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The Impact of Emissions Trading Systems on Manufacturing Installation Productivity: Evidence from Japan*

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Abstract

This study examines the impact of the Tokyo and Saitama regional emissions trading systems (ETSs) on the productivity of Japan's manufacturing installations. Utilizing data from the Economic Census for Business Activity and the Census of Manufacture, we measure the total factor productivity (TFP) of both regulated and unregulated manufacturing installations. Subsequently, we estimate the extent to which the ETSs impact the TFP of regulated manufacturing installations. Our findings indicate that the TFP of regulated installations increases after the implementation of ETS compared to that of unregulated installations. Furthermore, the results of factor analysis suggest that investment trends in equipment differ between regulated and unregulated installations. These findings underscore the interaction between environmental regulations and installation productivity in Japan, contributing to policy discussions on effective climate change mitigation strategies.

Keywords: Emissions trading system, TFP, Difference-in-differences

JEL classification: Q54, D24

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1. Introduction

Emissions trading systems (ETSs) have emerged as pivotal mechanisms in global initiatives aimed at fostering carbon mitigation by creating a market for emissions allowances and offering economic incentives for installations to reduce their emissions. To achieve these objectives, installations are mandated to adopt various compliance measures, such as investing in green technologies, replacing equipment, and modifying operational processes, which may, in turn, influence their economic performance, particularly total factor productivity (TFP). Despite the expanding body of literature examining the impacts of ETSs (Sun et al., 2023; Teixidó et al., 2019; Verde & Borghesi, 2022; Wang & Kuusi, 2024), empirical evidence concerning their effects on the TFP of installations remains limited, especially within Japan's energy-intensive manufacturing sector.

While ETSs generally aim to achieve reduction targets in a cost-efficient manner through innovation and productivity gains, they may also impose financial and operational burdens on regulated firms (Baier et al., 2006), potentially affecting TFP (Mo et al., 2023). These inconsistent impacts underscore the necessity of investigating the influence of ETSs on productivity, an issue that may be further complicated by regulatory strategies designed to mitigate adverse effects during the initial compliance stage.

Recognizing the potential adverse effects of these compliance burdens in the initial stage, policymakers may announce the regulation in advance to provide installations with a transitional period to prepare for compliance with the forthcoming reduction targets. Such announcement periods are crucial for installations, allowing them to adjust operations, invest in cleaner technologies, and upgrade equipment to meet targets, which may potentially affect TFP before the implementation of regulations. However, during this period, installations may face financial pressures due to increased compliance costs associated with new technologies (Xu et al., 2022), changes in operational processes, and personnel training. These additional costs may adversely impact short-term performance, reducing profits and limiting investment in research and development activities (Dechezleprêtre & Sato, 2017; Esso & Keho, 2016). Conversely, during the middle and later compliance stages, these regulations can transform environmental costs into economic incentives for productivity improvements, enabling installations to transition from initial productivity declines to enhanced productivity (Benatti et al., 2024; Pan et al., 2019). Despite the significance of these dynamics, existing literature has not thoroughly examined how ETSs affect TFP across different compliance stages, particularly during the announcement period within Japan's manufacturing industry.

In light of these considerations, this study investigates the impact of Japan's regional ETSs on TFP, taking into account both the announcement and compliance periods. The Tokyo and Saitama local governments announced the implementation of their regional ETSs in 2007 and 2008, respectively. Approximately 13% of manufacturing installations are regulated by the Tokyo ETS, while the proportion reaches 70% for the Saitama ETS (Sadayuki & Arimura, 2021). Consequently, focusing on manufacturing installations regulated by the Tokyo and Saitama regional ETSs enables a detailed examination of the ETS's impact on manufacturing TFP. This study considers the staggered announcement years of the Tokyo and Saitama ETSs as policy shocks, employing a difference-in-differences (DiD) methodology based on the Callaway and Sant'Anna (2021) estimator to estimate their impacts on TFP using installation-level data covering the period from 2002 to 2016.

The empirical findings indicate that the introduction of Japan's regional ETSs increases energy TFP by 1.4% for manufacturing installations following a public announcement, underscoring the significant contribution of ETSs to productivity improvements. To ensure the reliability of this result, this study conducts multiple robustness tests, including tests on parallel trends, placebo tests, analysis of regions with uniform electricity prices, and unconfoundedness assumption and stable unit treatment value assumption. Further mechanism analysis reveals that these gains are driven not by increased capital investments but by enhanced operational efficiency. Moreover, the stage-dynamic analysis explores the differential impacts on manufacturing productivity of installations at specific stages, demonstrating that although no evidence supports TFP increases during the announcement period, installations improve their TFP during the first compliance period.

Beyond these empirical contributions, this study further enriches the literature by focusing on the announcement period of ETS. We provide an empirical investigation into the impact of Japan's regional ETSs on manufacturing installations' TFP during the announcement period, a topic largely overlooked in previous literature. By focusing on the announcement period and analyzing a detailed installation-level dataset, this study explores how regulatory compliance affects installation behavior and productivity. Understanding the effects during the announcement period is crucial, as installations often begin adapting their operations, investing in cleaner technologies, and modifying strategies in response to upcoming regulations. These actions may lead to financial consequences and reductions in productivity (Chen et al., 2024). By focusing on this period, this study can assess whether the impact of ETSs begins before official implementation, providing an important perspective for comprehensively evaluating its impact. Additionally, it contributes to the understanding of the stage-specific impacts of ETSs on manufacturing productivity, highlighting the dynamic interaction between installations and regulatory frameworks across different compliance stages.

The remainder of this study is organized as follows. Section 2 introduces the background of Japan's regional ETSs and literature related to this study. Section 3 describes the data and estimation model. Section 4 presents the estimation results and robustness checks. Section 5 provides further analysis and mechanism analysis. Section 6 concludes the paper.

2. Japan's regional ETSs and literature review

2.1. Japan's regional ETSs

2.1.1 Background

In 2007, the Tokyo government announced the introduction of Japan's first regional ETS, scheduled to commence operations two years later. Facing similar economic and environmental challenges as Tokyo, Saitama, with its substantial manufacturing base in the Kanto area, began preparing for analogous regulatory frameworks around the same period. Although the specific timeline for the announcement of the ETS in Saitama is less clear, historical patterns of Saitama following Tokyo's environmental initiatives suggest that it would likely implement the same regulation once Tokyo proceeded with its implementation. This was substantiated by the signing of an "Agreement on the Diffusion of Cap-and-Trade Schemes in the Capital Region" between Tokyo and Saitama, formalizing their partnership. Subsequently, when Tokyo introduced the Tokyo Carbon Reduction Reporting Program in 2002, a precursor to the Tokyo ETS, Saitama Prefecture promptly adopted a similar program. Furthermore, in August 2008, the Saitama prefectural government conducted a briefing session for business operators on the forthcoming ETS, underscoring Saitama's commitment to aligning with Tokyo's environmental strategies.

Based on this pattern of regulatory adoption, it is reasonable to consider the announcement period of the Saitama ETS as commencing around 2008. Both the Tokyo and Saitama ETSs introduced phased reduction targets, calculated based on baseline emissions derived from CO_2 emissions over any consecutive three-year period from 2002 to 2006. Installations were notified of their specific emission reduction targets starting from the announcement period. The Tokyo ETS covers approximately 1,200 installations across all industries, while the Saitama ETS regulates around 600 installations. Both ETSs regulate installations with annual energy consumption exceeding 1,500 kiloliters of crude oil equivalent (approximately 2,800 tons of CO_2). An installation exceeding this threshold for three consecutive years, on average, will be included in the regulated installation list of Japan's regional ETSs. The primary focus of the Tokyo ETS is on commercial and service industries, whereas the Saitama ETS mainly covers manufacturing installations.

The initial compliance period for manufacturing installations under the Tokyo ETS extended from 2010 to 2014, whereas for the Saitama ETS, it spanned from 2011 to 2014. Both ETSs established an initial emission reduction target of 6% for this period. The subsequent compliance period for both regions covered 2015 to 2019, during which the Tokyo ETS increased its reduction target to 15%, while the Saitama ETS set a target of 13% (see Table 1). Installations that exceed their reduction targets are eligible to earn credits equivalent to the excess reductions. These allowances can be banked for use in the following compliance period. Conversely, installations that face challenges in meeting their targets can utilize emissions allowances and various alternative credits to achieve compliance.

Table 1

Information on Tokyo and Saitama ETS.

	Tokyo ETS		Saitama ETS	
	Office building	Manufacturing installation	Office building	Manufacturing installation
Sectors	Service, industrial, and public sectors		(Mainly) Manufacturing industry	
Inclusion threshold	Installations with annual energy consumption exceeding 1,500 kiloliters of crude oil equivalent (approximately 2,800 tons of CO_2)			
Base-year emissions	Calculated on the basis of baseline emissions derived from the CO_2 emissions of any consecutive three-year period from 2002 to 2006			
Announcement	2007		2008	
First period	2010~2014		2011~2014	
Second period	2015~		2015~	
Reduction target (First period)	8%	6%	8%	6%
Reduction target (Second period)	17%	15%	15%	13%
Number of regulated installations and buildings	1300		600	
Penalty mechanism	Yes		No	

A significant distinction between the Tokyo and Saitama ETSs lies in their penalty mechanisms (Arimura et al., 2021). Regulated installations under the Tokyo ETS are subject to penalties, including monetary fines and public notification of noncompliance, if they fail to meet their emission reduction targets (Onuma & Arimura, 2021). In contrast, the Saitama ETS does not impose penalties for noncompliance, rendering it a voluntary ETS, which is unique in nature among countries. Nevertheless, in Saitama, a substantial proportion of regulated installations remains within the Saitama ETS at all stages due to requirements for installations whose emissions exceed the threshold for three consecutive years. This stability facilitates a more controlled comparison between regulated and unregulated installations, thereby enhancing the validity of the analysis.

2.1.2 Permit information

A critical aspect of evaluating the effectiveness of ETSs on productivity involves examining permit information during compliance periods. In the context of the two regional ETSs, regulated installations have the option to reduce their emissions not only through ETS permits but also via alternative mechanisms such as "Tokyo Small and Medium-sized Installations Credits," "Renewable Energy Credits," "Credits from Outside Tokyo," "Tokyo Linkage Credits," and "Saitama Linkage Credits" since the first compliance period. These alternatives offer a more flexible approach for installations encountering challenges in reducing emissions solely through internal measures.

According to official reports, during the first compliance period of the Tokyo ETS, over 90% of installations met reduction targets through their own efforts. The emissions reduction achieved via traded Tokyo ETS permits amounted to 160.7 thousand t-CO_2, compared to a total reduction of 10,272 thousand t-CO_2, representing approximately 1.5% of the total reduction. As emissions reduction targets became more stringent during the second compliance period, reliance on traded permits increased, yet it still accounted for only 5.5% of the total reductions achieved through permit trading. In the case of Saitama, despite the voluntary nature of its ETS potentially influencing permit usage, more than 88% of installations in the first compliance period and 80% in the second compliance period achieved reductions through their own efforts. During the second compliance period, installations achieved a reduction of only 352 thousand t-CO_2 through traded Saitama ETS permits, compared to a total reduction of 15 million t-CO_2.

The data from both the Tokyo and Saitama ETSs indicate that a majority of regulated installations tend to comply with emissions targets by implementing internal efforts rather than relying extensively on the trading market. This suggests that only a small number of installations meet the regulatory emissions reduction target through trading, indicating that Japan's market mechanism may not be functioning optimally. It potentially reflects a preference among installations to achieve long-term reductions by enhancing their capabilities, such as productivity, rather than purchasing external credits.

Moreover, the permit prices in both ETSs have exhibited a similar downward trend from their inception, ultimately reaching significantly low levels (see Fig. 1). Specifically, the data reveals that in Tokyo, the permit price was 115.66 USD per ton of CO_2 in 2012, which steadily declined to 4.41 USD in 2022. Similarly, in Saitama, the permit price commenced at 119.81 USD per ton of CO_2 in 2011 and decreased to 3.83 USD in 2022. This decline in permit prices can be attributed to several factors. Firstly, the substantial emission reductions achieved through internal measures resulted in a surplus of allowances in the market, thereby reducing the demand for permits. Secondly, the limited trading activity, as most installations met their targets without heavily relying on external credits, further contributed to the oversupply. This situation, coupled with the absence of penalties in Saitama's ETS and effective compliance in Tokyo, diminished the economic incentives for installations to engage in trading, leading to lower permit prices over time.

In summary, the lower trading credit volume and reduced permit prices in both the Tokyo and Saitama ETSs provide valuable insights for our analysis. Regulated installations in both regions demonstrate similar behavior in prioritizing internal emission reductions over the purchase of external credits, even when cheaper permits are available in the market. The stability of regulated installations and the similarity of economic incentives and market conditions in both regional ETSs support the validity of combining Tokyo and Saitama in our analysis. Thus, Japan's two regional ETSs offer an opportunity to investigate the impact of ETSs on productivity in manufacturing installations, providing a more comprehensive understanding of the effectiveness of ETSs in driving TFP enhancements.

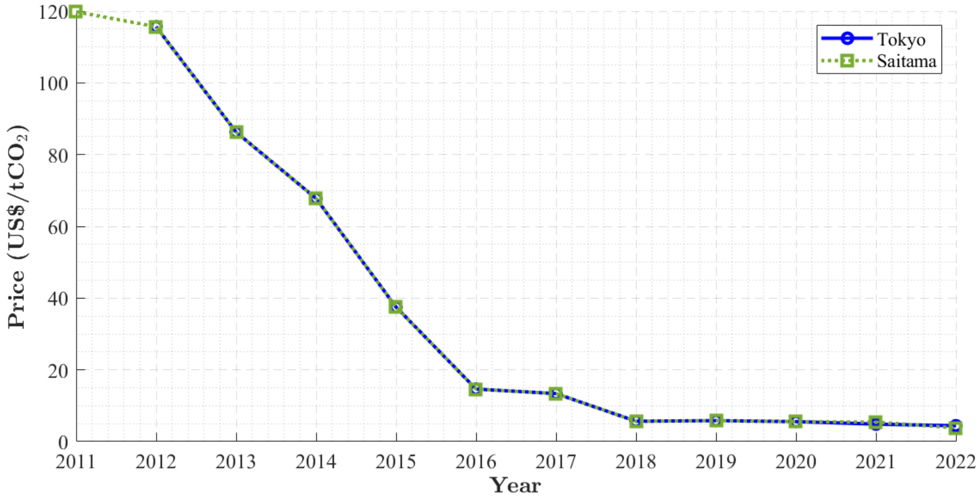

Fig. 1. ETSs price for Tokyo and Saitama.

Note: Price data sourced from the World Bank.

2.2. Literature review

2.2.1 Literature on EU, China, and Korea

ETSs have emerged as crucial mechanisms for reducing CO_2 emissions, offering economic incentives to installations while fostering technological innovation and productivity improvements to achieve long-term sustainability (Wu & Wang, 2022). Numerous recent studies have examined the effects of ETS and environmental regulations on firm productivity within the European Union, China, and Korea. These investigations provide valuable insights into the impact of productivity regulations across diverse economic contexts. Albrizio et al. (2017) explored the influence of environmental policy stringency on industrial and firm productivity in OECD countries. Their findings suggest that more stringent environmental policies are associated with short-term productivity growth in the most productive industries and firms. This implies that rigorous environmental regulations can drive innovation and efficiency among leading firms, enabling them to offset compliance costs through productivity gains.

Conversely, He et al. (2020) analyzed the effect of environmental regulation on firms' TFP in China, revealing a reduction in productivity by over 24% following the implementation of regulations. This finding suggests that stringent environmental regulations can impose significant costs on firms under close scrutiny, potentially impeding their performance. Meanwhile, Benatti et al. (2024) investigated the dynamic impact of environmental regulation, finding that increased regulatory stringency leads to a slowdown in productivity growth for high-emission firms compared to their low-emission firms. When high-emission firms face elevated compliance costs and are compelled to make adjustments, their short-term productivity improvements may be affected. However, the study also observes that regulations accompanied by technological support initially negatively impact productivity growth but tend to enhance it following the initial adjustment period.

In the context of the EU ETS, Dechezleprêtre et al. (2023) examine the influence of the EU-ETS on both carbon emissions and economic performance, demonstrating a statistically significant enhancement in economic performance. Concurrently, Colmer et al. (2024) argue that investments in clean production technologies within the EU may be costly primarily during the transition phase. Their study suggests that these investments negatively affect productivity in the short term due to adjustment costs. Nevertheless, such investments are crucial for achieving long-term sustainability and may result in productivity gains once firms have adapted to the new technologies. This suggests that the impact of environmental regulations can vary across different implementation stages, initially causing a reduction in productivity during the adjustment period but leading to productivity gains in the long term. This stage-specific impact aligns with the focus of our study, which investigates how Japan's regional ETSs affect TFP at different stages.

In the context of China's and Korea's markets, Bai et al. (2023) analyze the TFP of listed enterprises under the China carbon market pilots, revealing that the TFP of firms in high-carbon industries improved significantly compared to other industries. This suggests that environmental regulations can also incentivize firms in carbon-intensive industries to enhance productivity gains. Feng et al. (2020) propose that the SO_2 emissions trading program in China assists regulated firms in improving their productivity. Kim and Bae (2022) explore Korea's ETS and find that the mechanisms firms employ to reduce carbon emissions vary by industrial sector. Manufacturing firms tend to enhance energy efficiency, while electricity generation firms substitute fossil fuels with clean energy sources. This underscores the importance of industry-specific responses to environmental regulations, which is particularly pertinent to our study focusing on the manufacturing industry in Japan.

2.2.2 Literature on Japan

Although Japan implemented ETSs later than other countries or regions, and its schemes are limited to regional applications, their efficacy in reducing CO_2 emissions has been substantiated. Hamamoto (2021b) assesses the effectiveness of the Saitama ETS in reducing CO_2 emissions during the initial compliance period. Despite the absence of penalties for non-compliance, the study found a significant reduction in emissions from regulated installations, indicating that even voluntary ETSs can incentivize firms to adopt emission reduction measures. Furthermore, Hamamoto (2021a) posits that manufacturing installations may have employed relatively cost-effective emissions reduction strategies during the first compliance period to meet the targets. However, during the second compliance stage, when emission reduction targets became more stringent, installations likely needed to invest more resources in high-efficiency equipment and enhance their productivity to comply with the stricter regulations.

Yajima et al. (2021) examine changes in electricity, steam, and fossil fuel consumption patterns following the implementation of the Tokyo and Saitama ETSs. While they report that reductions in manufacturing installations led to decreased energy consumption under the Tokyo ETS, they were unable to find conclusive evidence that the Saitama ETS reduced energy consumption. This finding appears to contradict official reports from the Tokyo and Saitama governments and the findings of Hamamoto (2021a), which emphasize the potential of ETSs to promote emissions reduction through efficiency improvements. This discrepancy highlights a gap in understanding the mechanisms by which ETSs affect energy consumption and emissions in the Japanese context.

These inconsistent results suggest the need for further investigation into the mechanisms of energy and emissions reduction through ETSs. Understanding these mechanisms is crucial for examining the impact of ETSs, particularly across different compliance stages, including the announcement period. However, recent studies do not fully explore the effect of ETSs on productivity in manufacturing installations during the announcement period. This gap underscores the necessity for empirical research to analyze the dynamic impacts of ETSs on installation productivity.

In summary, recent literature indicates that the impacts of environmental regulations and ETSs on productivity are influenced by factors such as productivity levels, industry sector, and the stage of policy implementation. While productivity is enhanced in firms through technological innovation, some installations face higher compliance costs during the initial stage, which complicates productivity improvement. Therefore, considering stage dynamics and regulation mechanisms of ETSs is important when analyzing their impacts on productivity in the context of Japan.

3. Data and methodology

3.1. Data source

This study utilizes installation-level data from the Census of Manufacture, conducted by the Ministry of Economy, Trade, and Industry (METI) of Japan, spanning the years 2002 to 2016. The sample covers approximately 45,000 installations annually across four-digit manufacturing sectors, offering data on production value, employee numbers, electricity and energy consumption, fixed assets, and intermediate material costs.

For the years 2011 and 2015, the study employs data from the Economic Census for Business Activity, jointly conducted by the METI and the Ministry of Internal Affairs and Communications (MIC). This census has been implemented every five years since 2012.[2] The Census of Manufacture targets installations with more than four employees in the manufacturing industry, mandating all installations to complete and submit the form to the government. In years when the Economic Census for Business Activity is conducted, the Census of Manufacture is not administered. By integrating data from these two censuses, this study compiles panel data from 2002 to 2016, which is used to estimate the TFP of installations and to analyze the impact of the Tokyo and Saitama ETSs on productivity[3].

This study focuses on manufacturing installations with more than 30 employees, as installations with fewer than 30 employees are not required to report fixed asset amounts, which are crucial for our analysis. The descriptive statistics of all variables are presented in Table 2.

While the dataset includes information on energy and electricity expenditures, this study faces a limitation due to the absence of specific data on the actual quantities of energy and electricity consumed. Without detailed consumption data, accurately measuring energy usage and incorporating it into TFP metrics is challenging. Although Japan relies on imported oil, with prices that do not significantly vary across regions, regional variations still exist. Estimating energy consumption by dividing expenditure by average energy prices could introduce substantial inaccuracies due to these variations, potentially leading to biases in productivity calculations. As Marin and Vona (2021) argued, increases in energy prices result in significant reductions in energy consumption, with more pronounced effects over the long term. Nevertheless, this study considers the TFP estimation calculated from the original data as a baseline result for evaluating data reliability and accuracy. However, to consider the issue on regional variations, this study tries adjust installations' electricity expenditure by using average regional electricity prices, which is shown in Section 5.3.

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[2] We utilized data of the Economic Census for Business Activity for the years 2011 and 2015. The survey was conducted in 2012 and 2016 to collect data pertaining to each preceding year.

[3] "Installation" in this study refers to a manufacturing site, which is generally described as a "plant" or "establishment".

Table 2

Descriptive statistics.

	Obs	Mean	S.D.	Min	Max
Inputs and output of TFP					
Employment (Number of persons)	202019	145.96	206.352	1	5385
Expenditure of electricity and fuel (ten thousand yen)	202019	13026.06	45904.04	2	1799776
Fixed assets (ten thousand yen)	202019	118618.0	348283.7	1	15851265
Intermediate material costs (ten thousand yen)	202019	239973	576360	0	13914263
Production value (ten thousand yen)	202019	518702	1037679	17478	10142741
Outcome and estimates					
TFP	202016	4.058	0.405	0.304	8.153
Payment (ten thousand yen)	202019	71207.14	130737.9	25	4003395
Shipment value of products (ten thousand yen)	202019	504304.1	1041084.	0	41075600
Usage of freshwater (m^3)	202019	1981.78	22937.36	1	1736666
Export ratio	202019	3.085	11.265	0	100

3.2. Measuring TFP

This study aims to estimate the TFP of installations within the manufacturing industry to represent installation productivity. The methodology for estimating TFP has been extensively explored in the literature, including works by Olley and Pakes (1992), Blundell and Bond (1998), Levinsohn and Petrin (2003), Jefferson et al. (2008), and Wooldridge (2009). Ackerberg et al. (2015) have posited that the Olley-Pakes methodology may encounter issues related to functional dependence, potentially leading to identification challenges. Concurrently, Guo and Zhang (2023) have suggested that the methodologies of Jefferson and Blundell-Bond may be susceptible to endogeneity and a lack of comprehensive information. To address potential biases in the estimation of production function parameters, Wooldridge (2009) recommends employing proxy variables within a generalized method of moments (GMM) framework to more effectively control for unobserved productivity shocks impacting the production function. Consequently, this study adopts the Wooldridge methodology to estimate production functions for installation TFP. The installation-level TFP is estimated as per equation (1).

$$log\ (TFP_{it}) = log(Y_{it}) - \hat{\alpha}_L log(L_{it}) - \hat{\alpha}_K log(K_{it}) - \hat{\alpha}_m log(M_{it}), \qquad (1)$$

where TFP_{it} is the total factor productivity for installation i in year t, Y_{it} is installation output, L_{it} and K_{it} are labor and capital inputs, respectively. M_{it} is the intermediate input including the expenditure of electricity and fuel (ten thousand yen) and intermediate material costs (ten thousand yen). $\hat{\alpha}_L$, $\hat{\alpha}_K$, and $\hat{\alpha}_m$ are elasticities that are estimated based on one-step GMM estimator suggested by Wooldridge (2009). This study follows Li et al. (2021) and Dang et al. (2024) employing installation output as the output measure, the number of employees as the labor input, fixed assets as the capital input, and the expenditure on raw materials and energy consumption as the intermediate input. To verify the robustness of the TFP estimation, this study also employs the Olley-Pakes methodology with the Ackerberg et al. (2015) correction following existing literature (Ren et al., 2022).

3.3. Empirical methodologies

The identification strategy uses in this study to ascertain the causal effect of the Tokyo and Saitama ETS on installation TFP employs the DiD method. Given the staggered nature of the announcement period of the two regional ETSs, this study adopts the DiD method based on the Callaway and Sant'Anna (2021) estimator to address heterogeneity in announcement year. This method provides a framework for estimating the average treatment effect (ATT) on the treated by defining treatment groups based on the specific time of adoption and comparing these groups to a suitable control group comprised of units not yet treated by that time. This approach can manage the heterogeneity in treatment effects over time and across different adoption cohorts, thereby enhancing the reliability of our estimates.

This study classifies installations regulated by ETSs as the treatment group, specifically those that exceed the energy consumption threshold for three consecutive years. Conversely, the control group consists of installations that have not yet been, and never have been, regulated by the ETSs within Japan. To account for observed confounders and time-invariant unobserved heterogeneity, a set of explanatory variables and store-level fixed effects are included in the model. Time fixed effects are also incorporated to control for common shocks affecting installations. Following Chen et al. (2024) and Clò et al. (2024), the DiD model based on staggered data is constructed as follows:

$$TFP_{it} = \alpha + \beta ETS_{it} + X_{it}\delta + \mu_t + \gamma_i + \varepsilon_{it}. \quad (2)$$

where TFP_{it} represents the TFP for installation i in year t. ETS_{it} is a dummy variable with a value of one for installation complying with the Tokyo or Saitama ETS. X_{it} is a vector of control variables, which includes employee pay (ten thousand yen), the shipment value of products (ten thousand yen), the export ratio, the usage of freshwater (m^3), and area (m^2). All continuous variables are logarithmically transformed. The subscript i refers to the installation, and t denotes the year. μ_t and γ_i are the annual fixed effect and installation fixed effect, respectively. ε_{it} is an error term.[4]

4. Empirical results

4.1. Result of TFP

This study presents an intuitive visualization of the results through a graph that plots the average estimated TFP based on the Wooldridge (2009) method for both regulated (treatment) and unregulated (control) installations (Fig. 2). The figure illustrates the TFP trend calculated by total energy expenditure for both groups over the study period, with the green line representing regulated installations and the blue line representing unregulated installations. The study identifies a consistent TFP gap between the regulated and unregulated installations, particularly during the announcement phase. A notable aspect highlighted in the figure is the abnormal decrease in TFP for both regulated and unregulated installations from 2008 to 2009, indicating that installations in Japan were affected by the global financial crisis. Conversely, a significant upward trend is observed after the implementation (years 2010 and 2011) exclusively for the regulated installations, resulting in a substantial gap between the two groups in the figure after 2010. This suggests that regulated installations may have adjusted their production activities in anticipation of environmental regulations, indicating a temporary improvement in productivity in compliance with new regulations. However, one or two years following the implementation of the ETSs, the trend converged again. This convergence suggests that the initial TFP gains observed in regulated installations were not sustained over the long term. Our data indicate that while ETS may enhance TFP in the short run, its long-term impact remains limited. This pattern underscores the necessity to further investigate

[4] The standard error was estimated using the Wild Bootstrap procedure with 1,000 repetitions.

the stage dynamics of ETSs' impact on productivity, particularly in the context of Japan's manufacturing sector.

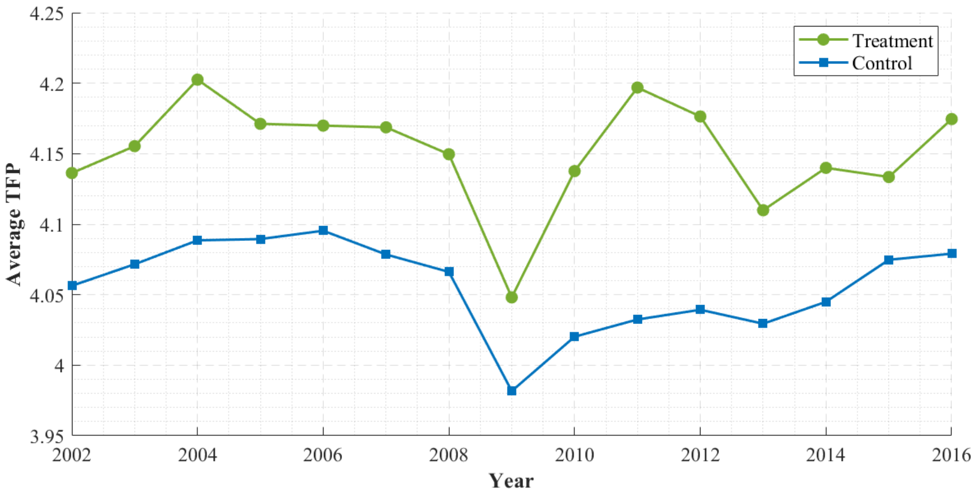

Fig. 2. Annual average total factor productivity across two groups.

4.2. Baseline and stage-dynamic results

4.2.1 Baseline result

The empirical findings for TFP, calculated based on energy expenditure and estimated using equation (2), are detailed in Table 3, Column (1). The coefficient of the ATT reveals that the announcement and implementation of Japan's regional ETSs has a positive and statistically significant effect on the TFP of regulated installations. Specifically, the ATT is 0.016 and significant at the 5% level, indicating that the TFP of regulated installations increased by approximately 1.6% relative to unregulated installations following the announcement of the ETSs.

This result indicates that the announcement and subsequent implementation of the ETSs prompted regulated manufacturing installations to enhance their productivity. The observed increase in TFP may be attributed to installations adopting more efficient production processes, investing in technology, or optimizing resource utilization in anticipation of future emissions reduction targets. Tokyo and Saitama announced the ETSs three to four years prior to their formal implementation, providing installations with a relatively extended transition period to adjust their strategies and operations. This early announcement likely mitigated the potential shock of sudden regulatory changes and facilitated a smoother adaptation to the new environmental regulations.

A further consideration is the increase in energy prices in Japan, particularly electricity prices, following the Great East Japan Earthquake in 2011. Since energy prices directly influence the calculation of TFP as input costs, an increase in energy prices without a corresponding increase in energy consumption would result in a decline in measured TFP. Specifically, if energy consumption remained stable or increased during the study period, higher energy prices would reduce TFP. This suggests that the study might underestimate the impact of the ETS on TFP. Unfortunately, due to data limitations, it is not possible to confirm individual installations' energy prices, and our estimation strategy thus represents the most accurate assessment possible under these constraints. To address this issue, we adjusted installations' electricity expenditure by incorporating an indicator derived from average regional electricity prices, as detailed in Section 5.3.

Table 3

The impact of ETSs on TFP calculated by energy expenditure.

TFP	(1)	(2)
ATT	0.016^{**}	0.020^{**}
	(0.007)	(0.008)
Controls	Yes	Yes
Fixed effects	Yes	Yes
Observation	202016	202019
Methods	Wooldridge	OP

Notes: This table presents the aggregation of the overall coefficient of ATT based on the Callaway and Sant'Anna (2021) estimator. Columns (1) and (2) display the coefficients of ATT derived using the Wooldridge methodology and the Olley-Pakes methodology, respectively. Observations that are never regulated and those not yet regulated serve as the control group. The standard error is estimated using the Wild Bootstrap procedure with 1,000 repetitions. Subsequent tables employ the same analytical procedures. *p < 0.1; **p < 0.05; ***p < 0.01.

4.2.2 Stage-dynamic results

While this study provides an overall ATT of Japan's regional ETSs on TFP, it is crucial to understand the variations in these effects across different regulatory stages. Environmental policies, such as ETSs, may not affect productivity over time. Instead, installations may require time to adjust before taking actions, such as investing in or adopting new technologies, which ultimately lead to increases in TFP. Clò et al. (2024) highlight this aspect, examining the dynamic impacts of environmental shocks and finding that their effects can vary between the short and long term.

In the context of Japan's regional ETSs, installations might initially face uncertainties and higher compliance costs. Over time, as they adapt their operational strategies and invest in energy-efficient technologies, productivity gains may become more pronounced. However, such improvements may only appear during specific compliance periods. To capture these time-dependent impacts, this study investigates how ETSs influence TFP at different regulatory stages, enabling the identification of periods when installations achieve the greatest productivity improvements. Specifically, this study distinguishes the period into the announcement stage, the period from announcement to the first compliance stage, and announcement to the early second compliance stage.

The stage-specific analysis is presented in Table 4. During the announcement period, $ATT_{announce}$ is 0.007 but not statistically significant, indicating that installations do not immediately enhance their TFP. In other words, although installations may start to conduct activities to comply with upcoming regulation or make early investments, such efforts do not translate into gains in productive efficiency at this initial stage.

Table 4

Stage-specific result of ETSs.

TFP	(1)	(2)	(3)
$ATT_{announce}$	0.007		
	(0.005)		
$ATT_{annfirst}$		0.017^{**}	
		(0.007)	
ATT			0.016^{**}
			(0.007)
Controls	Yes	Yes	Yes
Fixed effects	Yes	Yes	Yes
Observations	123684	176289	202016
Covering stages	Announcement	Announcement to first	Announcement to early second

Notes: *p < 0.1; **p < 0.05; ***p < 0.01.

However, the first compliance stage demonstrates a significant positive impact, which is indicated by $ATT_{annfirst}$. Combined with the results in Column (1), these findings suggest that, while installations do not exhibit immediate TFP improvements, they are able to implement effective operational adjustments during the first compliance period, resulting in measurable productivity gains. This result is also in line with the finding from Benatti et al. (2024) who mentioned that while the productivity growth might be reduced initially, it tends to be enhanced following the initial adjustment period.

Nevertheless, the impact of TFP improvements diminishes when examining the early second compliance stage. A considerable explanation, as reported by the Tokyo and Saitama governments, is that installations achieved substantial emissions reductions and productivity gains during the first compliance period. The reduction targets for the second compliance period are relatively low for the installations, which may not sufficiently incentivize further investments or technological advancements. In summary, the stage-dynamic analysis underscores the importance of considering temporal dynamics in assessing the impact of ETSs.

4.3. Robustness tests

4.3.1 Different methodologies on estimating TFP

While the baseline estimation of TFP utilizing the Wooldridge (2009) method yields relatively reliable results, confirming the robustness of our findings through the application of alternative methodologies is important. Employing different estimation techniques for TFP may provide evidence regarding the reliability of the TFP estimation. Consequently, this study re-estimates TFP using the Olley-Pakes methodology. Column (2) in Table 3 presents the results of this alternative estimation. The ATT is positive and statistically significant at conventional levels, with a range of 0.02, consistent with our baseline results. The similarity of the ATT coefficient estimate across different methods suggests that the effect of ETSs on TFP is a stable and robust finding.

4.3.2 Parallel trends

To ensure the robustness of our baseline results, this paper conducts supplementary analyses to evaluate the parallel trends assumption. A fundamental premise for obtaining a consistent estimate of the ATT in a DiD methodology is the parallel trends assumption. This assumption posits that, in the absence of treatment, the average outcomes for the treated and control groups would have followed the same trend over time. This study employs the estimator proposed by Callaway and Sant'Anna (2021), which necessitates that the parallel trends assumption holds conditionally based on observed covariates. Although it is unable to directly test this assumption empirically, we can assess whether the trends prior to the announcement are parallel, thereby evaluating its validity in the context of this study. The specification can be expressed as:

$$TFP_{it} = \sum_{\tau} \theta^{\tau} E_t^{\tau} + X_{it}\delta + \mu_t + \gamma_i + \varepsilon_{it}. \tag{3}$$

Here, τ takes value of from -5 to 9, where $\tau = -1$ denotes two years prior to the announcement, $\tau = 0$ represents the announcement year, and $\tau = 1$ indicates one year after the announcement. The year before the announcement is excluded from the estimation as it serves as the baseline year. The indicator variable E_t^{τ} equals 1 if installation i at time t is τ periods away from the announcement. The effects observed during the pre-announcement period are represented by θ_{τ}.

Table 5

The results of dynamic DiD.

TFP	(1)		(2)
θ_{-5}	0.005	θ_3	0.029
	(0.013)		(0.019)
θ_{-4}	-0.002	θ_4	0.045***
	(0.006)		(0.013)
θ_{-3}	-0.002	θ_5	0.011
	(0.010)		(0.010)
θ_{-2}	-0.005	θ_6	0.014
	(0.009)		(0.012)
θ_{-1}	0.004	θ_7	0.005
	(0.009)		(0.011)
θ_0	0.010**	θ_8	0.021*
	(0.005)		(0.011)
θ_1	0.002	θ_9	-0.019
	(0.007)		(0.023)
θ_2	0.010		
	(0.009)		
Controls		Yes	
Fixed effects		Yes	
Observation		202016	

Notes: *p < 0.1; **p < 0.05; ***p < 0.01.

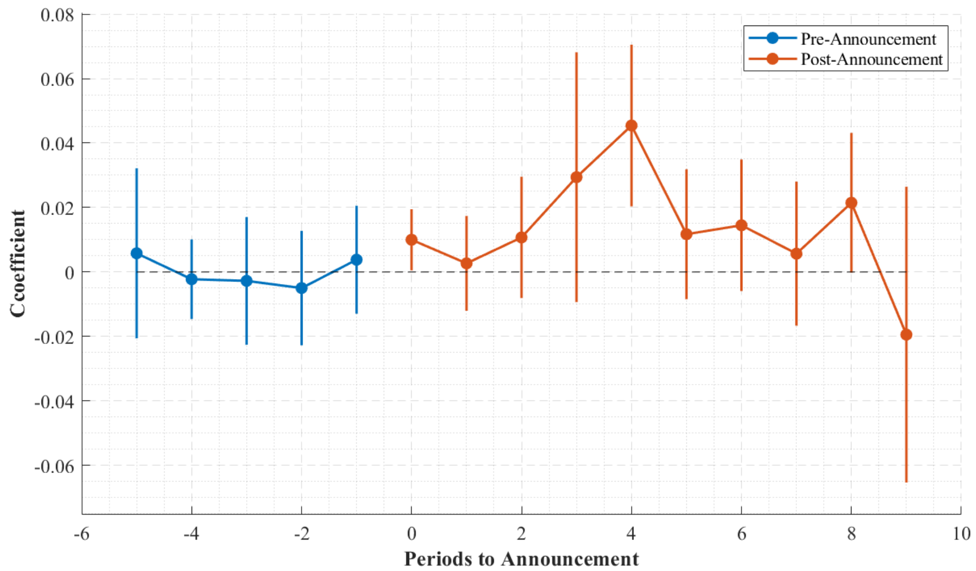

Fig. 3. Parallel trends.

Table 5 displays the estimated coefficients for various relative time periods, while Fig. 3 plots the pre-announcement estimates alongside their 95% confidence intervals. Under the null hypothesis that the parallel trends assumption is valid, these estimates should approximate zero. As shown in Fig. 3 and Table 5, the estimated effects during the pre-announcement periods are nearly zero and lack statistical significance. This absence of significant effects suggests that the treated and control groups exhibited similar trends prior to the implementation of the ETSs, thereby supporting the validity of the parallel trend assumption in our analysis. Consequently, this study concludes that the parallel trends assumption is upheld, thereby enhancing the credibility of the causal interpretation of our DiD estimates.

4.3.3 Placebo test

While the baseline results indicate that ETSs contribute to the enhancement of TFP, it is crucial to confirm that these improvements are not influenced by other unobserved factors or regulatory changes. To address this issue, this study adopts the methodology of Ferrara et al. (2012) and Cai et al. (2016), by randomly selecting installations from our full sample to serve as a counterfactual treatment group, thereby assessing whether the counterfactual treatment effect impacts TFP. Specifically, this study randomly select 162 installations (similar to the actually regulated installations in the matched sample) as the counterfactual group (Liu & Lu, 2015; Zhu et al., 2019; Yu & Zhang, 2022). To simulate the treatment assignment process, announcement years are randomly assigned to these installations, ensuring that the distribution of announcement years in the counterfactual group mirrors that of the actual treated group. For example, if 26 installations in the actual treatment group were announced in 2007 and 136 in 2008, then 26 randomly selected installations in the counterfactual group are assigned an announcement year of 2007, and 136 are assigned 2008. This procedure is repeated 500 times to obtain the distribution of the counterfactual estimators. Fig. 4 plots the density distribution of the counterfactual coefficients, which is concentrated around 0 with a mean value of 0.0039. The value of the ATT (dashed line) from the baseline result exceeds the value of the 95th percentile value of the counterfactual estimators (solid line), suggesting that the counterfactual effect is reached or exceeded in less than 5% of the 500 placebo tests. We conclude that there is no significant effect in these counterfactual datasets, and the baseline results are unlikely to be spurious (Li & Meng, 2023), indicating that omitted variables are unlikely to account for the effect on TFP.

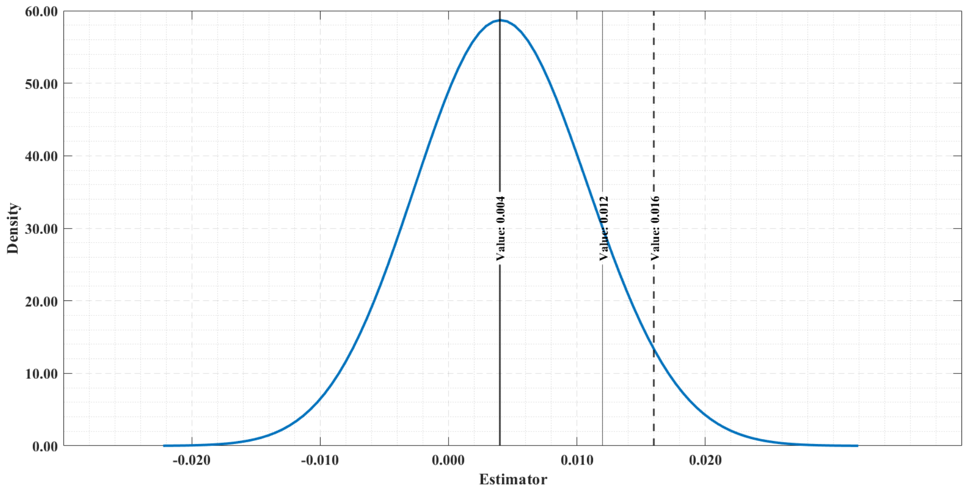

Fig. 4. Placebo test.

Notes: The kernel density estimation is applied to the coefficient values with an adjusted bandwidth to ensure a smoother representation of the density curve. This adjustment is implemented to enhance the interpretability of the plot, facilitating a clearer visualization of the overall trend. It is crucial to emphasize that this adjustment does not modify the underlying data values; rather, it improves the visual clarity of the distribution for more effective presentation.

4.3.4 Impact of ETSs on TFP in regions with uniform electricity price

While the baseline results utilize energy expenditure, such as electricity expenditure, to estimate TFP, regional variations in electricity prices may introduce bias into our analysis. Differences in electricity prices across regions can influence the cost of energy inputs independently of productivity changes, potentially confounding the estimated impact of ETSs on TFP. To address this issue, we conduct an analysis using only observations from prefectures mainly served by the Tokyo Electric Power Company (TEPCO) in the Kanto area. By focusing on regions served almost exclusively by a single electricity provider, we aim to minimize bias arising from regional electricity price differences.

The regions included in this analysis are Tochigi, Gunma, Ibaraki, Saitama, Chiba, Tokyo, Kanagawa, and Yamanashi prefectures.[5] By ensuring that installations are subject to a consistent set of electricity price structures, this study aims to eliminate regional price fluctuations that could confound our estimated TFP to the extent possible. We re-estimate the regional ETSs' impact on TFP using a DiD framework, as presented in Table 6 (1). The results indicate that the ATT is in line with the estimates from the baseline results (Table 5), suggesting that the impact of ETSs on TFP remains robust when controlling for regional electricity price differences. This supports the conclusion that ETSs have a positive impact on TFP in TEPCO-served regions. These findings enhance the reliability of our previous results and suggest that regional differences in electricity prices do not bias the estimated effect of ETSs on TFP. By restricting the analysis to regions with a uniform electricity provider, this study mitigates the potential confounding effect of heterogeneous energy costs on the study results.

Table 6

The results of impact of ETSs on TFP in restricted area.

	(1)	(2)
ATT	0.014*	0.001
	(0.008)	(0.005)
Controls	Yes	Yes
Fixed effects	Yes	Yes
Observation	59458	200490

Notes: *p < 0.1; **p < 0.05; ***p < 0.01.

4.3.5 Tests on SUTVA

The identification strategy employed in our analysis relies on the Stable Unit Treatment Value Assumption (SUTVA). This assumption posits that unregulated installations remain

[5] Shizuoka Prefecture was excluded from the analysis because only a portion of it is covered by TEPCO.

unaffected by other unregulated installations, a condition that is inherently untestable (Fowlie et al., 2012; Koch & Mama, 2019; Themann & Koch, 2021). Although SUTVA cannot be directly verified due to its reliance on unobservable counterfactuals, we can assess the potential for violations by examining specific cases where interference might occur. By analyzing the data under various configurations, we can evaluate whether our results are robust to potential spillover effects. To investigate possible violations of SUTVA, this study conducts robustness checks by constructing alternative treatment and control groups to estimate treatment effects.

Following the methodology of Oak and Bansal (2022), this study conducts robustness tests by constructing alternative treatment and control groups. Yang et al. (2023) argued that regulated firms may shift their investments to regions with lower regulatory levels, potentially causing spillover effects that could introduce estimation bias. In the context of this study, this implies that unregulated installations within the Tokyo and Saitama prefectures might be influenced by the ETSs, thereby violating the SUTVA assumption. Consequently, this study designates unregulated installations within Tokyo and Saitama prefectures as the alternative treatment group. Due to the staggered announcement of the ETSs, we assign the announcement year of 2007 to unregulated installations in Tokyo and 2008 to those in Saitama, corresponding to the actual announcement years for the regulated installations. The alternative control group comprises unregulated installations located in regions other than Tokyo and Saitama. All regulated installations are excluded from this analysis.

By treating the unregulated installations in Tokyo and Saitama as if they are subject to the ETSs, we can examine the potential spillover effects of ETSs on unregulated installations. If significant treatment effects are observed in this analysis, it would suggest that unregulated installations in Tokyo and Saitama prefectures are affected by the ETSs through regional spillovers, thereby violating SUTVA and potentially biasing our original estimates. The results are presented in Table 6, Column (2), which shows no significant evidence of ATT for alternative regulated installations, indicating no changes in TFP for unregulated installations within Tokyo and Saitama compared to those in other regions. This lack of significant effects suggests that potential violations of SUTVA due to spillover effects are unlikely to significantly bias our treatment effect estimates and confirms the robustness of our conclusions.

4.3.6 Tests on unconfoundedness

Estimating the ATT necessitates the critical assumption of unconfoundedness, which asserts that treatment assignment is independent of potential outcomes, conditional on a set of observed pre-treatment covariates (Armstrong & Kolesár, 2021). This assumption is vital to ensure that the estimated treatment effects are not biased by confounding variables.

This study employs the estimator proposed by Callaway and Sant'Anna (2021) to estimate the ATTs, acknowledging the potential for confounding issues. Although inverse propensity score weighting is utilized to achieve balance between treated and control groups on observed covariates (Imbens & Rubin, 2015), it remains imperative to evaluate the plausibility of the unconfoundedness assumption within our context. However, it is unable to empirically confirm the presence of confounding without relying on untestable assumptions. To address this limitation and enhance the credibility of our analysis, this study conducts several tests inspired by approaches in the existing literature.

Initially, following Valente (2023), this study attempts to address potential confounding by incorporating a set of pre-treatment characteristics into the estimation. These characteristics are factors that may influence both the likelihood of an installation being regulated under the ETSs and the potential outcomes related to productivity. According to Valente (2023), socio-economic characteristics such as income levels, building sizes, and labor-related variables have been controlled for, as they can affect both environmental performance and the propensity to adopt environmental policies. In our case, however, due to limitations in accessing detailed governmental statistics and confidentiality constraints, we are unable to merge our dataset with external data sources that contain such comprehensive pre-treatment characteristics. Nevertheless, this study controls for observable characteristics of the installations, such as the proportion of female employees. The results, presented in Table 7 Column (1), indicate a similarity in significance with the baseline result (Table 5). Therefore, the test on unconfoundedness suggests that our baseline result is reliable.

Second, this study employs an analytical approach that involves constructing a counterfactual scenario by artificially altering the timing of the treatment implementation (Löschel et al., 2019). This method is designed to assess whether the unconfoundedness assumption is violated by determining if the baseline result is influenced by other potential confounding factors. Such tests provide a way to evaluate the robustness of the analysis, specifically examining their validity against potential violations. This approach serves to check if an observed effect could manifest even in the absence of the actual treatment, which could occur due to other confounding factors or mere coincidences in the data (Eggers et al., 2023). In this study, a counterfactual treatment group is constructed by considering the installation two years prior to the announcement year for the Tokyo and Saitama ETSs separately.[6] This strategy aims to capture any influence from potential confounding factors that could interfere with the effects of the real announcement. If the announcement is indeed effective, insignificant effects should be observable in the counterfactual group during the placebo period. Conversely, significant effects during this period would indicate potential violations of the unconfoundedness assumption, suggesting that observed changes in electricity reduction might not solely be attributable to the treatment. Table 7, Columns (2) to (4), presents the results of the counterfactual analysis for both ETSs, Saitama ETS, and Tokyo ETS, respectively. The counterfactual treatment effects for the three scenarios are not statistically significant, indicating that there are no impacts on TFP attributable to the treatment. This confirms that no confounding factors affect the announcement effects observed during the actual announcement periods, suggesting that the reductions in TFP are attributable to the ETSs and not due to changes that might have coincidentally aligned with the timing of the announcement.

Table 7

Unconfoundedness test.

TFP	(1)	(2)	(3)	(4)
ATT	0.014^{*}	0.013	0.015	0.003
	(0.007)	(0.009)	(0.010)	(0.019)
Controls	Yes	Yes	Yes	Yes
Fixed effects	Yes	Yes	Yes	Yes
Observation	201535	202016	201761	200745
ETSs	Both	Both	Saitama	Tokyo

Notes: This table presents the aggregation of the overall coefficient of ATT based on the Callaway and Sant'Anna (2021) estimator. The table presents the aggregation of the overall coefficient based on the estimator by Callaway and Sant'Anna (2021). It reports the coefficients of ATT using the Wooldridge methodology. Observations that are never regulated and those not yet regulated serve as the control group. The standard error is estimated using the Wild Bootstrap procedure with 1,000 repetitions. *p < 0.1; **p < 0.05; ***p < 0.01.

5. Further analysis and discussion

5.1. Mechanism analysis on ETSs

[6] Given that the announcement year for Tokyo is one year before Saitama's, this study employs a two-year period prior to the announcement year to verify the violation as thoroughly as possible.

One mechanism by which regulated installations respond to ETSs is through the upgrading of equipment to more environmentally friendly alternatives, thereby enhancing productivity. This observation is consistent with the findings of Hamamoto (2021b), who noted that under the Saitama ETS, installations tended to invest in environmentally friendly equipment during the first compliance period. Similarly, Yu et al. (2023) argue that the strengthening of environmental regulations can increase the sales revenue of new products, thereby promoting industrial innovation and diversification. Conversely, when facing stringent environmental regulations, regulated installations may choose to outsource their production processes to unregulated installations to avoid high environmental costs. Outsourcing enables installations to concentrate on their core competencies while reducing compliance expenses. Therefore, in the context of our study, which identifies a statistically significant increase in TFP, particularly during the first compliance period, it is crucial to investigate whether investments in new machinery, buildings, and other operational adjustments contributed to this productivity improvement.

To explore these mechanisms, this study examines the impact on new equipment purchases, new building acquisitions, outsourcing expenditures, and changes in inventory levels (measured as the difference between year-start and year-end inventory), as presented in Table 8. Investments in new machinery and equipment can directly enhance production efficiency and productivity by incorporating advanced technologies and automation. Additionally, acquiring new buildings or upgrading existing installations can improve production processes through better layout, energy efficiency, and capacity expansion. Modern installations may also facilitate the integration of new technologies and workflows that enhance productivity.

The results presented in Table 8 Column (1) reveal that, regulated installations significantly reduced investments in new equipment, despite experiencing an increase in TFP, which presents a counterintuitive finding relative to Hamamoto (2021b). Several potential explanations exist for this observation. Firstly, installations might choose to upgrade or refurbish their existing equipment rather than acquiring new equipment. The increased costs associated with the ETS (Dechezleprêtre & Sato, 2017) may incentivize installations to conserve financial resources by enhancing existing equipment. This approach could enhance productivity without manifesting as increased expenditure on new equipment or a substantial change in overall fixed assets. This strategy is particularly viable under short-term financial constraints, enabling installations to comply with ETS requirements at reduced capital costs. Additionally, the limited availability and high cost of land in densely populated urban areas such as Tokyo and Saitama may pose barriers to physical expansion or the addition of new equipment. Second, regulated installations might tend to conduct more efficient management and operational practices rather than expanding their investments. Improvements in management practices can lead to enhanced performance and productivity independent of additional capital or equipment investments (Bloom & Van Reenen, 2010). Finally, regulated installations may prefer investing in intangible assets, such as knowledge and technology-based resources or human capital enhancement, rather than physical capital. These intangible capital improvements may enhance productivity but are not reflected in measures of equipment investment (Corrado et al., 2009), thus explaining the observed decrease in equipment investment alongside increased TFP under ETSs. Indeed, Hamamoto (2020) found that each regulated installation invests in intangible management systems instead of equipment to improve energy efficiency and mitigate CO_2 emissions during the first compliance period in Saitama prefecture. Therefore, the estimation results imply that the investment of regulated installations should focus on such intangible systems rather than tangible equipment.

Column (2) of Table 8 indicates an insignificant impact on building investments during the study period, suggesting that structural changes contributed to productivity gains during this time. The results from Column (3) demonstrate insignificant positive impacts on outsourcing activities. This suggests that installations subject to the Tokyo and Saitama ETSs, which are not exceedingly stringent, tended to comply with the reduction targets independently and aimed to improve their TFP to achieve long-term sustainability, rather than outsourcing their production processes to other installations. The lack of significant evidence suggests that Japan's regional ETSs may not exert additional pressure on installations to outsource production, even as regulated installations reduced their investment.

Results concerning changes in inventory levels are presented in Column (4), which can reflect adjustments in production planning, demand forecasting, and supply chain management. Efficient inventory management reduces holding costs, minimizes waste, and optimizes resource utilization, thereby contributing to higher productivity. The insignificant coefficients for the inventory gap indicate that regulated installations did not significantly alter their inventory levels compared to unregulated installations. This suggests that inventory management was not a primary mechanism through which the ETSs affected TFP.

Table 8

Mechanism analysis.

	(1) Equipment	(2) Building	(3) Outsource	(4) Inventory gap
ATT	-0.615***	-0.197	0.113	-824.906
	(0.145)	(0.185)	(0.147)	(3302.398)
Other ATTs	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
Fixed effects	Yes	Yes	Yes	Yes
Observation	161289	128673	202019	202019

Notes: This table presents the aggregation of the overall coefficient of ATT based on the Callaway and Sant'Anna (2021) estimator. Observations that are never regulated and those not yet regulated serve as the control group. The standard error is estimated using the Wild Bootstrap procedure with 1,000 repetitions. The inventory gap is not logarithmically transformed. This table exclusively displays coefficients from the announcement and compliance periods. *p < 0.1; **p < 0.05; ***p < 0.01.

5.2. Heterogeneity analysis on regional ETSs

While the Tokyo and Saitama ETSs have relatively similar regulatory frameworks and cooperative mechanisms, heterogeneity in their impacts on TFP may arise due to regional differences in industrial structures, installation characteristics, and enforcement stringency. Investigating the separate effects of the two regional ETSs allows us to understand whether and how the impact of ETSs on TFP varies between different regions. Consequently, this study differentiates between the Tokyo ETS and the Saitama ETS to assess their individual impacts on TFP. The results are presented in Table 9.

For the Saitama ETS, the results in Column (1) of Table 9 exhibit a pattern consistent with the baseline result, demonstrating positive effects during the compliance period. This suggests that the ETS in Saitama effectively incentivized installations to enhance their productivity, potentially through investments in energy-efficient technologies, process optimizations, or other productivity-enhancing measures. Conversely, the results for the Tokyo ETS in Column (2) indicate an insignificant impact of ETSs. This suggests that regulated installations in Tokyo do not experience improvements in TFP. This may be attributed to Tokyo's industrial structure, which is more service-oriented with a smaller proportion of manufacturing installations compared to Saitama, potentially affecting the overall impact of the ETS on productivity. Additionally, the smaller sample size of manufacturing installations in Tokyo could reduce the statistical power of the analysis, making it more challenging to detect effects. In summary, the results of the heterogeneity analyses indicate that while the Saitama ETS has a positive and statistically significant impact on TFP, the Tokyo ETS has an insignificant impact on TFP. These differences underscore the necessity of considering regional factors in policy evaluation and design.

Table 9

Individual impact of Tokyo and Saitama ETS.

TFP	(1)	(2)
ATT	0.017^{*}	0.011
	(0.009)	(0.013)
Controls	Yes	Yes
Fixed effects	Yes	Yes
Observation	201761	200745
ETSs	Saitama	Tokyo

Notes: This table presents the aggregation of the overall coefficient of ATT based on the Callaway and Sant'Anna (2021) estimator. Observations that are never regulated and those not yet regulated serve as the control group. The standard error is estimated using the Wild Bootstrap procedure with 1,000 repetitions. *p < 0.1; **p < 0.05; ***p < 0.01.

5.3. Analysis accounting for regional electricity prices

Given the regional disparities in electricity prices and their impact on input expenditures used in TFP measurement, there is a potential concern regarding the possibility of these variations introducing bias into the baseline results. This issue is particularly pertinent following the Great East Japan Earthquake in 2011, which resulted in increases in electricity prices in Saitama and Tokyo compared to other regions. Fig. 5 plots the trends in average electricity prices for Tokyo and Saitama in comparison to other regions, based on data from the annual financial statements of Japan's regional major electric power companies.[7] The figure demonstrates a similar trajectory in electricity prices between the treatment regions (Tokyo and Saitama) and the control regions (Other) throughout the

[7] The average price for each electric power company was calculated by dividing the revenue from electricity sales by the volume of electricity sold. Prior to 1999, many installations were required to purchase electricity from regional monopoly electricity companies due to government regulations in Japan. Since 1999, nearly all installations have had the freedom to choose their electricity suppliers in Japan as a result of government deregulation.

study period, showing a smaller gap between two groups around the announcement period.

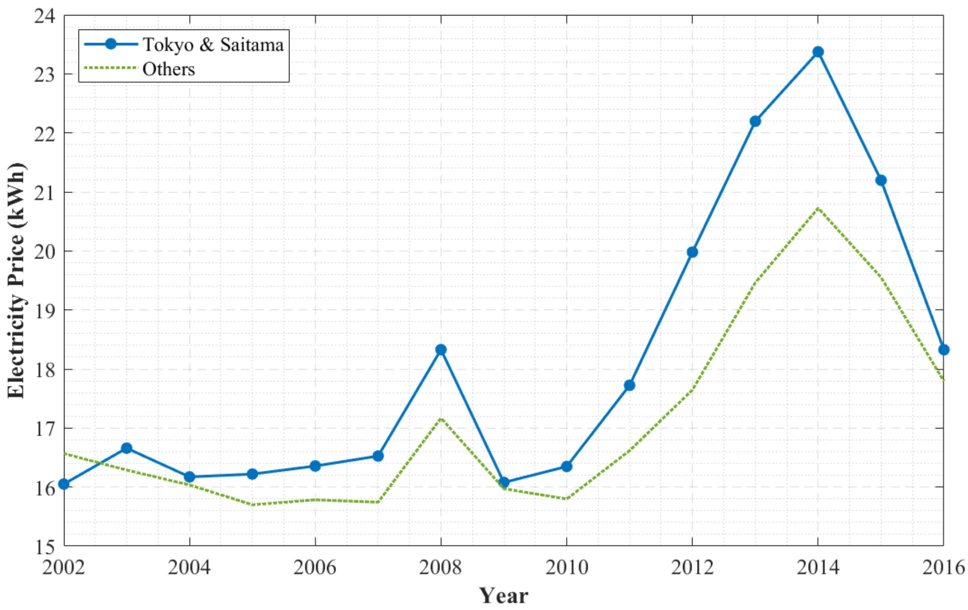

Fig. 5. Trends in electricity prices.

Note: In this figure, the Saitama and Tokyo regions are subject to the same electricity pricing as determined by the Tokyo Electric Power Company.

The price increases in Tokyo and Saitama regions may potentially affect the TFP measurement, as higher electricity prices directly raise input costs, thereby affecting measured productivity. Therefore, without considering these price variations might result in underestimating the impacts of the ETS on TFP. However, due to data constraints, detailed installation-level electricity prices are unavailable for this study. Nonetheless, this study endeavors to mitigate such biases by incorporating region-specific average electricity price indicators into the TFP calculation.

To achieve this, we utilize regional electricity price data from the electric power company that monopolistically supplied electricity to their respective areas prior to the commencement of market liberalization in 1999. Meanwhile, using Tokyo Electric Power Company's average electricity prices for 2002 as a baseline, we developed a deflator of electricity unit prices for each regional electric power company. This deflator is then applied to adjust the annual change in electricity expenditures of installations based on their geographic location (electric power company's service area before 1999), thereby enabling a more accurate measurement of installations' TFP adjusted for price variations.

Fig. 6 plots the trends in average adjusted TFP for the regulated and unregulated installations. Compared to the original TFP trends (Fig. 2), adjusting for regional electricity prices does not alter the patterns between the two groups. Meanwhile, Table 10 presents the estimation results of the impact of ETSs on adjusted TFP for each stage. While, after accounting for the regional variations in electricity prices, the range of coefficients in Table 10 does not appear to increase as mentioned in Section 4.2.1, the result is consistent with our baseline results, reaffirming the robustness of our findings. Overall, this analysis on adjusting for regional variations in electricity prices confirms that the baseline result is not driven by regional variations in electricity pricing, suggesting that the impact of ETSs is attributable to the regulations rather than a confounding regional prices factor.

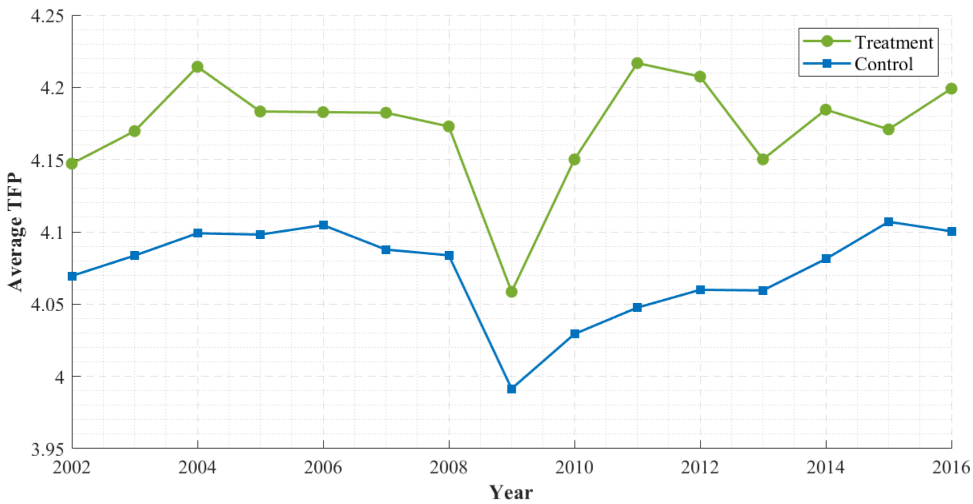

Fig. 6. Average adjusted TFP.

Table 10
Results considering regional electricity prices.

TFP’	(1)	(2)	(3)
$ATT_{announce}$	0.007		
	(0.005)		
$ATT_{annfirst}$		0.017^{**}	
		(0.007)	
ATT			0.016^{**}
			(0.007)
Controls	Yes	Yes	Yes
Fixed effects	Yes	Yes	Yes
Observations	123684	176289	202016
Covering stages	Announcement	Announcement to first	Announcement to early second

Notes: This table presents the aggregation of the overall coefficient of ATT based on the Callaway and Sant’Anna (2021) estimator. Observations that are never regulated and those not yet regulated serve as the control group. The standard error is estimated using the Wild Bootstrap procedure with 1,000 repetitions. *p < 0.1; **p < 0.05; ***p < 0.01.

6. Conclusion and policy implications

This study examines the influence of Japan’s regional ETSs, Tokyo and Saitama ETSs, on the TFP of manufacturing installations, employing a DiD methodology based on the Callaway and Sant’Anna (2021) estimator for the period 2002 to 2016. This study investigates how regional ETSs affect TFP especially during the announcement periods. It offers insights into the dynamic interaction between environmental regulations and productivity within Japan’s manufacturing industry.

The results show a positive impact of Japan’s regional ETSs on TFP, suggesting that the ETSs improve TFP within Japan’s context. The dynamic DiD analysis suggests that the improvement on TFP occur at the beginning of announcement and each compliance stage, especially during the first compliance period. Mechanism analysis further indicates that TFP growth is attributable to operational changes rather than increased capital investment. Regulated installations tend to adopt optimized inventory management, thereby enhancing efficiency without substantial expenditures on new equipment or installations. The heterogeneity analysis underscores that while the Saitama ETS consistently exerts a significant positive impact on TFP, the Tokyo ETS demonstrates a significant positive effect only at a specific stages, highlighting the importance of considering regional factors in policy evaluation. In summary, Japan’s regional ETSs positively affect TFP within manufacturing installations, primarily through strategic operational adjustments rather than capital-intensive investments. The most substantial productivity improvement occurs at the beginning of compliance periods, underscoring the importance of initial regulatory encouragement. The heterogeneity between the Tokyo and Saitama ETSs suggests that regional differences should be considered when designing and implementing policies.

The findings from this study carry significant policy implications. First, while environmental regulations must be stringent enough to ensure productivity improvement, financial pressures may hinder installations’ ability to invest in productivity enhancements, such as financial incentives and operational adjustments, particularly for small and medium-sized installations. Second, the observed decrease in TFP over time suggests a need for continuous evaluation of policy impacts. Policymakers should regularly assess the effectiveness of ETSs and be prepared to adjust regulations to sustain productivity enhancements and environmental benefits.

While this study offers significant insights, it also presents several limitations that suggest avenues for future research. Firstly, the absence of data on energy consumption, capital investments, and innovation constrains the study’s ability to comprehensively capture the mechanisms of ETSs. In particular, energy price variations may potentially impact the accuracy of TFP measurements. Consequently, future research could employ more detailed data to examine these mechanisms. Secondly, the analysis is confined to the initial stage of compliance and the announcement period. The estimated TFP trend depicted in Fig. 2 indicates that the TFP of regulated installations tends to decline in the second compliance period compared to the first. However, the sample for this study includes only two years of the second compliance period, precluding a definitive assessment of whether regulation in this period enhances the TFP of regulated installations. A more comprehensive understanding of the long-term effects of ETSs on productivity would benefit from the inclusion of subsequent compliance periods. Thirdly, exploring technological innovation and its interaction with environmental regulations could provide deeper insights into how ETSs affect TFP. Evaluating the adoption of new technologies and their impact on both emissions and productivity would enhance our understanding of the pathways through which ETSs exert their influence.

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Appendix

A.1 Analysis Excluding the Tohoku Region

A potential concern regarding our baseline results is the possibility that the Great East Japan Earthquake of 2011 may have influenced investment behavior, particularly prompting installations within the affected Tohoku region (Aomori, Iwate, Akita, Yamagata, Miyagi, and Fukushima) to reallocate resources towards rebuilding local installations rather than investing in new equipment elsewhere.

Table A.1.

Analysis without Tohoku region

	(1) TFP	(2) Equipment
ATT	0.016^{**}	-0.603^{***}
	(0.007)	(0.145)
Other ATTs	Yes	Yes
Controls	Yes	Yes
Fixed effects	Yes	Yes
Observation	185055	148203

Notes: This table presents the aggregation of the overall coefficient of *ATT* based on the Callaway and Sant'Anna (2021) estimator. Observations that are never regulated and those not yet regulated serve as the control group. The standard error is estimated using the Wild Bootstrap procedure with 1,000 repetitions. The inventory gap is not logarithmically transformed. This table exclusively displays coefficients from the announcement and compliance periods. *p < 0.1; **p < 0.05; ***p < 0.01.

The empirical results excluding the Tohoku region are presented in Columns (1) and (2) of Table A.1, which demonstrate that the ATT for TFP and new equipment investment closely align with the ATT in Table 3 Column (1) and Table 10 Column (1). Several explanations may account for this finding. First, while the Great East Japan Earthquake might have affected investment patterns, particularly by inducing rebuilding efforts or the purchase of new equipment in affected regions, the number of installations in our study is relatively small. Consequently, their exclusion may not significantly impact the aggregate results. This explanation is consistent with Todo et al. (2015), who argue that while the Great East Japan Earthquake induced disruptions such as severe supply chain issues, their aggregate impacts are often mediated or reduced at the national level. Second, even if the earthquake prompted local rebuilding efforts, those investments likely focused on the basic reconstruction of existing installations rather than on productivity-enhancing new equipment.

Therefore, this result indicates that the increase in TFP and reduction in equipment investments are unlikely to be attributed to earthquake-induced investment reallocations or reconstruction-related expenditures. Instead, the results underscore our interpretation in Section 5.1, which posits that the improvement in TFP is primarily achieved through enhanced operational efficiency in the production process or management rather than through an increase in new equipment investment.