in the first column. CO_2 emissions (1000 tonnes), CO_2 intensity (tonnes CO_2/ 100,000,000 CNY), output (100,000,000 CNY). In panel A we describe means of variables for the period from 2006 to 2013, which is before the launch of ETS pilots. Panel B presents means of variables for the period of 2014 to 2019 (CO_2) or 2014 to 2017(CO_2 intensity and output), which is after the launch of ETS pilots. The last column "All industries in All regions" refers to the entire sample and the other columns are broken into subsamples by whether they are ETS pilots and whether they are covered industries. Panel C depicts the difference and rate of change between the average value of each indicator post-launch and the average value in 2006-2013.

This section presents means for the outcome variables of our analysis. We compare the treated group to the control group in both the baseline period (2006-2013) and the treated period (2014-2019 or 2014-2017). The treated group consists of regulated industrial sectors in ETS pilots, while the control group consists of non-regulated industrial sectors in ETS pilots and all industrial sectors in non-ETS regions. In order to compare the treated industries in ETS pilots and their counterparts in non-ETS regions, we include five industries covered by most ETS pilots as "treated industries" in non-ETS regions. They are Petroleum Processing and Coking, Raw Chemical Materials and Chemical Products, Nonmetal Mineral Products, Smelting and Pressing of Ferrous Metals and Electric Power, Steam and Hot Water Production and Supply.

Table A1 shows that treated industries have larger amounts of emissions and higher CO_2 intensity than non-treated industries in both ETS pilots and non-ETS regions, and industries in ETS pilots tend to have fewer CO_2 emissions and lower CO_2 intensity overall. Units for CO_2 emissions are 1000 tonnes, and for CO_2 intensities are tonnes CO_2/ 100,000,000 CNY in our following description. In ETS regions, the mean value of CO_2 emissions of treated industries in 2006-2013 is 24,447 while the figure is 1,255 for control industries; the average CO_2 intensity for treated industries is 26,265 while it was 4,043 for the control industries. The situation is similar for the post-launch period. Overall, industries in ETS pilots emit fewer CO_2 emissions and have lower CO_2 intensities compared to non-ETS regions. In the baseline period, the overall average CO_2 emissions in ETS pilots is 6,461 while that is 9,128 in non-ETS regions; The average CO_2 intensity in ETS pilots is 9,032 while the figure is 25,639 in non-ETS regions. The case is similar after the launch of ETS pilots.

Treated industries in ETS pilots experienced a 35.8% decline in mean values of CO_2 intensity after the launch of ETS pilots, the decline is larger than that of treated industries in non-ETS pilots or control industries in ETS pilots. Although CO_2 emissions of treated industries experienced an increase, the increase was less than in other groups.

Appendix Ⅱ

Table A2: Regional Achievements of energy-saving targets in the 11th FYP

Regions	2005		2010	
	Energy consumption per unit of GDP (Tonnes of standard coal/10,000 CNY)	Planned decrease rate during the 11th FYP (%)	Energy consumption per unit of GDP (Tonnes of standard coal/10,000 CNY)	Achieved decrease rates compared to 2005 (%)
Beijing	0.792	-20.00	0.582	-26.59
Tianjin	1.046	-20.00	0.826	-21.00
Hebei	1.981	-20.00	1.583	-20.11
Shanxi	2.890	-22.00	2.235	-22.66
Inner Mongolia	2.475	-22.00	1.915	-22.62
Liaoning	1.726	-20.00	1.380	-20.01
Jilin	1.468	-22.00	1.145	-22.04
Heilongjiang	1.460	-20.00	1.156	-20.79
Shanghai	0.889	-20.00	0.712	-20.00
Jiangsu	0.920	-20.00	0.734	-20.45
Zhejiang	0.897	-20.00	0.717	-20.01
Anhui	1.216	-20.00	0.969	-20.36
Fujian	0.937	-16.00	0.783	-16.45
Jiangxi	1.057	-20.00	0.845	-20.04
Shandong	1.316	-22.00	1.025	-22.09
Henan	1.396	-20.00	1.115	-20.12
Hubei	1.510	-20.00	1.183	-21.67
Hunan	1.472	-20.00	1.170	-20.43
Guangdong	0.794	-16.00	0.664	-16.42
Guangxi	1.222	-15.00	1.036	-15.22
Hainan	0.920	-12.00	0.808	-12.14
Chongqing	1.425	-20.00	1.127	-20.95
Sichuan	1.600	-20.00	1.275	-20.31
Guizhou	2.813	-20.00	2.248	-20.06
Yunnan	1.740	-17.00	1.438	-17.41

Xizang	1.450	-12.00	1.276	-12.00
Shaanxi	1.416	-20.00	1.129	-20.25
Gansu	2.260	-20.00	1.801	-20.26
Qinghai	3.074	-17.00	2.550	-17.04
Ningxia	4.140	-20.00	3.308	-20.09
Xinjiang	Separately assessed			

Table A3: Regional Achievements of energy-saving targets in the 12th FYP

Regions	Energy-saving decrease rate targets in the 12th FYP (%)	Targets for annual average growth rates of energy consumption from 2014 to 2015 (%)	Evaluation result
Beijing	17	2.9	Overfulfilled
Tianjin	18	2.6	Fulfilled
Hebei	17	2.6	Overfulfilled
Shanxi	16	3.1	Fulfilled
Inner Mongolia	15	3.5	Fulfilled
Liaoning	17	2.8	Fulfilled
Jilin	16	4.5	Fulfilled
Heilongjiang	16	3.5	Fulfilled
Shanghai	18	3.2	Overfulfilled
Jiangsu	18	2.5	Overfulfilled
Zhejiang	18	3.1	Overfulfilled
Anhui	16	2.7	Overfulfilled
Fujian	16	2.4	Fulfilled
Jiangxi	16	3.3	Fulfilled
Shandong	17	2.2	Fulfilled
Henan	16	3.4	Overfulfilled
Hubei	16	2.6	Overfulfilled
Hunan	16	3.0	Fulfilled
Guangdong	18	2.9	Overfulfilled
Guangxi	15	4.1	Fulfilled
Hainan	10	6.0	Fulfilled
Chongqing	16	3.2	Fulfilled
Sichuan	16	3.1	Fulfilled

Guizhou	15	3.4	Overfulfilled
Yunnan	15	4.0	Fulfilled
Xizang	10		Fulfilled
Shaanxi	16	3.7	Fulfilled
Gansu	15	3.5	Fulfilled
Qinghai	10	5.1	Fulfilled
Ningxia	15	3.5	Fulfilled
Xinjiang	10	3.4	Basically fulfilled

Note: Data for Xizang Autonomous Region is temporarily missing.