Essays on the Impact of Carbon Mitigation Policies on Abatement and Innovation in Japan

GUANYU LU

(STUDENT ID: 3218A505-2)

Dissertation for

Doctor of Philosophy in

Economics

Submitted to
Graduate School of Economics
Waseda University
Tokyo

Supervisors:
Prof. Toshi H. Arimura
&
Prof. Yasushi Kondo

Acknowledgements

My Ph.D. journey at Waseda University has been a truly captivating and enriching experience. Successfully completing this endeavor would have been nearly insurmountable without the support and guidance provided by my supervisors, mentors, teachers, and family. As a Ph.D. student, I was afforded the privilege of broadening my horizons and forging invaluable connections with esteemed international scholars, whose insights I deeply cherish. I would like to convey my heartfelt appreciation to all the esteemed professors and dedicated office staff within the Faculty of Political Science and Economics for their support. The Ph.D. journey marks not only a significant milestone but also the commencement of my academic career. Fueled by the knowledge and experiences gained thus far, I am committed to redoubling my efforts and making meaningful contributions to both academia and society at large.

I cannot express the depth of my gratitude to my supervisor, Prof. Toshi H. Arimura, for his invaluable guidance, the opportunities he provided for attending workshops and conferences, and his unwavering support throughout my academic research. In particular, Prof. Arimura's encouragement and mentorship played a crucial role in transforming me from a novice into a researcher. Beyond academia, he also enriched my understanding of Japan's history, stories, and culture, which has greatly enriched my study abroad experience. Words fall short in expressing the immense appreciation I have for the generous assistance and support I received as his Ph.D. student.

I am deeply grateful to Prof. Makoto Sugino (Housei University) and Prof. Tetsuya Horie (Sophia University) for their guidance in completing my first paper during my Ph.D. journey. Although my initial struggles with research, they patiently mentored me on how to conduct thorough research and offered invaluable advice. Their support facilitated my accelerated learning, fostered my growth as a researcher, and helped me to conduct independent research. Additionally, I would like to extend my thanks to Prof. Nakai (Fukui Prefectural University) for assisting and guiding me through my first conference presentation and poster session. Prof. Nakai patiently taught me how to apply for research funding and improved my writing skills in Japanese, which helped me obtaining the JSPS KAKENHI grant. Moreover, I would also like to express my gratitude to Prof. Yasushi Kondo for providing me with the opportunity to serve as a Teaching Assistant for the econometrics course. This experience greatly enhanced my coaching skills. I am genuinely moved by the kindness and dedication of professors. I extend my sincerest gratitude to Prof. Taisuke Sadayuki (Seijo University) and Prof. Kenta Tanaka (Musashi University) for their guidance in writing economics papers and for providing me with opportunities to expand my knowledge of econometric methods and techniques. Their expertise was indispensable in the completion of Chapters 3 and 4 of my dissertation, and I am truly appreciative of their invaluable contributions. In particular, Prof. Kenta Tanaka's guidance in conducting facility-level studies and assistance in grant applications were invaluable. I also extend my sincerest gratitude to Prof. Akao for providing me with the opportunity to serve as a Research Assistant and staff member of the Asian Association of Environmental and Resource Economics (AAERE). Moreover, I am thankful to Prof. Han (Osaka Metropolitan University) for his help in securing my Ph.D. position at Waseda University, as the supervisor during my master's studies.

I must also acknowledge the vital financial assistance I received during my doctoral research. The SOMPO Environmental Fund, JSPS KAKENHI Grant Number 21K20134, Environment Research and Technology Development Fund of the Environmental Restoration and Conservation Agency of Japan (2-2008), China Scholarship Council, and Research Institute of Economy, Trade and Industry have generously supported my dissertation work, and their contributions have been instrumental in its successful completion.

Furthermore, I extend my gratitude to all the students in Prof. Arimura's research seminar for fostering a collaborative learning environment. In particular, I wish to express my appreciation to my friends Mriduchhanda Chattopadhyay, Naonari Yajima, and Hongyu Zhu, who have been consistent support and help over the past few years.

Finally, I cannot overlook the unwavering support of my family members in China, my mother, sister, uncle, and cousin, who have consistently stood by my side in times of need. They truly deserve my utmost respect and love. I would like to specifically acknowledge my father, my grandma, and my grandpa, who are no longer with us. I deeply regret not being present during their final moments, as I was out of the country at the time. Nevertheless, I believe they would be filled with immense joy today, witnessing the submission of my dissertation. It was their dream to see me earn my doctorate degree from Waseda University. I humbly seek their blessings and dedicate my doctoral dissertation to their memory.

Abstract

This dissertation comprises of three empirical papers in environmental economics focusing on both voluntary and mandatory environmental instruments in Japan, covering three key dimensions, industries, firms and facilities. This dissertation introduces three papers individually, emphasizing background, contributions and data.

The second chapter, titled "Success and failure of the voluntary action plan: Disaggregated sector decomposition analysis of energy-related CO_2 emissions in Japan", evaluates the role of the voluntary action plan (VAP) in emission reduction by analyzing highly disaggregated data of 197 sectors from 1980 to 2015 using the logarithmic mean Divisia index method. The results indicate that the increase in CO_2 emissions among Japanese industries is mainly caused by the increase in indirect CO_2 emissions. Moreover, the energy consumption structure has progressively shifted from fossil fuels to electricity. The decomposition analysis highlights two key points. (1) The VAP is ineffective in reducing emissions in sectors with low market concentration. (2) Energy intensity targets of the VAP does not lead to a significant reduction in CO_2 emissions. Thus, this chapter concludes that the contribution of the VAP in reducing CO_2 emissions is limited. Evidence from our research suggests four directions for future policy design and implications.

The third chapter, titled "Does Emissions Trading Scheme Induce Incentive of Innovation and Carbon Leakage? Evidence from Japan", investigates how firms make a decision between innovation and outsourcing under Japan's regional ETS by adopting the unique firm-level data from 2003 to 2018 based on the difference-in-differences method. The results highlight two key findings: (1) Japan's regional ETS promoted R&D while having no significant effect on outsourcing overall. The result suggests, by taking into consideration other studies finding no evidence of within-firm carbon leakage under the Japan's regional ETS, that the ETS has contributed to innovation activities without inducing carbon leakage. (2) targeted firms not actively engaged in R&D after the introduction of ETS increased outsourcings instead. This implies that the ETS may induce carbon leakage through outsourcing when the emission reduction target becomes overwhelming for the targeted firms to achieve by means of innovation.

The fourth chapter, titled "The impacts of the Tokyo and Saitama ETSs on the energy efficiency performance of manufacturing facilities", estimates the energy efficiency of facilities in Japan using stochastic frontier analysis (SFA) from 2002 to 2016 by using the Economic Census for Business Activity and Census of Manufacture, and explores the impacts of Tokyo and Saitama ETSs on energy efficiency. Our results highlight three key findings: (1) Energy efficiency of facilities that targeted by ETSs decreased during the announcement period. (2) Conversely, no difference in energy inefficiency between targeted and nontargeted facilities in the implementation period of the ETSs is found through the results. (3) the estimation results imply that carbon leakages through outsourcing did not occur during the implementation period.

Content

List of Tables

List of Figures

Chapter 1

Introduction

1.1 Background of environmental regulations in Japan

Greenhouse gas emission reductions have become a challenging issue for the world in recent years. To mitigate the salient impacts of climate change, Japan has actively participated in various conventions, such as the Kyoto Protocol and Paris Agreement.

Over the years, Japan's administration has proposed numerous environmental policies to reduce CO_2 emissions. For instance, between 2005 and 2012, the Japan Voluntary Emission Trading Scheme (J-VETS) was implemented, following the model of the EU-ETS. Its goal was to facilitate cost-effective and greenhouse gas reductions, while also accumulating knowledge and experience for officially implementing the ETS. Throughout its compliance period, up to 85 participating facilities managed to achieve emission reductions ranging from 9% to 29% based on the baseline year.

From 2008 to 2012, the Japan Verified Emissions Reduction (J-VER) scheme was launched, which offered carbon offset credits to firms and facilities (Hiroshima, 2012). Under J-VER, firms could earn emission credits for voluntarily reducing emissions; these credits could then be traded, offsetting some or all costs associated with emission reduction efforts. The scheme was beneficial to project members, such as local governments responsible for extensive forest management and facilities that faced challenges in reducing emissions to reduction costs. During the project period, the number of projects and verified credits increased to 201 and 155, accounting for 289,000 t-CO_2 emissions. Simultaneously, the Domestic Clean Development Mechanism (CDM) was implemented during that period, targeting small and medium enterprises to achieve the Kyoto Protocol's targets (Kuramochi, 2015). Large enterprises could receive credits by funding small and medium enterprises to help them meet their reduction targets, such as the voluntary action plan (VAP). Verified credits by the Domestic CDM increased from 92 to 2,432, accounting for 36,000 to 150,400 t-CO_2 emissions over this period.

Post 2012, the Japan Credit (J-Credit) was implemented by the central government, merging J-VER and Japan's domestic CDM (Kobayashi, 2016). J-Credit offered government-verified credits from projects such as the introduction of energy-saving equipment, the use of renewable energy, or CO_2 absorption through forest management. As of 2022, the projects and t-CO_2 emissions of verified credit are 975 and 8,890, respectively, with three-quarters of the credits coming from solar energy generation. The goal for 2030 is to reach 15,000 t-CO_2 emissions of verified credit.

In the same year as J-Credit's launch, the Japanese government implemented the Carbon Dioxide Tax as a countermeasure (an environmental tax for global warming; Arimura and Iwata, 2015). This tax aimed to reduce fossil fuel consumption, including oil, natural gas, and coal, playing a substantial role in promoting renewable energy and energy-saving measures in firms, facilities, and households in Japan. The tax was levied in three stages over three and half years, charging 289 yen per ton CO_2 emissions. Specifically, in the final stage, the tax rate for oil was 760 yen per kiloliter; for natural gas, it was 780 yen per ton, and for coal, it was 670 yen per ton.

It is apparent that most Japan's environmental regulations primarily target firms and facilities through the above introduction, albeit with one notable exception: the VAP. This was administered by the

Japan Business Federation (Keidanren) from 1997 to 2012 and targeted approximately 40 sectors, each with distinct emission reduction targets. These targets are classified as CO_2 absolute targets, CO_2 intensity targets, energy absolute targets, and energy intensity targets, aiming to reduce CO_2 emissions and solid waste generation (Sugino and Arimura, 2011). Compared with other environmental policies, the regulatory authority cannot penalize industrial associations that fail to meet the emission reduction target when they participate in the VAP. Moreover, individuals do not face stringent penalties even if they fail to achieve the target. The VAP's evaluation is important in the context of the Paris Agreement: if the VAP is effective, it can contribute to climate mitigation; if it is ineffective in the mitigation of CO_2 emissions, the Japanese government cannot rely on the voluntary approach to achieve the target under the Paris Agreement. Therefore, investigating the changes of CO_2 emissions from the manufacturing sectors in Japan can evaluate the effort of VAP on mitigation.

On the other hand, in the recent year, the emissions trading scheme (ETS) has become an effective tool to mitigate the impacts of climate change and gradually gained global the attention, as reported by IPCC (2023). The European Union (EU) implemented the first EU ETS in 2005, along with many other countries such as China, South Korea, and Austria. Japan launched two regional ETSs in the Tokyo and Saitama prefectures respectively.

In 2007, the Tokyo metropolitan government, announced that the first regional ETS in Japan would be started in 2010. The emission reduction target of Tokyo ETS of each facility was calculated based on the emissions between 2002 and 2006. Tokyo ETS covers approximately 1,700 facilities in all industries, including commercial and service ones, with an energy consumption of more than 1,500 kℓ of crude oil equivalent per year (approximately 2,800 tons of CO_2). The Tokyo ETS introduced step-by-step strength reduction targets based on the baseline emissions calculated from the CO_2 emissions of any consecutive three-year period between 2002 and 2006. Targeted facilities are obliged to report their CO_2 emissions to the local government and accept a third party to verify their reported CO_2 emissions. For the targeted manufacturing facilities, the first compliance period of the Tokyo ETS was 2010–2014 with a 6% reduction target, and the second compliance period was 2015–2019 with a 15% reduction target. If a targeted facility reduced emissions beyond the reduction target, it could receive credits in the equivalent amount (emissions allowances) for excess emission reduction, and allowances could be banked for only one following consecutive compliance period. If a facility had difficulty achieving its reduction targets, it could use not only emissions allowances but also alternative credits such as renewable energy credits and credits for small- and medium-sized facilities located in Tokyo. If the targeted facilities could not comply with the reduction targets, they would incur a penalty charge, and their names would be published.

Saitama prefecture, which is a neighbor of Tokyo metropolitan area, also introduced a regional ETS (Saitama ETS) one year after the Tokyo ETS was implemented. The design of the Saitama ETS mainly follows that of the Tokyo ETS, with the same year of announcement, covered industries, inclusion threshold, baseline emissions, trading method, and additional offset credits. Unlike the Tokyo ETS, which covers commercial and service industries, the Saitama ETS covers manufacturing facilities, which account for more than 70% of the total targeted facilities. Since the Saitama ETS was introduced one year later than the Tokyo ETS, the first compliance period was 2011–2014. However, different from the Tokyo ETS, the Saitama ETS has a unique feature: the targeted facilities are not penalized by any authority, even if they fail to comply with reduction targets. That is, the Saitama ETS is a voluntary ETS, which also makes it the only voluntary ETS in the world. For this reason, the reduction target of the second compliance period was relatively lax compared to the targets of the Tokyo ETS, which were set at 13% (the targets of the second compliance period were the same). Compared to the VAP, Japan's regional ETSs are suitable for analysis at the firm and facility levels.

1.2 Research objective and contributions of the dissertation

In the context introduced above, this dissertation aims to explore the extent to which Japan's environmental regulations and action contribute to carbon mitigation and technological innovation among the firm, facility and industrial level respectively from various aspects and in what ways. While a growing body of literature exists on environmental regulations, mainly focusing on the EU, US, and China, there is a gap in extensive evidence from other countries, particularly Japan. Regarding on voluntary environmental regulations, existing literature indicated the uncertainties and feasibility of the regulation in the EU and US (Paton, 2000; Cunningham and Clinch, 2004). Regarding the literature on the ETSs, the impact on innovation and carbon leakage are investigated in EU (Martin et al., 2013; Martin et al., 2014; Borghesi et al., 2015; Naegele and Zaklan, 2019; Calel, 2020) and China (Cui et al., 2018; Chen et al., 2020; Ren et al., 2022).

Japan, however, presents a unique scenario in the analysis of environmental regulations. First, the strong social norms in Japanese culture impose a greater societal responsibility on industries, firms, and facilities to comply with reduction targets. This is evident even in regulations without penalties, such as the VAP. Second, Japan's regional ETSs are characterized by free allocation and lower liquidity in allowance transactions, instrumental in mitigating carbon leakage risks. The limited effectiveness of these ETSs in price signaling may motivate firms to pursue emission reductions through internal technological innovations rather than other measures like production relocation that could lead to carbon leakage. This indicates that Japan's regional ETSs design may primarily drive firms towards achieving emissions reduction targets through technological innovation, rather than others such as relocation of production that may induce carbon leakage. Given these unique aspects, a detailed examination of the environmental regulation in Japan is important. Therefore, this dissertation focusses on VAP at the industrial level and ETSs at both firm and facility level, which offers a comprehensively evaluation and understanding of Japan's environmental regulations during long time period from an economic perspective. The contribution of this dissertation is are summarized as follows.

The second chapter examines the VAP's effectiveness on changes in CO_2 emissions from 1980 to 2011 in 197 sectors. To the best of my knowledge, only a limited number of studies have investigated the VAP, and none have done so at such a detailed sectoral level. This chapter offers an in-depth and comprehensive analysis of the factors, namely scale, composition, and technique effect, that influence changes in CO_2 emissions. While Wakabayashi and Arimura (2016) investigated the effectiveness of the VAP in aiding firms to meet reduction targets, this chapter pinpoints specific sectors regulated by VAP that have contributed to emission reductions across varied target types. Furthermore, I identify sectors that contribute CO2 emission reductions by analyzing market concentration data. Additionally, the existing literature mainly focused on direct CO_2 emissions; in contrast, this chapter considers both direct and indirect CO_2 emissions. Given the shift of energy consumption to electricity, analysis without considering indirect emissions may lead to the biased results; therefore, through the consideration of indirect CO_2 emissions, changes in CO_2 emissions across not only manufacturing sectors but also service sectors can be accurately assessed. In summary, this chapter fills the gaps in the existing literature by exploring the diverse effects of the VAP on changes in CO_2 emissions across different sectors.

The third chapter examines the effects of Saitama ETS on innovation and outsourcing-induced carbon leakage at the manufacturing-firm level by using official firm survey data—named from the Basic Survey of Japanese Business Structure and Activities—based on the difference in differences method. This chapter contributes to the literature by examining the substitutability between firms' innovation and outsourcing activities under the ETS, leveraging the Saitama ETS introduced in 2011. A growing body of literature explored the impacts of ETSs on technological innovation (Martin et al., 2013; Teixidó et al., 2019; Calel, 2020), and carbon leakage (Koch and Basse Mama, 2019; Gao et al., 2020; Bartram et al., 2022). While many studies investigated how ETS affects firms' innovation in many countries, no study focused on the innovation in Japan at the firm level. Hamamoto (2021) conducted a study on the enhancement of low-carbon technology under the Saitama ETS, utilizing facility-level data and focusing on the adoption of high-efficiency machinery and devices. However, innovation predominantly occurs at the firm level; as such, a comprehensive assessment of innovation, as undertaken in this chapter, is both timely and essential. Additionally, Sadayuki and Arimura (2021) also investigated the impact of ETSs on carbon leakage in Japan, specifically examining CO_2 emissions within firms, which leaves room for further investigation. Moreover, this chapter focuses on firms that had a priori innovation activity. Environmental regulations aim to spur firms to improve environmental performance to reduce emissions. Firms that pursued innovation independently before the ETS may continuously make considerable effort to develop after ETS, and an experience of innovation success would encourage firms to pursue subsequent innovations. This argument is also applicable to the case of firms under ETS. However, no existing study has examined whether the targeted firms that adopted innovation contributed to subsequent innovation after the ETS. Further, empirical studies that have examined carbon leakage—and in particular, outsourcing-induced carbon leakage under the ETS—are still limited.

Unlike the third chapter, which uses firm-level data, the fourth chapter explores the effects of Japan's regional ETSs on energy efficiency performance and carbon leakage at the facility level based on data from the Census of Manufacture and Economic Census for Business Activity. This chapter builds upon prior research by offering a facility-level analysis in Japan, specifically focusing on the Tokyo and Saitama ETSs. While some studies investigated whether ETSs improve energy efficiency performance (Borghesi et al., 2015; Lutz, 2016; Chen et al., 2021), only a few analyzed such effects at the facility-level. By focusing on facilities that directly participate in the production process, it is possible to accurately assess the impact of ETSs on energy efficiency compared to the literature that has not used facility-level data. To my knowledge, Löschel et al. (2019) is the only study to use facility-level data (accumulated at the firm level) to analyze the impact of the EU-ETS on energy efficiency. Moreover, this chapter investigates how targeted facilities prepared to comply with ETSs before the implementation. Targeted facilities may respond to ETSs before their implementation to comply with uncertain upcoming emission-reduction costs. During the announcement period, targeted facilities already understand the emission reduction required to comply with the regulation of ETS, which enables them to adopt strategies to comply with the upcoming reduction targets. Although the emission amount during the announcement period does not affect emission reduction, the results still show that targeted facilities' energy inefficiency increase during this period. That is, this chapter confirms the importance of considering the effect during the announcement period when analyzing the ETS.

Chapter 2

Success and failure of the voluntary action plan: Disaggregated sector decomposition analysis of energy-related CO_2 emissions in Japan

2.1 Introduction

The Japanese government has been working to mitigate the salient impacts of climate change by actively participating in many conventions, such as the Kyoto Protocol and the Paris Agreement. In the context of climate change policy, the 2016 Paris Agreement has become the most important agenda for the Japanese government. This is not the first time the Japanese government has worked on climate change policy. The government has been working on the issue since the birth of the Kyoto Protocol.

To avoid governmental intervention in the form of environmental regulations, the Keidanren implemented the VAP to reduce GHG emissions and solid waste generation from 1997 to 2012 (Sugino and Arimura, 2011). Before 2010, Japan implemented a few voluntary carbon pricing policies to achieve emission reductions. Unlike the European Union (EU) under the Kyoto Protocol, Japan did not implement a mandatory carbon policy, such as a domestic emission trading scheme (ETS) or a carbon tax, to combat climate change. In the Japanese manufacturing sector, emission reduction mainly relied on the VAP. Compared with other environmental policies, the regulatory authority cannot penalize industrial associations that fail to meet the emission reduction target when they participate in the VAP. Moreover, individual firms do not face penalties even if they fail to achieve the target. The evaluation of the VAP is important in the context of the Paris Agreement. If the VAP is effective, it can contribute to SDGs as well as climate mitigation. If the VAP is ineffective in the mitigation of CO_2 emissions, the Japanese government cannot rely on the voluntary approach to achieve the target under the Paris Agreement.

Since the VAP is voluntary, it lacks core principles that constitute existing environmental, climate change, and energy laws (Heffron et al., 2015). For example, the “polluter pays principle” and the “principle of energy justice” is not fulfilled because the VAP targets are based on industrial targets rather than firm-specific targets, which leads to burden inequality. If the VAP is ineffective, then regulatory intervention in the form of energy tax reforms or rational use of energy based on the principle of energy laws will be necessary.

Many studies have investigated the effectiveness of voluntary energy and environmental policy approaches. Brophy et al. (1995) pointed out that it is difficult to improve the environmental performance of firms without using the legislative approach alongside the voluntary approach. Paton (2000) argued that there are uncertainties associated with the effectiveness and efficiency of voluntary programs compared with other policy instruments. The case study found that the environmental policy based on the voluntary partnership in the U.S. did not achieve the interim objectives. Cunningham and Clinch (2004) questioned the feasibility of voluntary approaches as environmental policies. They addressed three issues: the presence free riders, shortage of funds to enforce the regulation, and the lack of public awareness of voluntary approaches. This chapter can be categorized in this stream of studies. In particular, it is categorized as a case study of a policy inducing the collapsed incentive of firms. As pointed out by Brophy et al. (1995), Keidanren 's VAP failed to form the proper incentives to encourage firms to reduce emissions.

As Jones and Yoo (2009) argued, pressure from society, the government, and nongovernmental organizations encourages firms to comply with voluntary targets. Thus, firms' reputations may be damaged if they do not participate or fail to meet the targets set forth by the VAP, which would inflict indirect damage on these firms. In addition, the progress of the VAP was monitored by a governmental committee under the Ministry of Economy, Trade and Industry (METI). Furthermore, the JFB allowed associations and industries to set the type of target themselves, which were classified as CO_2 absolute targets, CO_2 intensity targets, energy absolute targets, and energy intensity targets (Arimura, 2015). Few studies have focused on individual firms in terms of whether they met the voluntary targets. For instance, Wakabayashi and Arimura (2016) observed that the VAP encourages small and medium-sized enterprises (SMEs) to set reduction targets. However, Arimura et al. (2019) suggested that agreements on voluntary targets can be relatively achieved easily when emissions are concentrated among few firms.

However, it is necessary to clarify whether emission reduction was achieved successfully through the implementation of the VAP or through other factors, such as changes in the industrial structure, technical innovation, and economic recessions. Therefore, this chapter quantifies the driving factors behind the changes in energy-related CO_2 emissions, which will provide us with valuable information to evaluate the effectiveness of current and future policies and thus enable us to provide options in designing regulations to realize emission reduction targets.

2.2 Methodologies

The logarithmic mean Divisia index (LMDI) method has been widely used to investigate the drivers of changes in CO_2 emissions. The advantages of the LMDI method include 1) the ability to factor reversal properties without leaving residuals, 2) the handling of zero values, and 3) consistency in aggregation (Ang, 2015; Zhang et al., 2016). Moreover, both additive and multiplicative decomposition analyses are used in the LMDI method. Additive decomposition analysis exhibits the aggregation of quantity-decomposed effects with a physical unit (Wang and Feng, 2017), while multiplicative decomposition analysis exhibits the aggregation of intensity-decomposed effects without a physical unit (Su et al., 2017). In this chapter, the additive LMDI method is adopted to investigate the changes in direct and indirect CO_2 emissions in Japan from 1980 to 2015. The detailed calculation of CO_2 emissions is shown in Appendix of second chapter. To evaluate how each sector contributes to the changes in CO_2 emissions in the long term, this chapter decomposes the changes in CO_2 emissions into scale, structure composition, and technique effects at the most detailed sectoral level based on an input-output table of Japan. The scale effect reflects the changes in pollution emissions brought about by changes in economic activities, the composition effect represents the changes in emissions induced by changes in the industrial structure, and the technique effect reflects the changes in emissions due to changes in emission intensity.

Since the total CO_2 emissions are emitted by *N* sectors in an economy, each sector emits co_{2i}. Let yi represents the output for sector i, Y represents the total output for the entire economy, and e_i represents CO_2 emission in sector i. Thus, following Levinson (2009), the aggerated CO_2 emissions can be written as:

$$CO_2 = \sum_{i=1}^{N} co_{2i} = \sum_{i=1}^{N} \frac{co_{2i}}{yi} \times \frac{yi}{Y} \times Y = \sum_{i=1}^{N} e_i = Y \sum_{i=1}^{N} \varphi_i \theta_i, \quad (2.1)$$

where θ is the share of sectorial output to total output, and φ is the CO_2 intensity for each sector. In the additive LMDI method, the changes in CO_2 emissions between period t and the previous period $t-1$ are represented by three factors:

$$\Delta CO2 = CO2^t - CO2^{t0} = \sum_{i=1}^{N} e_i^t - \sum_{i=1}^{N} e_i^{t-1} = \Delta E_{tot} = \Delta E_Y + \Delta E_{\varphi_i} + \Delta E_{\theta_i}, \tag{2.2}$$

where the three elements in equation (2.2) represent the scale (ΔE_Y), composition (ΔE_{φ_i}), and technique (ΔE_{θ_i}) effects. e_i^t is the emissions in period t for sector i. The LMDI method leaves no residual in the decomposition process, leading to its uniqueness. Furthermore, logarithmic changes are used to show the effect of changes in E_{tot}, and the logarithmic average of two elements in two periods is used to explore the effect of the contribution of factors. For additive decomposition, the changes in CO_2 emissions are decomposed using the following equation:

$$\Delta E_{tot} = \Delta E_Y + \Delta E_{\varphi_i} + \Delta E_{\theta_i}$$
$$= \sum_i L\left(e_i^t, e_i^{t-1}\right) \ln\left(\frac{Y^t}{Y^{t-1}}\right) + \sum_i L\left(e_i^t, e_i^{t-1}\right) \ln\left(\frac{\varphi_i^t}{\varphi_i^{t-1}}\right) + \sum_i L\left(e_i^t, e_i^{t-1}\right) \ln\left(\frac{\theta_i^t}{\theta_i^{t-1}}\right), \tag{2.3}$$

where the element, $L\left(e_i^t, e_i^{t-1}\right)$, is given by the following:

$$L_i\ \left(e_i^t, e_i^{t-1}\right) = \frac{e_i^t - e_i^{t-1}}{\ln e_i^t - \ln e_i^{t-1}}. \tag{2.4}$$

Combining equations (2.3) and (2.4), the three effects are calculated through the equations in the additive LMDI method as follows:

$$\Delta E_Y = \sum_i \frac{e_i^t - e_i^{t-1}}{\ln e_i^t - \ln e_i^{t-1}} \ln\left(\frac{Y^t}{Y^{t-1}}\right). \tag{2.5}$$

$$\Delta E_{\varphi_i} = \sum_i \frac{e_i^t - e_i^{t-1}}{\ln e_i^t - \ln e_i^{t-1}} \ln\left(\frac{\varphi_i^t}{\varphi_i^{t-1}}\right). \tag{2.6}$$

$$\Delta E_{\theta_i} = \sum_i \frac{e_i^t - e_i^{t-1}}{\ln e_i^t - \ln e_i^{t-1}} \ln\left(\frac{\theta_i^t}{\theta_i^{t-1}}\right). \tag{2.7}$$

2.3 Data

This chapter combines the 2011 "Embodied Energy and Emission Intensity Data for Japan Using Input–Output Tables" (3EID) (Nansai, 2019) and Japan's input–output table from 1980 to 2015. The 3EID provides information on energy consumption and emission factors for more than 30 types of fossil fuels, such as coke, fuel oil A, gasoline, and naphtha, which are directly consumed by sectors classified in the Japanese input–output table, which allows us to analyze the trend of CO_2 emissions. Additionally, it should be noted that the data used in this chapter does not account for CO_2 emissions originating from international marine oil. The Value and Quantity Tables (VQT), providing consumption of electricity, private power generation, and steam and hot water supply, is used in this chapter for calculating the in direct CO_2 emissions. Besides, this chapter calculates the weighted average of the market concentration ratio (top four firms) of relative sectors that corresponds to the sector classification by adopting information from the Japan Industrial Productivity (JIP) database[1].

2.4 Results

2.4.1 Changes in CO_2 Emissions

This chapter attempts to analyze the changes in total CO_2 emissions at the national level. Concurrently, this chapter makes a modest attempt to analyze the changing trends and characteristics in Japan.

<Fig. 2.1 approximately here>

Fig. 2.1 presents direct and indirect CO_2 emissions at the industrial level, highlighting the manufacturing, service, electricity, gas and heating supply industries. From 1980 to 2015, the Japanese industry experienced an increase in overall CO_2 emissions from 737 mt-CO_2 to 1,016 mt-CO_2, with the peak in 2015 (approximately 13% higher than that of the 1990 level). The decline in total CO_2 emissions during the period from 2005 to 2011 reflects the Great Financial Crisis from 2007 to 2008 and the Great East Japan Earthquake in 2011. For instance, it can be observed that the total CO_2 emissions of the manufacturing industry gradually increased from 424 mt-CO_2 in 1980 to 477 mt-CO_2 in 2015. In 2015, while the CO_2 emissions of the manufacturing industry dropped by 4.2% compared to 2011, they still accounted for 47% of the total CO_2 emissions. As evident from Fig. 2.1, direct CO_2 emissions decreased while indirect emissions increased in the manufacturing industry. More importantly, the share of indirect emissions to total emissions increased during the period, especially in the service industry, indicating that the structure of energy consumption within Japanese industries has gradually shifted away from fuel consumption toward electricity.

Since the structure of energy consumption has shifted to electricity, indirect CO_2 emissions need to be considered. The analysis reveals that ignoring indirect emissions leads to the illusion that CO_2 emissions have decreased within the manufacturing industry since 1990. However, when indirect CO_2 emissions are considered, CO_2 emissions in the manufacturing industry have actually continued to increase since 2005. This implies that excluding indirect emissions can be misleading.

In contrast to the manufacturing industry, I find that the total CO_2 emissions of the service industry have increased significantly since 1980. It must be noted that the service industry does not use fossil fuels as much as the manufacturing industry. Thus, direct CO_2 emissions alone do not represent the actual total CO_2 emissions situation. Hence, indirect CO_2 emissions are very important. The indirect CO_2 emissions of the service industry grew by 53% from 1990 to 2015, from 43 mt-CO_2 to 67 mt-CO_2. By comparing the share of total CO_2 emissions of the manufacturing and service industry, I find that the share of the manufacturing industry declined from 58% to 48%, whereas the percentage of the service industry doubled from 5.2% to 10.7% during the same period.

By comparing the manufacturing industry results with those of the service industry, the findings show that the shares of total CO_2 emissions of the manufacturing and service industries accounted for 58% and 5.2% in 1980 and 48% and 10.7% in 2015, respectively. The percentage of the service industry doubled during these 35 years in Japan, illustrating the increases in economic activity of the service industry and the

[1] I began by aligning the JIP sector with the 197 sectors discussed in this chapter. Subsequently, using the market concentration ratio (top four firms) from 1996 as a basis, I recalculated the ratio for sectors regulated by VAP based on the output of each sector from 1995.

growing burden that this industry is placing on the environment. I can also identify this change in a finer sector classification. In the manufacturing sector, I observed a constant decrease in the output from the woven fabric apparel, cement, and video equipment sectors. In contrast, I observe a constant increase in output from the “health and hygiene” and “social welfare” in the service sector. To analyze the driving forces behind the changes in CO_2 emissions, I discuss the results of the additive LMDI method based on equation (2.4) in the next section.

2.4.2 Decomposition Results at Industrial level

Fig. 2.2(A) and (B) show the industrial-level results of the composition and the technique effect for the manufacturing and service industries, respectively. Since the scale effect represents the entire effect of all industries, it is not decomposed at the industrial level. The bar on the far right shows the overall effect between 1990 and 2011, when the VAP was implemented. For the manufacturing industry, the technique effect increased emissions by approximately 50 mt-CO_2 between 1990 and 2011, while the composition effect decreased emissions by more than 250 mt-CO_2 during the same period. The technique effect initially increased CO_2 emissions before 2000 and then reduced CO_2 emissions afterward, and the maximum value was achieved between 1990 and 1995. This finding indicates that the CO_2 intensity has gradually improved compared with the prior period. The contribution of the composition effect in reducing emissions from the manufacturing industry reached 250 mt-CO_2 from 1990 to 2011, which may reflect the decline in domestic output and the fact that developing countries attract dirty production processes or investments from developed countries, due to a lack of stringent environmental regulations (Copeland and Taylor, 2004).

<Fig.2 .2 approximately here>

In contrast, Fig. 2.2(B) shows a positive value for the composition effect for most periods, implying that the composition effect of the service industry increases CO_2 emissions. The technique effect from 1990 to 2011 is negative. However, if I examine the technique effect in detail, I observe that the technique effect is positive, meaning that it has increased CO_2 emissions since 2000. This finding indicates that the CO_2 emissions of the service industry cannot be ignored, and thus, it is necessary to consider regulations to reduce CO_2 emissions from the service industry.

2.4.3 Decomposition Results for the Sectors that Participated in the VAP

The previous section focused on the entire manufacturing and service industry. However, the results for sectors within the manufacturing industry may differ greatly due to the VAP. Thus, in this section, I will focus on sectors that participated in the VAP, which not only provides the most detailed emission reduction information but also allows us to investigate the effectiveness of the targets set forth under the VAP.

JFB announced the “Voluntary Action Plan on the Environment” in an effort to reduce emissions while inhibiting a firm's economic burden. JFB’s VAP allows industrial or trade associations to voluntarily set targets regarding CO_2 emissions, CO_2 intensity, energy consumption, and energy intensity, with the aim of reducing the emissions from relevant firms by installing new environmental technology or improving the efficiency of their production processes. Note that none of the firms are obligated to achieve the target set by the associations within their sectors. Although the VAP is free from regulatory surveillance, the Japanese government conducts annual evaluations and verification of the progress made through relevant advisory councils.

<Table 2.1 approximately here>

Table 2.1 summarizes the sectors that participated in the VAP. These sectors are categorized into three groups by the type of target set by each sector. The first group is the absolute target, which specifies the total amount of GHG emissions or energy consumption reduction that must be achieved. The second group is the intensity target, which aims to improve the emissions intensity or energy intensity. The third group is the mixed target, which contains both absolute and intensity targets. Since emission reduction in the manufacturing sector in Japan mainly relied on the VAP before 2010, the technique effect between 1990 and 2011 can be partially reflected by the impacts of the VAP.

<Table 2.2 approximately here>

Table 2.2 shows the results of the composition and technique effect from 1990 to 2011. The composition effect is negative for approximately 70% of the sectors that participated in the VAP. In contrast, the technique effect was negative for only 40% of the sectors. Compared with the decomposition results at the industrial level, the reduction in emissions for the sectors that participated in the VAP is attributed to the composition effect, not the technique effect. Moreover, the relationship between the types of VAP targets and the signs of the technique effect is ambiguous. In particular, the technique effect for sectors with energy intensity targets does not exhibit negative values (i.e., a decrease in emission intensity), except for the aluminum sector. This fact implies the following. (1) The energy intensity target of the VAP failed to reduce CO_2 emissions by improving production processes. (2) The VAP failed to achieve energy justice in the manufacturing industry. If the Japanese government intends to achieve the 2030 Japanese targets, it cannot rely on only the VAP. Other sectors, such as the household and transportation sectors, need to compensate for the shortcomings of the manufacturing industry.

The decomposition results at the sector level did not show a clear-cut relationship between the type of target set under the VAP and the technique effect. To further explore why the impact of the VAP shows different signs for the technique effect at the sectoral level, I investigate the correlation between the technique effect and the market concentration[2], which is shown in Fig. 2.3. The market concentration of a given sector is considered as an important characteristic that affects firm behavior such as investment decisions (Chortareas et al., 2021). The horizontal axis represents the market concentration (in percentage), while the vertical axis depicts the technique effect value (in t-CO_2).

<Fig. 2.3 approximately here>

I find that sectors with markets that are more concentrated tend to have larger technique effects. This trend can be observed for the following reasons. First, social pressure from investors and consumers has caused firms to become more socially responsible for their production and management, which leads to larger firms reducing CO_2 emissions. In addition, stakeholders have increasingly demanded that firms disclose information about their energy consumption and GHG emissions (Melville and Whisnant, 2014).

[2] The market concentration becomes higher as the number of firms in the sector decreases, and vice versa. However, note that this trend may be influenced by inter-firm competition and the exit of firms from the industry.

Second, the Japanese government conducts an annual evaluation and verification of the progress in terms of how much each sector has fulfilled its VAP target. These evaluation and verification reports are publicly available through the internet. Third, the smaller the number of firms in a given sector, it is more likely that the social and association pressure placed on each firm is to increase (Azar et al., 2020). Hence, firms in a sector with higher market concentration are highly motivated to achieve the sectoral VAP target through the adoption of green production technologies, which is reflected in the technique effect. In other words, the impact of the VAP is smaller for sectors with lower market concentration. Fourth, despite the non-penalty nature, the VAP successfully reduced emission to a certain degree. This may be related to strong social norms within the Japanese culture. Thus, firms continue to make efforts towards reducing emissions because of peer pressure. COVID-19 is interesting evidence of this cultural tendency: Although there are no penalties, most Japanese people still wear masks and have been vaccinated.

I can consider another reason for this observation. In addition to large firms, SMEs that joined the JFB are also restricted under the VAP. However, the total R&D expenditure of large firms is 15 times higher than that of SMEs, based on a whitepaper on SMEs in Japan. This indicates that large firms have more financial resources to carry out technological innovation than SMEs to meet the VAP target. Moreover, the sector with high market concentration is dominated by large firms. Thus, individual outcomes of efforts to reduce CO_2 emissions by large firms in a sector with high market concentration can appear more directly. In contrast, if a sector is constituted by many SMEs (a lower level of market concentration), the emission reduction effect from the VAP may be difficult to observe, since actions taken by small firms are not apparent compared to those of large firms. Thus, a positive sign of the technique effect is observed in Fig. 2.3 for sectors with low market concentration.

2.5 Conclusion

This chapter evaluates the effect of the VAP by adopting the additive logarithmic mean Divisia index (LMDI) method from 1980 to 2015 in Japan. Concurrently, this chapter explores the driving forces behind CO_2 emissions at the disaggregated level in Japan and investigated the trends of direct and indirect CO_2 emissions. The analysis reveals that total CO_2 emissions have increased during the study period, with emissions from the manufacturing industry peaking in 2011. However, CO_2 emissions from manufacturing industry still constitute approximately 45% of Japan's total CO_2 emissions. In particular, the direct CO_2 emissions of the manufacturing industry decrease, whereas indirect CO_2 emissions increase. This trend suggests a restructuring of energy consumption from fossil fuels to electricity. Conversely, CO_2 emissions from the service industry continue to increase throughout the study period, indicating insufficient control over emissions from service industry.

Based on the decomposition analysis, I find that the reductions in the manufacturing industry's CO_2 emissions contribute from changes in industrial structure. This finding aligns with the trend of manufacturing facilities outsourcing their production processes or investing in developing countries. Finally, based on the results, I find that VAP might contribute to emission reductions among sectors with higher market concentration. In other words, the VAP failed to reduce CO_2 emissions in sectors with lower market concentration. Moreover, the results also indicated that the energy intensity target of the VAP failed to reduce CO_2 emissions.

Tables

Table 2.1 Sectors that participated in the VAP.

Sector name	Code
Sectors with an absolute target	
Pig iron	1
Industrial equipment	2
Sugar	3
Railway	4
Sake (liquors)	5
Sanitary equipment (medical instruments)	6
Pharmaceuticals (medicaments)	7
Residential	8
Electric wire	9
Glass	10
Sectors with an intensity target	
Petroleum product	11
Chemical-related sectors	12
Paper	13
Cement	14
Construction	15
Mining (gravel, quarrying)	16
Aluminum	17
Copper	18
Bearing	19
Beverage	20
Limestone	21
Machine tool	22
Milling	23
Ship	24
Sectors with a mixed target or other target	
Production of car bodies and parts	25
Rubber	26

Note: The translation of the sectors in this table is based on the report of VAP.

Table 2.2 Effects from 1990 to 2011

	Effects (10^5 t-CO_2)	
Sector name	Composition	Technique
Sectors with an absolute target		
Pig iron	-768.01	-369.603
Industrial equipment	10.34	-2.199
Sugar	-13.76	-3.324
Railway	0.16	-0.207
Sake (liquors)	-0.36	-6.146
Sanitary equipment (medical instruments)	1.55	0.01
Pharmaceuticals (medicaments)	1.57	9.34
Residential	-10.03	4.83
Electric wire	-5.42	5.08
Glass	-28.95	1.60
Sectors with an intensity target		
Petroleum product	-218.01	-32.88
Chemical-related sectors	-107.57	106.75
Paper	-76.25	39.82
Cement	-296.11	126.67
Construction	3.47	-8.27
Mining (gravel, quarrying)	-29.82	21.39
Aluminum	-8.80	-22.33
Copper	-3.64	2.67
Bearing	-10.01	12.65
Beverage	38.21	-2.49
Limestone	-29.82	21.39
Machine tool	10.34	-2.19
Milling	-3.14	2.54
Ship	-2.62	0.65
Sectors with a mixed target or other target		
Production of car bodies and parts	20.58	-8.68
Rubber	-13.04	2.14

Figures

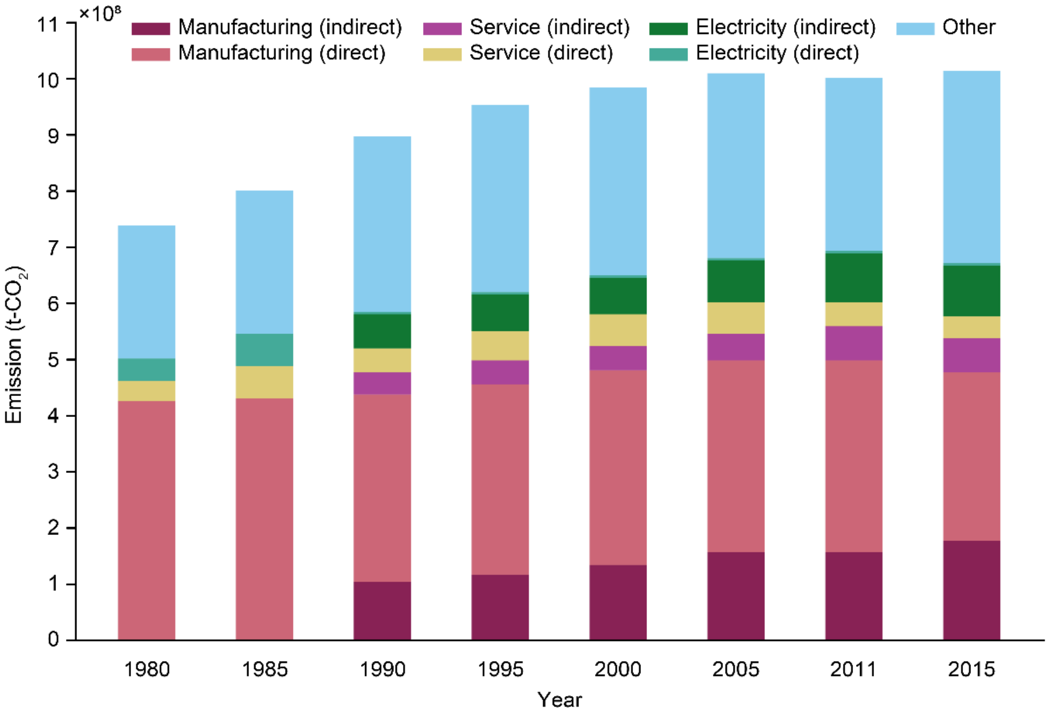

Figure 2.1. Direct and indirect CO_2 emissions at the industrial level

Note: We use 1990 emission intensities to calculate sectoral CO_2 emissions for 1980 and 1985. Thus, the CO_2 emissions from 1980 to 1985 are not decomposed into direct or indirect emissions. The light color represents direct CO_2 emissions.

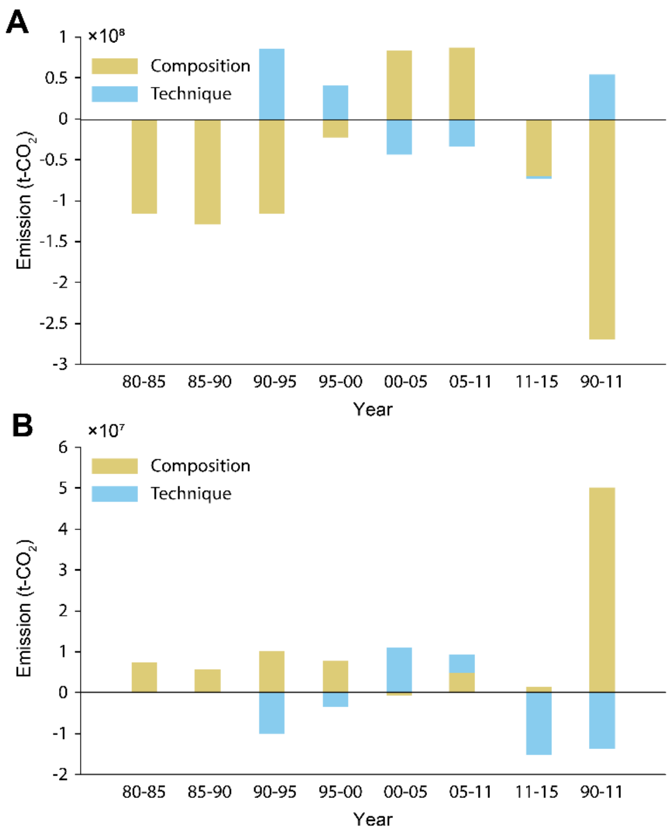

Figure 2.2. Composition and technique effects for the manufacturing and service industry

Note: "80–85" in the figure indicates the period from 1980 to 1985.

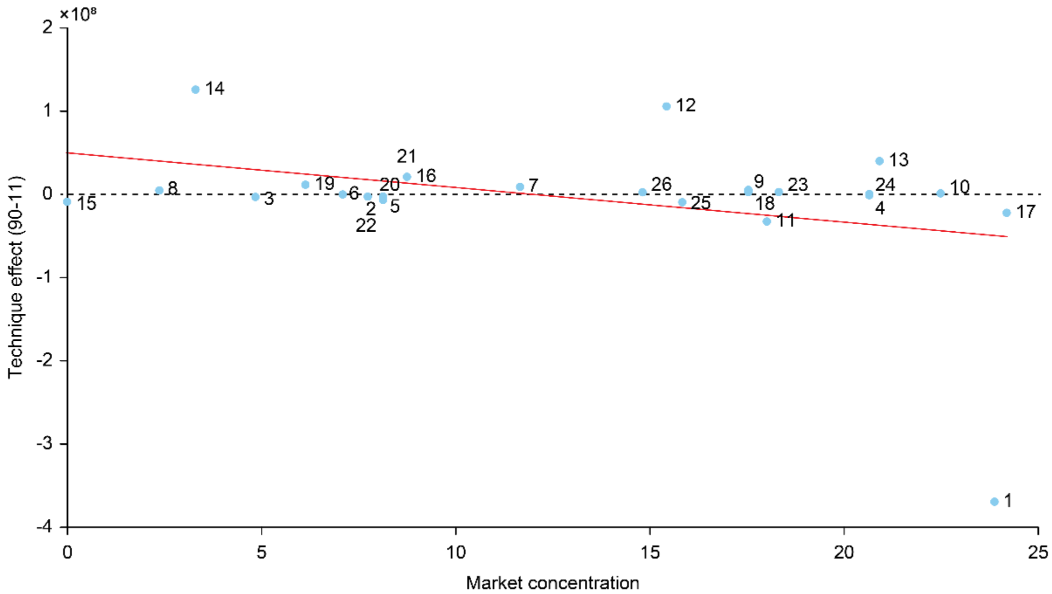

Figure 2.3. Relationship between the technique effect and market concentration

Note: The numbers in this figure correspond to the numbers in Table 2.2. The R-square value and t statistic are 0.12 and 1.84, respectively.

Appendix

Indirect CO_2 emissions is defined as CO_2 emissions emitted from power generation and heat. First, I calculate the emission intensity for electricity, private power generation and steam and hot water supply for all periods *t*, using the following equation:

$$Emission\ intensity_j^t = \frac{CO_2\ emissions_j^t}{TC_j^t}, \quad (A.2.1)$$

where *j* represents electricity, private power generation, and steam and hot water supply, *t* represents 1980, 1985, 1990, 1995, 2000, 2005, 2011, and 2015, and TC_j^t represents the total consumption of energy *j* at time *t*. Next, using the emission intensity calculated above, I can calculate indirect CO_2 emissions for sector *i* at time *t* as:

$$Indirect\ CO_2\ emissions_{ij}^t = Emission\ intensity_j^t \times EC_{ij}^t, \quad (A.2.2)$$

where EC_{ij}^t is the consumption of electricity, private power generation, or steam and hot water supply for each sector *i* at time *t*.

In theory, I can calculate indirect emissions for each industry using equation (A.2.2). However, there is a critical issue that needs to be addressed concerning the VQT. The volume of energy consumption for a few sectors fluctuates from the previous year, which leads to drastic increases and decreases in the value of indirect CO_2 emissions.[3] Therefore, I apply the share of consumption reported in the VQT for 1995 to estimate the amount of energy used for 1990, 2000, 2005, 2011 and 2015. This means that I ignore improvements in energy consumption achieved by each sector *i*.

I estimate the amount of energy used for 1990, 2000, 2005, 2011 and 2015 using the following equations for electricity, private power generation, and steam and hot water supply

$$Input\ ratio_{ij}^{1995} = \frac{Energy\ Consumption_{ij}^{1995}}{\sum_i^{197} Energy\ Consumption_{ij}^{1995}}, \quad (A.2.3)$$

$$\widehat{EC_{ij}^t} = Input\ ratio_{ij}^{1995} \times \sum_i^{197} Energy\ Consumption_{ij}^t. \quad (A.2.4)$$

where the total consumption of energy *j* is the sum of consumption of energy *j* at all sectors. Finally, I calculate indirect emissions for each sector by replacing EC_{ij}^t with $\widehat{EC_{ij}^t}$ in equation (A.2.2).

[3] The indirect emissions calculated from the data reported in the VQT differs from the national inventory data provided by National Institute for Environmental Studies of Japan, https://www.nies.go.jp/gio/aboutghg/index.html.

Chapter 3

Does Emissions Trading Scheme Induce Innovation and Carbon Leakage? Evidence from Japan

3.1 Introduction

3.1.1 Background

Climate change caused by increasing carbon dioxide (CO_2) emissions has become a global challenge. Carbon pricing such as emissions trading scheme (ETS) and carbon tax have been attracting attention as an effective tool to mitigate the climate change. Since the European Union (EU) implemented the EU ETS in 2005, ETSs have been introduced around the world. While vast studies have reported that the ETS has helped firms targeted by the ETS (hereafter referred to as "targeted firms") reduce their CO_2 emissions (Martin et al., 2016; Zhang et al., 2020), there are fewer studies on how targeted firms have achieved their reduction targets.

Targeted firms can adopt several strategies to achieve the reduction target of ETS. The first strategy is through self-help effort, such as fuel switching, appliance replacement, and energy efficiency improvements in the production process. Some of these methods require research and development (R&D) and will take some time before emission reductions are realized. The second strategy is to shift production process from target facilities/areas to other areas, which can reduce within-firm emissions in relatively short time. However, this may lead to carbon leakage through three channels: (i) outsourcing (i.e., contracting out the production process to another firm), (ii) intensive margin (i.e., shifting production activities to unregulated facilities within the firm), and (iii) extensive margin (i.e., downsizing target facilities below the targeting threshold and establishing new facilities in unregulated regions). Lastly, the third strategy is to purchase emissions allowances from other targeted firms having reduced emissions more than reduction targets, which is the simplest and immediate solution to comply with ETS.

A growing body of literature on ETS investigate firms' decisions regarding innovation and carbon leakage at intensive and extensive margins, while research on outsourcing and emissions trading at firm/facility level is still limited due to the data availability. Regarding the literature on innovation, some studies report positive impacts of ETSs on R&D (Martin et al., 2013; Ren et al., 2022), patents (Calel & Dechezleprêtre, 2016; Chen et al., 2021), and investment in low carbon equipment (Hamamoto, 2021), while some other studies indicate a limited impact (Rogge et al., 2011; Löfgren et al., 2014; Chen et al.,2020). Regarding the impact of ETSs on carbon leakage, the empirical findings also vary by studies, ranging from positive leakage (Fell & Maniloff, 2018; Gao et al., 2020; Bartram et al., 2022) and limited impact (Sartor, 2013; Martin et al., 2014; Branger et al., 2016; Koch and Basse Mama, 2019) to negative leakage (Sadayuki & Arimura, 2021). Regarding on the allowances, the literature indicated that facilities accounting for more than a quarter of the total cap did not participate in any trade in the initial phase (Hintermann et al., 2016), and explained the potential reasons for this result (Jaraitė et al., 2010; Heindl, 2012).

The diversity of results may be due in part to the research setting of the existing studies, which has focused on a single strategy without considering alternatives. In practice, a firm makes a joint decision on, say, investment in energy-efficiency development, outsourcing of production process and trading of emissions allowances. The decision is made based on various conditions such as the expected cost and return of each strategy, its financial situation, and its attitude toward the uncertainty in future ETS. If a well-funded firm anticipates that improving its production process will be more cost-effective than outsourcing or purchasing emission credits in the long run, it will choose to invest in R&D over other alternatives. Concerns about higher purchase prices for emission credits and stricter future reduction targets also contribute to the promotion of R&D. On the other hand, firms that anticipate little benefit from R&D in terms of energy efficiency or that have limited resources and time to conduct R&D may choose to outsource part of their production process or purchase emission credits from other firms. Therefore, it is important to consider alternative options jointly to understand the comprehensive mechanism of firms' decision-making on emission reduction, while it has not been done in the previous literature.

This chapter contributes to the literature by examining the substitutability between firms' innovation and outsourcing activities under the ETS, leveraging the Saitama ETS introduced in 2011. Analyzing the Saitama ETS, compared to other ETSs in the world, is advantageous for three reasons in achieving the objectives of this chapter. First, the majority of targeted firms under the Saitama ETS belong to the manufacturing industry, allowing us to examine the effect of ETS on R&D and outsourcing. Second, the influence of ETS on outsourcing, if present, is most likely to be emerged under a regional ETS because it induces domestic outsourcing more easily than a national ETS. If the Saitama ETS has limited influence on outsourcing, it is unlikely that the introduction of a national ETS will induce outsourcing to foreign countries, thereby causing domestic firms to lose competitiveness. Third, access to a confidential data coupled with the feature of regional ETS provide an ideal environment for examining the impact of ETS. As of 2020, the Saitama ETS has jurisdiction over approximately 500 firms as opposed to California C&T has jurisdiction over 330 firms, even though Saitama prefecture is less than 1% of the size of California. Using firm-level panel data provided by Ministry of Economy, Trade and Industry (METI), I conduct a difference-in-differences (DID) (analysis) leveraging geographic clustering of firm sample, controlling for the confounding effects of regional differences on the results.

The DID (analysis) shows that the introduction of the Saitama ETS promoted R&D, especially at firms that had initiated R&D prior to the ETS, while it did not lead to an increase in outsourcing overall. Prior studies have shown that the Saitama ETS promoted energy efficient technologies at manufacturing facilities within its jurisdiction (Hamamoto, 2021) and supported target firms in reducing emissions from facilities in both Saitama and other prefectures (Sadayuki & Arimura, 2021). When considering the findings from this chapter and existing literature, it is confirmed that the Saitama ETS has contributed to an enhancement on innovation activities without inducing overall carbon leakage. The further analysis, however, reveals the heterogeneity in the impact on outsourcing among targeted firms. In particular, targeted firms not actively engaged in R&D in response to the ETS increased outsourcing instead. This is because R&D was not as cost-efficient as outsourcing for these firms. The result implies that, in the future, the ETS may induce carbon leakage through outsourcing when the emissions reduction target becomes overwhelming for targeted firms to achieve through innovation alone.

3.1.2 Japan's regional ETSs

Japan's regional ETSs were implemented in Tokyo and Saitama prefectures in 2010 and 2011, respectively. The first compliance period of the ETSs lasted until 2014, followed by the second period from 2015 to 2019.

The ETSs cover firms from various industries, such as commercial and manufacturing industries, operating at least one facility in Tokyo or Saitama prefectures with an annual energy consumption of 1500 kl in crude oil equivalent or more[4]. These firms were assigned the emissions caps based on emissions reduction targets, which varied between those set for commercial and manufacturing industries, and the emissions baseline calculated from average emissions during any three consecutive years from 2002 to 2007. Japan's ETSs provided firms the free allocation of emissions allowances equal to the amount of excess reduction. Although the allowances can be traded, the transaction shares of total emissions reduction for both ETSs amount to only 3% during the second compliance period.

Manufacturing firms account for approximately 80% of total targeted firms/organizations under the Saitama ETS, while the ratio is less than 10% under the Tokyo ETS (Japan's Ministry of Internal Affairs and Communications (MIC) & Ministry of Economy, Trade and Industry (METI), 2017). This chapter focuses on the innovation and production outsourcing, thus examining only the Saitama ETS. For the manufacturing industry, the Saitama ETS was set 6% during the first compliance period and was raised to 13% in the second compliance period. Compared to the Tokyo ETS, the Saitama ETS is somewhat voluntary, as it does not financially penalize targeted firms even if they fail to comply with reduction targets. However, their names will be published.

3.2 Methodologies

3.2.1 Basic model

Difference-in-differences (DiD) is a widely used method to evaluate policies. It identifies the impact of a policy by comparing differences in interest outcomes before and after the policy intervention and between the treatment and control groups. In this chapter, firms are categorized under the treatment group if they are targeted by the Saitama ETS after 2011. Firms are categorized into the control group if they are not targeted by the Saitama ETS during the chapter period. In practice, I initially paired the firms targeted by the Saitama ETS with those from the Basic Survey of Japanese Business Structure and Activities year by year. Second, I identified consistently present targeted firms throughout the study period for constructing the panel data. This resulted in 143 firms for the panel data, in contrast to the approximately 400 manufacturing firms listed as targeted on the official Saitama ETS website. By comparing changes of the treatment and control group in values representing innovation and outsourcing activities, this chapter examines how the Saitama ETS contributed to these activities. Since the data period ranges from 2006 to 2018, it covers the pre-period of the Saitama ETS, first compliance period (2011–2014), and a part of the second compliance period (2015 – 2019). As the impact of the ETS can differ by phases, I divide the treatment period into two phases. The baseline DiD model is constructed as follows:

$$Y_{it} = \beta_1 ETS_i \times Post1114_t + \beta_2 ETS_i \times Post1518_t + \boldsymbol{X}_{it} B + \mu_t + \gamma_i + \varepsilon_{it}, \quad (3.1)$$

where the dependent variable, Y_{it}, is a logarithmic value of the outcomes regarding firm *i* in year *t*. I examine

---

[4] The targeting threshold follows the benchmark of the Energy Conservation Act (Arimura and Iwata, 2015). The 1,500 kl in crude oil equivalent is approximately 2,800 tons of CO2. As reference, a hotel with 300 bedrooms and a department store with 30,000 square meters of floor area are approximately equivalent to the facility size at the targeting threshold.

two outcomes, that is, R&D and outsourcing. I transformed the outcome variables by adding 1 to each value and taking the logarithm of the transformed value.

On the right-hand side of the equation, ETS_i is a dummy variable taking value 1 if firm i falls in the treatment group (i.e., targeted by the Saitama ETS after 2011), and $Post1114_t$ and $Post1518_t$ are dummy variables taking value 1 if year *t* falls between 2011 and 2014 (i.e., first compliance period) and between 2015 and 2018 (i.e., second compliance period), respectively. The coefficients of the interaction terms of these variables, β_1 and β_2, measure the impact of the ETS on the outcome during the two compliance periods.

To estimate the impact of the ETS on firms' R&D and outsourcing activities, I consider other factors that could influence these activities. For this purpose, the firm-level fixed effect, μ_t, is controlled for capturing time-invariant unobserved effects of firms' characteristics; the annual fixed effect, γ_i, is controlled to capture the year-specific shock that is common to all Japanese firms. *B* is a series of coefficients of $\boldsymbol{X}_{it}$, which is a set of time-variant firm-level characteristics that can affect the outcome Y_{it}, besides the introduction of ETS and unobservable time and individual fixed effects. All continuous variables are transformed into logarithm values. Lastly, ε_{it} is an error term, which is assumed to be clustered at the firm level.

3.2.2 Model for Heterogeneity Analysis

Innovation experience is a key element of subsequent innovation (Mansfield, 1968; Kelly & Amburgey, 1991; Peters, 2009). I hypothesize that firms that had conducted R&D before complying with the ETS had the advantage of accelerating R&D after the ETS was implemented compared to firms that had not actively conducted R&D. To test this, I ran two regressions. First, I restricted samples to firms that had not actively conducted R&D during the pre-implementation period, that is, firms with zero R&D experience from 2003 to 2009 (hereafter firms without R&D experience) and estimated the pooled ordinary least squares (OLS) model without the intercept and control variables during the period from 2011 to 2018 as follows:

$$Y'_{it} = \beta_1^1 ETS_i \times Post1114_t + \beta_2^1 ETS_i \times Post1518_t + \beta_3 Post1114_t + \beta_4 Post1518_t + \varepsilon_{it}. \qquad (3.2)$$

In equation (3.2), the outcome variable (Y') is a dummy taking the value 1 if firm i has innovation activities. ETS_i is a dummy variable taking value 1 if firm *i* is targeted by ETS, and $Post1114_t$ and $Post1518_t$ are dummy variables for both compliance periods. Through equation (3.2), if coefficients β_1^1 and β_2^1 are statistically insignificant, I can confirm that firms without R&D did not have innovation experience during both compliance periods.

Second, another heterogeneity analysis is adopted to investigate how the Saitama ETS affected firms with innovation experience during subsequent innovation. I restricted samples to firms that had conducted R&D during the pre-implementation period, that is, firms whose R&D is positive at least one year between 2003 and 2009 (hereafter firms with R&D experience), and estimated the equation based on equation (3.1) as follows:

$$Y_{it} = \beta_1^2 ETS_i \times Post1114_t + \beta_2^2 ETS_i \times Post1518_t + \boldsymbol{X}_{it} B^2 + \mu_t + \gamma_i + \varepsilon_{it}. \qquad (3.3)$$

In equation (3.3), the outcome variable is R&D, and ETS, $Post1114_t$, $Post1518$, and $\boldsymbol{X}_{it}$ follow equation (3.1).

3.3 Data and Summary Statistic

This chapter uses annual firm-level panel data gathered between 2003 and 2018 from the Basic Survey of Japanese Business Structure and Activities, conducted by the Japan Ministry of Economy, Trade and Industry (METI). This survey covers all firms in Japan that have more than 50 employees or at least 30 million JPY of stated capital or contribution. This survey records more than 200 items of information on approximately 30,000 firms annually, including firms' identification (name and address) as well as various characteristics and financial information (number of employees, sales, exports, R&D, outsourcing, assets, and liabilities). The data accurately investigate firm-level innovation and outsourcing. I follow Cole et al. (2021), who use data similar to that used in our study, to handle the missing values and outliers for obtaining the unbalanced panel of 1909 observations for targeted firms and 87,142 observations for untargeted firms for the period from 2003 to 2018. To eliminate the possible impact of Tokyo ETS on our study, we exclude firms targeted by the Tokyo ETS from our sample.

In this chapter, R&D activities of firms targeted by the Saitama ETS represent innovation activities, such as reducing plastic usage for product packaging, developing technologies to reduce fuel and electric power consumption, and developing environmentally friendly products. To avoid costs associated with environmental regulations, firms tend to outsource energy (pollution) intensive production processes to other firms (Cole et al., 2021). Based on the survey data and literature, carbon leakage is measured based on outsourcing, that is, the transfer of production processes or outsourcing of firms' activities. However, the survey data have changed the definition of outsourcing activities since the 2010 survey (converted to 2009 data). CO (2013), an official report from the Cabinet Office of Japan, suggested that it is necessary to consider these changes carefully when analyzing data, including 2008 and 2009. The data show unusual changes in firms' outsourcing from 2008 to 2009. Therefore, I use data from 2009 to 2018 for examining the ETS on outsourcing and e prior data for testing the parallel trends assumption. Table 3.1 shows the descriptive statistics of the treatment and control groups.

<Table 3.1 approximately here>

In Figure 3.1, I also illustrate the average trend of the key outcome variable, R&D. The data suggests that while R&D experienced a decline from 2008 to 2009, it began to rise consistently after the implementation of the Saitama ETS in 2011, continuing this upward trend until the conclusion of the first compliance period.

<Figure 3.1 approximately here>

Multiple firms' characteristics are controlled in this chapter. Firm scale is the natural logarithm of the firm's employment (Capasso et al., 2013). Firm age is the natural logarithm of the survey year that deducts the firm's foundation and adds 1 (Zhu et al., 2019). Firm structure is the ratio of capital to labor (Aghion et al., 2013). A firm's capital structure is denoted by the liabilities–to–assets ratio. The export dummy variable, which can be considered as the new technology and experience obtained by exports, is also controlled in this chapter (Ren et al., 2020; Yang et al., 2017). Moreover, the dummy variable for stock options is also considered. The values of continuous variables are converted to 2015 prices based on the GDP deflator.

3.4 Results

3.4.1 Basic Results

Table 3.2 shows the estimation results of equation (3.1). Columns (1) and (2) present the results for R&D and outsourcing, respectively. In column (1), the coefficient of the interaction term $ETS_i \times Post1114_t$ is 0.214 and statistically significant at the 5% level, which indicates that targeted firms increased R&D investment by 21% compared with untargeted firms during the first compliance period of the Saitama ETS. The result shows that the ETS promotes innovation. However, the coefficient of the interaction term $ETS_i \times Post1518_t$ is not significant, implying that targeted firms did not engage in R&D during the second compliance period as in the first compliance period, which is consistent with Xie et al. (2017) that firms may be reluctant to further increase their compliance costs to invest in new technologies once excess mitigation is achieved. In fact, an official report by Saitama prefecture[5] provides evidence to confirm the results that the reduction in total emissions from the first to the second compliance periods increased by only 7%. It means that the Saitama ETS did not motivate firms to further reduce CO_2 emissions, which is consistent with the result indicating an insignificant impact on innovation during the second compliance period. Another possible explanation is that the Saitama ETS offered a reserve policy that allows firms to reserve allowances from the first to second compliance period. Even though only 4% of targeted firms used the reserving allowances to meet their targets, this mechanism will probably crowd out any improvement in innovation during the upcoming compliance periods.

In column (2), the coefficients of interaction terms $ETS_i \times Post1114_t$ and $ETS_i \times Post1518_t$ show positive signs while they are not statistically significant. Therefore, the result indicates that targeted firms increased their outsourcing after ETS implementation. The insignificant impact of the Saitama ETS on outsourcing can be explained by targeted firms that are willing to achieve emissions mitigation from a long-term perspective. Even though outsourcing can be a short-term solution to achieve the reduction targets, it is not cost efficient in the long-term. At the same time, in the context of stringent reduction targets in the upcoming compliance period, improving R&D in the early stage of the ETS is a reasonable strategy to comply with future targets instead of increasing outsourcing activities. Therefore, targeted firms may not have adequate reason to outsource their production process as a temporary measure to meet the reduction targets.

<Table 3.2 approximately here>

3.4.2 Robustness Tests

To ensure the implication of the result, I conducted several robustness checks. This chapter adopted (1) a matched DiD model based on the propensity score, (2) parallel trend tests, (3) stability of unit treatment

[5] See https://www.pref.saitama.lg.jp/a0502/sakugen.html

values assumption (SUTVA), and (4) placebo tests to examine the robustness of the basic results.

3.4.2.1 Parallel Trend Test

An important precondition of the DiD method to consistently estimate the treatment effect is that in the absence of a policy intervention, outcomes in the treatment group would have the same trend as outcomes in the control group. However, as outcomes in the treatment group are not observable without intervention, researchers tested the assumption by examining trends in the pre-treatment period (Sant'Anna & Zhao, 2020). I tested the parallel trends assumption by estimating the following model:

$$Y_{it} = \sum_{t \in pre-period} \beta_t ETS_i \times D_t + X_{it}B + \mu_t + \gamma_i + \varepsilon_{it}. \quad (3.4)$$

D_t represents the dummy variable indicating year t. I considered 2010 as the base year, which is one year prior to the implementation of the ETS for R&D. The definition of outsourcing activities changed since 2009 in the survey data so that parallel trends during all periods cannot be investigated. However, the assumption of parallel trend can be checked based on whether pre-compliance periods induce variability between the treatment and control groups (Ren et al., 2022). Therefore, this chapter plots the parallel trend from 2003 to 2009 for outsourcing. Figures 3.2 and 3.3 show the estimates of β_t with 95% confidence intervals for R&D and outsourcing, respectively. The figures suggest parallel trends of the outcomes between both treatment and control groups during the pre-implementation period.

<Figure 3.2 approximately here>

< Figure 3.3 approximately here>

3.4.2.2 Matched DiD

To validate the robustness of the baseline results, I adopted the matched DiD model based on the propensity score (PSM-DiD). Propensity matching is an optimal strategy to ensure that the regulatory status of the ETS is a randomly assigned conditional on firm characteristics (Zhu et al., 2019; Lu et al., 2023). It leverages the large sample size with significant differences in characteristics across firms. I first matched targeted firms with non-targeted firms one-to-one by the nearest neighbor matching estimator (Abadie et al., 2004). Based on the existing literature, Pairs of firms were matched by firm observable characteristics such as scale, capital–labor ratio, age, financing constraints, and trade (Aghion et al., 2013; Löschel et al., 2019). All matching variables were matched one year prior to the implementation of Saitama's ETS. The sample size is reduced based on the strict conditions to restrict the matching process to match close firms. However, the accuracy and robustness of the results satisfy the loss in sample size (Dehejia & Wahba, 1999). Second, I used matched firm pairs to estimate the casual effect by the DiD method. The results of the PSM-DiD suggest the same implication as the main results despite larger standard errors with a smaller sample size (Table 3.3).

<Table 3.3 approximately here>

I also explore the R&D considering firm's scale characteristic by using the outcome variable, which is the ratio of R&D to the firm's sales. This further dissects R&D activities and is presented in Table 3.4, column (1). The coefficients of the interaction terms $ETS_i \times Post1114_t$ and $ETS_i \times Post1518_t$ are statistically significant, which differs with the findings in Table 3.2, column (1). Therefore, to ensure the robustness of these findings, I examine the outcome variable ratio of R&D to sales using the matched sample. The results, based on the insignificant coefficients of the PSM-DiD (analysis), suggest that the findings on ratio of R&D to sales may not be entirely reliable. Additionally, I conducted similar analyses for the ratio of outsourcing to sales, as presented in Table 3.4, columns (3) and (4). These findings align with the baseline results.

<Table 3.4 approximately here>

3.4.2.3 Stability of Unit Treatment Values Assumption (SUTVA)

The DiD method relies on the stability of unit treatment values assumption (SUTVA), assuming that non-targeted firms are not affected by targeted firms (Fowlie et al., 2012). In this chapter, a probable situation where SUTVA violations can occur is that R&D progress among targeted firms in Saitama prefecture generates spillover effects on surrounding firms, thus increasing R&D among untargeted firms in the same prefecture. For instance, it happens when they compete with targeted firms, thereby leading to untargeted firms increasing their R&D. In this case, the DiD approach underestimates the impact of ETS on R&D. In practice, however, the SUTVA cannot be proven empirically. The strategy is to test if the SUTVA is violated in a specific case. I excluded targeted firms from the samples and ran a regression model in which untargeted firms in Saitama prefecture are now considered as a treatment group, and firms outside Saitama prefecture constitute the control group. Violations appear when DiD terms are statistically significant, indicating that the ETS affects untargeted firms in Saitama prefecture. Table 3.5, column (1) shows the results, indicating that the DiD terms are not significant. I concluded, therefore, that non-targeted firms in Saitama are not influenced by the regional ETS to adjust their innovation strategy.

<Table 3.5 approximately here>

3.4.2.4 Placebo Test

A placebo test is conducted to further check the validity of the robustness test. Basically, the placebo test follows Ferrara et al. (2012) and Cai et al. (2016) by randomly choosing firms from the sample as the counterfactual treatment group. The omitted variable or other unobserved factors that may influence the treatment effect of the treated can be validated by the placebo test. As counterfactual treatment firms are randomly selected, the counterfactual treatment effect should be statistically insignificant on R&D if the impact of the omitted variable or other unobserved factors is not present. In other words, if the counterfactual firm group significantly affects R&D, the placebo effect exists, and the result is deemed unreliable. In this chapter, I randomly selected 143 firms, which is equal to the number of firms that targeted by Saitama ETS in reality in the sample, as the counterfactual firm group to estimate the treatment effect (Yu & Zhang, 2022). Following Lu et al. (2017), I generated counterfactual data 500 times to obtain the distribution of the counterfactual DiD estimators. Figure 3.4 plots the density distribution of 500 coefficients highlighting the real DiD estimator (dash line) and counterfactual DiD estimator (solid line). I find that the density distribution concentrates to 0 with a mean value of -0.003 and standard deviation of 0.0846, and the real DiD estimator is larger than the counterfactual DiD estimator. I concluded that the real DiD estimator is significantly different from the counterfactual estimator, indicating that the placebo effect does not exist.

< Figure 3.4 approximately here>

3.4.3 Heterogeneity analysis

3.4.3.1 Heterogeneous effects on innovation

In Table 3.6, columns (1) and (2) show the results of equations (3) and (4), respectively. I find that the coefficients ETS × $Year_{1114}$ and ETS × $Year_{1518}$ are insignificant, indicating that firms without R&D activities before the ETS was implemented did not increase their innovation activities during the compliance periods in column (1). Column (2) shows that the interaction term $ETS_i \times Post1114_t$ on R&D is statistically significant. It highlights that targeted firms with innovation experience promote subsequent innovations during the compliance period of the Saitama ETS because they have gained more experience to accelerate development and maintain the innovation status after the implementation of the Saitama ETS. Combined with column (1) in Table 3.6, it can be concluded that increases in R&D are contributed by firms with experience in R&D activities during the pre-implementation period.

<Table 3.6 approximately here>

Moreover, to gain a comprehensive understanding of above results, I examined the average sales trends between firms with prior R&D activities and those without, which is depicted in Figure 3.5. The findings reveal that firms with prior R&D activities have average sales approximately seven times higher than those without prior R&D. This suggests that while the surge in R&D is attributable to firms with pre-existing R&D activities, their ability to undertake innovative actions ahead of others is likely due to their relatively larger scale.

< Figure 3.5 approximately here>

3.4.3.2 Heterogeneity in outsourcing

Although the results did not show the significant impact of the Saitama ETS on outsourcing activities, firms that did not innovate actively may tend to increase their outsourcing activities to meet the reduction targets owing to the incentive on increased outsourcing by these firms. In this chapter, I offer two types of heterogeneity analysis based on the median value of the R&D growth rate. Specifically, I focused on the impact of the ETS on outsourcing in two different samples that distinguish firms with lower and higher median values of R&D growth rate. I calculated the R&D growth rate for the treatment and control groups while considering other effects based on equation (3.1). If the outcomes are significant in the two types of heterogeneity analysis, I can confirm that firms with lower R&D growth rate increase outsourcing. Table 3.5 shows the results of the heterogeneity analysis in columns (3) and (4). Column (3) indicates that firms with a lower R&D growth rate increased their outsourcing activities during the Saitama ETS compliance period compared with non-targeted firms. However, column (4) indicates that firms with higher R&D growth rates did not increase their outsourcing after the Saitama ETS was implemented. Combined with these results, I can conclude that targeted firms with a lower R&D growth rate tend to increase their outsourcing activities.

3.5 Conclusions

This Chapter examines if firms targeted by the Saitama ETS improved their R&D and outsourcing activities. Unique firm-level data were used based on DiD methods from 2003 to 2018. Robustness tests are conducted to confirm the robustness of the results such as parallel trend tests, PSM, SUTVA, and placebo tests. Moreover, heterogeneity analysis examines the relationship between innovation and outsourcing under the Saitama ETS. This chapter highlights two key conclusions.

First, the analysis suggests that the Saitama ETS encourages targeted firms to improve their R&D during the early phase of ETS. Specifically, to meet the reduction targets, after implementing the ETS, targeted firms made significant efforts to increase their R&D investment during the first compliance period to improve their energy efficiency performance in production processes. In particular, firms with prior innovation experience improve R&D activities during the first compliance period, which implies that firms had R&D activities accelerated development or maintained their innovation status following the introduction of the Saitama ETS. However, although reduction targets during the second compliance period became more stringent, targeted firms were hesitant to continuously improve innovation from the first to the second compliance periods. This suggests that targeted firms tend to concentrate their R&D investments in the initial phase. Another possible explanation is that, targeted firms may be preparing for the reduction targets in the third compliance period, which limited their ability to increase R&D efforts. These results remain valid after several robustness tests.

Second, I find that targeted firms do not outsource their production process while complying with the Saitama ETS. Apparently, the ETS did not stimulate outsourcing-induced carbon leakage. However, the heterogeneity analysis shows that targeted firms with lower R&D growth rates increased their outsourcing activities during the compliance period. In practice, to comply with the ETS, targeted firms can employ multiple strategies, including through both improvement on R&D and outsourcing production processes. Therefore, based on the results, I conclude that firms that cannot actively improve their energy efficiency through R&D or allocate sufficient funds for R&D reduce CO_2 emissions by outsourcing their production processes.

Even though this chapter explores the impact of the Saitama ETS, the findings should be interpreted with caution for the following reasons. First, the Saitama ETS targets at the facility level and not firm level. As this chapter does not evaluate facility activities, I could not fully capture the impact of the ETS, especially in outsourcing activities. Second, the survey only provides total R&D information for each firm. Thus, the results may overestimate or underestimate the influence of the ETS on efforts to improve technological innovations.

Tables

Table 3.1. Descriptive statistics

	Treatment group				
	Obs	Mean	S.D.	Min	Max
R&D (million JPY)	1909	4.97	23.73	0	309.69
Outsourcing (million JPY)	1208	4.71	16.85	0	201.31
Capital to labor ratio	1909	58.23	55.47	2.87	528.42
Employment	1909	2002.3	4194.0	52	39761
Liability to assets ratio	1909	0.59	0.26	0.03	2.46
Age	1909	60.03	22.52	1	114
Stock option	1909	0.24	0.42	0	1
Export dummy	1909	0.48	0.49	0	1

	Control group				
	Obs	Mean	S.D.	Min	Max
R&D (million JPY)	87142	1.11	14.56	0	923.46
Outsourcing (million JPY)	54363	2.45	725.99	0	6205.71
Capital to labor ratio	87142	37.10	43.19	1.05	1586.74
Employment	87142	469.58	1964.40	50	82560
Liability to assets ratio	87142	0.58	0.27	0.01	7.04
Age	87142	51.25	17.60	1	174
Stock option	87142	0.16	0.37	0	1
Export dummy	87142	0.38	0.49	0	1

Notes: Outsourcing activities are investigated for the period from 2009 to 2018.

Table 3.2. Basic results

	(1)	(2)
Outcome variables	ln(R&D)	ln(Outsourcing)
Period	2003-2018	2009-2018
ETS × $Post_{1114}$	0.214**	0.275
	(0.097)	(0.180)
ETS × $Psot_{1518}$	0.168	0.189
	(0.144)	(0.290)
Employment	0.685***	0.518***
	(0.0612)	(0.135)
Capital labor ratio	0.310***	0.347***
	(0.042)	(0.096)
Firm age	0.0207	0.129
	(0.065)	(0.131)
Liability to asset ratio	-0.094**	0.019
	(0.037)	(0.070)
Stock option dummy	0.028	-0.061
	(0.049)	(0.096)
Export dummy	0.155***	0.282***
	(0.032)	(0.074)
Year-fixed effect	Yes	Yes
Firm-fixed effect	Yes	Yes
Observations	89,051	55,571
R-squared (Within)	0.017	0.020

Notes: This table presents the results obtained from the DiD (analysis). Standard errors reported in parentheses are clustered at firm level. *p < 0.1; **p < 0.05; ***p < 0.01. All continuous variables are transformed into logarithm functions. Value 1 is added to the value of outcome variables before the log transformation.

Table 3.3. Results based on PSM-DiD (analysis)

	(1)	(2)
Outcome variables	ln(R&D)	ln(Outsourcing)
Period	2003-2018	2009-2018
ETS × $Post_{1114}$	0.272*	0.400
	(0.158)	(0.289)
ETS × $Psot_{1518}$	0.108	0.485
	(0.180)	(0.412)
Controls	Yes	Yes
Year-fixed effect	Yes	Yes
Firm-fixed effect	Yes	Yes
Observations	3,657	2,297
R-squared	0.025	0.023

Notes: This table presents the results obtained from the PSM-DiD (analysis). Standard errors reported in parentheses are clustered at firm level. *p < 0.1; **p < 0.05; ***p < 0.01. All continuous variables are transformed into logarithm functions.

Table 3.4. Results based on outcome variables considering firms' scale characteristic

	(1)	(2)	(3)	(4)
Outcome variables	ln(R&D/Sale)		ln(Outsourcing/Sale)	
Period	2003-2018		2009-2018	
ETS × $Post_{1114}$	0.0017*	-0.003	0.002	0.002
	(0.0009)	(0.002)	(0.004)	(0.007)
ETS × $Psot_{1518}$	0.003**	0.0000	-0.002	-0.0006
	(0.0015)	(0.002)	(0.005)	(0.008)
Controls	Yes	Yes	Yes	Yes
Year-fixed effect	Yes	Yes	Yes	Yes
Firm-fixed effect	Yes	Yes	Yes	Yes
Observations	89,051	3,657	55,571	2,297
R-squared	0.026	0.047	0.008	0.014

Notes: This table presents the results obtained from the DiD and PSM-DiD (analysis) for two different outcome variables. Columns (1) and (3) represent the results from the DiD (analysis), while Columns (2) and (4) present the results from the PSM-DiD (analysis), corresponding to each of outcome variable. Standard errors reported in parentheses are clustered at firm level. *p < 0.1; **p < 0.05; ***p < 0.01. All continuous variables are transformed into logarithm functions.

Table 3.5. Results of SUTVA

	(1)
Outcome variable	ln(R&D)
ETS' × $Post_{1114}$	-0.0734
	(0.0789)
ETS' × $Psot_{1518}$	-0.127
	(0.104)
Control variables	Yes
Year-fixed effect	Yes
Firm-fixed effect	Yes
Observations	86,600
R-squared	0.017

Notes: Standard errors reported in parentheses are clustered at firm level. *p < 0.1; **p < 0.05; ***p < 0.01. All continuous variables are transformed into logarithm functions.

Table 3.6. Results of heterogeneity analysis

	(1)	(2)	(3)	(4)
	Firms without R&D	Firms with R&D	Heterogeneity in outsourcing	
Outcome variables	R&D Dummy	ln(R&D)	ln(Outsourcing)	
Period	2011~2018	2003~2018	2009-2018	
			~50%	50%~
ETS × $Post_{1114}$	-0.0245	0.288**	0.515*	-0.009
	(0.0166)	(0.117)	(0.290)	(0.268)
ETS × $Psot_{1518}$	0.0118	0.251	0.528	-0.095
	(0.0308)	(0.174)	(0.495)	(0.425)
Control variables	No	Yes	Yes	Yes
Year-fixed effect	No	Yes	Yes	Yes
Firm-fixed effect	No	Yes	Yes	Yes
Observations	15,497	58,123	18,102	18,222
R-squared	0.099	0.023	0.020	0.028

Notes: Standard errors reported in parentheses are clustered at firm level. *p < 0.1; **p < 0.05; ***p < 0.01. All continuous variables are transformed into logarithm functions.

Figures

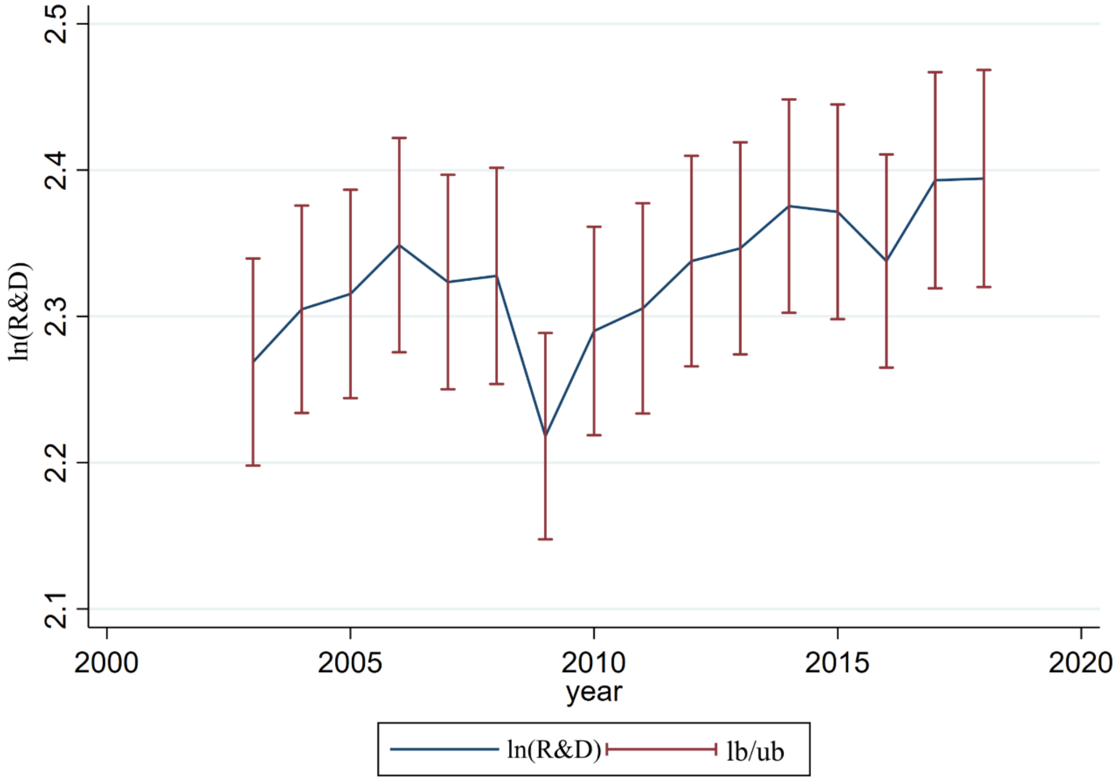

Fig.3.1 Average trend of R&D

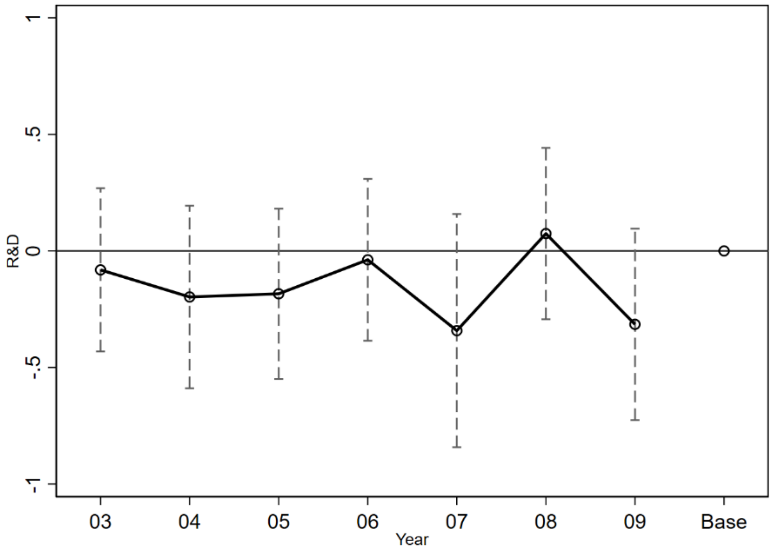

Fig.3.2 Parallel trend of impact on R&D

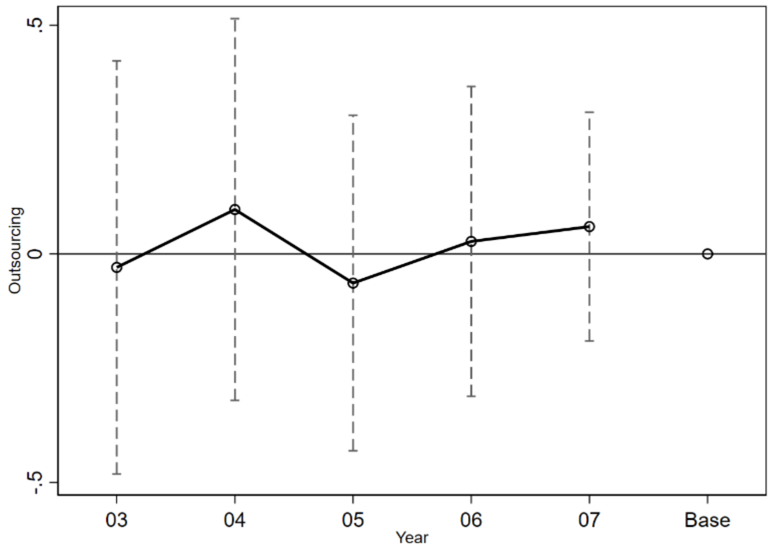

Fig.3.3 Parallel trend of impact on outsourcing

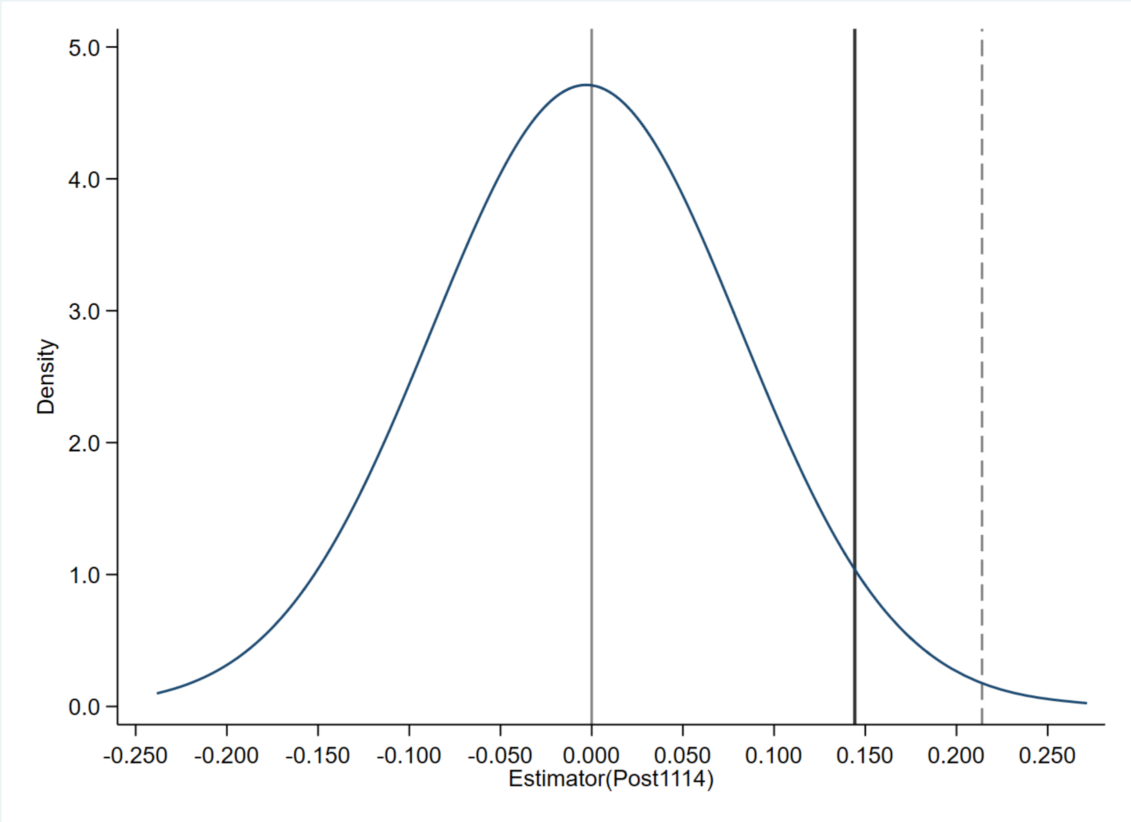

Fig.3.4 Placebo test

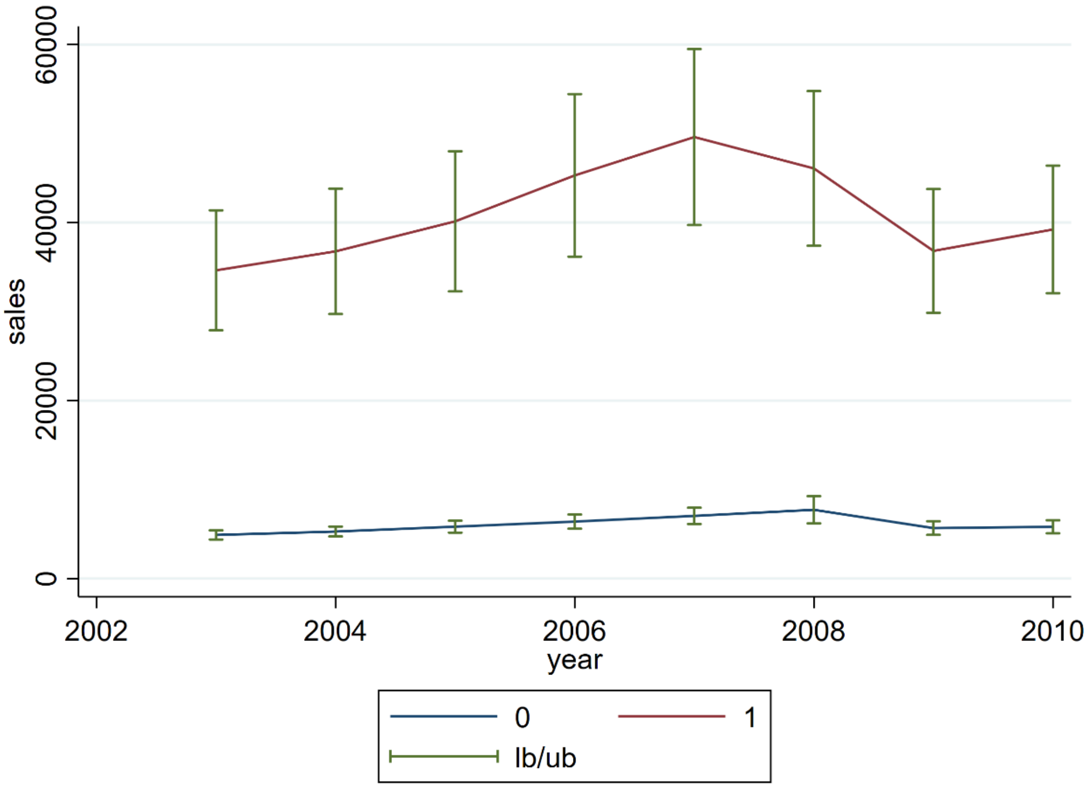

Fig.3.5 Average sales of firms with and without priori R&D activities

Notes: In this figure, the blue line, labeled '0', represents firms that did not engage in prior R&D activities. Conversely, the red line, labeled '1', denotes firms that had priori R&D activities.

Chapter 4

The Impacts of the Tokyo and Saitama ETSs on the Energy Efficiency Performance of Manufacturing Facilities

4.1 Introduction

4.1.1 Background

Greenhouse gas emissions reductions have become a challenging issue for the world in recent years. Emissions trading schemes (ETSs) are effective tools for addressing the carbon mitigation issue. The first ETS was implemented in the European Union (EU) in 2005. Since then, many countries, such as Japan and China, have implemented regional or national ETSs. ETSs have contributed to the reduction of CO_2 emissions in many countries, as confirmed by the literature (Hu et al., 2022).

While ETSs can undoubtedly contribute to carbon mitigation, they also increase the costs for entities, potentially resulting in a loss of industrial competitiveness. This asymmetric effect of ETSs may not effectively encourage entities to improve energy efficiency for CO_2 emissions reduction but instead prompt the relocation of production[1].

The early literature on environmental regulations and energy efficiency presents varying perspectives. Several studies based on neoclassical economic theory have suggested that environmental regulations increase environmental costs and additional burdens, resulting in energy inefficiency (Jorgenson & Wilcoxen, 1990; Verhoef & Nijkamp, 2003). However, Porter and Van der Linde (1995) argued that appropriate environmental regulations encourage firms to innovate new technologies to reduce CO_2 emissions while improving productivity. In fact, environmental regulation might change entities' decisions on innovation or production processes across different compliance stages, thereby resulting in different impacts on energy efficiency varying from stage to stage. In the initial stage of regulation, the increases in environmental costs may have a greater impact on the reduction of entities' profits, hindering research and development and increasing inefficiency.

In contrast, regulation may encourage regulated firms to upgrade their equipment or technologies to comply with stricter targets in the later stage, improving firms' performance as upgrades promote greater efficiency in energy and other inputs (Peuckert, 2014). In practice, the estimated impact of ETSs on energy efficiency performance remains controversial. Recent studies found that ETSs can improve energy efficiency performance (Borghesi et al., 2015; Lutz, 2016; S. Zhang et al., 2016; Löschel et al., 2019; Chen et al., 2021; Li et al., 2021). Conversely, other studies showed impact of ETSs on energy efficiency is not always improve energy efficiency of regulated firms. For instance, Cui et al. (2016) investigated the energy efficiency of the EU aviation industry and found that the ETS did not improve efficiency. Koch and Themann (2022) found that different impacts of EU ETS on firm's productivity across countries. Overall, the findings from the

[1] In this paper, the energy efficiency describes a level at which entities cannot use less energy and inputs to produce additional outputs.

literature remain inconclusive and mainly focus on the energy efficiency within the EU-ETS and China ETS.

Regarding environmental regulations and the relocation of production, importantly, even if the energy efficiency of facilities targeted by ETSs (hereafter referred to as targeted facilities) is improved by ETSs, the advancement of energy efficiency may result from a shift in production, leading to the issue of carbon leakage. Early studies argued that environmental regulations may tend to relocate production facilities to regions with less stringent regulations (Kellenberg, 2009; Candau & Dienesch, 2017). Compared to long term efforts required for energy efficiency, relocation of production, such as outsourcing, can immediately reduce emissions and avoid the high costs of mitigating pollution emissions (Cole et al., 2017; Antonietti et al., 2017). A few recent studies investigated whether outsourcing activities contribute to the reduction of local CO_2 emissions and found that the outsourcing activity is one way for pollution offshoring to occur (Cole et al., 2021). That is, outsourcing of production may induce carbon leakage from targeted regions to nontargeted regions. In particular, in countries or regions that only adopt geographically restricted environmental regulations, outsourcing activities become a more viable option for targeted facilities to achieve the target. If carbon leakage occurs from targeted facilities to nontargeted facilities, the energy efficiency of targeted facilities may increase despite the inability to achieve total emissions reduction. Therefore, an analysis that simultaneously considers the potential for carbon leakage is necessary for estimating the impact on energy efficiency.

This chapter investigates whether Japan's regional ETSs affect facilities' energy inefficiency and outsourcing activities by combining stochastic frontier analysis (SFA) and the difference-in-differences (DID) method based on propensity scores from 2002 to 2016. I adopt unique official facility-level (installation level) data of Japan, covering multiple compliance periods of ETSs, including the announcement period, which informs targeted facilities in advance to prepare upcoming reduction targets. The findings of this chapter highlight two key insights. First, I find that Japan's regional ETSs diminish the energy efficiency of targeted facilities during the announcement period, but the ETSs do not affect the energy inefficiency during the compliance periods. Second, I find no evidence to support the claim that Japan's regional ETSs increase outsourcing activities either before or during its compliance period.

The analysis contributes to discussions in previous studies in the following two ways. First, this chapter reveals the impact of Japan's regional ETS on targeted facilities' energy efficiency. While some studies have investigated whether ETSs improve energy efficiency at the firm level, almost none have analyzed such effects at the facility level. To my knowledge, Löschel et al. (2019) is the only study to use facility-level data (accumulated at the firm level) to analyze the impact of the EU-ETS on energy efficiency. By focusing on facilities that directly participate in the production process, the impact of ETSs on energy efficiency can be accurately assessed compared to the literature that did not use facility-level data.

Second, this chapter contributes to the literature on the effect on the announcement period, which has received insufficient attention. Targeted facilities may respond to ETSs before their implementation to comply with uncertain upcoming emissions reduction costs. During the announcement period, targeted facilities already understand the emissions reduction required to comply with the regulation of the ETS, enabling them to adopt strategies to comply with the upcoming reduction targets. Although emissions during the announcement period do not affect the emissions reduction target of facilities, the results still show that targeted facilities' energy inefficiency increases during this period. This chapter not only addresses the controversy in the literature but also explores the behavior of targeted facilities before ETS implementation.

4.1.2 Japan's regional ETSs

In 2007, the Tokyo government announced the establishment of the first regional ETS in Japan in 2010 to combat climate change. Following the Tokyo ETS, Saitama prefecture, a neighbor of Tokyo metropolitan area, introduced a regional ETS (Saitama ETS) one year after the Tokyo ETS. Both the Tokyo and Saitama ETSs introduced step-by-step strength reduction targets, calculated on the basis of baseline emissions derived from the CO_2 emissions of any consecutive three-year period from 2002 to 2006. Each facility was apprised of its emissions reduction target from the announcement period in 2007. The Tokyo and Saitama ETSs cover approximately 1,200 and 600 facilities in all industries with an energy consumption of more than 1,500 kℓ of crude oil equivalent per year (approximately 2,800 tons of CO_2). The main target of the Tokyo ETS is commercial and service industries, whereas the Saitama ETS mainly covers manufacturing facilities. Approximately 70% of the targeted facilities in the Saitama ETS are manufacturing facilities.

For the manufacturing targeted facilities, the first compliance period of the Tokyo ETS is 2010 to 2014, while for the Saitama ETS, it is from 2011 to 2014. Both ETSs established a reduction target of 6% in the first compliance period. The second compliance period of the two ETSs is from 2015 to 2019. In this period, the reduction target of the Tokyo ETS set 15% emissions reduction from targeted facilities as the goal. Saitama ETS targeted 13% emissions reduction of the targeted facilities. If a targeted facility reduces emissions beyond the reduction target, it can receive credits (emissions allowances) in the equivalent amount for excess emission reduction. The allowances can be banked for only one following consecutive compliance period. If a facility has difficulty achieving its reduction targets, it can use emissions allowances and several alternative credits. A notable distinction between the Tokyo and Saitama ETSs is penalties when the facilities violate the compliance amount of CO_2 emissions. The Saitama ETS does not penalize targeted facilities that fail to comply with reduction targets, making it a voluntary ETS and the only one of its kind in the world. In contrast, under the Tokyo ETS, facilities failing to comply with reduction targets face penalties, including financial charges and public disclosure of noncompliance.

This chapter takes several advantages by focusing on Japan's ETSs as follows. First, the unique data from the Census of Manufacture provides information on manufacturing facilities, including those regulated by ETSs. Hance, this chapter has sufficient conditions to estimate the effects of Japan's ETS on energy efficiency. To my knowledge, no studies has examined the effect of Japan's regional ETSs on energy efficiency. Second, geographically restricted ETSs offer a suitable case for analyzing outsourcing-induced carbon leakage. Such ETSs may provide an incentive to targeted facilities to shift their production processes domestically to avoid environmental costs, leading to carbon leakage. The data provide information on outsourcing; thus, I can analyze whether carbon leakage occurs through outsourcing activities.

4.1.3 Energy efficiency and environmental regulation

Energy efficiency improvement can contribute to CO_2 emissions reduction. It can contribute more than 40% of the carbon mitigation required by 2040 to comply with the Paris Agreement, which has become an urgent issue for the world to achieve global climate targets (IEA, 2018). In 2022, Japan's government enacted the Revised Energy Conservation Act that aims to improve energy efficiency and increase the usage of renewable energy to achieve carbon neutrality by 2050 and a 46% emission reduction by 2030. It imposes a 1% annual improvement in the energy efficiency of all energy resources. Moreover, energy efficiency improvement is also emphasized in the policy formulation procedure (Al-Mansour, 2011; Wang et al., 2012; Zhao et al., 2019). Appropriate environmental regulations are designed to aid energy efficiency improvement to mitigate and avoid potential shifts in production. In summary, investigating the relationship between energy efficiency and environmental regulations can provide evidence for the effectiveness of regulation and help policymakers improve the quality of regulations.

4.2 Methodologies

4.2.1 Measuring of energy efficiency

The impact of environmental regulation on energy efficiency is a topic of significant interest, a particularly as these regulations frequently aim to reduce CO_2 emissions through technological innovation and improvements in energy efficiency. In this context, accurately measuring energy efficiency is crucial for studies investigating the impact of environmental regulation on efficiency. Previous studies have developed methods for estimating the appropriate energy efficiency of each economic entity. Li et al. (2017) reviewed these methodologies to estimate the energy efficiency of high-energy-consuming industries. In particular, they mentioned SFA and data enveloped analysis (DEA) as major approaches for estimating the energy efficiency of these industries. DEA is a nonparametric approach to estimating efficiency without specifying the functional form for the frontier and distribution assumptions (Charnes et al., 1978; S. Zhang et al. 2016). That is, DEA is unable to distinguish between inefficiency and random noise. Without consideration of random noise, the requirements for data are more stringent. DEA can also be affected by statistical errors in the data, which may lead to bias in efficiency measurement (Shao et al., 2016).

SFA is a parametric approach proposed by Aigner et al. (1977). A strategy was provided for evaluating the efficiency scores for units to distinguish between the mediation and restorative measures of units (Dagar et al., 2021). Compared with DEA with fixed frontier, SFA exploits specifying random noise so that the statistical noise term and nonnegative random disturbance term in the equation can be distinguished. Because SFA accounts for random error, it estimates a facilities' efficiency to be closer to the frontier compared to DEA. In other words, SFA can potentially provide a more nuanced view of efficiency by distinguishing between inefficiency and statistical noise (Shao et al., 2019). Moreover, efficiency measured through SFA is the absolute efficiency value, making it possible to conduct a comparative analysis of effective production units (Coelli et al., 2005). Numerous studies adopted SFA for measuring energy efficiency (Lundgren et al., 2016; Haider and Mishra, 2021). However, there is a gap in the literature regarding the efficiency of facilities targeted by Japan's ETSs. In this chapter, I adopt the true fixed-effect SFA model following Greene (2005) to measure the facilities' energy inefficiency, considering the heterogeneity across facilities. The SFA model evaluates how closely a firm's production output approaches the maximum possible output (the 'production frontier') achievable with a given set of inputs and fixed technology. The 'production frontier' represents a benchmark of optimal output. In this context, a facility's energy inefficiency refers to the difference between its current performance and the optimal performance that could be achieved with a given set of inputs and technologies. For instance, facilities operating on the frontier are deemed fully efficient, meaning that they are producing the maximum feasible output with their available inputs and technology. Conversely, the greater the distance a facility has from this frontier, the less efficient it is considered. In practice, the estimation of the stochastic production frontier function, which can maximize an output from given inputs, based on Aigner et al. (1977) and Meeusen and van Den Broeck (1977) is used in this chapter. Based on panel data, the estimation is given as equation (4.1).

$$\ln(y_{it}) = f(\boldsymbol{x}_{it}) + \varepsilon_{it}. \tag{4.1}$$

Where y_{it} is the output of facility *i* in year *t*. ε_{it} can be represented by $v_{it} - u_{it}$. In this chapter, I use production value as the output[6]. $f(\boldsymbol{x}_{it})$ is the determinants of the production frontier, $\boldsymbol{x}_{it}$ is the input vector, v_{it} is the independent disturbance error term with a zero mean and constant variance distributed $v{\sim}N(0, \sigma_v^2)$, and u_{it} is the time-varying nonnegative random disturbance term indicating the technical inefficiency with an exponential distribution. v_{it} is assumed to be independent of u_{it}. This chapter assumes that $f(\boldsymbol{x}_{it})$ takes the form of a Cobb–Douglas function. The input vector $\boldsymbol{x}_{it}$ includes labor, the usage of electricity and coal for energy (ten thousand yen), fixed assets (ten thousand yen), and intermediate material costs (ten thousand yen). This chapter estimates the stochastic frontier in the four-digit sector within Japan's manufacturing industry to ensure that specific industrial technologies are considered. The energy efficiency can be calculated by following equation:

$$TE_{it} = \frac{y_{it}}{y'_{it}} = \frac{exp[f(\boldsymbol{x}_{it}) + v_{it} - u_{it}]}{exp[f(\boldsymbol{x}_{it}) + v_{it}]} = exp(-u_{it}). \qquad (4.2)$$

Where y_{it} represents the output of equation (4.1), while y'_{it} represents the facility's potential output on its stochastic frontier. This implies that equation (4.2) is used to estimate the energy efficiency of the facilities, assessing how effectively the facility converts a given set of inputs into output. Essentially, it measures the facility's ability to maximize its output given its current set of inputs and its available technology. The efficiency is quantified as a value ranging from 0 to 1, with 1 indicating perfect efficiency. Then the energy inefficiency is calculated by following equation:

$$IE_{it} = 1 - TE_{it}. \qquad (4.3)$$

4.2.2 Basic Model

The identification strategy in this chapter for investigating the impact of ETS on energy inefficiency and outsourcing activities is the DiD method based on the propensity score matching (PSM) aiming to overcome the selection bias between targeted and nontargeted facilities due to the policy, facility-level heterogeneity, and confounding factors that may affect targeted and nontargeted facilities. Existing studies already revealed that the matching method can remove selection bias in the sample (Abadie, 2005). Also, this method is an optimal strategy to ensure that the regulatory status of ETS is randomly assigned based on facility characteristics (Zhu et al., 2019). The procedure was wieldy used to assess the regulatory status of an ETS, conducting the random assignment based on observable characteristics (Löschel et al., 2019; Calel & Dechezleprêtre, 2016).

The identification strategy is specified in the following two steps. The first step is selecting and matching targeted facilities with similar untargeted facilities, conditional on the observable characteristics of the facilities. In practice, this chapter matches one targeted facility with one (or more) nontargeted

[6] Production value is defined as follows;
Shipment value + (Year-end production stock value – Production stock value at the start of the year) + (Year-end value of products in progress and half-finished product - Value of products in progress and half-finished product at the start of the year)

facilities with similar characteristics. The matched pairs can be identical in all factors except for the dependent variable (energy efficiency estimated through SFA) of DiD estimation. By giving extremely harsh conditions to restrict the sample to match more close facilities will lead to several targeted facilities that cannot be matched with suitable facilities to apply the DID model. However, the accuracy and robustness of the method compensate for the loss of sample size (Dehejia & Wahba, 1999). The nearest neighbor matching estimator is adopted to carry out the above procedure (Abadie et al., 2004) in the four-digit sector.

This chapter follows Löschel et al. (2019) to match pairs by inputs of the stochastic production frontier function in the first year of the data. I also include employee pay, the shipment value of products, the export ratio, the usage of freshwater, and area as matching variables to further reduce potential selection bias. Replacement is allowed in the estimation to ensure that the nontargeted facilities can be matched multiple times with targeted facilities. Matching quality is evaluated through a comparison of the differences between targeted facilities and nontargeted facilities in all matching variables, which will be introduced later.

The second step estimates the effects of ETSs based on matched pairs by applying the DID method that is an effective tool for evaluating policy instruments by estimating the treatment effect (Imbens & Wooldridge, 2009). The causal relationship between environmental regulation and outcome variables can be evaluated based on the DID method by comparing the treatment and control groups. I classified the sample (facilities) into treatment and control groups based on whether facilities were targeted by the Tokyo and Saitama ETSs. Following the process of the ETSs, this chapter distinguishes the implementation period from the announcement period (2007 to 2009 or 2010), the first compliance period (2010 or 2011 to 2014), and the second compliance period (2015 to 2016). The baseline DID model is conducted as follows:

$$Y_{ijt} = \beta_1 ETS_{ij} \times P_t^{an} + \beta_2 ETS_{ij} \times P_t^1 + \beta_3 ETS_{ij} \times P_t^2 + \boldsymbol{X}_{ijt} B + \mu_t + \gamma_i + \theta_j + \varepsilon_{it}. \quad (4.4)$$

where the subscript *i* is the facility, *j* is the sector, and *t* is the year. Y_{it} represents the outcomes, including the energy inefficiency estimated based on equation (4.3) and outsourcing activities. ETS is a dummy variable with a value of one for facilities targeted by the Tokyo or Saitama ETS. P_t^{an}, P_t^1, and P_t^2 represent the announcement period and the first and second compliance periods, respectively. $\boldsymbol{X}_{it}$ is a vector of control variables including 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. μ_t, θ_j, and γ_i are the annual fixed effect, sectoral fixed effect and facility fixed effect, respectively. ε_{it} is an error term.

The estimation relies on conditional unconfoundedness, in which the outcome distribution of facilities is independent of the assignment of regulatory status. However, unconfoundedness cannot be directly tested. Moreover, the identification strategy assumes the stable unit treatment value assumption (SUTVA), which requires that the regulation affects only targeted facilities, excluding the spillover effect. Similar to unconfoundedness, this assumption also cannot be directly tested. However, by analyzing estimations with alternative specifications, I can confirm whether the results violate the SUTVA. In this cchapter, I apply some tests to assess the validity of the assumption. I show the details about the tests and their results in Section 4.4.3.

4.3 Data and Summary Statistic

This chapter leverages facility-level data from the Census of Manufacture conducted by the Ministry of Economy, Trade, and Industry (METI) of Japan between 2002 and 2016 (except for 2011 and 2015). The sample covers approximately 45,000 facilities annually for four-digit manufacturing sectors, providing information such as production value, the number of employees, the usage of electricity and fuels for energy, fixed assets, and intermediate material costs. For the years 2011 and 2015, this chapter utilizes data from the Economic Census for Business Activity from the METI and the Ministry of Internal Affairs and Communications (MIC), which has been implemented every 5 years since 2012 by the METI and the MIC. The Census of Manufacture targets facilities with more than 4 employees in the manufacturing industry, and all facilities are required to fill out and submit the form to the government. In this chapter, I focus on the sample of manufacturing facilities with more than 30 employees in this census. The facilities with fewer than 30 employees did not need to report the amount of fixed assets. The census records 90 items of information. The total sample covers approximately 45,000 facilities annually for four-digit manufacturing sectors, including production value, the number of employees, the usage of electricity and fuels for energy, fixed assets, and intermediate material costs. Compared with the Census of Manufacture, the Economic Census for Business Activity provides more detailed information and targets all facilities in Japan. In years when the Economic Census for Business Activity is conducted, the Census of Manufacture is not administered. This chapter combines the data of the two censuses to obtain panel data between 2002 and 2016. The panel data can be used to estimate the facilities' energy efficiency and to analyze the impact of the Tokyo and Saitama ETSs on the estimated energy efficiency.

After handling the missing values and outliers as well as the matching process, I obtain an unbalanced panel of 2,316 observations for the period from 2002 to 2016. All matched facility pairs are in the same four-digit sectors with similar characteristics, including all inputs of the stochastic production frontier function. That is, all matched facilities are exposed to the same input and sectoral-specific shocks and trends. Matching quality is evaluated through a comparison of the mean difference in the matched groups, which is shown in Table 1. Before matching, the average value of almost all variables shows significant differences between targeted and nontargeted facilities, excluding the export ratio and the usage of freshwater. The differences mean that the characteristics of the facilities may have sample bias between the targeted and nontargeted facilities. After matching, the average value of all matching variables does not show statistically significant differences between each sample group. Therefore, the matched sample can overcome the sample bias problem when I perform DID estimation. The descriptive statistics of all variables are shown in Table 2.

4.4 Results

4.4.1 Energy inefficiency results

I provide an intuitive way to view the results with the aid of a graph that plots the energy inefficiency of the matched targeted and nontargeted facilities before and after the implementation of the Tokyo and Saitama ETSs (see Fig. 4.1). Fig. 4.1 shows the energy inefficiency of the matched targeted and nontargeted facilities, highlighting the announcement and compliance periods of the ETSs. The red line represents targeted facilities, and the blue line represents nontargeted facilities. I found that the energy inefficiency of the two groups appears to be roughly comparable, particularly during the preannouncement period. An upward trend after the announcement is found only for the targeted facilities, creating an enormous gap between the two groups in the figure from 2007 to 2011. This means that the targeted facilities took action to change their production activities when they knew that they would face environmental regulation. However, one year after the implementation of the ETSs, the trend became similar again. Another noteworthy feature is that I do see an abnormal increase in inefficiency in both targeted and nontargeted facilities from 2008 to 2009, which reflects that the facilities in Japan were affected by the global financial crisis.

4.4.2 Basic Results

The baseline results of energy inefficiency and outsourcing activities are shown in Table 4.3 Columns (1) and (2), respectively, based on equation (3). Column (1) shows that the impact of the ETSs on energy inefficiency is statistically significant at the 10% level only for the coefficient of the interaction term $ETS \times P^{an}$. This indicates that the energy inefficiency of targeted facilities increased by 13% compared with nontargeted facilities in the announcement period. It seems that the targeted facilities tended to change their production activities to comply with the reduction targets before ETS implementation.

Three or four years before the official implementation of the ETSs, the Tokyo and Saitama governments announced that an ETS would be launched to provide a buffer to targeted facilities for revision strategies for their production. Potential strategies for facilities include fuel switching, investment in renewable energy technologies, investment in new clean technologies, and the purchase of advanced equipment, which may lead to lower energy efficiency and productivity in the short term. When targeted facilities face uncertainty about upcoming environmental regulations, they may complete adjustments during the announcement period.

According to the official reports of the Tokyo and Saitama ETSs, both ETSs achieved excess reductions during the first compliance period. Such excess reductions may stem from targeted facilities taking strategies as discussed earlier, which induces an increase in the adjustment cost of production, resulting in energy inefficiency. During the announcement period, targeted facilities become aware of their specific emissions targets, calculated based on their emissions between 2002 and 2006, and tend to take preemptive strategies to address the future uncertainty of ETSs, such as the price of allowance and reduction targets, before ETS implementation.

Notably, only 10% of targeted facilities achieve targets by trading allowances, highlighting the limited opportunities for reducing mitigation costs in allowance trading. Japan's ETS market faces multiple challenges, including a lack of financial exchange market of allowances for targeted facilities, inaccessible transaction records for other traders, low transaction liquidity, and scarce price information about the allowance. These issues result in lower liquidity for allowance transactions in Japan's ETS market compared to the EU ETS and China ETS, indicating that Japan's ETSs fail to fulfill their price signaling function. In this context, the targeted facilities must strive to achieve the emissions reduction target through their own efforts, avoiding uncertainty related to purchasing additional emissions allowance from the market. Therefore, targeted facilities tend to decrease their CO_2 emissions, despite the rapid loss of production efficiency in the early stage.

Moreover, the coefficients of the interaction terms in the compliance periods ("$ETS \times P^1$" and "$ETS \times P^2$") are not significant. The estimation results indicate that the Tokyo and Saitama ETSs did not affect the energy efficiency of the targeted facilities, which can be explained by following two reasons. First, this chapter focuses on the impact of ETSs on energy efficiency at the facility level instead of the firm or regional level, as investigated by the literature, which might be a reason why the results are inconsistent with those of the literature. Firm- or regional-level data cannot directly capture production activities as inputs and outputs to measure energy efficiency. Only one study adopted facility-level data, Löschel et al. (2019), which aggregated facility-level data to firm-level data to measure energy inefficiency. Compared with Löschel et al. (2019), this chapter uses the characteristics of facilities in the matching process, including not only the input of SFA but also other characteristics used as control variables in the DID model.

Second, another possible reason might be the difference in scale merit. Especially in the case of the Tokyo and Saitama ETSs, in which facilities with more than 2,800 tons of CO_2 emissions are covered, the Tokyo and Saitama ETSs target relatively small-scale facilities compared with China's national ETS and the EU-ETS. Therefore, the targeted facilities of Tokyo and Saima ETSs might not be able to enjoy the scale merit for emissions reduction. However, through the results, the impact of Japan's ETSs on energy inefficiency has undergone a radical transformation from the announcement period to the compliance period, which is confirmed. This result implies that the implementation of an ETS may decrease targeted facilities' energy inefficiency.

Column (2) shows that the ETSs did not induce an increase in outsourcing activities during the announcement and compliance period. The insignificant effect of ETSs on outsourcing activities indicates that the targeted facilities did not take a strategy of outsourcing their production process to other facilities. This result is in line with previous findings. Martin et al. (2014) interviewed 761 managers of both EU ETS and non-EU ETS firms in six European countries to determine whether the company planned to downsize operations or relocate abroad soon in response to carbon pricing. They concluded that the average downsizing risk is low in the case of the EU-ETS. Most interviewed managers report that future carbon pricing has no impact on their location decisions. In line with these previous findings, the results imply that Japan's regional ETSs also did not cause leakage behavior of each facility through outsourcing.

4.4.3 Robustness Tests

4.4.3.1 Unconfoundedness assumption

The matching strategy assumes conditional unconfoundedness, which cannot be tested in principle. This chapter conducts three tests to confirm unconfoundedness by following the previous literature. First, I conduct a placebo test to confirm whether the baseline result is affected by potential confounding regulations. Because the targeted facilities may be affected by other local environmental regulations, the results may capture the impacts of these regulations rather than the ETSs. Therefore, I conduct a placebo test by implementing potential confounding regulations one year before the announcement of Japan's regional ETSs (Löschel et al., 2019). In practice, I conduct a counterfactual treatment group to capture the impact of the potential confounding regulation since 2006. I still distinguish the period to announcement and compliance period in the analysis. If the facilities in the counterfactual group are not affected by the potential confounding regulations, the estimates of the counterfactual group should be insignificant. Table 4.4, Column (3) shows the result of the placebo treatment effects for the baseline result, which indicates the statistically nonsignificant effect of counterfactual ETSs on energy inefficiency, meaning that the conditional unconfoundedness assumption holds for the matching process.

Second, I conduct a test to check whether omitted variable bias exist in the analysis based on Oster (2019) by following Koch and Themann (2022). Oster (2019) provided a series of analysis to confirm this potential effect by focusing on bound for the interest coefficient (β_1 in equation (4.3) in this chapter). This identification can be realized by using the R-squared and a selection proportionality δ that captures the changes in coefficients conditional on two different specifications of different explanatory variables. Specifically, based on Oster (2019), if the estimated bounds fall in the 99.5% confidence interval of the interest coefficient, I can conclude that the interest coefficient is unlikely affected by unobservable factors that are at least as important as the observable factors. For the δ, if the value is larger than 1, for instance, indicating that the unobservable factors need be twice of important than other observable factors to no longer explain the effect of interest coefficient (See Oster, 2019). This chapter found that the bound falls within the 99.5% confidence interval of β_1 and the δ is 1.64 indicating the announcement effect is unlikely affected by omitted variable bias.

Third, I conduct another alternative placebo test to confirm whether the baseline result is affected by the omitted variables or other unobserved factors. I follow Ferrara et al. (2012) and Cai et al. (2016) by randomly selecting firms from the full sample as a counterfactual treatment group to check whether counterfactual treatment effect affects energy inefficiency. Due to the random selection, the effect of the counterfactual treatment group should not affect energy inefficiency when the omitted variable or other unobserved factors do not exist. If the counterfactual group significantly affects energy performance, the placebo effect exists so that the result is unreliable. In practice, I randomly select 106 facilities (similar to the actually targeted facilities in the matched sample) in a four-digit sector as the counterfactual group (Yu & Zhang, 2022). This procedure was repeated 500 times to obtain the distribution of the counterfactual estimators. I require the counterfactual targeted facilities to also face an announcement period of 3 to 4 years based on whether they were targeted by the Tokyo or Saitama ETS. Fig. 4.2 plots the density distribution of the counterfactual coefficients, in which the distribution concentrates on 0 with a mean value of -0.023 and a standard deviation of 0.080. The real value of the significant estimator $ETS_{ij} \times P_t^{an}$ (dashed line) is larger than the value of the 95th percentile of the counterfactual estimators (solid line), indicating that the counterfactual effect is reached or exceeded by less than 5% in the 500 placebo tests. I conclude that omitted variables are unlikely to induce the effect on energy inefficiency, and the assumption holds.

4.4.3.2 SUTVA

Additionally, I need to test whether this chapter can permit the SUTVA. The identification strategy relies on the SUTVA, which indicates that nontargeted facilities are not affected by targeted facilities, which also cannot be tested in principle (Fowlie et al., 2012; Themann & Koch, 2021). In the regions of the ETSs, nontargeted facilities may also be affected by the ETSs through the spillover effect from targeted facilities. For example, if nontargeted facilities compete with nontargeted facilities in a specific region, the performance of nontarget facilities is affected by the performance of targeted facilities that are affected by the ETS. Additionally, a positive spillover effect on energy and production efficiency may occur between targeted and nontargeted facilities if facilities have some information channel. Even if the SUTVA cannot in principle be tested, by analyzing the specific cases of the violation of the STUVA, I can check whether the assumption holds.

I analyze two cases by changing the treatment and control groups of the DID analysis: (1) changing the treatment group to a nontargeted facility in Tokyo and Saitama and changing the control group to a nontargeted facility from all regions except for Tokyo and Saitama; and (2) changing the treatment group to a targeted facility in Tokyo and Saitama and changing the control group to a non-ETS-regulated facility from all regions of the country except for Tokyo and Saitama. The results are shown in Table 4.4, Column (4) and (5), respectively. Table 4.4, Column (4) shows a nonsignificant effect in three periods, indicating no difference between nontargeted facilities in ETS regions and nontargeted facilities in regions excluding ETS regions. Column (5) shows a significant effect on energy inefficiency during the announcement period between targeted and nontargeted facilities in regions excluding ETS regions. In summary, I conclude that nontargeted facilities are not affected by targeted facilities; thus, the SUTVA holds.

4.4.3.3 Other robustness tests

This chapter provides additional results for different matching specifications to check the robustness of the baseline results. In particular, I first analyze using the different matching ratios of nontargeted facilities to targeted facilities from one to five to one to twenty (Löschel et al., 2019). I impose restrictions similar to those in the baseline analysis on the alternative specifications in the matching process and DID estimations. Table 4.5 shows that all estimated coefficients of energy inefficiency during the announcement period are significant. Table 4.6 shows the results of outsourcing activities based on different specifications, and they are consistent with the baseline results. I conclude that the effects of the Tokyo and Saitama ETSs on energy inefficiency and outsourcing activities at the individual facility level are robust in the announcement period.

A precondition of the DID method is the targeted and nontargeted facilities following parallel trends over the pretreatment period (Callaway & Sant'Anna, 2021). Even though the matching process in this chapter confirmed no difference between the two groups before the announcement, the parallel trend of the DID estimators still needs to be clarified. The parallel trend is tested using the following equation based on Jacobson et al. (1993).

$$Y_{it} = \sum_{j=2002}^{2016} \beta_t ETS_{ij} \times D_t + \boldsymbol{X}_{ijt} B + \mu_t + \gamma_i + \theta_j + \varepsilon_{it}. \tag{4.4}$$

Where D_t is the dummy variable for the period of 2002 to 2016 except for 2006, which is the year before the announcement of the ETS as the base year. Fig. 4.3 shows the parallel trends of the ETSs in energy inefficiency by plotting β_t with a 95% confidence interval. I find that the coefficients are nearly 0 during the pre-announcement period, which indicates that the trend between the two groups is similar. Therefore, I conclude that the parallel trend assumption holds.

4.5 Conclusion

This chapter investigates the impact of the Tokyo and Saitama regional ETSs on the energy inefficiency and outsourcing activities of targeted manufacturing facilities from 2003 to 2016. Through the propensity score matching adjusted DID method, the causal effect of Japan's ETSs on energy inefficiency, which is measured as the distance to the production frontier at the facility level based on stochastic frontier analysis, can be examined.

The empirical results highlight that Japan's regional ETSs diminished energy efficiency at the facility level in the manufacturing sector during the pre-compliance (announcement) period of the ETSs. It can be concluded that this is attributed to increases in the adjustment costs of production, such as equipment replacement or improvement in technologies, as targeted facilities prepare for emission reduction methods prior to ETS implementation to comply with future uncertainties. During the compliance period, however, the results suggest that Japan's regional ETSs do not increase the energy inefficiency of targeted facilities. In contrast to previous studies that found that the China and EU ETSs improved the energy efficiency of firms and facilities (Chen et al., 2021; Löschel et al., 2019), this chapter does not consider CO_2 emissions as an input for calculating energy efficiency. Generally, targeted facilities tend to decrease CO_2 emissions more than nontargeted facilities. Therefore, if this chapter considers the CO_2 emissions that is unable to access in this chapter for estimating energy efficiency, the near results with previous studies may be found for Japan's

ETSs. Furthermore, the results also indicate that Japan's regional ETSs do not increase outsourcing activities at the facility level. I conclude that Japan's ETSs not only increase targeted facilities in reducing their energy efficiency performance but also in inhibiting the potential risk of outsourcing-induced carbon leakage during the compliance period.

The interpretations of the empirical analysis results need to be made with caution. It is crucial to keep in mind that I matched facility pairs only in terms of observable characteristics. Although I include inputs of SFA in measuring energy efficiency to ensure that facilities with the same performance can be matched, factors such as energy prices and electricity prices need to be carefully considered in the analysis. Electricity prices directly affect the costs and electricity consumption of facilities, particularly in Japan, where electricity prices differ depending on the region. However, I cannot control for prices in facilities or industries. This means that the matching process allows facilities from the two regions under study to be matched as a pair, and these two facilities probably face different difficulties in energy efficiency improvement.

Tables

Table.4.1 Equivalence tests for matched targeted and nontargeted facility

	Matched			Non matched		
Variables	Targeted	Nontargeted	Difference	Targeted	Nontargeted	Difference
Inputs and output						
Energy inefficiency	0.189	0.165	-0.023	0.189	0.174	-0.014
Employment	402.952	362.343	-40.609	402.952	153.372	-249.5***
Total energy used (ten thousand yen)	33258.03	32411.58	-846.445	33258.03	13235.36	-20022***
Fixed assets (ten thousand yen)	464736.8	393535.8	-71200.9	464736.8	149546.7	-315190***
Intermediate material costs (ten thousand yen)	1006195	1173885	167690	1006195	296739	-709455***
Sales (ten thousand yen)	2008026	2250472	242445	2008026	619663	-1388363***
Controls						
Payment (ten thousand yen)	254087	217425	-36662.1	254087	80375.8	-173712***
Shipment value (ten thousand yen)	1978083	2219671	241587	1978083	605661.8	-1372421***
Export ratio	3.490	3.687	0.196	3.490	2.086	-1.403
Usage of freshwater (m^3)	4983.70	4081.44	-90.225	4983.70	3992.79	-990.909
Area (m^2)	59004.1	59550.5	546.362	59004.1	39382.2	-19621.88

Notes: This table reports mean value and its difference between targeted and nontargeted facilities in the samples for the all variables including energy efficiency. The difference is tested by T-test. To prove the matching process quality, the median difference of unmatched and matched pairs is shown in the table simultaneously. Energy inefficiency is not used in the matching process. *$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.

Table.4.2 Descriptive statistics

	Obs	Mean	S.D.	Min	Max
Inputs and output					
employment	2,310	339.07	569.527	30	4948.0
total energy used	2,310	28100.41	54386.5	154	588998
fixed assets	2,310	324388	626589	1	11200000
intermediate material costs	2,310	969163.9	3475289	19	63500000
sales	2,310	1822360	5263358	10248	68100000
Controls					
energy inefficiency	2,310	0.163077	0.102	0.034	0.98
payment	2,310	197229.9	373016.3	3979	3527124
shipment value	2,310	1741736	5192844	0	68400000
area	2,310	49758.89	94170.86	288	1245675
usage of freshwater	2,310	2613.258	12050.3	1	185150
export ratio	2,310	4.59787	11.850	0	86.05

Table.4.3 Baseline results

Outcome variables	ln(Energy inefficiency)	ln(Outsourcing)
	(1)	(2)
ETS × P^{an}	0.133* (0.0703)	0.0450 (0.158)
ETS × P^1	0.0480 (0.0768)	0.139 (0.175)
ETS × P^2	0.158 (0.103)	-0.0144 (0.222)
Payment	-0.0409 (0.0419)	1.045*** (0.130)
Shipment value	-0.0376** (0.0147)	0.0992*** (0.0251)
Area	0.0151 (0.0522)	-0.362*** (0.131)
Usage of freshwater	0.00738 (0.0184)	-0.0458 (0.0432)
Export ratio	0.0399* (0.0210)	0.0614 (0.0491)
Year-fixed effect	Yes	Yes
Facility-fixed effect	Yes	Yes
Sector-fixed effect	Yes	Yes
Observations	2,266	2,266
R-squared	0.394	0.862

Notes: Standard errors reported in parentheses are clustered at facility level. *p < 0.1; **p < 0.05; ***p < 0.01.

Table.4.4 Results for identifying two assumptions

	Unconfoundedness	SUTVA	
	(3)	(4)	(5)
ETS × $P^{06\text{-}10}$	0.115 (0.0711)		
ETS × $P^{11\text{-}16}$	0.0476 (0.0840)		
ETS × P^{an}		0.0132 (0.250)	0.143* (0.0733)
ETS × P^{1}		-0.226 (0.214)	0.0523 (0.0829)
ETS × P^{2}		-0.166 (0.208)	0.154 (0.106)
Controls	Yes	Yes	Yes
Fixed effects	Yes	Yes	Yes
Observations	2,266	2,183	1138
R-squared	0.392	0.541	0.411

Notes: Standard errors reported in parentheses are clustered at facility level. *p < 0.1; **p < 0.05; ***p < 0.01.

Table.4.5 Results for robustness tests of inefficiency

	(6)	(7)	(8)	(9)
	1:5	1:10	1:20	Baseline
ETS × P^{an}	0.119** (0.0570)	0.111** (0.0555)	0.120** (0.0545)	0.133* (0.0703)
ETS × P^{1}	0.0649 (0.0644)	0.0671 (0.0632)	0.0756 (0.0619)	0.0480 (0.0768)
ETS × P^{2}	0.0933 (0.0822)	0.0965 (0.0773)	0.0969 (0.0760)	0.158 (0.103)
Controls	Yes	Yes	Yes	Yes
Fixed effects	Yes	Yes	Yes	Yes
Observations	6,690	11,197	18,307	2,266
R-squared	0.301	0.264	0.218	0.394

Notes: Standard errors reported in parentheses are clustered at facility level. *p < 0.1; **p < 0.05; ***p < 0.01.

Table.4.6 Results for robustness tests of outsourcing

	(10)	(11)	(12)	(13)
	1:5	1:10	1:20	Baseline
ETS × P^{an}	-0.0404 (0.160)	-0.0331 (0.160)	-0.0957 (0.153)	0.0450 (0.158)
ETS × P^{1}	0.122 (0.168)	0.0843 (0.172)	0.00809 (0.162)	0.139 (0.175)
ETS × P^{2}	0.0933 (0.0822)	0.0965 (0.0773)	0.0969 (0.0760)	-0.0144 (0.222)
Controls	Yes	Yes	Yes	Yes
Fixed effects	Yes	Yes	Yes	Yes
Observations	6,690	11,197	18,307	2,266
R-squared	0.783	0.768	0.751	0.394

Notes: Standard errors reported in parentheses are clustered at facility level. *p < 0.1; **p < 0.05; ***p < 0.01.

Figures

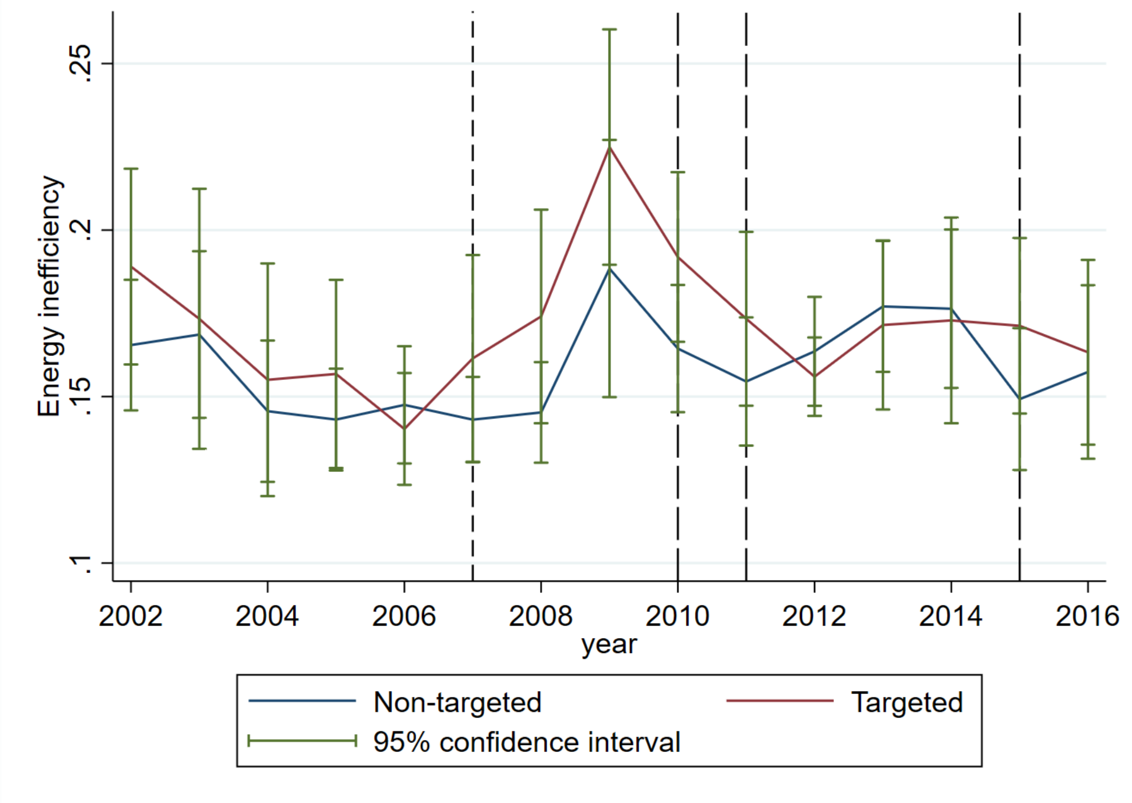

Fig.4.1. Energy inefficiency of matched targeted and nontargeted facilities

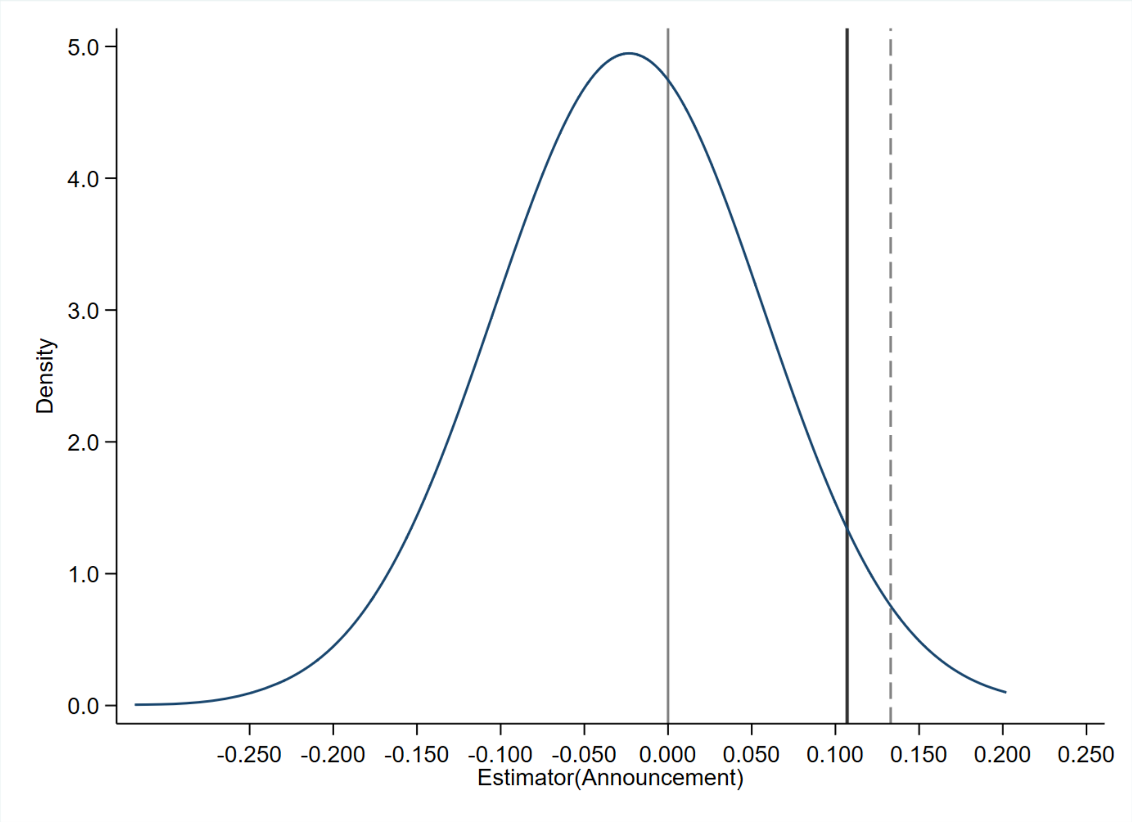

Fig.4.2. Placebo test

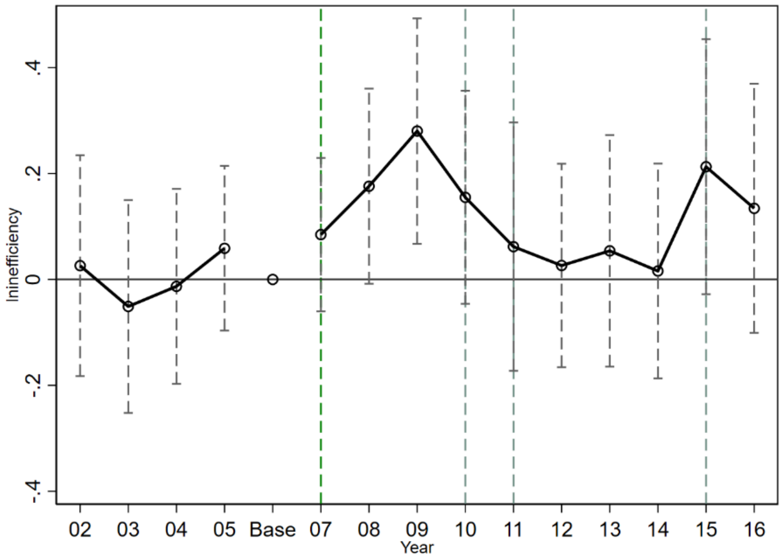

Fig.4.3. Parallel test

Chapter 5

Conclusion: Summary of the dissertation and policy implications

In this dissertation, I conduct a comprehensive evaluation of the impact of Japan's major environmental initiatives and regulations—from the industrial, sectoral, and firm levels down to the facility level—on changes in CO_2 emissions, innovation, energy efficiency performance, and carbon leakage. I confirm that the VAP, a sectoral-level initiative by industry associations, contributes to emission reduction under certain circumstances. However, it is important to maintain awareness regarding the reduction of emissions from the manufacturing industry as this abatement is associated with changes in the industrial structure and a shift in energy consumption from fossil fuels to electricity. Moreover, through the firm-level analysis on the Saitama ETS's innovation and carbon leakage, I find that innovation activities, which are often driven by firms' headquarters, are improved by the Saitama ETS without leading to carbon leakage. However, carbon leakage tends to occur at the facility level, and relying on firm-level analysis may not fully capture the impact of ETS on carbon leakage. Nevertheless, through the facility-level analysis conducted in the research, this dissertation can still provide compelling results on carbon leakage induced by Japan's ETSs. Additionally, it evaluates whether Japan's ETSs induce energy inefficiency at the facility level. Although I find that ETSs reduce energy efficiency performance during the announcement period (pre-implementation period) due to increased costs associated with preparing for upcoming reduction targets, energy efficiency does not decrease during the compliance period. Based on these findings, I offer policy recommendations for each chapter.

In the second chapter, I assess the impact of the VAP on CO_2 emissions across all industries in Japan utilizing input-output and 3EID data. Through the decomposition analysis, I examine the impact on changes in direct and indirect CO_2 emissions, thereby evaluating the VAP's effectiveness and identifying which factors contribute to emission reduction in Japan. The results show that although the direct CO_2 emissions in the manufacturing industry decrease, the indirect CO_2 emissions increase, indicating the energy consumption shift from fossil fuel to electricity. Moreover, the service industry's CO_2 emissions continue to increase throughout the study period, which signifies insufficient control over emissions in this sector. The results also suggest that the VAP has a limited influence on reducing CO_2 emissions in sectors with lower market concentration. In light of these findings, I propose four policy recommendations targeted at the manufacturing, service, and power sectors.

First, the analysis suggests that the VAP failed to provide incentives to sectors with low market concentration to reduce CO_2 emissions. Additionally, the VAP failed to reduce CO_2 emissions for sectors in the manufacturing industry with energy-intensive targets; its contribution to CO_2 emission reduction is limited, and energy efficiency is not improved through it. It can be concluded that relying on the VAP is insufficient to achieve the goal of the Kyoto Protocol. An example to prove this conclusion is that, in meeting the Kyoto Protocol targets, the purchase of Clean Development Mechanism (CDM) credits is necessary to achieve the targets for the Japanese economy. Even though this chapter shows the failure of the VAP, the findings can still provide implications for the current and future climate policy discussion. As mentioned by Sokołowski and Heffron (2022), energy policy failures need to pay attention to the support of meeting the objectives of the Paris Agreement and other climate policies. The results also suggest that mandatory policies such as carbon tax and national ETS may be more appropriate to achieve the target under the 2016 Paris Agreement and carbon neutrality.

Second, I observe that the technique effect has reduced CO_2 emissions in the manufacturing industry since 2000. However, in recent years, the reduction from the technique effect has become smaller; therefore, I propose the following policy recommendations. First, policies to promote technological innovations are necessary. The government should implement policies that focus on providing incentives to invest in low-carbon technologies by adopting instruments such as carbon pricing. Second, the combustion efficiency of fossil fuels has limited future improvement potential; thus, it is necessary to promote electrification or expansion of renewable energy.

Third, the results show an increase in indirect CO_2 emissions in Japan; in particular, the service sector suffers from an increase in indirect emissions. Therefore, it is crucial to implement low carbonization and decarbonization regulations targeting the service industry. However, Japan's service industry is not fully covered by the VAP. In the service industry, unlike in the manufacturing industry, the power of industrial associations may be weaker, and thus, the VAP cannot be successfully implemented. One successful policy toward the service sector in Japan is ETS, and the Tokyo ETS succeeds in reducing emissions from the service sectors. Therefore, ETS will be effective in reducing emissions from non-manufacturing industries.

Fourth, the current Japanese regulation only focuses on energy efficiency and fails to provide incentives for decarbonization toward the power sector, which is also under the VAP. The power sector achieves the emission reduction target under the VAP by purchasing credits through the CDM; this allows the emissions from the power sector, as well as the total CO_2 emissions from all sectors through indirect emissions, to increase. Thus, regulation supporting the reduction of carbon content and decarbonization from electricity is required. For instance, the expansion of renewable energy or a set of limits or standards for CO_2 emissions from electricity generating units in Japan's power sector would be effective. If the Japanese government legally sets a threshold for the ratio of minimum power generation by renewable energy in the energy sector, the emission reduction from the energy sector can be directly expected. Japan has already adopted feed-in tariffs and is now moving to feed-in premiums. The Japanese government has also implemented a requirement for non-fossil fuel power generation through the non-fossil fuel credit market. These policies must be continued and expanded to offer an incentive for reducing emissions from the electric power industry. Moreover, to promote the procurement of renewable energy by private firms, the Ministry of the Environment of Japan encourages participation in RE100, which is a global initiative for enterprises committing to using 100% renewable electricity. This trend toward RE100 will be useful in improving the CO_2 intensity of the power sector.

In the third chapter, I assess the impact of Japan's Saitama Emissions Trading Scheme (ETS) on firms' innovation and carbon leakage, leveraging unique firm-level survey data from 2003 to 2018. The results highlight that the Saitama ETS enhances the research and development (R&D) of targeted firms during the initial phase of the ETS without inducing carbon leakage; specifically, firms with a prior innovation exhibit improving R&D activities during the first compliance period. However, despite the increasingly stringent reduction targets set from the second compliance period onward, the Saitama ETS does not encourage firms to continually increase their R&D from the first to the second compliance periods. Based on the results, I propose several policy recommendations. First, it is necessary to remain vigilant with regard to the increase in the outsourcing activities of firms that do not actively invest in R&D, which is induced by the Saitama ETS. Compared to firms that actively invest in R&D, these firms may have limited financial resources or are the small and medium enterprises; how to prevent such firms from outsourcing their production process to other untargeted firms is an important issue. Japan launched its Domestic Clean Development Mechanism to reduce the CO_2 emissions of both small and medium manufacturing enterprises. Under this program, large firms can provide financial support to these firms and receive credits. Local governments can also adopt similar schemes to reduce the risk of firms shifting their production activities due to insufficient R&D funds. In the absence of penalties, the Saitama ETS improves firm-level innovation activities. If the government provides more support and strengthens regulations, the targeted firms will be able to improve their performance. However, with reduction targets becoming gradually stringent, some firms are likely to outsource their production process to eliminate environmental costs; this is especially true in the absence of additional subsidies for firms with carbon leakage risks and for relatively small firms. Therefore, policies that can benefit firms with a substantial risk of carbon leakage, such as those under the EU ETS, must be implemented.

Unlike in the third chapter, which focuses on the firm level, in the fourth chapter, I assess the impact of the both Saitama and Tokyo ETS on energy inefficiency and outsourcing activities at the facility level using the official facility-level survey data from 2002 to 2016. Through the propensity score matching-adjusted difference in differences method, the results highlight that Japan's regional ETSs reduce facilities' energy efficiency during the announcement period of the ETSs. However, ETSs do not enhance energy efficiency during the compliance period. Moreover, the results also highlight that Japan's regional ETSs do not increase outsourcing activities at the facility level. The findings presented in this chapter are consistent with those from Chapter 3, where no significant outsourcing activity was induced at the firm level. However, it is crucial to differentiate between the definitions of "outsourcing" used in these two chapters, which are based on distinct governmental databases. In Chapter 3, outsourcing is defined as a contractual relationship where a Japanese firm collaborates with another domestic or international firm to produce a custom input for the Japanese firm's production process. Meanwhile, in Chapter 4, outsourcing is defined by the processing fees that firms must pay when they are supplied or commission another domestic firm to manufacture goods, and it emphasizes domestic production outsourcing activities. Given these distinctions, it is evident that the term "outsourcing" encompasses various operational and financial dimensions depending on the context. While Chapter 3 emphasizes the collaborative aspect of production, Chapter 4 sheds light on the financial implications of domestic production outsourcing. Therefore, even though both chapters arrive at similar conclusions, it is crucial to appreciate these subtleties for comprehensively analyzing the outsourcing on firms and facilities in Japan in future studies.

Based on the results, I propose several crucial policy implications for future carbon pricing in Japan. First, policymakers need to consider the impact of energy inefficiency before ETS implementation, particularly in the announcement period. ETSs prompt targeted facilities to comply the environmental regulation through striving for energy transition toward a low-carbon production process, which may incur additional environmental costs for the targeted facility. While such excitations may promote energy efficiency in the long term, they may also result in a decrease in production and energy efficiency in the short term. Nonetheless, if ETS can provide a suitable environment for facilities to effectively transact emission allowance, the inefficiency arising from emission reduction can be minimized. With regard to whether the targeted facilities can adjust the mitigation costs using allowance transactions under the appropriate policy design, this chapter finds contrasting results, namely that CO_2 emissions can be reduced without sacrificing energy efficiency.

Second, it is important to note that ETS does not affect the energy efficiency of targeted facilities during the compliance period. Compared to previous studies, the calculation of energy inefficiency in this chapter does not take account the CO_2 emissions due to the restricted data. If CO_2 emissions are considered one of the production factors during compliance periods, the targeted facilities' estimated energy efficiency may increase. One important finding of this chapter is that Japan's regional ETSs did not lead to efficiency loss for the targeted facilities. Although the energy efficiency of these facilities decreased in the announcement period, the energy efficiency gap between targeted and nontargeted facilities eventually disappeared. This may be attributed to energy efficiency being recovered from short-run emission-reduction investments, which initially increased inefficient energy use and other production inputs. Additionally, the policy uncertainty of the ETSs decreased from an early stage. The targeted facility initially struggled to understand the allowance price and regulation effect, and once the ETS was implemented, the facilities learned about the regulatory effect and allowance market system, which led to a decrease in policy uncertainty. Further analysis is needed to reveal the primary factor contributing to the recovery of energy efficiency. Nevertheless, Japan's regional ETSs can mitigate CO_2 emissions without energy efficiency loss and carbon leakage through production outsourcing.

Third, combining the insights of chapter 3 and chapter 4, it becomes clear that while the ETS bolsters R&D activities, it does not induce energy inefficiency during the compliance period. This progression indicates that targeted firms or facilities are leveraging R&D to enhance their technical knowledge, which in turn optimizes productivity throughout the production process. However, a notable observation is that this augmentation in technical knowledge, while beneficial, does not directly translate to (or benefit) improved energy efficiency. This gap underscores the importance of a two-pronged approach: first, it is necessary to amplify investments in energy-efficient production equipment; second, fostering a culture of energy consciousness within firms or facilities is paramount. Workshops, training sessions, and awareness campaigns can be instrumental in reshaping the mindset of employees at all levels, ensuring that energy efficiency becomes an integral part of the organizational ethos. Furthermore, the government can play a proactive role by facilitating collaborations between industries, firms (facilities), and energy experts. These experts, with their specialized knowledge, can provide tailored guidance, best practices, and actionable insights to firms, ensuring that they are not only compliant with regulations but also at the forefront of sustainable and efficient production (Wakabayashi and Arimura, 2016; Yajima and Arimura, 2022).

Based on the conclusions drawn from each chapter, I detail the detailed policy implications of the VAP and Japan's ETSs. From a comprehensive perspective, I also provide recommendations for future environmental regulations, drawing insights. First, while I observe evidence of emission reduction in the manufacturing industry, the lack of effective regulation is contributing to the increase in emissions at the service-industry level; therefore, regulations such as the ETS with 1500 kl energy consumption threshold need to be revisited and reformulated specifically for the service industry. Given that the service industry does not consume as much energy as the manufacturing industry, adopting different inclusion standards for such industries could potentially enhance emission reduction within the service industry. Second, it is important to implement environmental regulations that encourage entities—especially small and medium enterprises often constrained by limited financial resources—to continually innovate and maintain their energy efficiency performance. Local governments can aid in this endeavor by establishing inter-firm innovation centers or networks to not only enhance communication between the government and enterprises but also foster stronger inter-enterprise relationships. This initiative can promote technological innovation and production efficiency among entities that may otherwise be unable or reluctant to innovate technological advancements and promote production efficiency.

In summary, this dissertation evaluates, in three chapters, Japan's environmental initiatives and regulations in terms of emission reduction, innovation, energy performance, and carbon leakage from multiple perspectives. While I highlight certain limitations of current regulations in the policy implications, the resolution of Japan's (local) governments and economic organizations to reduce emissions is undeniable. A particularly exciting finding of this dissertation is that voluntary and nearly non-punitive environmental instruments effectively motivate entities in Japan to reduce their emissions and enhance their technologies. Even though energy efficiency performance does not see substantial improvements during the initial phase of Japan's ETSs, I anticipate that it will as the reduction targets become more stringent in subsequent phases. Additionally, outsourcing-induced carbon leakage does not occur at the firm or the facility level, which bodes well for overall emission reduction in Japan. I firmly believe that the results and implications from this dissertation can make a meaningful contribution to the current environmental economics literature. Furthermore, I sincerely hope that the essays in this dissertation will serve as steppingstones for the advancement of related environmental economic research in the future.

References

Abadie, A. (2005). Semiparametric difference-in-differences estimators. Review Economic Studies, 72(1), 1-19.

Abadie, A., Drukker, D., Herr, J. L., & Imbens, G. W. (2004). Implementing matching estimators for average treatment effects in Stata. Stata Journal, 4(3), 290–311.

Aghion, P., Van Reenen, J., & Zingales, L. (2013). Innovation and institutional ownership. American Economic Review, 103(1), 277–304.

Aigner, D., Lovell, C. K., & Schmidt, P. (1977). Formulation and estimation of stochastic frontier production function models. Journal of Econometrics, 6(1), 21-37.

Al-Mansour, F. (2011). Energy efficiency trends and policy in Slovenia. Energy, 36(4), 1868-1877.

Ang, B.W. (2015). LMDI decomposition approach: a guide for implementation. Energy Policy, 86, 233–238.

Antonietti, R., De Marchi, V., & Di Maria, E. (2017). Governing offshoring in a stringent environmental policy setting: Evidence from Italian manufacturing firms. Journal of Cleaner Production, 155, 103-113.

Arimura, H.T. (2015). Japanese domestic environmental policy: with a focus on climate change and air pollution policy, in: Managi, S. (Ed.), The Routledge HandBook of Environmental Economics in Asia. Routledge, London, UK, pp. 516–553.

Arimura, T., & Iwata, K. (2015). An evaluation of Japanese environmental regulations. Springer Books.

Arimura, T.H., Kaneko, S., Managi, S., Shinkuma, T., Yamamoto, M., & Yoshida, Y. (2019). Political economy of voluntary approaches: a lesson from environmental policies in Japan. Economic Analysis and Policy, 64, 41–53.

Azar, J., Marinescu, I., & Marshall, S. (2020). Labor market concentration. Journal of Human Resources, 55.

Bartram, S. M., Hou, K., Kim, S. (2022). Real effects of climate policy: Financial constraints and spillovers. Journal of Financial Economics, 143(2), 668–696.

Borghesi, S., Cainelli, G., & Mazzanti, M. (2015). Linking emission trading to environmental innovation: evidence from the Italian manufacturing industry. Research Policy, 44(3), 669-683.

Brophy, M., Netherwood, A., & Starkey, R. (1995). The voluntary approach: an effective means of achieving sustainable development? Eco-Management and Auditing: The Journal of Corporate Environmental Management, 2(3).

Branger, F., Quirion, P., Chevallier, J. (2016). Carbon leakage and competitiveness of cement and steel industries under the EU ETS: Much ado about nothing. Energy Journal, 37(3).

Cai, X., Lu, Y., Wu, M., & Yu, L. (2016). Does environmental regulation drive away inbound foreign direct investment? Evidence from a quasi-natural experiment in China. Journal of Development Economics, 123, 73–85.

Calel, R. (2020). Adopt or innovate: Understanding technological responses to cap-and-trade. American Economic Journal: Economic Policy, 12(3), 170-201.

Calel, R., & Dechezleprêtre, A. (2016). Environmental policy and directed technological change: evidence from the European carbon market. Review of Economics and Statistics, 98(1), 173-191.

Callaway, B., & Sant'Anna, P. H. (2021). Difference-in-differences with multiple time periods. Journal of Econometrics, 225(2), 200-230.

Candau, F., & Dienesch, E. (2017). Pollution haven and corruption paradise. Journal of Environmental

Economics and Management, 85, 171-192.

Capasso, M., Cusmano, L., & Morrison, A. (2013). The determinants of outsourcing and offshoring strategies in industrial districts: Evidence from Italy. Regional Studies, 47(4), 465–479.

Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision making units. European Journal of Operational Research, 2(6), 429-444.

Chen, S., Shi, A., Wang, X. (2020). Carbon emission curbing effects and influencing mechanisms of China's Emission Trading Scheme: The mediating roles of technique effect, composition effect and allocation effect. Journal of Cleaner Production, 264, 121700.

Chen, X., Fu, Q., & Chang, C.-P. (2021). What are the shocks of climate change on clean energy investment: A diversified exploration. Energy Economics, 95, 105136.

Chortareas, G., Noikokyris, E., & Rakeeb, F. R. (2021). Investment, firm-specific uncertainty, and market power in South Africa. Economic Modelling, 96, 389-395.

Coelli, T. J., Rao, D. S. P., O'Donnell, C. J., & Battese, G. E. (2005). An introduction to efficiency and productivity analysis. Springer Science & Business Media.

CO. (2013). Annual Economic and Financial Report of 2013 (Cabinet Office).

Cole, M. A., Elliott, R. J., Okubo, T., & Zhang, L. (2021). Importing, outsourcing and pollution offshoring. Energy Economics, 103, 105562.

Cole, M. A., Elliott, R. J., & Zhang, L. (2017). Foreign direct investment and the environment. Annual Review of Environment and Resources, 42(1), 465-487.

Cui, Q., Wei, Y. M., Yu, C. l., & Li, Y. (2016). Measuring the energy efficiency for airlines under the pressure of being included into the EU ETS. Journal of Advanced Transportation, 50(8), 1630-1649.

Cunningham, J. A., & Clinch, J. P. (2004). An organizing framework for the implementation of environmental voluntary approaches. European Environment, 14(1), 30-39.

Copeland, B, R., & Taylor, M. (2004). Trade, Growth, and the Environment. Journal of Economic Literature, 42, 7-71.

Dagar, V., Khan, M. K., Alvarado, R., Usman, M., Zakari, A., Rehman, A., Murshed, M., & Tillaguango, B. (2021). Variations in technical efficiency of farmers with distinct land size across agro-climatic zones: Evidence from India. Journal of Cleaner Production, 315, 128109.

Dechezleprêtre, A., Gennaioli, C., Martin, R., Muûls, M., & Stoerk, T. (2022). Searching for carbon leaks in multinational companies. Journal of Environmental Economics and Management, 112, 102601.

Dehejia, R. H., & Wahba, S. (1999). Causal effects in nonexperimental studies: Reevaluating the evaluation of training programs. Journal of the American statistical Association, 94(448), 1053-1062.

Fell, H., Maniloff, P. (2018). Leakage in regional environmental policy: The case of the regional greenhouse gas initiative. Journal of Environmental Economics and Management, 87, 1–23.

Ferrara, E. L., Chong, A., & Duryea, S. (2012). Soap operas and fertility: Evidence from Brazil. American Economic Journal: Applied Economics, 4(4), 1–31.

Fowlie, M., Holland, S. P., & Mansur, E. T. (2012). What do emissions markets deliver and to whom? Evidence from Southern California's NOx trading program. American Economic Review, 102(2), 965–993.

Gao, Y., Li, M., Xue, J., Liu, Y. (2020). Evaluation of effectiveness of China's carbon emissions trading scheme in carbon mitigation. Energy Economics, 90, 104872.

Greene, W. (2005). Reconsidering heterogeneity in panel data estimators of the stochastic frontier model. Journal of Econometrics, 126(2), 269-303.

Hamamoto, M. (2021). Impact of the Saitama Prefecture target-setting emissions trading program on the

adoption of low-carbon technology. Environmental Economics and Policy Studies, 23(3), 501–515.
Haider, S., & Mishra, P. P. (2021). Does innovative capability enhance the energy efficiency of Indian Iron and Steel firms? A Bayesian stochastic frontier analysis. Energy Economics, 95, 105128.
Heffron, R. J., McCauley, D., & Sovacool, B. K. (2015). Resolving society's energy trilemma through the Energy Justice Metric. Energy Policy, 87, 168-176.
Heindl, P. (2012). Transaction costs and tradable permits empirical evidence from the EU emissions trading scheme. ZEW Discussion Papers, 12.
Hintermann, B., Peterson, S., & Rickels, W. (2016). Price and Market Behavior in Phase II of the EU ETS: A Review of the Literature. Review of Environmental Economics and Policy.
Hiroshima, T. (2012). Trends and issues on the Japan Verified Emission Reduction (J-VER) scheme and carbon offset in Japan. Bulletin of University of Tokyo Chiba Forest, 127, 1-16.
Hu, Y., Li, R., Du, L., Ren, S., & Chevallier, J. (2022). Could SO2 and CO_2 emissions trading schemes achieve co-benefits of emissions reduction? Energy Policy, 170, 113252.
IEA. (2018). Energy Efficiency 2018. https://www.iea.org/reports/energy-efficiency-2018
IPCC. (2023). Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 35-115.
Imbens, G. W., & Wooldridge, J. M. (2009). Recent developments in the econometrics of program evaluation. Journal of Economic Literature, 47(1), 5-86.
Jacobson, L. S., LaLonde, R. J., & Sullivan, D. G. (1993). Earnings losses of displaced workers. American Economic Review, 685-709.
Jaraitė, J., Convery, F., & Di Maria, C. (2010). Transaction costs for firms in the EU ETS: lessons from Ireland. Climate Policy, 10(2), 190-215.
Jorgenson, D. W., & Wilcoxen, P. J. (1990). Environmental regulation and US economic growth. Rand Journal of Economics, 314-340.
Kellenberg, D. K. (2009). An empirical investigation of the pollution haven effect with strategic environment and trade policy. Journal of International Economics, 78(2), 242-255.
Kelly, D., & Amburgey, T. L. (1991). Organizational inertia and momentum: A dynamic model of strategic change. Academy of Management Journal, 34(3), 591–612.
Kobayashi, N. (2016). Carbon Credit Current Trend and REDD+ Projects. Tropical Peatland Ecosystems, 585-598.
Koch, N., Mama, H. B. (2019). Does the EU Emissions Trading System induce investment leakage? Evidence from German multinational firms. Energy Economics, 81, 479–492.
Koch, N., & Themann, M. (2022). Catching up and falling behind: Cross-country evidence on the impact of the EU ETS on firm productivity. Resource and Energy Economics, 69, 101315.
Kuramochi, T. (2015). Review of energy and climate policy developments in Japan before and after Fukushima. Renewable and Sustainable Energy Reviews, 43, 1320-1332.
Löfgren, Å., Wråke, M., Hagberg, T., Roth, S. (2014). Why the EU ETS needs reforming: an empirical analysis of the impact on company investments. Climate Policy, 14(5), 537–558.
Levinson, A. (2009). Technology, International trade, and pollution from US manufacturing. American Economic Review, 99, 2177–2192.
Li, M., He, Y., & Tao, W. (2017). Modeling a hybrid methodology for evaluating and forecasting regional energy efficiency in China. Applied Energy, 185, 1769-1777.
Li, S., Liu, J., & Shi, D. (2021). The impact of emissions trading system on corporate energy efficiency:

Evidence from a quasi-natural experiment in China. Energy, 233, 121129.
Löschel, A., Lutz, B. J., & Managi, S. (2019). The impact of the EU ETS on efficiency and economic performance–an empirical analyses for German manufacturing firms. Resource and Energy Economics, 56, 71–95.
Lu, G., Tanaka, K., & Toshi, H. A. (2023). The Impacts of the Tokyo and Saitama ETSs on the Energy Efficiency Performance of Manufacturing Facilities. Research Institute of Economy, Trade and Industry (RIETI).
Lu, Y., Tao, Z., & Zhu, L. (2017). Identifying FDI spillovers. Journal of International Economics, 107, 75–90.
Lutz, B. J. (2016). Emissions trading and productivity: Firm-level evidence from German manufacturing. ZEW-Centre for European Economic Research Discussion Paper (16-067).
Mansfield, E. (1968). Industrial research and technological innovation; an econometric analysis.
Martin, R., Muûls, M., De Preux, L. B., Wagner, U. J. (2014). On the empirical content of carbon leakage criteria in the EU Emissions Trading Scheme. Ecological Economics, 105, 78–88.
Martin, R., Muûls, M., & Wagner, U. (2013). Carbon markets, carbon prices and innovation: Evidence from interviews with managers. In: Annual Meetings of the American Economic Association, San Diego.
Martin, R., Muûls, M., & Wagner, U. J. (2016). The impact of the European Union Emissions Trading Scheme on regulated firms: what is the evidence after ten years? Review of Environmental Economics and Policy
Meeusen, W., & van Den Broeck, J. (1977). Efficiency estimation from Cobb-Douglas production functions with composed error. International Economic Review, 435-444.
Melville, N.P., & Whisnant, R. (2014). Energy and carbon management systems. Journal of Industrial Ecology, 18, 920–930.
M.M. Sokołowski, & J.R. Heffron. (2022). Defining and conceptualising energy policy failure: the when, where, why, and how. Energy Policy, 161, p. 112745, 10.
Nansai, K. (2019) Embodied energy and emission intensity data for Japan using input–output tables (3EID), Tsukuba: National Institute for Environmental Studies
Naegele, H., Zaklan, A. (2019) Does the EU ETS cause carbon leakage in European manufacturing? Journal of Environmental Economics and Management, 93, 125–147.
Oster, E. (2019). Unobservable selection and coefficient stability: Theory and evidence. Journal of Business & Economic Statistics, 37(2), 187-204.
Paton, B. (2000). Voluntary environmental initiatives and sustainable industry. Business Strategy and the Environment, 9(5), 328-338.
Peters, B. (2009). Persistence of innovation: stylised facts and panel data evidence. Journal of Technology Transfer, 34(2), 226–243.
Peuckert, J. (2014). What shapes the impact of environmental regulation on competitiveness? Evidence from Executive Opinion Surveys. Environmental Innovation and Societal Transitions, 10, 77-94.
Porter, M. E., & Van der Linde, C. (1995). Toward a new conception of the environment-competitiveness relationship. Journal of Economic Perspectives, 9(4), 97-118.
R. Jones., & B. Yoo. (2009). Improving the Policy Framework in Japan to Address Climate Change. OECD Economics Department Working Studys, vol. 740, OECD Publishing, Paris (2009)
Ren, S., Hu, Y., Zheng, J., & Wang, Y. (2020). Emissions trading and firm innovation: Evidence from a natural experiment in China. Technological Forecasting and Social Chang, 155, 119989.
Ren, S., Yang, X., Hu, Y., & Chevallier, J. (2022). Emission trading, induced innovation and firm

performance. Energy Economics, 106157.

Rogge, K. S., Schneider, M., Hoffmann, V. H., 2011. The innovation impact of the EU Emission Trading System—Findings of company case studies in the German power sector. Ecological Economics, 70(3), 513–523.

Sadayuki, T., & Arimura, T. H. (2021). Do regional emission trading schemes lead to carbon leakage within firms? Evidence from Japan. Energy Economics, 104, 105664.

Sant'Anna, P. H., & Zhao, J. (2020). Doubly robust difference-in-differences estimators. Journal of Economics, 219(1), 101–122.

Sartor, O. (2013). Carbon leakage in the primary aluminium sector: What evidence after 6.5 years of the EU ETS? Available at SSRN: https://ssrn.com/abstract=2205516

Shao, S., Luan, R., Yang, Z., & Li, C. (2016). Does directed technological change get greener: empirical evidence from Shanghai's industrial green development transformation. Ecological Indicators, 69, 758-770.

Shao, S., Yang, Z., Yang, L., & Ma, S. (2019). Can China's energy intensity constraint policy promote total factor energy efficiency? Evidence from the industrial sector. Energy Journal, 40(4).

Su, B., Ang, B.W., & Li, Y. (2017). Input-output and structural decomposition analysis of Singapore's carbon emissions. Energy Policy, 105, 484–492.

Sugino, M., & Arimura, T.H. (2011). The effects of voluntary action plans on energy-saving investment: an empirical study of the Japanese manufacturing sector. Environmental Economics and Policy Studies, 13, 237–257.

Teixidó, J., Verde, S. F., & Nicolli, F. (2019). The impact of the EU Emissions Trading System on low-carbon technological change: The empirical evidence. Ecological Economics, 164, 106347.

Themann, M., & Koch, N. (2021). Catching up and falling behind: Cross-country evidence on the impact of the EU ETS on firm productivity. USAEE Research Paper Series (21-492).

Verhoef, E. T., & Nijkamp, P. (2003). The adoption of energy-efficiency enhancing technologies.: Market performance and policy strategies in case of heterogeneous firms. Economic Modelling, 20(4), 839-871.

Wakabayashi, M., & Arimura, T.H. (2016). Voluntary agreements to encourage proactive firm action against climate change: an empirical study of industry associations' voluntary action plans in Japan. Journal of Cleaner Production, 112, 2885–2895.

Wang, K., Wei, Y.-M., & Zhang, X. (2012). A comparative analysis of China's regional energy and emission performance: Which is the better way to deal with undesirable outputs? Energy Policy, 46, 574-584.

Wang, M., & Feng, C. (2017). Decomposition of energy-related CO_2 emissions in China: an empirical analysis based on provincial panel data of three sectors. Applied Energy, 190, 772–787.

Xie, R., Yuan, Y., & Huang, J. (2017). Different types of environmental regulations and heterogeneous influence on "green" productivity: evidence from China. Ecological Economics, 132, 104–112.

Yajima, N., & Arimura, T. H. (2022). Promoting energy efficiency in Japanese manufacturing industry through energy audits: Role of information provision, disclosure, target setting, inspection, reward, and organizational structure. Energy Economics, 114, 106253.

Yang, Z., Fan, M., Shao, S., & Yang, L. (2017). Does carbon intensity constraint policy improve industrial green production performance in China? A quasi-DID analysis. Energy Economics, 68, 271–282.

Yu, Y., & Zhang, N. (2022). Does industrial transfer policy mitigate carbon emissions? Evidence from a quasi-natural experiment in China. Journal of Environmental Management, 307, 114526.

Zhang, S., Lundgren, T., & Zhou, W. (2016). Energy efficiency in Swedish industry: A firm-level data envelopment analysis. Energy Economics, 55, 42-51.

Zhang, W., Li, K., Zhou, D., Zhang, W., & Gao, H. (2016). Decomposition of intensity of energy-related CO_2 emission in Chinese provinces using the LMDI method. Energy Policy, 92, 369–381.

Zhang, W., Li, J., Li, G., & Guo, S. (2020). Emission reduction effect and carbon market efficiency of carbon emissions trading policy in China. Energy, 196, 117117.

Zhao, H., Guo, S., & Zhao, H. (2019). Provincial energy efficiency of China quantified by three-stage data envelopment analysis. Energy, 166, 96-107.

Zhu, J., Fan, Y., Deng, X., & Xue, L. (2019). Low-carbon innovation induced by emissions trading in China. Nature Communications, 10(1), 1–8.