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Abstract

To promote renewable energy deployment, Japan introduced a feed-in tariff policy in 2012, financed through a surcharge on electricity prices for consumers. The Japanese government also offered a discount system for electricity-intensive industrial plants, exempting them from paying full surcharges. Using monthly plant-level data from 2005 to 2018, this study evaluated the exemption system’s impact on electricity and fossil fuel consumption for plants in the iron and steel, chemical products, and pulp and paper sectors. Our results show that the exempted iron and steel plants increased electricity purchase and consumption by 1.06% and 1.04%, respectively. The introduction of electricity efficiency as a new requirement for exemption applications after 2017 did not curb the rebound, as iron, steel, and pulp and paper plants increased their electricity consumption by 1.49% and 0.69%, respectively, after the reform. This result may call for the reform of the exemption system, with the possibility of a lower discount rate or tighter requirements for electricity efficiency.

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Impact of the Feed-in-Tariff Exemption on Energy Consumption in Japanese Industrial Plants

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Highlights:

- The introduction of an exemption from paying the feed-in tariff surcharge caused a rebound in electricity consumption among industrial plants.
- Iron and steel plants increased electricity purchase and consumption by 1.06% and 1.04%, respectively.
- The introduction of electricity efficiency requirements did not curb the rebound, as consumption among the iron, steel, pulp, and paper plants increased by 1.49% and 0.69%, respectively, after the reform.
- There was no significant difference in electricity demand elasticity between the exempted and non-exempted plants.

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Abstract:

To promote renewable energy deployment, Japan introduced a feed-in tariff policy in 2012, financed through a surcharge on electricity prices for consumers. The Japanese government also offered a discount system for electricity-intensive industrial plants, exempting them from paying full surcharges. Using monthly plant-level data from 2005 to 2018, this study evaluated the exemption system's impact on electricity and fossil fuel consumption for plants in the iron and steel, chemical products, and pulp and paper sectors. Our results show that the exempted iron and steel plants increased electricity purchase and consumption by 1.06% and 1.04%, respectively. The introduction of electricity efficiency as a new requirement for exemption applications after 2017 did not curb the rebound, as iron, steel, and pulp and paper plants increased their electricity consumption by 1.49% and 0.69%, respectively, after the reform. This result may call for the reform of the exemption system, with the possibility of a lower discount rate or tighter requirements for electricity efficiency.

Keywords: Feed-in-Tariff; Exemption from Climate Policy; Electricity-Intensive Industry; Plant-Level Data

JEL Classification Codes: Q48; Q41; D22

1. Introduction

Following the Great East Japan Earthquake and Fukushima Daiichi nuclear disaster, Japan witnessed a significant drop in electricity production from nuclear power plants. To reduce energy import dependency, the Japanese government implemented several policies to increase renewable energy production. The feed-in-tariff (FIT) policy was introduced in July 2012. It encourages the deployment of renewable energy plants through an elaborate system of subsidies (Agency for Natural Resources and Energy, 2021a). The costs associated with the guaranteed price are financed through a surcharge added to the electricity prices paid by all consumers. This policy's impact is two-fold: it acts as an incentive for renewable energy producers and, through an increase in electricity prices, encourages consumers to reduce their electricity demand. However, FIT is an expensive policy, and the necessary amount of funding increased the surcharge beyond government expectations (Tanaka et al., 2017). The surcharge size was initially set at a rate of 0.22 JPY/kWh for the fiscal year 2012, and has been growing to 2.98 JPY/kWh in fiscal year 2020 (Kansai Denryoku, 2021). Given the size of the surcharge, large private electricity consumers expressed concerns over the implementation of the FIT. Thus, a partial exemption from the surcharge was introduced at the same time as the policy. This particular exemption system was tightened in 2017, with the addition of an electricity efficiency requirement Exemption systems, along with voluntary agreements for energy efficiency efforts, are often introduced with carbon pricing instruments to avoid loss of competitiveness in the industrial sector (Ekins and Speck, 1999). Ekins and Speck (1999) identified the existing exemption or discount systems in Sweden, Denmark, Norway, and the Netherlands, where certain energy-intensive industries face lower tax rates on fossil fuel and energy products. However, Austria's implementation of the system acted as a reimbursement for energy-intensive industries (Ekins and Speck, 1999). Through a computable general equilibrium (CGE) framework, Böhringer and Rutherford (1997) simulated an exemption from a carbon tax in Germany and deemed it expensive, as it leads to welfare losses. Wage subsidies financed by taxes are a more appropriate solution to avoid carbon leakage (Böhringer and Rutherford, 1997). Using data on the Norwegian carbon tax, Bruvoll and Larsen (2004) revealed policy inefficiencies and identified sectoral exemptions as reasons for the small effect of the tax implemented since 1991. Recently, Martin et al. (2014a) analyzed the United Kingdom's Climate Change Levy, and the resulting exemptions for plants pledging to reduce emissions through Climate Change Agreements, although the study only used exempted plants as a control group. Martin et al. (2014b) focused on the free allowance system of the EU Emission Trading Scheme (ETS), which was deemed inefficient in its current form, and proposed an optimal reallocation scheme.

According to the literature, exemption schemes may lead to inefficiency and welfare losses. This study evaluates the effect of exemption from the Japanese FIT surcharge on three energy-intensive industries: iron and steel, pulp and paper, and chemical products. Specifically, it investigates whether the introduction of the policy triggered changes in electricity and fossil fuel consumption as well as the demand elasticity and if this impact differs between exempted and non-exempted plants. Furthermore, with the introduction of energy efficiency requirements in 2017, this study also explored the differences in electricity consumption patterns between the two phases of the exemption.

To the best of our knowledge, this is the first study to analyze the effects of an exemption system from the FIT surcharge and, thus, it contributes to the body of studies on exemptions. Our second contribution is the evaluation of the elasticity of electricity demand in the case of industrial plants, rather than the sector's aggregate demand evaluation, and the differentiation of the elasticity between exempted and non-exempted plants. Finally, this research is among the few that examine the impact of FIT on electricity consumption. While Tanaka et al. (2022) analyzed the effect of FIT on electricity consumption among households in Australia, we could not find studies that considered the policy's impact on industrial consumption.

The paper is organized as follows: section 2 describes the motivation and the hypothesis of this research, and explains in details the exemption system analyzed in this study. Section 3 details the theoretical background and estimation model and presents the data used in the analysis. Section 4 shows estimation results and Section 5 discusses implications, limitations and Section 6 concludes this study.

2. Literature review

2.1 Effect of FIT on electricity price

The FIT policy affects renewable energy production (see, for instance, Du and Takeuchi, 2020), and the change in energy input affects prices. Several studies have explored FIT introduction's impact on electricity retail prices. Specifically, Costa-Campi and Trujillo-Baute (2015) divided the effects of this policy into two components: the incentive costs, namely the surcharge passed onto consumers, and the wholesale price. Focusing on industrial electricity consumers in Spain, the study showed that the FIT policy in its current form contributes to an increase in retail prices; the consumer surcharge's effect offsets the decrease in wholesale prices, resulting in an increased overall price. A similar conclusion was drawn by Paraschiv et al. (2014) and Clò et al. (2015) in their analyses of the German and Italian electricity markets, respectively. However, some studies do not find such a relationship between FIT and retail prices. Using panel data on selected Organization for Economic Co-operation and Development (OECD) countries, Iimura and Cross (2018) assessed the effects of an increase in the renewable energy share on retail prices, disproving the idea that a higher share significantly impacts electricity prices.

2.2 Elasticity of electricity demand energy-intensive industries in Japan

A review of the literature showed that the FIT policy's introduction could result in higher electricity prices. However, the effect of this increase on industrial energy consumption depends on the elasticity of electricity demand in the analysis sector. Hence, this section discusses studies that analyze the industrial sector's response to electricity price changes in Japan.

In 1993, Matsukawa et al. (1993) examined the price-setting mechanism under regional monopolies, evaluated electricity demand's elasticity in the process, and presented two different estimates: -0.63 and -0.37 for industrial and residential consumers, respectively. Hosoe and Akiyama (2009) investigated the difference in electricity demand across regions using partial adjustment between 1976 and 2006. Combining industrial and commercial sectors, large variations were found in short-run elasticities, ranging from 0.09 to 0.30 with urban regions such as Tokyo, Kansai, and Chubu having lower elasticity (Hosoe and Akiyama, 2009). Using a similar methodology, Otsuka (2015) differentiated between industrial and commercial sectors, as well as short- and long-run elasticity and obtained industrial elasticity of -0.03 and -0.15 in the short and long run, respectively. Wang and Mogi (2017) included electricity market deregulation and structural changes in the market through a time-varying state-space model using a Kalman filter on a panel of nine regions between 1989 and 2014. The authors estimate that the demand elasticity of the industrial sector declined sharply from -0.797 in 1989 to -0.289 after 1995. Following the 2008 crisis, it further decreased to -0.020 in 2010 and recovered slightly to -0.160 in 2014 (Wang and Mogi, 2017).

Noting the variation in demand elasticity across sectors (industrial or residential) in the aforementioned studies, Hoshino (2013) also differentiated between industrial sectors, using Japanese data from 1956 to 2009 and a time-varying model. The study showed that the long-term elasticity of electricity demand in energy-intensive sectors was the highest. Specifically, it is between -0.16 to -0.11 for iron and steel, -0.14 to -0.08, and -0.20 to -0.21, respectively (Hoshino, 2013).

2.3 FIT Exemption System and Hypothesis

In the previous section, we showed that the introduction of the FIT policy may lead to higher electricity retail prices, and that energy-intensive industrial sectors are those whose demand will be changing most in response to electricity prices fluctuations. Thus, in Japan, these industrial plants may be particularly affected by the surcharge. For this reason, they are eligible to apply for the exemption offered by the Japanese government. In order to receive a discount from the surcharge, plants must apply to the Ministry of Economy, Trade and Industry (METI) every fiscal year, and prove that they fulfill the following requirements (Agency for Natural Resources and Energy, 2021b):

(1) They must be energy intensive plants, and must be able to prove that, in order to produce JPY1,000 worth of output, the plant requires at least 5.6 kWh of electricity.

(2) They must be able to prove that their annual electricity consumption is above one million kWh.

(3) The electricity consumption registered for condition (2) must represent more than 50% of the total electricity consumption of the plant.

Plants that meet the three requirements above are given a special annual discount of 80% on the FIT surcharge. Specifically, the exemption system underwent a revision in 2016. In 2017, METI added a fourth condition: to be exempted, plants should prove their efforts to improve electricity efficiency inside the plant. Specifically, plants must prove that the average change in electricity efficiency in the past five years is below 99% or that the change is below 105% if they can prove no worsening in efficiency in the past three years. Since 2017, the discount rate for exempted plants is still 80% if plants meet condition (4), but can remain as high as 40% for those meeting conditions (1)-(3) (Agency for Natural Resources and Energy, 2021b).

Exempting plants from paying the full FIT surcharge is not a commonly seen policy, and, to the best of our knowledge, only exists in Japan. Given that industrial plants, and especially those from energy-intensive sectors are more sensitive to electricity price changes (Hoshino, 2013), granting an 80% discount to certain plants may exacerbate changes in energy consumption between the plants. Thus, we hypothesize that there exists a difference in electricity consumption patterns between plants that receive the exemption and those that could not meet the exemption criteria. As discussed in the introduction of this paper, the exemption systems that usually accompany carbon pricing instruments such as carbon tax or ETS often result in inefficient policy outcomes and losses of welfare. Therefore, focusing on energy-intensive industries, we also decide to analyze whether the policy efficiently targeted plants that were more vulnerable to price changes by estimating the elasticity of electricity demand between the two types of plants.

3. Methodology and data description

3.1 Electricity and fossil fuel demand inside energy-intensive plants

In this section, we describe a theoretical model that explains the determinants of electricity and fossil fuel demand in the case of energy-intensive plants. The main feature of this model is to include the electricity price variation concerning the FIT surcharge, and exemption from the surcharge. As the study analyzes energy-intensive plants, we assume that energy consumption, $E,$ is a crucial factor in production and, thus, a key input in the production function of a representative plant. This is provided in equation (1).

$$Y = f(K, L, E)\, Y = f(K, L, E). \tag{1}$$

Furthermore, we assume that the production function is concave for all the three inputs and fulfills the Inada conditions.

Energy consumption comprises two types of products: electricity, which is purchased from retailers at a given price, P_{el} p_{el}, and fossil fuels, which are purchased from an external market at a price, P_{ff} p_{ff}. For simplicity, we assume that electricity and fossil fuels are perfect complements, at least in the short-term. Appendix A also provides a scatter plot of electricity and fossil fuel consumption for each sector in the analysis.

Since Japan has few fossil resources, fossil fuel purchases are almost entirely based on imports. Fluctuations in P_{ff} p_{ff} are influenced by the global oil and gas market, and we can assume that P_{ff} p_{ff} is determined exogenously. Given the large number of plants in Japan, we can also assume that P_{el} p_{el} is an exogenous factor in the model, and that plants are price takers. In this model, plants try to maximize their profit from selling their products Y Y in the market at a price P_Y p_Y. The plant maximization problem[3] is illustrated in equation (2):

$$\max_{K,L,E} P_Y f(K,L,E) - rK - wL - \left(P_{el} + P_{ff}\right)E$$

$$\max_{E} p_Y f(K,L,E) - rK - wL - (p_{el} + p_{ff})E \,.$$

(2)

Under perfect competition, we have three first-order conditions given by equations (3) to (5):

$$\frac{\partial f(K,L,E)}{\partial K} = \frac{r}{p_Y}$$

$$\frac{\partial f(K,L,E)}{\partial K} = \frac{r}{P_Y} \tag{3}$$

$$\frac{\partial f(K,L,E)}{\partial L} = \frac{w}{p_Y}$$

$$\frac{\partial f(K,L,E)}{\partial L} = \frac{w}{P_Y} \tag{4}$$

$$\frac{\partial f(K,L,E)}{\partial E} = \frac{p_{el} + p_{ff}}{p_Y} \,.$$

$$\frac{\partial f(K,L,E)}{\partial E} = \frac{P_{el}+P_{ff}}{P_Y} \tag{5}$$

Focusing on (5), we obtain the energy demand function of plants:

$$\partial E_{baseline} = \frac{P_Y \partial f(K,L,E)}{\left(P_{el}+P_{ff}\right)}$$

$$\partial E_{baseline} = \frac{p_Y \partial f(K,L,E)}{p_{el} + p_{ff}} \,. \tag{6}$$

The energy demand depends on the relative price of output, electricity, and fossil fuels as well as the marginal output production inside the representative plant.

With the introduction of FIT, a surcharge $s > 0$ $s > 0$ is added to electricity prices. The demand function becomes (7).

$$\partial E_{surcharge} = \frac{p_Y \partial f(K,L,E)}{(p_{el} + s) + p_{ff}}$$

$$\partial E_{surcharge} = \frac{P_Y \partial f(K,L,E)}{\left(P_{el}+s+P_{ff}\right)}$$

(7)

As explained in the introduction, certain plants can receive a discount δ δ on the surcharge, of the size 0.8 or 0.4. The plant demand function is reduced to (8).

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[3] A possible criticism of this model is that profit maximization decision is not taken inside the plants, but by the owning firms. However, it is reasonable to assume that firms aggregate each plant's profit maximization decision into a single representative plant. Thus, the model holds.

$$\partial E_{exemption} = \frac{P_Y \partial f(K,L,E)}{(P_{el} + (1-\delta)s + P_{ff})}$$

$$\partial E_{exemption} = \frac{p_Y \partial f(K,L,E)}{(p_{el} + (1-\delta)s) + p_{ff}}$$

(8)

Since $s > 0$ $s > 0$, the relationship between demand functions (6) to (8) is:

$$\partial E_{surcharge} < \partial E_{exemption} < \partial E_{baseline}$$

$$\partial E_{surcharge} < \partial E_{exemption} < \partial E_{baseline} .$$

(9)

Energy demand is reduced by the introduction of a surcharge on electricity prices if electricity and fossil fuel prices are held constant. Since we assume that electricity and fossil fuels are the perfect complements, we may disregard fossil fuels' price in the dynamic analysis. We focus on changes in electricity demand and presume that changes in fossil fuel demand follow the same pattern. The dynamic analysis is presented in Table 1; it explores the relative fluctuations of the surcharge and electricity prices and their effect on energy demand.

Table 1. Analysis of energy demand regarding electricity price fluctuations

	(1) $s < \partial P_{el}$ $s < p_{el}$	**(2)** $s = \partial P_{el}$ $s = p_{el}$	**(3)** $s > P_{el}$ $s > p_{el}$
(A) $\partial P_{el} > 0$ $\partial p_{el} > 0$	$\partial E_{surcharge} < \partial E_{baseline}$ $\partial E_{surcharge} < \partial E_{baseline}$	$\partial E_{surcharge} < \partial E_{baseline}$ $\partial E_{surcharge} < \partial E_{baseline}$	$\partial E_{surcharge} < \partial E_{baseline}$ $\partial E_{surcharge} < \partial E_{baseline}$
(B) $\partial P_{el} < 0$ $\partial p_{el} < 0$	$\partial E_{surcharge} > \partial E_{baseline}$ $\partial E_{surcharge} > \partial E_{baseline}$	$\partial E_{surcharge} = \partial E_{baseline}$ $\partial E_{surcharge} = \partial E_{baseline}$	$\partial E_{surcharge} < \partial E_{baseline}$ $\partial E_{surcharge} < \partial E_{baseline}$

Note: "$\partial E_{surcharge}$ $\partial E_{surcharge}$" refers to the change in energy consumption compared to the baseline scenario $\partial E_{baseline}$ $\partial E_{baseline}$, where no surcharge is introduced.

Line (A) presents a case wherein electricity prices increase. Then, regardless of the relative size of the surcharge, the energy demand will decrease based on equation (7). The second line (B) proposes to analyze the case wherein electricity prices decrease, for instance, caused by increased domestic electricity generation due to adoption of renewable energy. If the surcharge is smaller than the decrease in electricity prices (case 1), then the energy demand will still increase as the price drop will offset the surcharge. However, if the surcharge is larger than the price decrease (case 2), the energy demand will decrease. If both decrease (case 3), the energy demand will remain at the same level as in the baseline scenario described in equation (6). Based on Table 2, we can assume that plants receiving a discount (exemption) from the surcharge are more likely to follow case (1), especially before the 2016 reform. Thus, we may observe an increase in electricity and fossil fuel consumption for exempted plants, as electricity prices (excluding the surcharge) between 2012 and 2018 decreased in most regions after 2014 (as shown in Appendix B).

3.2 Estimation strategy

The estimated equation is based on the theoretical model. However, several parameters of the model cannot be observed or measured, such as the technology level inside the plant, which affect the marginal production level. We estimate equation (10) using electricity consumption and purchases with fossil fuel consumption as dependent variables.

$$Dependent\ variable_{it} = \alpha_{it} + \beta_1 electricity\ price_{jt} + \beta_2 exemption_{it} + \beta_3 electricity\ price_{jt} \times exemption_{it} + \beta_4 facility\ employee_{it} + \delta_1 SETS + \delta_2 TETS + \eta_1 CDD_{it} + \eta_2 HDD_{it} + \sum_{m=2004}^{2019} \gamma_m year_t + \sum_{o=1}^{313} \rho_o facility_i + \theta X_{it} + \epsilon_{it} + u_{it}$$

$$\ln(Dependent\_Variable_{i,t}) = \alpha_{i,t} + \beta_1 \ln(electricity\_price_{i\in r,t}) + \beta_2 exemption_{i,t} + \beta_3 electricity\_price_{j,t} \times exemption_{i,t} + \beta_4 TETS + \beta_5 SETS + \theta X_{i,t} + \gamma_{i,t} + \varepsilon_{i,t} + u_{i,t} \quad , (10)$$

where $Dependent\ Variable_{it}$“$Dependent\_Variable_{i,t}$” represents electricity purchase and consumption and fossil fuel consumption for plant i at time t ; α $\alpha_{i,t}$ is a constant term; $electricity\ price_{jt}$ $electricity\_price_{i\in r,t}$ is the price elasticity of electricity in region r[4]; $exemption_{it}$ $exemption_{i,t}$ is a dummy variable taking the value “1” if plant i is exempted in year or month t; $SETS, TETS$ $TETS$ and $SETS$ are a dummy variables taking the value “1” if the

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[4] We use regional electricity price as a proxy for transaction at the plant level. Each region is defined as the territory under each Electric Power Company (EPCO), that is, Hokkaido, Tohoku, Tokyo, Hokuriku, Chubu, Kansai, Shikoku, Chugoku, Kyushu and Okinawa.

plant is a target of Tokyo ETS or Saitama ETS, respectively; $facility\ employee_{it}$ $X_{i,t}$ is a vector containing control variables and the number of employees at the plant levelCDD_{it}, the number of cooling and heating degree days for the plant i in a given month$year_t$, firm sales (in logarithmic form) and firm's ROE; $facility_i$ $\gamma_{i,t}$ is plant fixed effect; X_{it} ; ϵ_{it} $\varepsilon_{i,t}$ and $u_{i,t}$ u_{it} are idiosyncratic and composite error terms, respectively.

The variables of interest are the exemption dummy variables, taking the value 1 if the plant has been targeted by exemption from the FIT scheme, and 0 otherwise; but the study also closely examines price elasticity's impact on electricity consumption.

In April 2010, Tokyo prefecture introduced ETS, covering plants consuming over 1,500kl of crude oil equivalent for three years in a row. A year later, Saitama, a neighboring prefecture, introduced a similar cap and trade scheme with the same requirements. Notably, the emissions targets were slightly different, and the Saitama ETS did not include punishments or fines for those that did not achieve the desired target. While the exemption and ETS differ in the energy input requirement (electricity or crude oil equivalent), both target large energy consumers and, hence, may overlap. Previous studies (Arimura and Abe, 2021; Hamamoto, 2021; Sadayuki & Arimura, 2021; Yajima et al., 2020) have shown that the Japanese ETS reduces energy consumption or CO_2 emissions, whereas our theoretical model suggests that the exemption system could encourage further electricity or fossil fuel consumption. Therefore, we included ETS in this study, as policies may have conflicting effects on industrial plants.

Due to a lack of available data at the plant level, we used firm sales and the return rate as a proxy for plant output. We also assumed that the technological level of a plant is constant over time. Hence, we choose to estimate equation (10) using a plant fixed effects (FE) model for electricity consumption and purchase, as well as fossil fuel consumption as dependent variables.

Since the exemption system was reformed in 2016, we would also like to explore whether the introduction of an electricity efficiency requirement triggered any change in the behavior of exempted plants. Hence, we estimated a second model, as expressed in equation (11):

$$\begin{aligned}
&Dependent\ variable_{it}\\
&\quad = \alpha_{it} + \beta_1 electricity\ price_{jt} + \beta_2 exemptionP1_{it}\\
&\quad + \beta_3 electricity\ price_{jt} \times exemptionP1_{it} + \beta'_2 exemptionP2_{it}\\
&\quad + \beta'_3 electricity\ price_{jt} \times exemptionP2_{it} + \beta_4 facility\ employee_{it}
\end{aligned}$$

$$+ \delta_1 SETS + \delta_2 TETS + \eta_1 CDD_{it} + \eta_2 HDD_{it} + \sum_{m=2004}^{2019} \gamma_m year_t + \sum_{o=1}^{313} \rho_o facility_i + \theta X_{it} + \epsilon_{it} + u_{it} \quad .$$

$$\ln(Dependent\_Variable_{i,t}) = \alpha_{i,t} + \beta_1 \ln(electricity\_price_{i\in r,t}) + \beta_2 exemptionP1_{i,t} + \beta_2' exemptionP2_{i,t} + \beta_3 electricity\_price_{j,t} \times exemptionP1_{i,t} + \beta_3' electricity\_price_{j,t} \times exemptionP2_{i,t} + \beta_4 TETS + \beta_5 SETS + \theta X_{i,t} + \gamma_{i,t} + \varepsilon_{i,t} + u_{i,t} \quad , (11)$$

where “$Dependent\_Variable_{i,t}$” represents electricity purchase and consumption and fossil fuel consumption for plant i at time t; $\alpha_{i,t}$ is a constant term; $electricity\_price_{i\in r,t}$ is the price elasticity of electricity in region r[5]; $exemptionP1_{i,t}$ ($exemptionP2_{i,t}$) is a dummy variable taking the value “1” if the plant *i* is exempted in year or month *t* during the first (second) phase of exemption; $TETS$ and $SETS$ are a dummy variables taking the value “1” if the plant is a target of Tokyo ETS or Saitama ETS, respectively; $X_{i,t}$ is a vector containing control variables, and comprises the number of employees at the plant level, the number of cooling and heating degree days for the plant *i* in a given month, firm sales (in logarithmic form) and firm’s ROE; $\gamma_{i,t}$ is plant fixed effect; $\varepsilon_{i,t}$ and $u_{i,t}$ are idiosyncratic and composite error terms, respectively.

The control variables in the second model are the same, but we differentiate between the two phases of exemption: the first phase, before the reform (2012–2016), is represented by the $exemptionP1_{i,t}$ $exemptionP1_{it}$ and the second (2017 onward) is represented by $exemptionP2_{it}$ $exemptionP2_{i,t}$.

3.3 Data description

3.3.1 Descriptive statistics

This study used monthly data from 2005 to 2018, as provided by the *current survey of energy consumption* (CSEC), conducted annually by the METI (METI, 2020a). A description of the survey was provided by the METI (2015). Although the survey targeted nine sectors, we focused only on iron and steel, pulp and paper, and chemical products, as these industries are over-represented among the exempted plants. Furthermore, Hoshino (2013) showed that iron

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[5] We use regional electricity price as a proxy for transaction at the plant level. Each region is defined as the territory under each EPCO, that is, Hokkaido, Tohoku, Tokyo, Hokuriku, Chubu, Kansai, Shikoku, Chugoku, Kyushu and Okinawa.

and steel, chemical, as well as pulp and paper industries are particularly vulnerable to price changes, and thus, are most likely to be affected by the FIT surcharge's introduction. The survey provided detailed information at the plant level on monthly fossil fuel and electricity consumption per fuel, and consumption target. The data were aggregated to create three dependent variables: electricity purchase and consumption and fossil fuel consumption. Specifically, electricity consumption is the sum of purchases from the external market and the total electricity generated on-site through waste heat or thermal co-generators. For plants with no electricity generation capacity, the electricity purchases and consumption are equal.

As the FIT system affects electricity prices through a surcharge, it is essential to include them in the analysis. This variable was obtained from the Federation of Electric Power Companies of Japan (2021)[6]. Specifically, data on transactions at the plant level are sensitive and not readily available. Instead, the study used regional prices and aggregate measures of the electricity sales and production, using the same method as Wang and Mogi (2017). Furthermore, since 2004, consumers with demand above 500 kW may choose their electricity retailer freely; hence, using the regional companies' prices is an approximation of the electricity prices paid by each plant. This approximation is valid to the extent that energy-intensive industrial plants are large consumers, and thus less likely to shift their retailing contracts to small-scale new entrants or to renegotiate their electricity contracts with new providers.

Since we investigated the FIT exemption's impact, the list of exempted plants and plants under the Tokyo and Saitama ETS was retrieved from METI's Agency for Natural Resources and Energy (Agency for Natural Resources and Energy, 2020) and the homepages of each government (Saitama Prefectural Government, 2021; Tokyo Metropolitan Government, 2021), respectively. The number of employees per plant was also retrieved using the Pollutant Release and Transfer Register (PRTR) publicly available from METI (2020b). This study used the Touyou Keizai Database to obtain yearly firm-level financial covariates, such as firm sales and return rate (Keizai, 2020). Based on data from temperature-measuring stations provided by the Japanese Meteorological Agency (JMA), we constructed HDD and CDD to capture monthly temperature variations. First, we matched each plant to its closest station. We then computed the number of HDD (CDD), that is, the number of days in a month where the temperature is

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[6] That is to say, Hokkaido Electric Power Company, Tohoku Electric Power Company, Tokyo Electric Power Company, Hokuriku Electric Power Company, Chubu Electric Power Company, Kansai Electric Power Company, Chugoku Electric Power Company, Shikoku Electric Power Company, Kyushu Electric Power Company and Okinawa Electric Power Company.

below 14°C (exceeds 24°C). Finally, the HDD (CDD) was calculated by totaling all the degrees above the temperature thresholds.

After combining the dataset with the control variables for the three sectors of interest, the sample contained 25,941 observations for 301 different plants.

Table 2. Descriptive statistics

Variable Name	Unit	Mean	Standard Deviation	Minimum	Maximum	Source
Electricity purchase	Thousands kWh	11419.28	20893.45	0	286260	METI (2020a)
Electricity consumption	Thousands kWh	19089.15	34070.43	1	330641	METI (2020a)
Fossil Fuel Consumption[7]	Crude Oil Equivalent, MJ	25298.66	83085.18	0	1052350	METI (2020a)
Iron	Binary	0.46	0.50	0	1	METI (2020a)
Chemical	Binary	0.39	0.49	0	1	METI (2020a)
Paper	Binary	0.14	0.35	0	1	METI (2020a)
Exemption	Binary	0.12	0.32	0	1	ANRE, 2020
Electricity Price	Yen per kWh	17.71	2.15	14.24	24.37	Federation of Electric Power Companies of Japan (2021)
Number of employees inside the plant	Count variable	406.08	559.85	4	9518	PRTR from METI (2020b)
Tokyo ETS	Binary	0.01	0.07	0	1	Tokyo Metropolitan Government (2021)
Saitama ETS	Binary	0.01	0.09	0	1	Saitama Prefectural Government, 2021
Cooling degree days	Count variable	12.67	36.36	0	262.1	JMA, 2020
Heating degree days	Count variable	109.58	158.97	0	826.3	JMA, 2020
Yearly Return on Equity (Firm)	Rate	0.11	2.73	-2.15	126	Keizai (2020)
Yearly firm sales	Millions Yen	1534000	2267477	1835	1.24E+07	Keizai (2020)

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[7] This variable contains: crude oil consumption, gasoline, naphtha, reformed oil, kerosene, natural gas liquids and condensate, diesel, fuel oil, hydrocarbon oil (byproduct), liquefied petroleum gas, petroleum hydrocarbon gas (byproduct), oil coke, coal and coal coke, natural gas, liquid natural gas, piped (city) gas, black liquor, waste material, waste tires, tar, high and light kerosene, oxygen. To convert these various fuels into crude oil equivalent, we used conversion coefficients provided by METI (2015).

Note: Number of observations for yearly return on equity is 25,659.

"METI," "ANRE," "PRTR" and "JMA" stands for the Japanese Ministry of Economy, Trade and Industry, Agency for Natural Resources and Energy, Pollutant Release and Transfer Register and Japanese Meteorological Agency, respectively.

Descriptive statistics for the sample are presented in Table 2 and show a highly heterogeneous sample. Approximately half comprises plants from the iron and steel sector, whereas chemical products account for nearly 40%. Pulps and paper was the smallest represented sector. This is could be because the CSEC only targeted paper and paperboard plants with a minimum of 50 employees, unlike the iron and steel, chemical products, or pulp, which covered all plants in Japan.

3.3.2 Exempted plants

As the analysis' focus is to assess the effect of the exemption system, this section provides more details on the exempted plants. Among the 301 plants, 59 plants were exempted from a total of 3,001 observations, representing slightly over 19% of the sample. Among the exempted plants, 35 were from the iron and steel sector, 22 from the chemical sector and only two from pulp and paper. As we have a total of 136, 116, and 47 plants in the iron and steel, chemical products, and pulp and paper sectors, exempted plants represent 26%, 19%, and 4%, respectively. Appendix C provides details on the frequency of exemption. Given that FIT exemption and ETS target the same type of energy-intensive plants, we also discuss the interaction between the two policies in Table 3.

Table 3. Interaction between exemption and ETS

Number of plants targeted by…	Both	ETS only	Exempted only	Neither	Total Prefecture
Exemption and Saitama ETS	1	3	0	2	6
Exemption and Tokyo ETS	0	2	0	1	3

Note: The numbers above only report plants located in Tokyo or Saitama prefectures. No chemical plants were targeted by the ETS within the sample. The Tokyo ETS did not target pulp or paper plants.

Source: Authors' compilation.

As expected, several plants in the sample were targeted by the prefectural ETS. Table 4 shows that the exemption system is more stringent, possibly because of the energy intensity requirement. The number of plants in the Tokyo ETS is also much smaller than that in Saitama, this can be explained by the residential aspect of the prefecture and its strong environmental regulations and high land prices.

4. Empirical results

4.1 Impact of the exemption system on electricity consumption patterns

This section presents the estimation results of equations 10 and 11 in Tables 4 and 5, respectively. Specifically, we focus on electricity purchase and consumption, as the surcharge is levied on electricity prices and, thus, theoretically, it affects electricity purchases and consumption directly.

Table 4. Fixed effects regression results: Electricity Model 1

	Iron and Steel Sector		Chemical Products Sector		Pulp and Paper Sector	
Dependent Variable	Electricity Purchase (log)	Electricity Consumption (log)	Electricity Purchase (log)	Electricity Consumption (log)	Electricity Purchase (log)	Electricity Consumption (log)
Electricity Price (log)	0.30	0.30	-0.21	-0.46***	-1.14	-0.33**
	(0.26)	(0.26)	(0.28)	(0.12)	(1.17)	(0.13)
Exemption	1.65**	1.63**	0.97	0.10	-1.10	-1.18**
	(0.81)	(0.80)	(0.87)	(0.61)	(4.71)	(0.52)
Exemption × Electricity Price (log)	-0.59**	-0.58**	-0.38	-0.06	0.42	0.41**
	(0.28)	(0.28)	(0.30)	(0.21)	(1.61)	(0.17)
Saitama ETS	-0.21***	-0.21***	omitted	omitted	0.47*	-0.04
	(0.07)	(0.07)			(0.25)	(0.02)
Tokyo ETS	-0.78***	-0.79***	omitted	omitted	omitted	omitted
	(0.22)	(0.07)				
Plant fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Sample size	11883	11883	9701	10 063	3473	3713
R-squared	0.04	0.04	0.01	0.05	0.04	0.13
Rho	0.96	0.96	0.88	0.95	0.88	0.99
Number of plants	136	136	116	116	47	47

Source: Authors' compilation. Robust standard errors are indicated in parentheses. "***," "**," and "*" denote statistical significance at the 1%, 5%, and 10% levels, respectively. In this sample, no plant in the chemical sector was targeted by the ETS; hence, this variable was omitted. Similarly, paper and pulp plants in the sample were only targeted by the Saitama ETS; hence, TETS was omitted. Control variables include plant employees, cooling and heating degree days, firm sales, and firm return on equity. The results are presented in Appendix D1.

Table 4 shows that the associated coefficients for the exemption (dummy and interaction terms) are significant for iron and steel as well as pulp and paper sectors when using electricity consumption as the dependent variable. The exemption system's effect is the sum of the dummy and interaction terms; thus, we also estimated the linear combination of the two coefficients and performed Wald tests for joint significance. Appendix E presents the results of these tests, which show that exemption leads to an increase in electricity consumption by 1.04% for iron and steel plants, whereas the exempted plants in the pulp and paper sector decreased their consumption by 0.77%. Plants exempted in the iron and steel sector also increased electricity purchases by 1.06%. However, the exemption system did not affect plants in the chemical sector.

Table 5. Fixed effects regression results: Electricity Model 2

	Iron and Steel Sector		Chemical Products Sector		Pulp and Paper Sector	
Dependent Variable	Electricity Purchase (log)	Electricity Consumption (log)	Electricity Purchase (log)	Electricity Consumption (log)	Electricity Purchase (log)	Electricity Consumption (log)
Electricity Price (log)	0.30 (0.26)	0.30 (0.26)	-0.21 (0.28)	-0.46*** (0.12)	-1.15 (1.17)	-0.33** (0.13)
Exemption Phase 1	1.37* (0.75)	1.35* (0.74)	0.55 (0.86)	0.05 (0.59)	-0.76 (4.76)	-0.87 (0.64)
Exemption Phase 2	2.39* (1.37)	2.33* (1.36)	3.90 (3.64)	0.69 (1.47)	-4.25 (3.66)	0.96** (0.42)
Exemption Phase 1 × Electricity Price (log)	-0.49* (0.26)	-0.48* (0.26)	-0.23 (0.30)	-0.04 (0.20)	0.30 (1.62)	0.30 (0.21)
Exemption Phase 2 × Electricity Price (log)	-0.86* (0.47)	-0.84* (0.46)	-1.39 (1.24)	-0.26 (0.50)	1.47 (1.26)	-0.28* (0.14)
Saitama ETS	-0.21*** (0.07)	-0.21*** (0.07)	omitted	omitted	0.47* (0.25)	-0.04 (0.02)
Tokyo ETS	-0.78*** (0.22)	-0.79*** (0.07)	omitted	omitted	Omitted	omitted
Plant fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Sample size	11 883	11883	9701	10 063	3473	3713
R-squared	0.04	0.05	0.01	0.05	0.04	0.13
Rho	0.96	0.96	0.88	0.95	0.87	0.99
Number of plants	136	136	116	116	47	47

Source: Authors' compilation. Robust standard errors are indicated in parentheses. "***," "**," and "*" denote statistical significance at the 1%, 5%, and 10% levels, respectively. In this sample, there was no plant in the chemical sector targeted by the ETS; hence, this variable was omitted. Similarly, paper and pulp plants in the sample were only targeted by the Saitama ETS; hence, TETS was omitted. Control variables include plant employees, cooling and heating degree days, firm sales, and firm return on equity. The results are presented in Appendix D2.

As discussed in the Introduction section, we also evaluated the effect of the exemption system's 2016 reform. The estimation results of equation 11 are presented in Table 5, while the complete results and post-estimation tests are available in Appendices D and E, respectively. Regardless of the model, the size and significance level of the coefficients of interest are roughly preserved. We did not observe a significant difference among plants producing chemicals, but those in the iron and steel sector showed an increase in their electricity purchase and consumption by 0.88% and 0.87% in the first phase and 1.53% and 1.49% in the second phase, respectively. Although there were no statistically significant coefficients in the first phase of exemption for pulp and paper plants, a rebound in electricity consumption in the second phase, estimated at approximately 0.69% was observed.

Since this study focused on energy-intensive sectors, regional ETS dummy variables for the target plants located in Tokyo and Saitama were also included. The estimates are significant and robust, as they do not change across the model specifications. Plants targeted by the Saitama ETS experienced a drop in electricity purchase and consumption by 0.21%. The impact of the Tokyo ETS is estimated to be larger, with a reduction of 0.78% and 0.79% in electricity purchases and consumption, respectively. The difference in the magnitude of the coefficients between the two policies could be explained by the fact that the Saitama ETS essentially remains a voluntary scheme with no penalty for non-compliers.

4.2 Impact of the exemption system on fossil fuel consumption patterns

As previously theorized, the exemption system may also affect fossil fuel consumption in the short run. This section presents and discusses the estimation results of equations (10) and (11), which are presented in Table 6.

Table 6. Fixed effects regression results: Fossil fuel consumption

Dependent Variable: Fossil Fuel Consumption	Iron and Steel Sector		Chemical Products Sector		Pulp and Paper Sector	
Electricity Price (log)	0.13	0.13	-0.58*	-0.58*	-0.34	-0.34
	(0.26)	(0.26)	(0.30)	(0.30)	(0.27)	(0.27)
Exemption	-0.35		-0.65		-0.33	
	(2.34)		(1.13)		(1.02)	
Exemption Phase 1		0.08		-0.75		-0.38
		(1.78)		(1.03)		(1.05)
Exemption Phase 2		-1.85		-0.18		0.62
		(4.52)		(3.06)		(0.88)
Exemption × Electricity Price (log)	0.09		0.18		0.15	
	(0.80)		(0.41)		(0.35)	
Exemption Phase 1 × Electricity Price (log)		-0.06		0.21		0.17
		(0.60)		(0.37)		(0.36)
Exemption Phase 2 × Electricity Price (log)		0.61		0.01		-0.17
		(1.55)		(1.07)		(0.31)
Saitama ETS	-0.29**	-0.29**	omitted	omitted	0.08	0.08
	(0.11)	(0.11)			(0.06)	(0.06)
Tokyo ETS	-0.64**	-0.64**	omitted	omitted	omitted	omitted
	(0.26)	(0.27)				

Plant fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Sample size	11 030	11 030	10 062	10 062	3 713	3 713
R-squared	0.04	0.04	0.03	0.03	0.11	0.11
Rho	0.98	0.98	0.95	0.95	0.98	0.98
Number of plants	136	136	116	116	47	47

Source: Authors' compilation. Robust standard errors are indicated in parentheses. "***," "**," and "*" denote statistical significance at the 1%, 5%, and 10% levels, respectively. In this sample, there was no plant in the chemical sector targeted by the ETS; hence, this variable was omitted. Similarly, paper and pulp plants in the sample were only targeted by the Saitama ETS; hence, TETS was omitted. Control variables include plant employees, cooling and heating degree days, firm sales, and firm return on equity. The results are presented in Appendix D3.

The results presented in Table 6 show that the exemption system did not have a statistically significant effect on fossil fuel consumption, regardless of the sector and exemption phase. Individual coefficients are insignificant, but the lack of effect is also confirmed by the test for joint significance and linear combinations (see Appendix E).

Similar to the other dependent variables, the Saitama and Tokyo ETS are significantly reducing fossil fuel consumption in the iron and steel sector, cutting it by 0.37% and 0.48-0.49%, respectively, consistent with Yajima et al. (2020), who showed that the impact of the Tokyo ETS on the consumption of liquefied petroleum gas was significant and negative.

4.3 Difference in demand elasticity between exempted and non-exempted plants

Finally, this study aims to explore whether there is a difference in price elasticity between exempted and non-exempted plants. It is important to derive such indicators, as the impact of pricing policies such as FIT depends on how elastic (or inelastic) the electricity demand is in the industry. Sectors (or plants) with inelastic demand are more likely to be strongly affected by such policies and may request exemptions from policymakers. This section presents the estimates for price elasticity and discusses whether these coefficients significantly differ between exempted and non-exempted plants.

Table 7. Elasticity of electricity demand

Dependent Variable	Sector	Type of Reported Value	Exempted		Non-Exempted	
			Plants	Observations	Plants	Observations
Electricity Purchase (log)	Iron and Steel Sector	Elasticity	-0.14	-0.18	0.31	0.25
			(0.10)	(0.25)	(0.32)	(0.28)
		Sample Size	4174	1725	7709	10158
	Chemical Products Sector	Elasticity	-0.97***	0.16	-0.20	-0.22
			(0.29)	(0.43)	(0.31)	(0.29)
		Sample Size	2696	1158	7005	8543

	Pulp and Paper Sector	Elasticity	-0.10 (0.23)	-0.38 (0.85)	-1.15 (1.19)	-1.14 (1.17)
		Sample Size	288	114	3185	3359
Electricity Consumption (log)	Iron and Steel Sector	Elasticity	-0.14 (0.10)	-0.18 (0.25)	0.32 (0.32)	0.26 (0.27)
		Sample Size	4174	1725	7709	10158
	Chemical Products Sector	Elasticity	-0.90** (0.33)	-0.49*** (0.12)	-0.47*** (0.13)	-0.46*** (0.12)
		Sample Size	2700	1162	7363	8901
	Pulp and Paper Sector	Elasticity	-0.27** (0.01)	0.17 (0.43)	-0.33** (0.13)	-0.33** (0.13)
		Sample Size	288	114	3425	3599
Fossil Fuel Consumption (log)	Iron and Steel Sector	Elasticity	0.09 (0.44)	1.43 (1.22)	0.01 (0.29)	-0.01 (0.27)
		Sample Size	4169	1719	6861	9311
	Chemical Products Sector	Elasticity	-1.37* (0.79)	-0.80*** (0.26)	-0.55 (0.33)	-0.55* (0.31)
		Sample Size	2698	1160	7364	8902
	Pulp and Paper Sector	Elasticity	0.13 (0.17)	0.21* (0.02)	-0.36 (0.27)	-0.34 (0.27)
		Sample Size	288	114	3425	3599

Source: Authors' compilation. Robust standard errors are indicated in parentheses. "***," "**," and "*" denote statistical significance at the 1%, 5%, and 10% levels, respectively. "Exempted plants" are plants that have received the exemption at least once between 2012 and 2018. "Non-Exempted plants" are those that do not receive any exemption. "Exempted observations" are observations for which the exemption dummy takes the value of "1," while "Non-Exempted observations" are those for which the dummy takes the value of "0." "Elasticity" is the coefficient associated with the logarithm of electricity price in the fixed effect regression. The control variables are presented in equations 10 and 11. The plant fixed effect was included in the regression. The complete results are provided in Appendices F and G.

Accordingly, we divide the sample into two parts: exempted and non-exempted observations. Since this leads to an imbalance in the number of observations, the sample is divided between plants that qualified for the exemption at least once and those that never received the exemption. The estimated coefficients for price elasticity are presented in Table 7.

Table 7 shows that majority of the estimated coefficients are not statistically significant; this could be explained by the use of an aggregated measure of electricity prices due to the confidentiality of transactions at the plant level. Therefore, we cannot draw any conclusions for plants in the iron and steel sector.

However, regardless of the dependent variable, we obtained statistically significant estimates for the chemical plants. The coefficients associated with electricity consumption are roughly similar for exempted and non-exempted plants and vary between -0.46 and -0.49. This similarity in demand elasticity could explain why exempted plants did not show a significant difference in electricity purchase and consumption in the previous section. These estimates are larger than those in the literature, as Hoshino (2013) found a long-term elasticity ranging between -0.08 and -0.14 for the chemical sector. This difference can be explained by the higher short-term responses to electricity prices. Table 8 shows similar estimates, varying between -0.27 and -0.33, for price elasticity in the case of electricity consumption of pulp and paper plants, which are similar to the estimates of Hoshino (2013), -0.20 to -0.21.

However, the estimates of electricity price elasticity for fossil fuels differ. Chemical plants have more inelastic demand, with higher coefficients ranging from -0.80 to -1.37, nearly twice as high as that of non-exempted plants (-0.55). The negative sign across the estimates confirms the complementary relationship between electricity and fossil fuels in energy-intensive plants. Nonetheless, we obtained a positive and marginally significant coefficient for the pulp and paper sector (+0.21), which suggests that integrated paper mills may substitute electricity with fossil fuels.

5. Discussion

5.1 Implications

There are several implications of the results presented in Section 4.

First, our study showed variation in the impact of the exemption depending on the sector, as the results differ greatly between iron and steel, chemical or pulp, and paper, despite all industries being energy-intensive. Specifically, iron and steel showed a rebound in electricity purchases and consumption, which can be attributed to the introduction of the exemption system. While this effect is not found in the chemical sector, and the pulp and paper sector experiences a decrease in electricity consumption among the exempted, the rebound calls for further attention regarding the implementation of the FIT exemption system.

To understand the impact of the introduction of electricity efficiency following the 2016 reform, we divided the exemption system into two phases and evaluated each phase individually. The results showed that the rebound in electricity consumption remains for plants in the iron and steel as well as pulp and paper sectors even after the introduction of the electricity efficiency requirements. Thus, our results imply that the new requirement did not deter such practices and, hence, another reform of the FIT exemption system may be warranted.

Second, we estimated the elasticity of electricity and fossil fuel demand, as this indicator determines the impact of policies that affect electricity prices, which is the case for FIT. This study showed that there was no clear difference between plants that received an exemption and those that did not, which raises questions regarding the fairness of the exemption policy. If both types of plants respond to electricity price changes in the same way, then granting an 80%

discount to some may not be appropriate and could lead to welfare loss, as Böhringer and Rutherford (1997) predicted with their simulation of a carbon tax.

Along with fairness issues and potential welfare losses, the additional energy consumed due to the rebound among exempts may have resulted in greenhouse gas emissions. Based on the statistically significant coefficients estimated in the previous section for Models 1 and 2, Figure 1a and 1b illustrate the additional aggregated CO_2 emissions resulting from the introduction of the exemption system.

Figure 1. Additional CO_2 emissions due to the introduction of the exemption scheme: Aggregated

Figure 1a. Estimates from Model 1

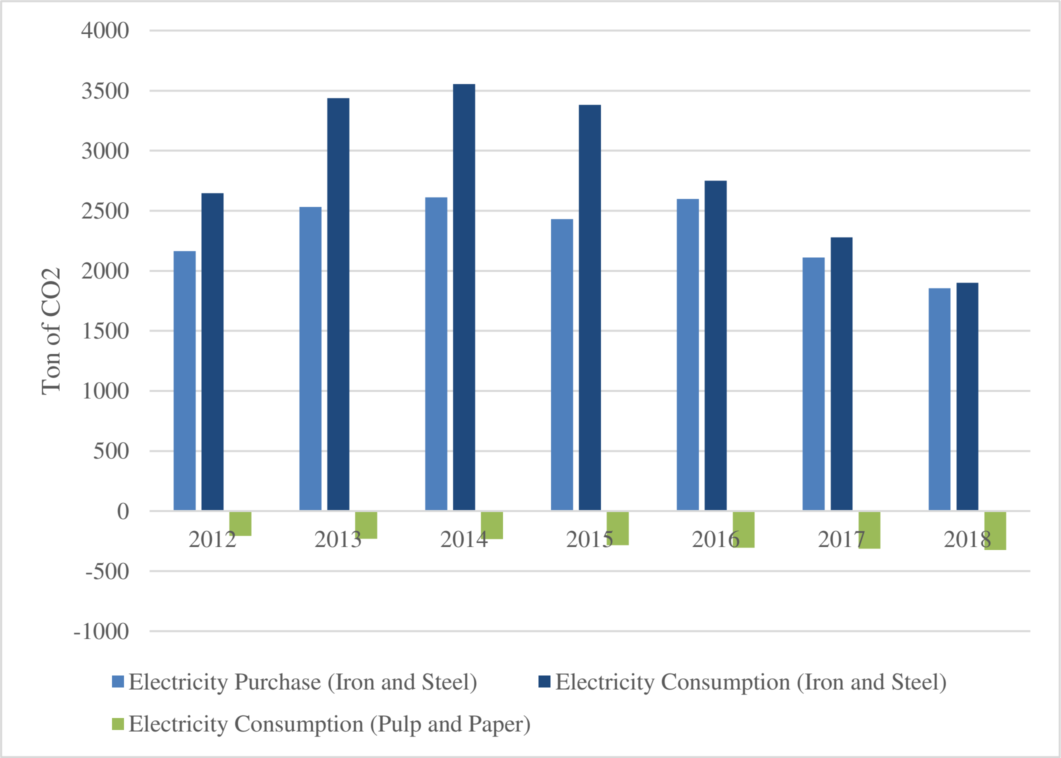
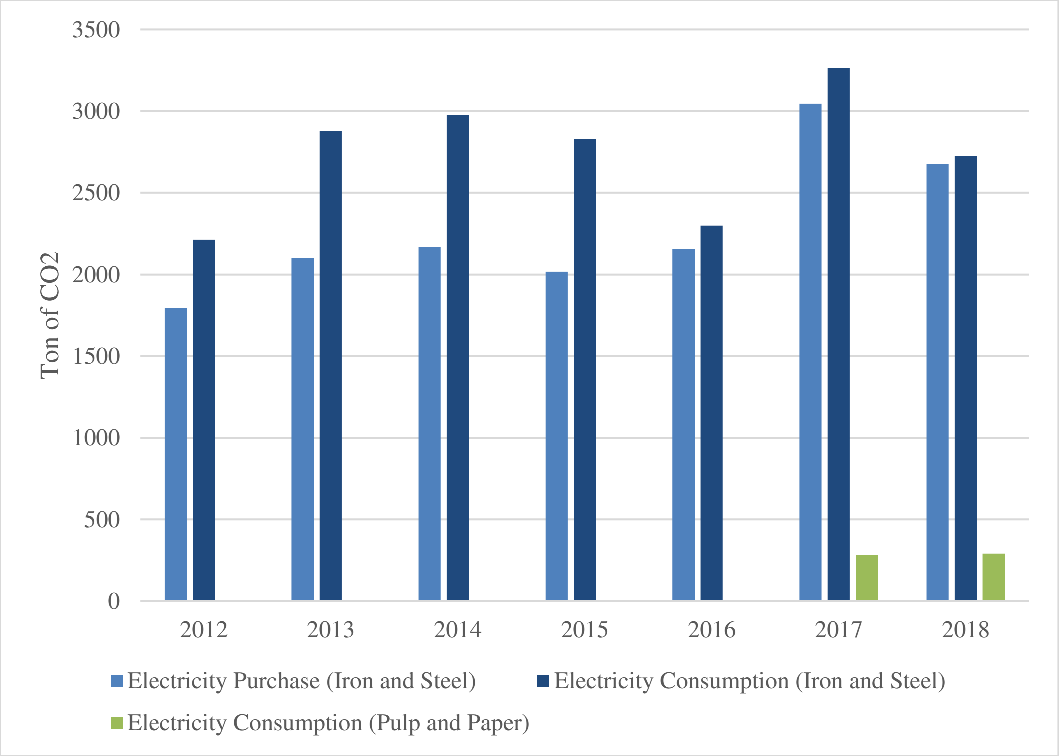


Figure 1b. Estimates from Model 2



Source: Authors' compilation. Details of the calculation method are presented in Appendix H. Only the coefficients for which the F-test and linear combination are shown to be statistically significant are reported.

Despite the efforts of the pulp and paper sector to reduce electricity consumption, there was an overall increase in CO_2 emissions (Figure 1); however, this was mostly attributed to the iron and steel plants sector, the sector with the largest share of exempted plants in our sample. Increase in emissions is an unforeseen consequence of the exemption system and provides another argument for further reforms.

6. Concluding remarks

The costs of policies promoting renewable energy deployment are often shouldered by end consumers, and the FIT policy is no exception. Such policies can be met with hostility from the industry, as certain manufacturing sectors tend to consume significant amounts of electricity and, hence, bear a heavy burden. To reach a consensus, it may be tempting for policymakers to introduce a discount in the levy for electricity-intensive manufacturers.

The results showed that the introduction of an exemption system following the implementation of FIT in Japan was accompanied by a rebound in electricity purchase and consumption for plants in the iron and steel sector. The reform of the system in 2016, which included electricity efficiency requirements, did not curb such trends. The estimated coefficients after the reform are even larger. This result implies that policymakers must be careful in designing such exemption systems to avoid any rebound and that a reform of the current scheme may be warranted.

The study also explored the difference in the elasticity of electricity and fossil fuel demand between plants that received and did not receive the exemption. There was no strong evidence of differences between the two types of plants, suggesting that both types may respond to price changes in the same way. Therefore, our findings suggest that in addition to a rebound in consumption and associated CO_2 emissions, the current exemption system may pose an issue of fairness.

This study has several limitations. First, due to the confidentiality of transactions at the plant level, electricity prices had to be approximated, even though it is likely that large consumers may receive preferential rates. Furthermore, because of the lack of economic variables provided with the original data, we had to considerably reduce the number of observations after combining the CSEC with external datasets; hence, our results' precision may have been affected by the process. Finally, we posit that electricity and fossil fuels are complementary inputs in the production process. While most of our estimates for demand elasticity seem to confirm this hypothesis, plants from the pulp and paper sector increased fossil fuel consumption with a rise in electricity prices, suggesting that these plants substitute electricity with fossil fuel. The substitution attempts among plants should be explored in further research.

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8 Authors' contribution:

Aline Mortha: conceptualization, methodology, data curation, investigation, writing - original draft, and visualization; **Naonari Yajima**: data curation, software, and validation; **Toshi H. Arimura**: supervision, funding acquisition, writing-review, and editing.

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