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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 do not suppress economic growth. This study shows that in the short run, a rate-based policy reduce firms' emissions at a rate greater than that specified by the regulation. We also compared the rate-based policy with the cap-and-trade policy and found that the former leads to a greater reduction in the real GDP than the latter. Furthermore, the decrease in output is tend to be more evenly distributed under the rate-based policy than under with a cap-and-trade policy. Our results suggest that the rate-based policy is inferior in terms of efficiency but is favorable in terms of ensuring the burden of emission reduction is shared equally.

1 Introduction

Although global efforts toward climate change mitigation have been focused on total emission amounts, some countries have declared emission targets relative to their GDP. For example, China and India, who are likely to be major arbiters of global climate change in the next century, have set such targets. The Chinese government is targeting to reduce the carbon dioxide emissions as a proportion of GDP in 2020 by 40–45% compared to the proportion in 2005. India has a similar policy to bring down its carbon intensity in 2020 by 20–25% compared to that in 2005.

The effects of regulation linking emissions to output (herein referred to as the emission rate) has been analyzed mostly by theoretical approach (Helfand 1991; Fisher 2003; Boom and Dijkstra 2009; Holland 2012)[*3]. Findings from the existing literature suggest that a rate-based regulation is inferior due to an implicit output subsidy. Fischer (2003) shows that the total amount of emissions tends to increase with the 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 in the rate-based policy increases compared to that in the cap-and-trade policy in the short

[*3] An exception is Holland (2009) that examined the efficiency of California's Low Carbon Fuel Standard.

term and long term. While these studies suggest that a rate-based policy cannot restrict total emissions and does not suppress economic growth, the extent of such a policy's impact has not been scrutinized empirically and quantitatively.

This study investigates the impact of a rate-based policy in Japan, using computable general equilibrium (CGE) analysis. While Japan's current target for greenhouse gas emissions are based on the total emission amount, introducing a rate-based target similar to China and India is a topic of discussion. As it allows an increase in production, the introduction of a rate-based policy is preferred by industries and trade unions likely to be affected by regulation. A report by the Japanese Ministry of the Environment on the introduction of the domestic cap-and-trade policy also referred to the possibility of introducing a rate-based policy (Japanese Ministry of the Environment 2010).

The results of this study suggest that within the framework of static CGE analysis, the rate-based policy can reduce emissions from firms at a greater rate than that specified by the regulation. In addition, we show that the rate-based policy tends to reduce the production more evenly across sectors. In contrast, the cap-and-trade policy can increase the output of sectors that emit less carbon dioxide and thereby promote a structural shift in the economy.

The remainder of the paper is organized as follows. Section 2 introduces the model. Section 3 explains the data used and the method of calibration. Section 4 presents simulation results on the rate-based policy that attain a 25% reduction in the emission rate from the base case. Section 5 compares the rate-based policy and the cap-and-trade-policy. Section 6 presents our concluding remarks.

2 The Model

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. 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 1. The household determines its consumption of goods so as 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 owing 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 4. 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, the household consumption, and the current account deficit is determined, and hence the total amount of saving. The total amount of savings is spent on investment goods at a constant rate.

3 Data and calibration

We perform a CGE simulation using the benchmark data of the base year. In the present study, the data comprise economic data and emissions data.

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). In addition, we use data on government savings in "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 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 can obtain the parameters for the production function, utility function, saving rate, tax rate, income, and emissions coefficient.

As data in the social accounting matrix are only expressed in terms of the value added, 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 are take the value one in the base year. Numerical computation is done with GAMS (general algebraic modeling system) and its solver, PATH.

4 Impacts of the rate based policy

Using the CGE model, we analyze the characteristics of emission regulations by the rate-based policy. When emissions trading by the rate-based policy is introduced, the profit function of the representative firm in the sector is expressed as follows:

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

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. We assume that emission regulations are imposed only on firms and not on the household. This is realistic since it is costly to allocate emission permits to households and allow them to trade. The 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 must 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 must be a seller of permits. Under the rate-based policy, the price of permits is determined by the demand and supply for emission permits, as:

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

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 so as to satisfy this equation. In the rate-based policy simulation, the business-as-usual (BaU) emission rate is calculated by dividing the BaU emissions by the BaU output. A rate-based policy is expressed by multiplying the BaU emission rate by a factor less than one. For example, a rate-based policy that requires a 10% reduction in the emission rate is expressed by multiplying the BaU emission rate by 0.9. This means that the firm must reduce emissions by 10% from the BaU emissions when it maintains its output at the BaU level.

Table 2 shows the results of a simulation for a 25% reduction in the emission rate. Note that the policy requires a 25% reduction from the BaU emission rate. Since the BaU data is of the Japanese economy in 2005, it means that the reference of the policy is emissions and output in 2005. After a 25% reduction in the emission rate, emissions from firms are reduced by more than 25%, with the actual value being −26.6%. Because the rate-based policy in this simulation is imposed only on firms, the emission reduction from the household is small at 0.59%. As a result, the total emission of carbon dioxide is reduced by 22.9%.

The total supply of emission permits is $\sum_i \alpha_i x_i$. By requiring α_i to be reduced by 25%, the output also becomes lower than the BaU output, and the emission is reduced by 26.6%, by more than the reduction required by the rate-based policy. Even though it seems the rate-based policy allows firms to increase emissions and output, it is not possible in the short run. Because capital and labor is limited, the economy does not grow beyond the BaU. Thus, emissions from firms is reduced by 26.6%, by more than the required reduction in emission rate (25%) by the rate-based policy in this analysis.

We can confirm that this result is robust to required emission rate. Figure 3 shows the impact of requiring lower emission rate on total emissions and firms' emissions of carbon dioxide. By requiring lower emission rate, total emissions and firms' emissions are reduced. Emissions from firms is always reduced by larger percentage than the required reduction in emission rate. The impact of requiring lower emission rate on the permits 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 with 25% reduction in emission rate. Although the total reduction in emission rate is 25%, the reduction in emission rate is different among sectors. 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`). It suggests that marginal cost of reducing the emission rate is relatively lower in these sectors.

5 Comparison of the cap-and-trade policy and the rate-based 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 by 25% from 1990 levels. There are some differences regarding to the settings of policy between this section and the previous section. The reference year of policies examined in this section is 1990, while that in the previous section is 2005. Policies in this section is targeting at total amount of emission, while that in the previous section is focusing on the emission rate of firms. We assume that regulations of emissions are imposed only on firms and not on the household in both policies.

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

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

We assume that emission permits are supplied by the government by auction and the household receives the revenue. In the cap-and-trade policy, permits price P_{CO_2} is determined by the demand and supply of emission permits as 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. In order to achieve the same target of total emissions, the real GDP under the rate-based policy is lower by 0.1% than that under the cap-and-trade policy. This means that the rate-based policy is inefficient. The permits price and the marginal abatement cost are higher in the rate-based policy than the cap-and-trade policy. Regardless the target in this section is the total emissions, the rate-based policy is focusing on the emission rate. Since the rate-based policy is a mixture of policies on emissions and output, it induces inefficient allocation of resources to attain the total emission target.

The reduction of emissions by 25% compared to the 1990 levels means the reduction by 28.8% compared to the 2005 levels. Total emissions from firms and the household are regulated to be 28.8% lower than the 2005 levels. Emissions from firms are reduced by 32.9% with the cap-and-trade policy and by 33.4% with the rate-based policy. Emissions from the household are reduced by 4.6% with the cap-and-trade policy and by 1.1% with the rate-based policy. Although the household are not required to reduce the emissions, their emissions are reduced because of the reduction in consumption due to the reduction in output of firms.

Figure 6 and Figure 7 show the changes in output for each sector, under the cap-and-trade policy and the rate-based policy. Under the both policies, output of three sectors that produce energy goods are significantly affected negatively: crude petroleum, coking coal, and natural gas (`foss`), petroleum and coal products (`p_c`), and gas and heat supply (`ghs`). On the other hand, output of iron and steel (`iron`) and electricity (`ely`) is reduced significantly with the cap-and-trade policy while modestly with the rate-based policy. In the rate-based policy, sectors with large outputs, 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 drop in output is small. Thus, these sectors does not significantly reduce output in the rate-based policy.

Reductions in output are more evenly distributed among sectors with the rate-based policy than that with the cap-and-trade policy. Comparing Figure 6 and Figure 7, it is apparent that the decrease in output with the rate-based policy is smaller than that in the cap-and-trade policy. This can be understood by arranging the equation (1) as:

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

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

There are three sectors that 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 effect.

We can summarize our result as follows. There is a tendency that the decrease in output is more evenly distributed in the rate-based policy compared with the cap-and-trade policy. Regarding to the sectors with lower emission of carbon dioxide (`iteq`, `semi`, and `preq`), output is increased with the cap-and-trade policy while it decreases with the rate-based policy. Since the rate-based policy aims to reduce emissions by setting the emission rate, there is an inefficiency in emission reduction. 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.

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 result in the case of a 25% reduction of the emission rate. From this table, we can see that the emissions fall by more than 25% regardless of the value of σ_E. 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 the production becomes more efficient.

Table 5 show the comparison of the cap-and-trade policy and the rate-based policy when σ_E changes. 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 larger σ_E. This is the same result as that 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 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 that the reduction of the emission rate and the output occur 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 the rate-based policy with the 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 due to the fact that 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 sector with higher BaU emission rate even though their emissions are large and has lower marginal abatement cost. In contrast, the cap-and-trade policy forces a significant emission reduction for the sector which has a low marginal abatement cost. Our result suggest that the rate-based policy is inferior in terms of efficiency, but favored in terms of equality of burden sharing among sectors.

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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%	−0.59%	1,327 yen	−0.45%

Note: Comparison with the actuals of 2005.

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

	Emissions (firm)	Emissions (household)	Permits price	Real GDP
Cap-and-trade	−32.9%	−4.6%	1,434 yen	−0.64%
Rate-based	−33.4%	−1.1%	2,096 yen	−0.74%

Note: GDP is change from BaU. Emissions is reduced 25% from 1990 level.

Table 4: Sensitivity analysis: −25% emission rate

Elasticity of substitution	$\sigma_E = 0.3$	$\sigma_E = 0.5$	$\sigma_E = 0.7$
Emissions (firm)	−27.6%	−26.6%	−26.3%
Real GDP	−0.84%	−0.45%	−0.34%

Note: Comparison with the actuals of 2005.

Table 5: Sensitivity analysis: comparison of policies

	Cap-and-trade policy			Rate-based policy		
	$\sigma_E = 0.3$	$\sigma_E = 0.5$	$\sigma_E = 0.7$	$\sigma_E = 0.3$	$\sigma_E = 0.5$	$\sigma_E = 0.7$
Real GDP	−0.89%	−0.64%	−0.52%	−1.35%	−0.74%	−0.54%
Permits price	2,659 yen	1,434 yen	943 yen	6,020 yen	2,096 yen	1,202 yen

Note: GDP is change from BaU. Emissions is reduced 25% from 1990 level.

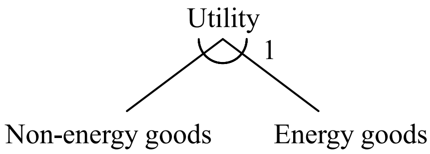

Figure 1: Consumption structure

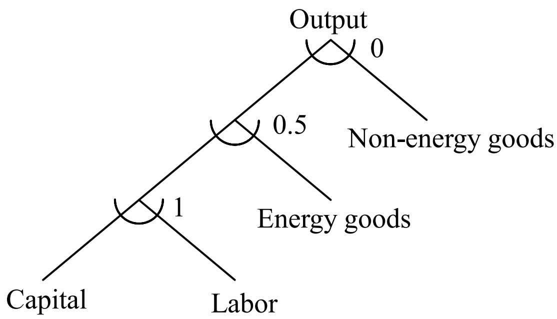

Figure 2: Production structure

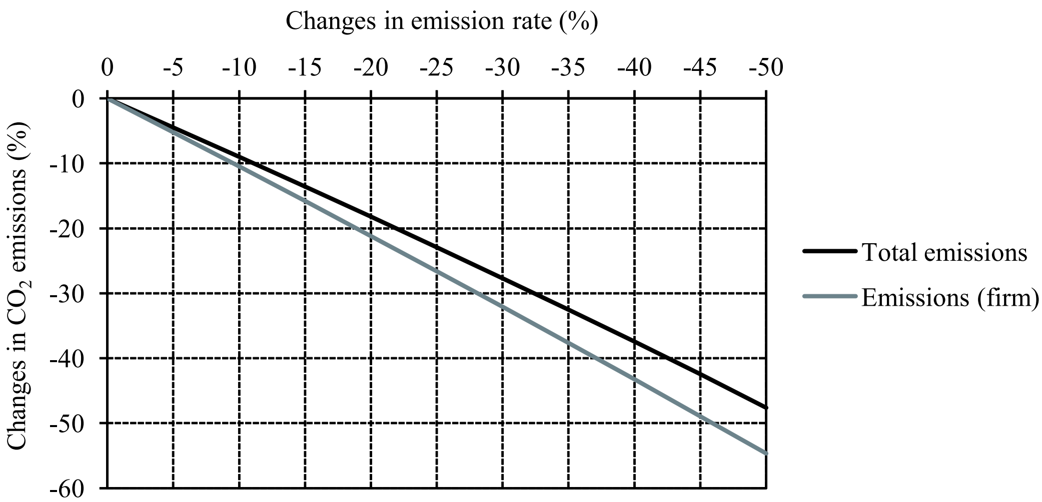

Figure 3: Changes in emission rate and CO_2 emissions

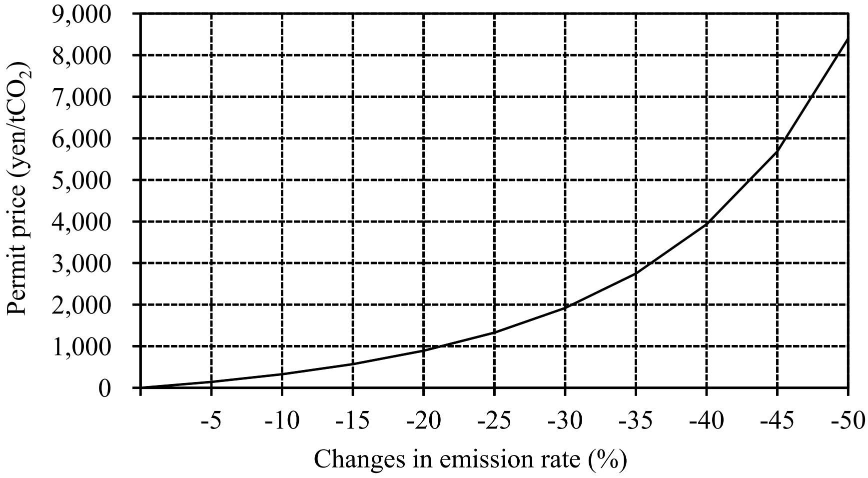

Figure 4: Changes in emission rate and permit price

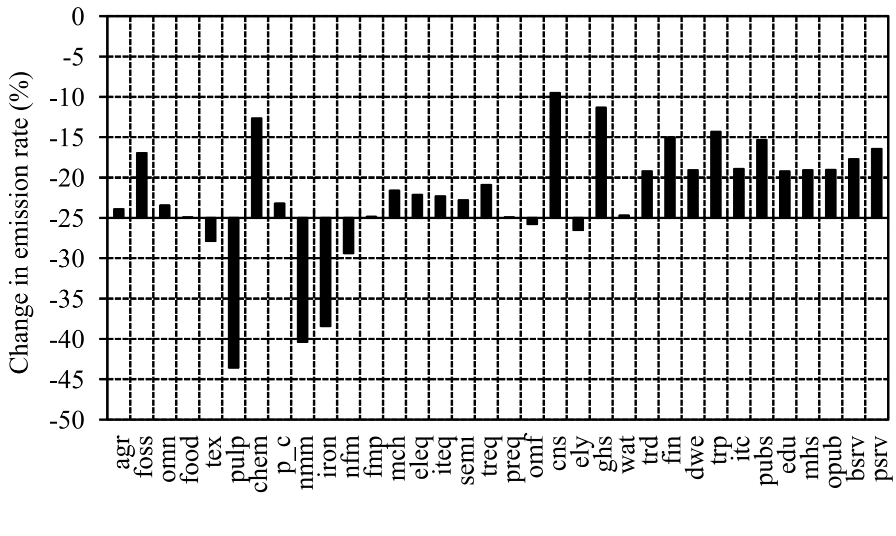

Figure 5: Changes in realized emission rates (−25% emission rate)

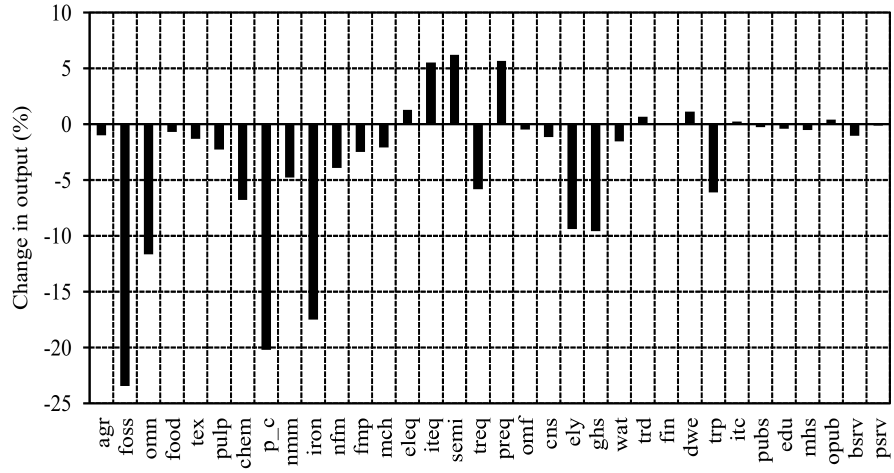

Figure 6: Changes in output under cap-and-trade policy (−25% total emissions)

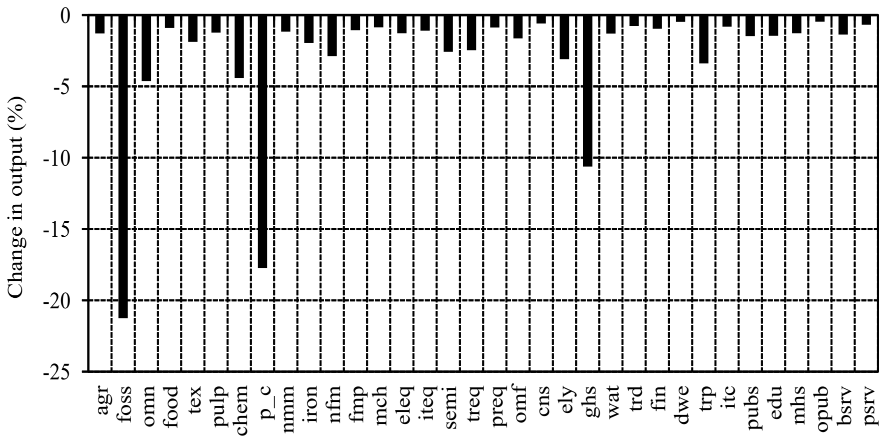

Figure 7: Changes in output under rate-based policy (−25% total emissions)