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A CGE Analysis of a Rate-based Policy for Climate Change Mitigation

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Abstract

We conducted a computable general equilibrium analysis of a policy to regulate carbon dioxide emissions per unit of production in Japan. It is often claimed that regulations based on emission rates might lead to an increase in carbon dioxide emissions but would not suppress economic growth. This study shows that in the short run, a rate-based policy does not lead to an increase in emissions. We also compared a rate-based policy with a cap-and-trade policy and found that the former leads to a greater reduction in the real GDP than the latter. Furthermore, the change in output tends to be more evenly distributed under a rate-based policy than under with a cap-and-trade policy, although the former is inferior in terms of cost-effectiveness.

1 Introduction

Although global efforts toward climate change mitigation have focused on total emission amounts, some countries have declared emission targets relative to their GDPs. For example, China and India, which are likely to be major actors in global climate change in coming decades, have set such targets. In the Intended Nationally Determined Contribution (INDC) submitted to UNFCCC, the Chinese government plans to reduce carbon dioxide emissions as a proportion of GDP by 60–65% between 2013 and 2030. India has a similar policy to reduce its carbon intensity by 33–35% between 2013 and 2030.

Compared to a cap-and-trade policy that restricts the total amount of emissions, it seems obvious that a regulation linking emissions to output (herein referred to a "rate-based policy") is an inefficient instrument in terms of social welfare (Fischer 2001). Because a rate-based policy can be regarded as providing a subsidy to output, it is difficult to attain the first best outcome with the policy. On the other hand, several studies have emphasized the flexibility of the rate-based target to respond to unanticipated changes in the amount of covered generation due to factors such as weather trends or unexpected changes in population or economic growth (Kolstad 2005; Pizer 2005; Quirion 2005; Jotzo and Pezzey 2007; Sue Wing et al. 2009; and Fischer and Springborn 2011). Thus, there might be a reason to prefer a rate-based policy because it is not subject to constraints on emissions. Motivations for the rate-based policy might also be political or distributional, because it does not constrain economic growth and it might be possible to mitigate the negative impact of regulations on industrial sectors.

The effects of rate-based emissions trading have mostly been analyzed mostly by a theoretical approach (Helfand 1991; Fischer 2003; Boom and Dijkstra 2009; Holland 2012).[1] Findings from the existing literature suggest that a rate-based regulation does not offer enough incentive to reduce emissions due to an implicit output subsidy. Fischer (2003) shows that the total amount of emissions tends to increase with a rate-based policy compared to a case where a cap-and-trade policy and the rate-based policy are used together. Boom and Dijkstra (2009) show that the amount of output under a rate-based policy increases compared to that under a cap-and-trade policy in the short term and long term. While these studies suggest that a rate-based policy might be inferior as a policy instrument, few study have done quantitative evaluations of the extent of such a policy's impact.

Some empirical studies have investigated the impact of emissions trading with output-based allocation (Fischer and Fox 2004; Takeda et al. 2013). The rate-based approach looks similar but is significantly different from the

[1] An example of such an empirical study is Holland (2009), which examined the efficiency of California's Low Carbon Fuel Standard.

emissions trading with output-based allocation. The former approach does not regulate the total amount of emission while the latter does. Under the former approach, the emission rate is exogenously given as a target and the total emission is endogenously determined. On the other hand, under the latter approach, the total emission is exogenously given as a target and the emission rate is endogenously determined. As a result, the rate-based approach does not ensure a reduction in the total amount of emission.

Using a computable general equilibrium (CGE) model, this study investigates the impact of a rate-based policy in Japan. While Japan has not introduced an emissions trading system, there has been serious discussion regarding the introduction of the emissions trading, including the rate-based emissions trading.[2] For example, the possibility of introducing a rate-based policy was mentioned in the Global Warming Basic Bill that was finally abolished at the end of 2012. Furthermore, in the pilot program for the domestic emissions trading implemented in 2008, participants could choose between absolute emissions target and a rate-based emissions target. Among the par-

[2]The industrial sector in Japan has strongly opposed to the introduction of a cap-and-trade policy. Keidanren, the biggest Japanese business lobbying organization, has claimed that the Japanese government should not implement a cap-and-trade style domestic emissions trading scheme, because of its negative impact on corporate operations (http://www.keidanren.or.jp/en/policy/2012/089.html).

ticipants in the pilot program, 30 chose the absolute emissions target and 45 chose the rate-based emissions target.[3]

The results of this study suggest that, within the framework of static CGE analysis, a rate-based policy does not lead to increased emissions of carbon dioxide. This is because capital and labor are limited, and the economy does not grow beyond business-as-usual (BaU). We also show that a rate-based policy tends to reduce production more evenly across sectors. In contrast, a cap-and-trade policy can increase the output of sectors that emit less carbon dioxide and thereby promote a structural shift in the economy. These results might explain why a rate-based policy is preferred by industrial sectors that are especially carbon intensive.

The remainder of the paper is organized as follows. Section 2 introduces the model and explains the data used and the method of calibration. Section 3 presents simulation results on the rate-based policy that attains a 25% reduction[4] in emission rate from the base case. Section 4 compares the rate-

[3]Similarly, the Clean Power Plan recently proposed by the US Environmental Protection Agency gives states flexibility in how they attain state-level carbon dioxide emissions. States can choose rate-based goals or absolute mass-based goals for emissions of carbon dioxide from existing power plants (Palmer 2015).

[4]In INDC, Japan sets an emissions reduction target of 26% reduction of emission levels between 2013 and 2030. This is equivalent to 25% reduction from the emission level in 2005.

based policy and the cap-and-trade-policy. Section 5 discusses the policy implication of results obtained. Section 6 presents a sensitivity analysis to check the robustness of the results in previous sections. Section 7 presents our concluding remarks.

2 The model

2.1 The model of the rate-based policy

When emissions trading by a rate-based policy is introduced, the profit function of the representative firm in the sector can be expressed as follows:

$$\max_{x,y_1,y_2} \quad P_x x - \{P_{y_1} y_1 + P_{y_2} y_2 + P_{CO_2}(h_{y_2} y_2 - \alpha x)\} \tag{1}$$

where x is output, y_1 is the input of non-energy goods, y_2 is the input of energy goods, h_{y_2} is the emission coefficient, and α is the emission rate. P_x, P_{y_1}, P_{y_2}, and P_{CO_2} represent prices of x, y_1, y_2, and emission permits, respectively.

Under the rate-based policy, α is exogenously determined as:

$$\alpha = 0.75 \cdot \frac{E^{BaU}}{x^{BaU}},$$

when the policy requires a 25% reduction in the emission rate from the the business-as-usual (BaU) case (E^{BaU} is total emission of the BaU scenario and x^{BaU} is total output of the BaU scenario). This means that the firm must reduce emissions by 25% from the BaU emissions when it maintains its output at the BaU level. In contrast, emissions trading with output-based allocation (Fischer and Fox 2004; Takeda et al. 2013) requires α to be:

$$\alpha = \frac{A}{x},$$

where A is initial allocation of emission permits and x is endogenously determined level of output. Under emissions trading with output-based allocation, α is endogenously determined so that it is certain whether we can attain the targeted emission rate.

We assume that emission regulations are imposed only on firms and not on the household sector. This is realistic because it is costly to allocate emission permits to households and allow them to trade. A firm's carbon dioxide emissions are represented by $h_{y_2}y_2$, while αx denotes the initially allocated emission permits. When the amount of emissions is larger than that allowed under the allocated emission permits ($h_{y_2}y_2 - \alpha x > 0$), the firm will be a buyer of permits at the permit price P_{CO_2}. By contrast, when the amount of emissions is smaller than the allocated emission permits ($h_{y_2}y_2 - \alpha x < 0$), the firm will be a seller of permits. Under the rate-based policy, the price of permits is determined by the demand and supply of emission permits:

$$\sum_i h_{y_{2i}} y_{y_{2i}} = \sum_i \alpha_i x_i \tag{2}$$

where i is the index of the firm. The LHS of (2) denotes the total demand for emission permits and the RHS denotes the total supply. P_{CO_2} is determined to satisfy this equation.

2.2 The model settings

We develop a static CGE model for the Japanese economy based on 2005 data. The model is composed of 34 sectors as listed in Table 1. It is assumed that three sectors, crude petroleum, coking coal, and natural gas (`foss`); petroleum and coal products (`p_c`); and gas and heat supply (`ghs`), produce energy goods and other sectors produce non-energy goods. The first sector (`foss`) deals with mining of petroleum, coal, and natural gas. The second sector (`p_c`) contains the industrial processes such as oil refining and the production of cokes. The third sector (`ghs`) is related to the supply of town gas and heat to industrial and residential users. Because electricity (`ely`) is secondary energy made from `foss` and `ghs`, it is not included in energy goods. Firms emit carbon dioxide from their production process as they use energy goods, while households emit carbon dioxide from their consumption of energy goods.

The model has three economic agents: a household, firms, and the government. In this analysis, a representative household that owns exogenously given capital and labor is assumed. The household provides capital and labor to firms and, using the income obtained, it purchases goods and saves money. It saves at a constant rate and gains utility from the consumption of goods.

Figure 1 shows that the household gains utility from consumption of energy and non-energy goods. The number in Figure 1 denotes the elasticity of substitution and it is assumed to equal one. The household determines its consumption of goods to maximize its utility under budget constraints.

Figure 2 shows the production structure of firms. A firm produces a primary production factor by using capital and labor, then produces a secondary production factor by using energy goods, and produces a final product by using non-energy goods. It is assumed that carbon dioxide emissions occur due to the use of energy goods. To maximize profits, firms determine the production quantity in this structure.

The final products are transformed into domestic goods and export goods. The domestic goods are transformed into Armington composite goods in combination with imported goods, on the assumption that there is an imperfect substitution between them (Armington 1969). The elasticity of substitution between domestic goods and imported goods and the elasticity of transformation between domestic goods and export goods are set at four. The value of the elasticity of substitution in our model comes from the reference value in Takeda (2007).

The government is supposed to collect three types of tax: a production tax, tariff, and tax on household income. It is assumed that the government consumes or saves the tax revenue at a constant rate.

For simplicity, a small country is assumed. As a result, the foreign currency prices of imported and exported goods are constant. As for the balance of payments, the amount of the current account imbalance is constant. In addition, the current account deficit is interpreted as foreign savings.

From the above settings, the government spending, household consumption, and current account deficit are determined, and hence the total amount of savings. The total amount of savings is spent on investment goods at a constant rate.

2.3 Data and calibration

We perform a CGE simulation using the benchmark data of the base year. The economic data comprise data on intermediate inputs, final consumption, investment, government expenditure, and exports and imports from the 2005 Input-output Tables for Japan (Statistics Bureau, Japanese Ministry of Internal Affairs and Communications 2009). Data on government savings are sourced from Income and Outlay Accounts Classified by Institutional Sector in 2005 (Economic and Social Research Institute 2007). We construct a social accounting matrix from these data for the CGE analysis. Emissions data of carbon dioxide are taken from the consumption and input of energy goods from the 3EID database (Nansai and Moriguchi 2012).

In a CGE analysis, calibration refers to a model estimation method that exactly reproduces the initial equilibrium of the estimated model. From the social accounting matrix, we obtain the parameters for the production function, utility function, saving rate, tax rate, income, and emissions coefficient. Because data in the social accounting matrix are only expressed in terms of the value, we must separate the value data into quantity and price data. For convenience, it is assumed that labor is the numeraire good, and the price for all production factors and all products take the value one in the base year. Numerical computation is performed with GAMS (general algebraic modeling system) and its solver, PATH.

3 Impacts of the rate-based policy

Table 2 shows the results of a simulation for a rate-based policy. Note that the policy requires a 25% reduction from the BaU emission rate. Because the BaU data is from the Japanese economy in 2005, the reference of the policy is emissions and output in 2005. Results show that emissions from firms are reduced by more than required reduction in emission rate; the exact reduction is 26.6%. On the other hand, the emission reduction from the household sector is small, at 0.6%. As a result, the total emission of carbon dioxide is reduced by 22.9%.

These results can be intuitively interpreted as follows. The total supply of emission permits is $\sum_i \alpha_i x_i$. By requiring α_i to be reduced by 25%, the output x_i also becomes lower than the BaU output, and the emission is reduced by 26.6%. The primary reason for this result is the short-run nature of our analysis. Even though the rate-based policy seems to allow firms to increase emissions and output, this is not possible in the short run. Available capital and labor are limited, therefore the economy does not grow beyond the BaU. Thus, emissions from firms is reduced by 26.6%, which is more than the required reduction in emission rate (25%) required by the rate-based policy in this analysis.

We confirm that this result is robust to the required emission rate. Figure 3 shows the impact of a lower emission rate on total emissions and firms' emissions of carbon dioxide. By requiring a lower emission rate, total emissions and firms' emissions are reduced. Emissions from firms are always reduced by a larger percentage than the required reduction in emission rate. The impact of requiring a lower emission rate on the permit price is shown in Figure 4. The permit price is increasing due to an increase in marginal abatement cost.

Figure 5 shows the realized emission rate in each sector under a rate-based policy. Although the total reduction in emission rate is 25%, the reduction in emission rate is different among sectors. The emission rate is greatly reduced in sectors such as pulp, paper, and wood products (`pulp`); ceramic, stone, and clay products (`nmm`); and iron and steel (`iron`). This suggests that the marginal cost of reducing the emission rate is relatively lower in these sectors. Figure 6 shows the initial emission rate for each sector in BaU. The figure shows that the initial emission rates for `pulp`, `nmm`, and `iron` are higher than other sectors. It is reasonable to expect that the marginal cost of reducing the emission rate is lower for those sectors with higher initial emission rates. On the other hand, sectors such as electricity (`ely`) and transportation (`trp`) have higher initial emission rates, while their changes in emission rates are modest. Therefore, the relationship between the initial emission rate and the impact of CO_2 regulation on each sector is not straightforward.

4 Comparison of the rate-based policy and the cap-and-trade policy

In this section, we compare the rate-based policy with the cap-and-trade policy, assuming that both policies reduce the total amount of emission as much as the reduction obtained in the analysis of the previous section. There are some differences regarding the settings of policy between this section and the previous section. The policy target in this section is the total amount of emission, while that in the previous section is the emission rate of firms. We assume that regulations are imposed only on firms and not on the household.

When emissions trading using the cap-and-trade policy is introduced, the profit function of the firm is represented as follows:

$$\max_{x,y_1,y_2} \quad P_x x - (P_{y_1} y_1 + P_{y_2} y_2 + P_{CO_2} h_{y_2} y_2) \tag{3}$$

We assume that emission permits are supplied by the government by auction and the household receives the revenue to avoid discussions on how to allocate initial permits. In practice, many cap-and-trade systems have allocated initial permits for free.[5]

[5] For example, the EU Emissions Trading System allocated almost all of its permits for free in the first period (2005−2007) and second period (2008−2012). In its third period (2013−2020), 57% of the total amount of allowances will be auctioned, while the remaining permits will be available for free allocation.

In the cap-and-trade policy, permits price P_{CO_2} is determined by the demand and supply of emission permits per the following equation:

$$\sum_i h_{y_2 i} y_{2i} = \bar{E} \tag{4}$$

where $\bar{E}$ is the total supply of emission permits by the government. The LHS of (4) denotes total demand for emission permits, and the RHS denotes total supply. Permits price P_{CO_2} is determined according to this equation.

Table 3 shows the results. Emissions from firms are reduced by 26.6% with the rate-based policy and by 26.2% with the cap-and-trade policy. Emissions from the household are reduced by 0.6% with the rate-based policy and by 3.2% with the cap-and-trade policy. The permits price and the marginal abatement cost are higher in the rate-based policy (1,365 yen/tCO_2) than the cap-and-trade policy (938 yen/tCO_2). The change in real GDP is -0.45% with the rate-based policy and -0.42% with the cap-and-trade policy.

These results can be intuitively interpreted as follows. The rate-based policy focuses on the given emission rate. Therefore, the rate-based policy is not effective as the cap-and-trade policy to attain the total emission target. It leads to the lower real GDP under the rate-based policy than that under the cap-and-trade policy. Although the difference in real GDP change is small (-0.03%), it means that the rate-based policy is less cost-effective than the cap-and-trade policy. Furthermore, emissions reduction from the household sector is modest for the rate-based policy. This is because the demand for energy goods is decreased by higher permits price compared to the cap-and-trade policy. As a result, the household increases consumption of energy goods as prices of these goods fall under the rate-based policy.

Figure 7 and Figure 8 show the changes in output for each sector, under the rate-based policy and the cap-and-trade policy. Under the both policies, the output of three sectors that produce energy goods are significantly negatively affected: crude petroleum, coking coal, and natural gas (`foss`); petroleum and coal products (`p_c`); and gas and heat supply (`ghs`). On the other hand, the output of iron and steel (`iron`) and electricity (`ely`) is reduced significantly with the cap-and-trade policy and modestly reduced with the rate-based policy. Under the rate-based policy, sectors with large emission rates, such as iron and steel and electricity, can get many permits free of charge from the government according to their BaU emission rate, so the reduction in output is small. Thus, these sectors does not significantly reduce output in the rate-based policy.

Changes in output are more evenly distributed among sectors with the rate-based policy than with the cap-and-trade policy. Variance in change of output is 11.8 under the rate-based policy, while it is 25.3 under the cap-and-trade. This can also be confirmed by graphically comparing the distribution among sectors in Figures 7 and 8 . The result might be explained by arranging the equation (1) as:

$$\max_{x,y_1,y_2} \quad (P_x + \alpha P_{CO_2})x - (P_{y_1}y_1 + P_{y_2}y_2 + P_{CO_2}h_{y_2}y_2). \tag{5}$$

Because αP_{CO_2} in the first term of the equation (5) is positive, the rate-based policy has features of a subsidy for output while imposing a tax on emissions. For this reason, the reduction rates of output in the rate-based policy can be smaller than those in the cap-and-trade policy for many sectors.

There are three sectors in which output increases in the cap-and-trade policy but decreases in the rate-based policy: information and communication electronics equipment (`iteq`), electronic components (`semi`), and precision instruments (`preq`). Carbon dioxide emissions from these sectors are very small. Of the total emissions in Japan of 2005, the share of `iteq` is 0.03%, `semi` is 0.25%, and `preq` is 0.03%. Therefore, with the introduction of the cap-and-trade policy, demand for these products increased. This suggests the possibility of changes in the industrial structure towards a low-carbon economy. The cap-and-trade policy can promote the growth in sectors related to information technology while the rate-based policy does not have such an effect.

We summarize our result as follows. There is a tendency for the variance in change of output to be smaller under the rate-based policy than under the cap-and-trade policy. Regarding the sectors with lower emissions of carbon dioxide (`iteq`, `semi`, and `preq`), output increases with the cap-and-trade policy while it decreases with the rate-based policy. Because the rate-based policy aims to reduce emissions by setting the emission rate, it does not provide enough incentive for firms to reduce emissions. As a result, the real GDP in the rate-based policy is smaller, albeit slightly in our case, than that in the cap-and-trade policy.

5 Discussion: policy implications

In this section, we discuss the policy implications of our results. The results obtained in Section 3 suggest that the emission reduction of firms is 26.6%, which is more than the required reduction in emission rate under the rate-based policy. This is because the emission permits decreased by more than 25%, due to the reduction of the emission rate and the output. At least in the short-run, it is likely that the rate-based policy can attain a comparable level of emissions reduction to that of policy instruments with absolute targets. Furthermore, the comparison between the rate-based policy and cap-and-trade policy in Section 4 suggests that the decrease in output tends to be more evenly distributed among each sector under the rate-based policy. The impacts of CO_2 regulation on the sectors that heavily depend on fossil fuels are mitigated by the rate-based policy. For example, the output of the iron and steel (`iron`) sector and the electricity (`ely`) sector are reduced significantly with the cap-and-trade policy and reduced modestly with the rate-based policy. This is in line with the political reasons for supporting the rate-based policy.

On the other hand, the downside of the rate-based policy can be summarized as follows. First, the real GDP under the rate-based policy is lower than that under the cap-and-trade policy. Even though the difference between the real GDP of these policies is slight, the cost-effectiveness is lower for the rate-based policy due to an implicit output subsidy. Second, the rate-based policy does not promote growth in sectors related to information technology. This means that the policy instruments might not help transform the economy to climate friendly one. The preferability of the rate-based policy depends on whether these downsides are smaller than the benefit of political consideration on the cost burden of sectors with higher emissions.

6 Sensitivity analysis

We conduct a sensitivity analysis to check the robustness of the results. We change the elasticity of substitution $\sigma_E = 0.5$ in the input of energy goods to $\sigma_E = 0.3$ or 0.7, and analyze how the results of static analysis would change.

Table 4 shows the comparison of the rate-based policy and the cap-and-trade policy with different σ_E. From this table, we can see that the emissions fall by more than 25% regardless of the value of σ_E in the the rate-based policy. Thus, the result of Section 4 is robust to the elasticity of substitution. When the elasticity of substitution σ_E is large, the real GDP is large and the emission reduction is small. This is because production becomes more efficient for a larger σ_E.

The reduction in the real GDP in the rate-based policy is higher than that in the cap-and-trade policy regardless of the value of σ_E. Thus, the result is in line with Section 5. We can also confirm that the real GDP becomes larger for a larger σ_E. This is the same result as in Table 4, while the lower permits price suggests that the marginal abatement cost is lower because of the increase in production efficiency. The permits price changes significantly according to σ_E, suggesting that technological change would have significant impact on the cost of climate change mitigation.

7 Conclusion

This study examined the effect of a rate-based policy with the emissions trading in Japan. By using the static CGE analysis, it is shown that emissions from firms is reduced by 25% or more when the emission rate is required to be reduced by 25% from the base year. This is caused by the reduction of the emission rate and the output that occurs at the same time. In the short-run, technological innovation is not taken into consideration and the emission reduction effect is large.

Furthermore, we compared a rate-based policy with a cap-and-trade policy, assuming the same level of emissions reduction. The result suggests that the rate-based policy reduces the real GDP more than the cap-and-trade policy. This is because the rate-based policy forces a reduction in emissions even in sectors whose marginal abatement costs are high.

The rate-based policy does not promote a reduction in emissions for the sectors with higher BaU emission rates, even though their emissions are large and they have lower marginal abatement costs. In contrast, the cap-and-trade policy forces a significant emission reduction for sectors that have a low marginal abatement costs. Our result suggests that the rate-based policy is inferior in terms of cost-effectiveness, but preferred by industrial sectors that may be strongly affected by the introduction of a cap-and-trade policy.

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References

[1] Armington, PS (1969) "A theory of demand for products distinguished by place of production", *IMF Staff Paper*, 16 (1), pp.159-178.

[2] Boom JT, Dijkstra B (2009) "Permit Trading and Credit Trading: A Comparison of Cap-Based and Rate-Based Emissions Trading Under Perfect and Imperfect Competition", *Environmental and Resource Economics*, 44, pp.107-136.

[3] Economic and Social Research Institute (2007) "Income and Outlay Accounts Classified by Institutional Sector", Economic and Social Research Institute, Cabinet Office, Government of Japan.

[4] Fischer, C (2001) "Rebating Environmental Policy Revenues: Output-Based Allocations and Tradable Performance Standards", Resources for the Future. RFF Discussion Paper 01-22, Washington, DC.

[5] Fischer, C (2003) "Combining rate-based and cap-and-trade emissions policies", *Climate Policy*, 3S2, pp.S89-S109.

[6] Fischer, C and Fox, A (2004) "Output-based allocations of emissions permits: Efficiency and distributional effects in a general equilibrium setting with taxes and trade", Discussion Papers dp-04-37, Resources For the Future.

[7] Fischer, C, Springborn, M (2011) "Emissions targets and the real business cycle: Intensity targets versus caps or taxes", *Journal of Environmental Economics and Management*, 62(3), 352-366.

[8] Helfand, GE (1991) "Standards versus standards: the effects of different pollution restrictions", *American Economic Review*, 81(3), pp.622-634.

[9] Holland, SP, Hughes, JE, Knittel, C (2009) "Greenhouse gas reductions under low carbon fuel standards?", *American Economic Journal: Economic Policy*, 1(1), pp.106-146.

[10] Holland, SP (2012) "Emissions taxes versus intensity standards: Second-best environmental policies with incomplete regulation", *Journal of Environmental Economics and Management*, 63, pp.375-387.

[11] Jotzo, F, Pezzey, JCV (2007) "Optimal intensity targets for emissions trading under uncertainty", *Environmental and Resource Economics*, 83, pp.280-286.

[12] Kolstad, C (2005) "The simple analytics of greenhouse gas emission intensity reduction targets", *Energy Policy*, 33, pp.2231-2236.

[13] Nansai, K, Moriguchi, Y (2012) "Embodied energy and emission intensity data for Japan using input-output tables (3EID): For 2005 IO table", CGER, National Institute for Environmental Studies, Japan. (available at: `http://www.cger.nies.go.jp/publications/report/d031/index-j.html`).

[14] Palmer, K, Paul, A (2015) "A primer on comprehensive policy options for states to comply with the Clean Power Plan", RFF Working Paper DP 15-15.

[15] Pizer, WA (2005) "The case for intensity targets", *Climate Policy*, 5(4), 455-462.

[16] Quirion, P (2005) "Does uncertainty justify intensity emission caps", *Resource and Energy Economics*, 27, 343-353.

[17] Statistics Bureau, Japanese Ministry of Internal Affairs and Communications (2009) "The 2005 Input-output Tables for Japan", Statistics Bureau, Japanese Ministry of Internal Affairs and Communications.

[18] Sue Wing, I, Ellerman, AD, Song, JM (2009) "Absolute vs. intensity limits for CO_2 emission control: performance under uncertainty", in: H Tulkens, R Guesnerie (Eds), The Design of Climate Policy, MIT Press, Cambridge, MA.

[19] Takeda, S (2007) "The double dividend from carbon regulations in Japan", *Journal of the Japanese and International Economies*, 21(3), pp.336-364.

[20] Takeda, S, Arimura, T, Tamechika, H, Fischer, C, Fox, A (2013) "Output-based allocation of emissions permits for mitigating the leakage and competitiveness issues for the Japanese economy", *Environmental Economics and Policy Studies*, 16(1), pp.89-110.

Table 1: Sector identifiers (34 sectors)

Identifiers	Sector description
agr	Agriculture, forestry and fishery
foss	Crude petroleum, coking coal, and natural gas*
omn	Other minings
food	Beverages and Foods
tex	Textile products
pulp	Pulp, paper, and wooden products
chem	Chemical products
p_c	Petroleum and coal products*
nmm	Ceramic, stone and clay products
iron	Iron and steal
nfm	Non-ferrous metal
fmp	Metal products
mch	General machinery
eleq	Electrical products
iteq	Information and communication electronics equipment
semi	Electronic components
treq	Transportation equipment
preq	Precision instruments
omf	Other industrial products
cns	Construction
ely	Electricity
ghs	Gas and heat supply*
wat	Water supply and waste disposal services
trd	Commerce
fin	Finance and insurance
dwe	Real estate
trp	Transport
itc	Information and communications
pubs	Public administration
edu	Education and research
mhs	Medical service, health, social security and nursing care
opub	Other public services
bsrv	Business services
psrv	Personal services

Note: * indicates energy goods.

Table 2: Emissions with a −25% emission rate

Total CO_2	Emissions (firm)	Emissions (household)	Permits price	Real GDP
−22.9%	−26.6%	−0.6%	1,327 yen	−0.45%

Note: Comparison with the actual numbers of 2005.

Table 3: Comparison of rate-based policy and cap-and-trade policy

	Emissions (firm)	Emissions (household)	Permits price	Real GDP
Rate-based	−26.6%	−0.6%	1,327 yen	−0.45%
Cap-and-trade	−26.2%	−3.2%	938 yen	−0.42%

Note: Emissions with a −25% emission rate. Comparison with the actual numbers of 2005.

Table 4: Sensitivity analysis: comparison of policies

	Rate-based policy			Cap-and-trade policy		
	$\sigma_E = 0.3$	$\sigma_E = 0.5$	$\sigma_E = 0.7$	$\sigma_E = 0.3$	$\sigma_E = 0.5$	$\sigma_E = 0.7$
Emissions (firm)	−27.6%	−26.6%	−26.3%	−26.2%	−26.2%	−26.2%
Real GDP	−0.84%	−0.45%	−0.34%	−0.58%	−0.42%	−0.34%
Permits price	3,663 yen	1,327 yen	786 yen	1,708 yen	938 yen	630 yen

Note: Emissions with a −25% emission rate. Comparison with the actual numbers of 2005.

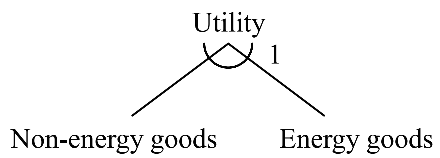

Figure 1: Consumption structure

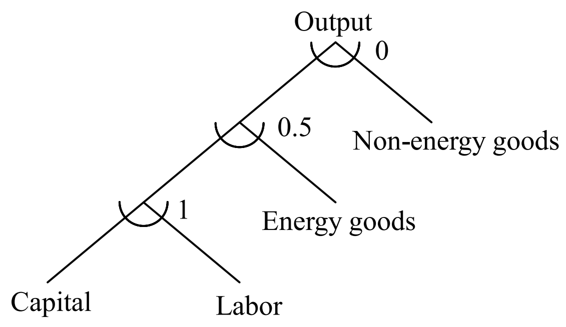

Figure 2: Production structure

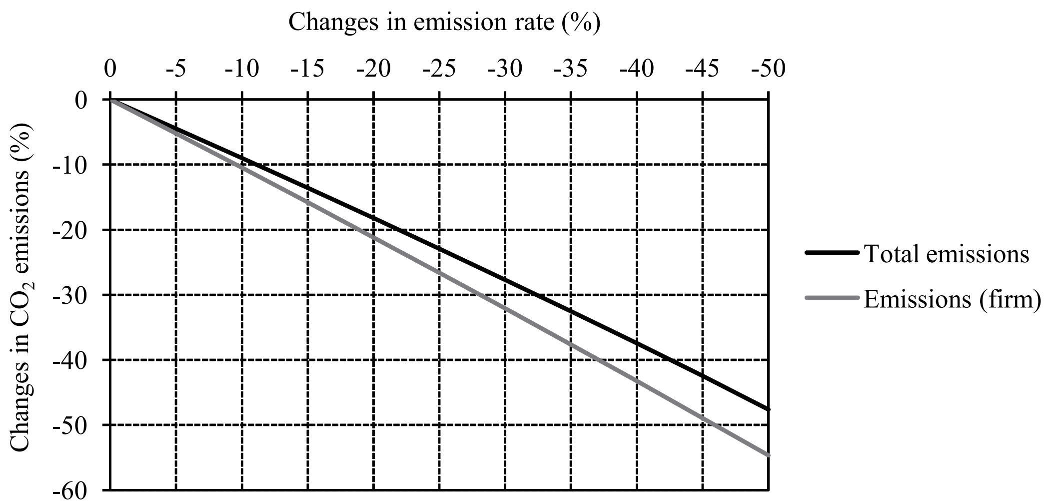

Figure 3: Changes in emission rate and CO_2 emissions

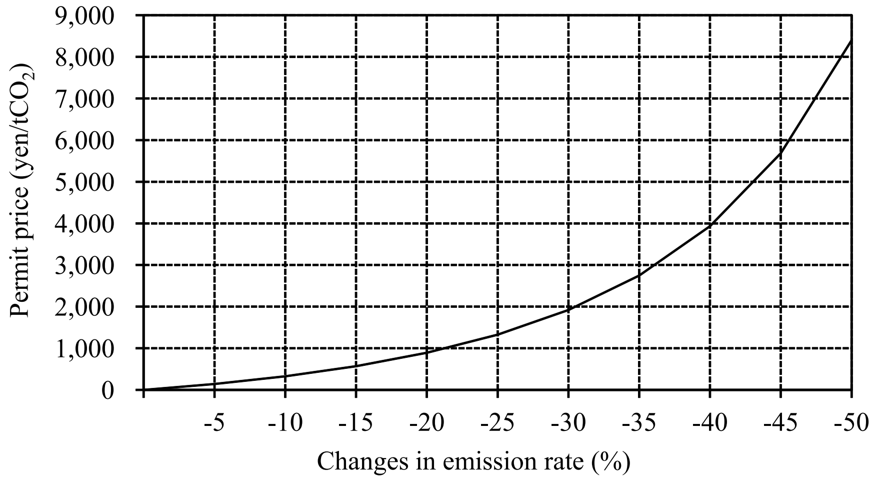

Figure 4: Changes in emission rate and permit price

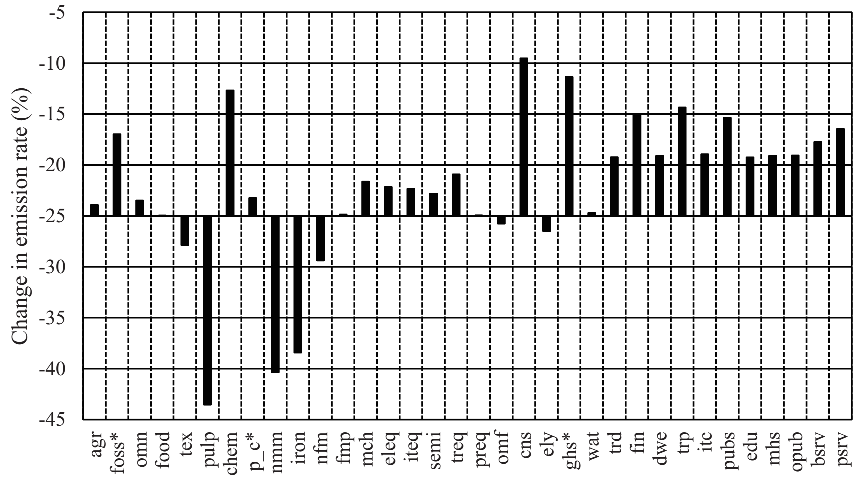

Figure 5: Changes in realized emission rates (−25% emission rate)

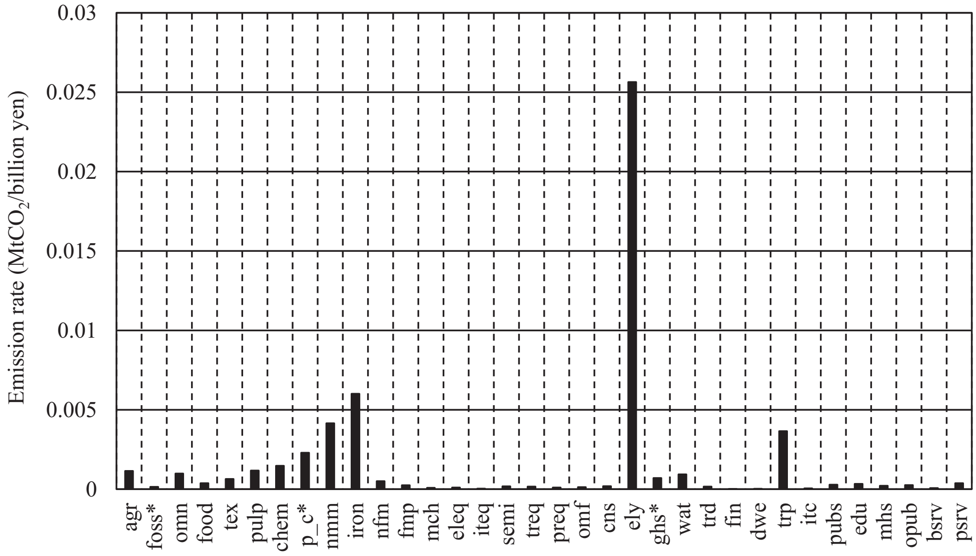

Figure 6: Initial emission rate

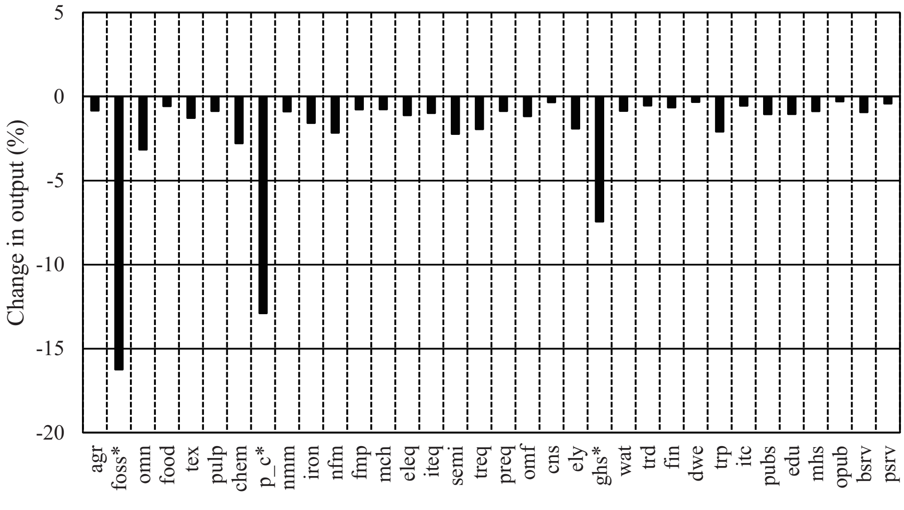

Figure 7: Changes in output under rate-based policy (−25% emission rate)

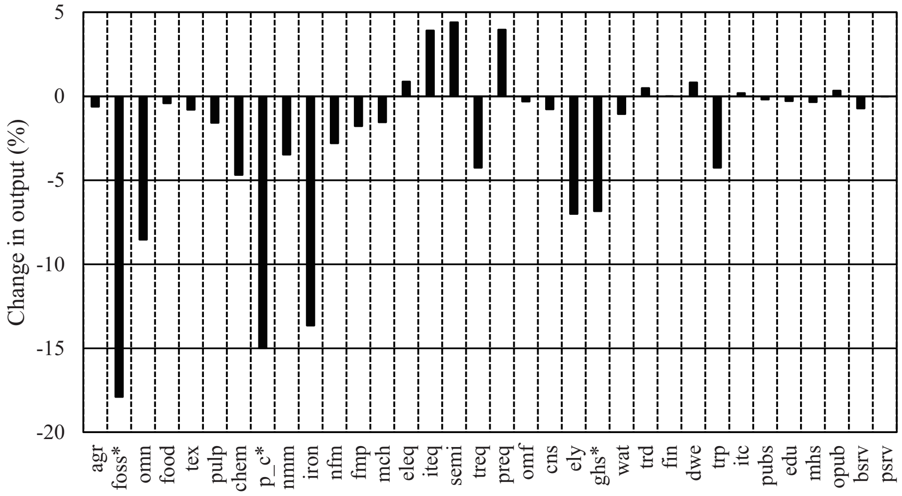

Figure 8: Changes in output under cap-and-trade policy (Emissions with a -25% emission rate)