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Abstract

The Tokyo ETS is the first emission trading scheme to control GHG emissions from office buildings. Although the Tokyo government claimed that Tokyo ETS had been successful, some argued that the emission reduction under Tokyo ETS was actually the result of electric power price increases triggered by the Great East Japan Earthquake in 2011. Using a facility-level data set for Japanese office buildings, we conducted an econometric analysis to examine the impact of Tokyo ETS. We found that half of the emission reduction is a result of the ETS, while the rest of the reduction is due to the electricity power price increase. Another unique feature of Tokyo ETS is that an accurate permit price is not publicly available due to its design. Using our estimated model, we found that the price is approximately $50 per ton of CO_2 in the early phase.

Key Words: Emission Trading Scheme, Electricity, Micro Data, Office buildings, Climate Change

JEL Code: Q54, Q41

1. Introduction

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Carbon pricing has become a popular economic instrument used to help mitigate greenhouse gases (GHGs), which cause climate change. Among carbon pricing techniques, emission trading schemes (ETSs) have gained attention. Notably, the European Union Emissions Trading Scheme (EUETS) was the first comprehensive ETS to control carbon dioxide (CO_2) emissions. In the US, the Regional Greenhouse Gas Initiative (RGGI) started in 2009, followed by the California system. Among Asian countries, Korea was the first to introduce a cap-and-trade scheme. Finally, China, the largest emitter of greenhouse gases (GHG), implemented seven regional ETSs in a pilot scheme and announced that it would introduce a national level ETS starting with the power sector (Duan, 2020).

The Japanese government has not yet adopted an ETS at the national level. The Tokyo metropolitan government, however, successfully introduced an ETS, the Tokyo Emissions Trading Scheme (Tokyo ETS), in 2010 (Arimura, 2015). This ETS is not only the first cap-and-trade ETS for CO_2 emissions in Japan but also the first in Asia. Furthermore, Tokyo ETS is unique among ETSs because the main target of this scheme is office buildings. Indeed, it is the first ETS to regulate GHG emissions from office buildings.

Tokyo ETS consists of several phases. Phase I started in 2010 and ended in 2014. Phase II started in 2015 and implemented a more stringent emission target. At the start of Phase II of Tokyo ETS, the Tokyo metropolitan government reviewed the level of emissions from the regulated buildings and confirmed an emission reduction of 25%.[4] It is not clear, however, if the ETS is actually the driver of the emission reduction during this period.

One should note that Japan experienced the Great East Earthquake in 2011, which was followed by the nuclear accident in Fukushima. This nuclear accident affected electricity supply in Japan, but the shortage of electricity capacity was particularly severe in Tokyo because the nuclear power plants in Fukushima belong to the Tokyo Electric Power Company (TEPCO), which is almost a monopoly in supplying electricity to the Tokyo area. Due to the accident, TEPCO had to rely on expensive natural gas to generate electricity, and moreover, it had to compensate for the damages caused by the nuclear accident. This cost was passed TEPCO's consumers, and so power prices in the Tokyo area increased sharply after the earthquake. Some people, therefore, hypothesized that the reduction in GHG emissions in the Tokyo area was caused by the electricity

[4] See Tokyo Metropolitan Government (2016) http://www.kankyo.metro.tokyo.jp/en/climate/cap_and_trade/index.files/3c08a5ad895b5130cb1d17ff5a1c9fa4.pdf (this is accessible as of August 18, 2019)

price increase and not by the ETS. This hypothesis is supported by those who viewed EUETS with skepticism and thus doubt that an ETS could work in the real world, especially after seeing the low permit prices in EUETS.

In addition to the price increase in the electricity, other factors may have contributed to the emission reduction in Tokyo. For example, the Japanese government adopted a rolling blackout immediately after the accident. In this scheme, the power companies intentionally stop power supply to one area for a certain period and then shift to stop the power supply to another area while the supply for the first area returns. In this way, the power companies were able to balance the total amount of electricity supply and demand. It could be argued that the experience of the rolling blackout could have incentivized consumers to save energy to avoid future blackouts.

This paper empirically investigates the effects of the Tokyo ETS to clarify the cause of emission reduction in Tokyo using facility-level panel data. By conducting a facility-level survey, we collected data on office buildings and university buildings in Japan. Our study is not the first to examine Tokyo ETS ex post. Roppongi et al. (2017) qualitatively reviewed the Tokyo ETS. Wakabayashi and Kimura (2018) conducted a quantitative ex-post analysis of Tokyo ETS with a combination of interviews and facility-level data analysis. However, this latter study suffers from omitted variable bias; notably, they ignored the influence of the power price increase on the GHG emissions from office buildings. This is the first study to examine the impact of Tokyo ETS on emissions by incorporating the impact of the power price increase.

This paper contributes to the empirical literature of ETSs. Until recently, researchers have focused on ex-ante analysis using a theoretical analysis or a computable general equilibrium analysis (e.g., Böhringer and Lange, 2005). Recently, however, researchers started to conduct ex-post analyses of ETS. For example, Martin et al. (2016) and Ellerman et al. (2016) reviewed the experience of EUETS. Others initiated ex-post econometric analyses as the ex-post data have become available. For example, Ellerman and Buchner (2008) and Anderson and Di Maria (2011) confirmed the effect of EU ETS on emission reductions in European countries under EU ETS in the first phase. Petrick and Wagner (2014) and Colmer et al. (2018) estimated not only the abatement effect of EU ETS but also its impact on some economic activities using a German and a French facility-level dataset. Calel and Dechezlepretre (2016) examined the impact of EUETS on innovation in European firms, measured with patents. RGGI, a regional ETS in the US, is also reviewed. Murray and Maniloff (2015) investigated why GHG emissions in RGGI states were reduced and examined the factors contributing to emission reduction in the region. Our study is in line with this stream of literature, but it is unique because we have examined the impact of ETS on office buildings. EUETS was designed for manufacturing facilities and power plants, and RGGI was designed for power plants, but Tokyo ETS was one of the first ETS focusing on office buildings.

One unique aspect of Tokyo ETS is that the financial sector plays a limited role. The Japanese industry association was against the introduction of ETSs, referring to it as a "casino (money game)" (Roppongi et al., 2017). They claimed that an ETS would invite speculation by financial companies, which would destroy its effectiveness. In response to this criticism, the Tokyo government created a unique design for its ETS: there is no auction or the exchange on the market where the price of the permit is made transparent. Thus, the price of permits in Tokyo ETS is somewhat mysterious. The second contribution of this paper is to reveal the implicit price of the permit through the estimated models.

This paper is constructed as follows. The next section reviews the basic design of Tokyo ETS. Section 3 explains the data, and the estimation results and the discussion are shown in section 4. Finally, section 5 concludes the paper.

2. Design of Tokyo ETS

The Tokyo metropolitan government established an emission target of a 25 percent reduction by 2020 from the 2000 level. Initially, they tried a voluntary scheme (Roppongi et al., 2017), but this did not lead to a substantial emission reduction. Thus, the Tokyo government decided to adopt a mandatory emission reduction scheme with flexibility, i.e., an ETS.

Tokyo ETS aims to mitigate the CO_2 emissions from large-scale facilities in the commercial and manufacturing sectors. Facilities that consume 1,500 kiloliters of oil equivalent per year or more are regulated in this system[5]. The emissions from these facilities amounted to approximately 40 percent of total CO_2 emissions from the commercial and manufacturing sector in Tokyo.

The Tokyo ETS was first announced in 2007. The first phase ran from 2010 to 2014 and the second phase is from 2015 to 2019. In the first phase, which is the target of our analysis, the mandatory CO_2 reduction targets were 8 percent for commercial buildings and 6 percent for manufacturing facilities from a base year level. Facilities had the flexibility to choose their baseline emission from the average of three consecutive years selected from 2002 to 2007. The emission target was tightened to 17 percent for office buildings and 15 percent for manufacturing facilities in Phase II, which lasted from 2015

[5] This is a typical threshold used in energy regulation in Japan. See Arimura and Iwata (2015) for details.

to 2019. In 2019, Tokyo metropolitan government announced the details of Phase III, which will continue from 2020-2024.

Tokyo ETS is a mandatory scheme, and any facility that cannot attain the goal set by Tokyo ETS faces a fine. This contrasts with Saitama ETS, which was modeled after Tokyo ETS and introduced in 2011. Saitama ETS is a voluntary scheme and thus has no fines (Hamamoto, 2020).

A unique feature of Tokyo ETS is that it regulates office buildings as well as industrial plants; indeed, commercial and office facilities account for approximately 80 percent of regulated facilities. In Tokyo, many manufacturing facilities moved to other regions after stringent environmental regulation was enforced in the 1970s and 1980s. Consequently, the majority of GHG emitters in Tokyo belong to the commercial or office sectors. This situation is quite different from that for existing ETSs implemented in other countries at the time of Tokyo ETS adoption in 2010. For example, EUETS regulated emissions from manufacturing facilities and power plants when it started in 2005. In another case, RGGI is a scheme targeting power plants. The main target of Korean ETS is manufacturing facilities (Oh, 2020,). Therefore, Tokyo ETS differed from other schemes in 2010 in that it regulated emissions from the service sector.

Though the Tokyo ETS is a regional ETS, there is a high number of regulated facilities. In the Tokyo area, all facilities consuming at least 1,500 kiloliters of oil equivalents per year are subject to Tokyo ETS; in 2013, for example, 1,392 facilities had to comply with the Tokyo ETS. The number of entities covered by the Korean ETS is approximately 600 (Oh, 2020, this issue). Thus, there is a high number of entities under the Tokyo ETS, although their total emissions are relatively low, at 12 million CO_2-tons in 2017, which is less than the emissions covered in the Korean ETS.

Tokyo ETS is also unique in how it measures GHG emissions. The emission from the usage of electricity, , as indirect emissions, is regulated because the majority of emission from commercial and office buildings are from their electricity usage. This is different from other ETS such as EUETS which focuses on emissions from fossil fuel combustion.

The CO_2 emissions from the electricity usage for facility are measured by multiplying its electricity consumption by the CO_2 intensity. The CO_2 emission intensity of electricity was 0.382 kg CO_2 per kWh[6] and fixed for the compliance period under Tokyo ETS. According to this method, the total emission under Tokyo ETS was approximately 11.8 million CO_2 tons in 2010.

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[6] This is average CO_2 intensity from 2005 to 2007. Under Tokyo ETS, the coefficient is fixed through all periods even when the emission intensity changes as power companies change the fuel mix. This fuel mix is hardly impacted by Tokyo ETS because most of power plants are located outside Tokyo or Saitama and do not face ETS.

To mitigate the burden of compliance, the Tokyo ETS provides four types of domestic offset credits. The first is *small- and medium-sized installation credits* within the Tokyo area. Large regulated facilities can earn credits by investing in energy efficiency in unregulated small and medium size facilities. Second one is *outside Tokyo Prefecture credits*. Organizations in Tokyo can earn emission reduction credits if they reduce emissions outside of Tokyo. Third, firms can use *Saitama credits*, i.e., credits from Saitama ETS. Saitama ETS is modeled after Tokyo ETS, and thus, the features of the two systems are similar, and the credits from the two systems are exchangeable. Finally, Tokyo ETS accepts *renewable energy certificates*. Facilities can earn credits if they invest in renewable energy. International credits such as CDM credits, however, cannot be used to offset GHG emissions in this scheme.

Facilities under Tokyo ETS can achieve their target through several methods; Table 1 shows the compliance methods by entity. First, they can reduce emissions: according to the Tokyo metropolitan government, 91 percent of facilities reduced emissions beyond the target. Alternatively, they can achieve their target by obtaining additional credits: approximately 9 percent of facilities achieved the target through the acquisition of credits.

Permit trading under Tokyo ETS is regulated in a unique manner. When facing the adoption of an ETS, some stakeholders were afraid that permit trading under an ETS could create a "casino" (Ropponogi et al., 2017). The manufacturing sector criticized ETSs by claiming that these systems invite speculation by the financial sector and thus are not effective as an instrument for environmental policy. In response to this criticism, the Tokyo government allows only "reduction credits" and not "emission credits". That is, one can earn credits only after achieving emission reduction. Moreover, there is no auction of permits. Only emitting entities can participate in trading, and the financial sector does not play a crucial role in the system. Consequently, the trades have been bilateral in many cases, and the trading of permits was not very active compared to other markets. The Tokyo government investigates the price through private interviews and publicizes the permit price; Figure 1 depicts the trajectory of permit prices. The price was initially approximately 10,000 JPY ($1,333) per CO_2 ton in 2011, but it fell to approximately 4,500 JPY ($37) per CO_2 ton in 2015 for reduction credits. These numbers are a reasonable conjecture but may not reflect the "true price" because the Tokyo metropolitan government does not reveal how it constructs prices.[7]

[7] Note that the prices of permits differ if they are "reduction credits" or "renewable credits" because renewable credits can be used for compliance purposes for another regulation in the power sector.

It should be noted that the reduction credits are bankable, and so credits from Phase I can be used in Phase II. However, they can only be carried for one phase; credits from Phase I cannot be used in Phase III.

Table 1 Compliance Methods

	Emission Trading	Internal Reduction Measures
Number of Facilities	124 (9%)	1,262 (91%)
Emission Reductions	192.7	10,080
(unit: 1,000 t-CO_2)	(1.9%)	(98.1%)

Note: The numbers in parentheses show the ratios for each row.

3. Data

We have obtained data from various sources as follows.

3.1. Dependent Variables and Other Facility-Level Data: Mail Survey

We chose the office building sector from among the regulated facilities for several reasons. First, under Tokyo ETS, office buildings represent the largest group among the commercial buildings. Hence, office buildings are the major target of regulations[8]. Second, among the regulated facilities, office buildings are relatively less influences by economic fluctuations in terms of energy consumption.

We conducted a mail survey in 2015. We sent questionnaires to 824 owners of office buildings across Japan. The population of office buildings was chosen from the database, which was constructed based on the Act on the Promotion of Global Warming Countermeasures run by the Ministry of the Environment. Facilities that consume 1,500 of energy must report their GHG emissions every year. From this database, we were able to obtain a list of the address of all office buildings. We received 414 replies from the office buildings, representing a reasonably high response rate of 50.2 percent.

Office building owners were asked to report their CO_2 emissions levels from 2009 to 2013; we also asked for electricity consumption and energy consumption, where energy consumption is the sum of electricity consumption and fossil fuel consumption. Respondents were also asked to report the number of employees, the floor area, their experience with the rolling blackouts and any other requests for energy savings from the

[8] There is only one fossil power plant, and there are a small number of manufacturing facilities in Tokyo.

power companies.

3.2. Electricity Price

We collected data on electricity prices from a publicly available database of the Federation of Electric Power Companies (FEPC) of Japan. Until the recent deregulation of the retail market in 2016, the Japanese power market had been divided into nine regions: Hokkaido, Tohoku, Tokyo, Chubu, Hokuriku, Kansai, Shikoku, Chugoku and Kyusyu[9]. We obtain charge revenues and volume of power demand for these nine regions from the FEPC. Following Hosoe and Akiyama (2009), we calculated the electricity price for each region by dividing the charge revenue based on the volume of power demand.

The power price has increased in Japan over the past 10 years, from 2006 to 2015. Before the Great East Japan Earthquake in 2011, electricity prices for all companies were fairly similar. However, after the earthquake, the price in the jurisdiction of the TEPCO saw a large increase. In particular, industry and commercial sectors in the TEPCO market faced a growth rate for electricity prices of 12.4 percent during the period 2010-2013.

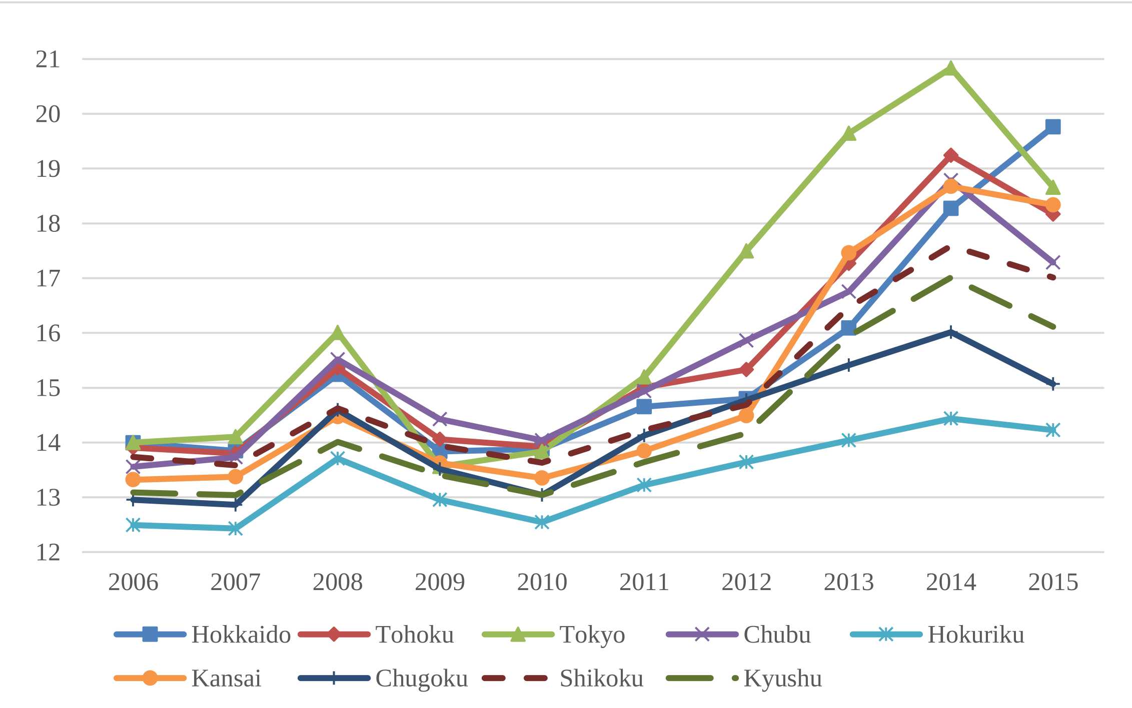

Figure 1: Changes in Electricity Prices (Yen/kWh), 2006-2015

TEPCO covers nine prefectures: Tokyo, Saitama, Chiba, Ibaraki, Tochigi, Gunma,

[9] Okinawa is excluded from the list because Okinawa is an isolated island.

Kanagawa, Yamanashi and Shizuoka. Among the nice prefectures, only Tokyo and Saitama have an ETS in place. Therefore, we can disentangle the impact of the ETS from the increase in power prices.

3.3. Savings Requests & the Rolling Blackout

In addition to power prices and ETS, other factors may also influence emissions.The Great East Japan Earthquake in 2011 damaged a few power plants. Most notably, among them is the nuclear power plant in Fukushima. This led to the shutdown of major nuclear power plants. Consequently, TEPCO faced a shortage of power supply. In response to this emergency, TEPCO introduced “rolling blackout”. Under this system, TEPCO intentionally stopped the electricity supply to a designated area. After several hours, another area faced the intentional blackout. In this way, TEPCO managed to supply electricity to their customers with limited capacity. In our survey, we asked if they had experienced the rolling blackout.

Another important aspect is demand-side management. In response to the electricity crisis, the government introduced “request to reduce the electricity consumption”. In our survey, we asked if the owners received this request.

We suspect that these experiences may have given incentives to save energy for consumers. We construct a dummy variable, *saving request/rolling blackout*, which takes the value one if the building owners faced either the rolling blackout or the request of electricity consumption reduction. In our sample, 41 percent of facilities faced this request.

3.4. Vacancy Ratio of Office Buildings

The emissions from office buildings are influenced by economic activities conducted in each building. To capture the economic activities in the building sector, we use the vacancy rate of office buildings in each region as a proxy for the vacancy rates for a building. We exploit publicly available data from Miki Shoji Co., ltd. which provides information on the office market in seven large business regions in Japan: Sapporo, Sendai, Tokyo, Yokohama, Nagoya, Osaka and Fukuoka. Unfortunately, this dataset does not offer information on all prefectures separately. We then assigned values to the office buildings based on proximity.

3.5. Cooling Degree Days and Heating Degree Days

To control the impact of weather conditions, we include cooling degree days (CDD) and heating degree days (HDD). This information is publicly available from the Japan Meteorological Agency. We calculated the CDD and HDD for each prefecture.

3.6. CO_2 Intensity

Following the method required by "*Act on Promotion of Global Warming Countermeasures*[10] ", owners of office buildings calculate their emissions by multiplying their electricity consumption by the CO_2 intensity of the power companies from which they purchase electricity. The CO_2 intensity, however, varies across power companies and time. After the earthquake in 2011, power companies had to rely heavily on coal power plants. Consequently, their CO_2 intensity sharply increased after 2011. Before the earthquake, in 2009, the CO_2 coefficient, on average, was 0.433 kg-CO_2 per kWh, and it rose to 0.524 kg-CO_2 per kWh in 2013. To control this impact, we include CO_2 intensity in the model for CO_2 emissions.

3.7. Summary Statistics

Table 2 illustrates the summary statistics. For some variables, we removed outliers from our analysis. Specifically, we excluded the top and bottom 1% of the distributions in the sample. The first panel of Table 2 shows summary statistics for office buildings. On average, the annual CO_2 emissions for an office building considering the total sample was 7,105 tons of CO_2. The summary statistics for office buildings in Tokyo and other regions are shown in the second and third panels of Table 2. From these panels, we find that the annual CO_2 emissions from office buildings in Tokyo was 7,463 tons of CO_2, whole office buildings in other regions accounted for 6,918 tons of CO_2. Hence, office buildings in Tokyo on average emit CO_2 more than those in other regions. We also find large differences between buildings in Tokyo and other regions in terms of size. Generally, office buildings in Tokyo have greater floor area and more employees than office buildings in other regions.

Table 2: Summary Statistics for 2009, Pretreatment Period

[10] This act mandates the owner of facilities with the consumption of 1,500 kl cued oil equivalent or more to report their CO_2 emissions to Japanese Ministry of the Environment annually.

	N	Mean	Std. Dev.	Min.	Max.
A. Full sample (mid-98%)					
CO_2 Emission [t-CO_2]	321	7105.4	5078.6	2410.0	36853.0
Electricity Consumption [GJ]	317	122545.6	87322.9	19911.0	695922.0
Energy Consumption [kl]	317	4086.0	2794.0	1548.0	17954.0
CO_2 Intensity (electricity) [t-CO_2/kWh]	313	0.000418	0.000084	0.000258	0.000918
Number of Employees	248	1950.6	2340.6	9.0	10000.0
Electricity Price [JPY/kWh]	321	13.7	0.3	13.0	14.4
B. Tokyo					
CO_2 Emission [t-CO_2]	124	7463.8	4869.8	2410.0	27038.0
Electricity Consumption [GJ]	121	133842.4	92624.4	41294.0	695922.0
Energy Consumption [kl]	121	4417.6	2976.5	1548.0	17954.0
CO_2 Intensity (electricity) [t-CO_2/kWh]	119	0.000438	0.000079	0.000324	0.000759
Number of Employees	97	3209.5	2723.3	23.0	10000.0
Electricity Price [JPY/kWh]	124	13.6	0.0	13.6	13.6
C. Other regions (excluding Saitama)					
CO_2 Emission [t-CO_2]	179	6918.6	5278.4	2450.0	36853.0
Electricity Consumption [GJ]	179	115675.3	84437.4	19911.0	454249.0
Energy Consumption [kl]	179	3893.6	2690.0	1550.0	15247.0
CO_2 Intensity (electricity) [t-CO_2/kWh]	178	0.000431	0.00009	0.000258	0.000918
Number of Employees	138	1175.4	1658.6	9.0	9000.0
Electricity Price [JPY/kWh]	179	13.7	0.4	13.0	14.4

Table 3 exhibits the change in the average annual CO_2 emissions from office buildings. The first column shows the emissions in Tokyo. The second column shows emissions in Saitama, which also had an ETS in place. Please note that there are only 20 observations in our sample for Saitama. The third column corresponds to emissions from the rest of Japan. One can see that CO_2 emissions in Tokyo decreased after the ETS was introduced in 2010, while emissions elsewhere increased in 2013 relative to 2009.

Table 3: Change in CO_2 Emissions by Region (unit: CO_2 ton)

	Regions		
year	Tokyo	Saitama	Other regions (excluding Tokyo and Saitama)
2009	8609.4	6494.0	7448.2
2010	8000.8	6189.5	6990.5
2011	6669.3	5360.7	6707.3
2012	7361.1	5875.2	7761.9
2013	7956.4	7351.7	8380.6

4. Econometric Model and Estimation Results

4.1. Econometric Model

To quantify the impact of the ETS, we estimated the following equations for office buildings and universities.

$$y_{it} = \tau \cdot Tokyo_i \cdot I(t \geq 2010) + x'_{it}\beta + \mu_i + \eta_t + \varepsilon_{it}$$

In this equation, y_{it} denotes the dependent variables for building i in year t: we used CO_2 emissions, electricity consumption and energy consumption. The variable $Tokyo_i$ on the right-hand side is a dummy variable that takes a value of one if the building i is located in Tokyo, zero otherwise. The function $I(\cdot)$ is the indicator function. Therefore, the above equation takes the form of differences in differences to estimate the causal effect of Tokyo ETS, so that parameter τ is of interest. The vector x_{it} is composed of some explanatory variables that include the electricity price and a dummy for Saitama ETS, which takes a value of one after 2011 if the office building is located in Saitama prefecture. In addition to these variables, the characteristics of facilities and other exogenous factors such as weather or vacancy rate of office buildings that vary over time are included in the vector. Individual fixed effects are captured by μ_i.

4.2. Estimation Results

Table 4 exhibits the estimation results from each of three models. Each model has two specifications. Models 1, 3, and 5 are base models, and models 2, 4, and 6 allow two possibilities to be examined: (1) the difference in effectiveness across years and (2) whether the magnitude of the emissions reduction depends on the size of the facility. To capture these effects, we added the interaction terms between $Tokyo \cdot I(t \geq 2010)$ and the year dummies and the number of employees to the base models. Based on the Hausman's test results, the fixed effect models were accepted in all specifications.

In models 1, 3, and 5, the estimated τ's are negative and statistically significant. These results show the effectiveness of Tokyo ETS. The size of the coefficient in model 1 is 0.066, suggesting that Tokyo ETS contributed to a 6.7 percent average annual reduction in GHG emissions on average.

In addition, the interaction terms for the year dummies and Tokyo ETS are included in models 2, 4 and 6. The coefficients of these terms indicate whether the Tokyo ETS had different effects on energy usage between 2011 and 2013. We find that the coefficients of the interaction terms of the year and Tokyo ETS are negative and statistically significant.

More specifically, the estimation results show that the Tokyo ETS had a relatively large impact on energy usage in 2011 and 2013 compared to its average impact from 2010 to 2013. To see if the three coefficients of the interaction terms are the same or not, we conducted the F test under the null hypotheses for linear restrictions. The results show that there are no statistically significant differences. Thus, our preferred model specification is model 1.

We also find that the Saitama ETS dummy is negative and statistically significant in many specifications except for models 1 and 5. This result suggests that Saitama ETS was useful in reducing GHG even though it is voluntary. We did not estimate the model interacting the year dummy and Saitama ETS because of the limited number of office buildings in Saitama.

Furthermore, the results from models 2, 4 and 6 show that the coefficients of the interaction terms of the building size (employee) and Tokyo ETS are negative and statistically significant. This result suggests that the larger the building is, the greater the emission reduction is. This is an intuitive result because one would expect more room for reduction for larger facilities.

The coefficients of electricity price are negative and statistically significant. In particular, the estimates in the electricity consumption models imply that the price elasticity of demand for electricity consumption is 0.39-0.45%. Hosoe and Akiyama (2009) found that the elasticity of electricity demand ranges from 0.09 to 0.30 in the short run. Although our estimates of the elasticity seem to be relatively higher, they are comparable when we consider the confidence interval of the estimate.

Looking at the coefficients of the dummy variable for the *saving request/rolling blackout*, which capture the existence of a request for voluntary power savings or experience of the rolling blackout, we find no impacts on CO_2 emissions, electricity consumption of energy consumption.

Table 4: Estimation Results

	Dependent variable					
	ln(CO_2 emissions)		*ln(electricity consumption)*		*ln(energy consumption)*	
Independent variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
dummy for 2010	0.087^{***}	0.066^{**}	0.039	0.002	0.054^{*}	0.03
	(0.030)	(0.031)	(0.030)	(0.032)	(0.029)	(0.031)
dummy for 2011	0.036	0.038	-0.011	-0.019	0.000	-0.004
	(0.034)	(0.032)	(0.034)	(0.033)	(0.032)	(0.032)
dummy for 2012	0.055	0.039	0.006	-0.022	-0.001	-0.023
	(0.040)	(0.040)	(0.041)	(0.041)	(0.038)	(0.039)
dummy for 2013	0.097	0.094	0.056	0.047	0.024	0.017
	(0.060)	(0.060)	(0.060)	(0.060)	(0.056)	(0.056)
Tokyo・I(t>2010)	-0.066^{***}	0.155	-0.058^{***}	0.189^{*}	-0.037^{*}	0.131
	(0.024)	(0.103)	(0.022)	(0.101)	(0.022)	(0.100)
Tokyo・I(t>2010) ・dummy for 2011		-0.081^{***}		-0.095^{***}		-0.067^{***}
		(0.024)		(0.020)		(0.019)
Tokyo・I(t>2010) ・dummy for 2012		-0.045^{*}		-0.036		-0.022
		(0.027)		(0.026)		(0.024)
Tokyo・I(t>2010) ・dummy for 2013		-0.083^{**}		-0.070^{**}		-0.056^{*}
		(0.034)		(0.031)		(0.031)
Tokyo・I(t>2010) ・ln(# of employees)		-0.025^{*}		-0.027^{**}		-0.018
		(0.013)		(0.012)		(0.012)
Saitama・I(t>2011)	-0.046	-0.081^{**}	-0.075^{*}	-0.108^{**}	-0.039	-0.062^{*}
	(0.033)	(0.035)	(0.043)	(0.043)	(0.034)	(0.034)
log(electricity price)	-0.519^{***}	-0.428^{**}	-0.452^{***}	-0.394^{**}	-0.355^{**}	-0.306^{**}
	(0.159)	(0.169)	(0.154)	(0.169)	(0.145)	(0.152)
saving request / rolling blackout	-0.023	-0.026	-0.018	-0.018	-0.019	-0.02
	(0.020)	(0.021)	(0.021)	(0.021)	(0.020)	(0.020)
ln(# of employees)	-0.359^{**}	-0.320^{**}	-0.117	0.019	-0.19	-0.105
	(0.154)	(0.156)	(0.158)	(0.170)	(0.149)	(0.157)
ln(cooling degree days)	-0.014	0.036	0.042	0.094	-0.019	0.009
	(0.102)	(0.115)	(0.092)	(0.102)	(0.085)	(0.096)
ln(heating degree days)	-0.007	0.004	-0.014	-0.003	-0.022	-0.015
	(0.026)	(0.026)	(0.024)	(0.024)	(0.024)	(0.024)
ln(vacant ratio)	0.354^{***}	0.367^{***}	0.408^{***}	0.419^{***}	0.377^{***}	0.385^{***}
	(0.108)	(0.108)	(0.113)	(0.112)	(0.105)	(0.105)
ln(CO_2 intensity)	0.754^{***}	0.750^{***}				
	(0.054)	(0.054)				
Adjusted R^2	0.352	0.357	0.276	0.289	0.259	0.265
Number of observations	1177	1177	1199	1199	1199	1199

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

4.3. Discussion

As shown in the previous section, our preferred specification is model 1, and thus we discuss the results using model 1. First, we can compare the impact of the ETS with that of the power price increase. Our estimation results suggest that the Tokyo ETS reduced CO_2 emissions by 6.7 percent annually. At the same time, the power price in TEPCO increased by 12.4 percent from 2010 to 2013. Because the price elasticity was estimated at 5.2 percent, our estimation results imply that the emission reduction due to the power price increase is approximately 6.4 percent. Thus, the impact of the ETS is comparable to the impact of the power price increase. Despite the skepticism of some regarding ETSs, the ETS indeed had a positive impact on emission reduction.

Second, we can also estimate the implicit permit price of Tokyo ETS from our estimation results. The emission reduction from the ETS is 6.7 percent; one can calculate how this translates to the price increase for the electricity. Given the estimated elasticity of electricity in model 1, the impact of the Tokyo ETS on electricity consumption corresponds to the impact of a 12.9 percent (=0.067/0.519) increase in electricity price. The electricity price under the TEPCO jurisdiction was 13.8 JPY/ kWh in 2010. If the price of power increased by 12.8%, the power price of 13.8 JPY/kWh would have been 15.6 JPY/ kWh, which is an increase in the power price by 1.8 JPY/ kWh. The CO_2 intensity for TEPCO was 0.000384 t-CO_2/ kWh in 2010. Thus, the implicit carbon price is estimated to be 4,688 JPY/ t-CO2 (approximately $52[11] per ton of CO_2), which is comparable to the permit price reported by the Tokyo government depicted in Figure 2. The price in 2011 was more than $80 and fell to $50 in 2014.

Finally, we discuss the size of the emission reduction. Our estimation results show that the ETS reduced emissions in Tokyo by 6.7 percent and that the power price increase contributed another 6.4% reduction. In sum, emissions in Tokyo were reduced by 13.1 percent. This number seems rather small compared to the reduction of 25% reported by the Tokyo government. This gap can be explained by two reasons. First, the Tokyo government uses the baseline emission while we use 2009 as our reference for the emissions reduction. The baseline for each facility was chosen from the average of three consecutive years from 2003 to 2007. Therefore, facilities tended to choose years for which they had higher emissions. This difference explains a major part of the gap. Second, Tokyo ETS was announced in 2007. Therefore, some facility managers may have started the reduction in 2008 or 2009. Consequently, the estimated reduction from our estimation would again be smaller than the number from the Tokyo government. In fact, Wakabayashi and Kimura (2018) also report an emission reduction under Tokyo ETS of 14% as of 2014, the last year of the first phase, compared with the 2009 level, which is

[11] According to the exchange market, one US dollar was valued at approximately 90 yen in 2011.

close to our estimate of 13%.

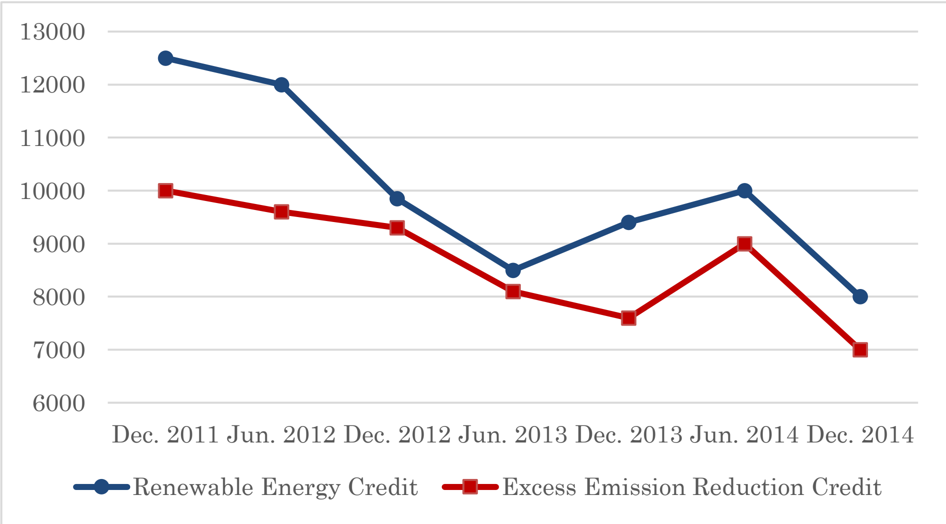

Figure 2: Permit Price (JPY/ CO_2 ton): Tokyo ETS

5. Conclusion

In this paper, we empirically investigated the impacts of Tokyo ETS using individual facility-level data for office buildings. We found that the Tokyo ETS overall has been successful in reducing CO_2 emissions relative to other regions. As expected, the power price increase contributed to emissions reduction in Tokyo, but the ETS also contributed. Thus, despite skepticism regarding the effectiveness of ETSs, it was proven that Tokyo ETS is an effective environmental policy tool.

We also recovered the implicit carbon permit price using our estimated model, which we found to be approximately \$50 per CO_2 ton. This price is somewhat lower than that in the Tokyo government report but still in a comparable range. One can note that the permit price in Tokyo is higher than the carbon price in Europe or North America (World Bank Group, 2019). Most of the permit prices in China's pilot scheme have been less than \$15 (Duan, 2020), and the permit price in the Korean market has been stable at less than \$20 (Oh, 2020). Thus, Tokyo ETS seems to have a higher carbon price.

Other aspects of Tokyo ETS, however, should be scrutinized in future work. For example, Tokyo ETS may have caused carbon leakage to other regions in Japan. Because neighborhood prefectures such as Kanagawa or Chiba have not introduced an ETS, some business may have moved or shifted economic activities to these areas from Tokyo. This is an important area of future work.

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