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Evaluation of Carbon Abatement Policies with Assistance to Carbon-Intensive Industries in Japan

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Abstract

The Japanese government is obliged to immediately introduce a national CO₂ abatement policy to comply with the Kyoto Protocol. However, opposition from carbon-intensive industries would delay the introduction of an abatement policy because it would place a large burden on them. Therefore, various assistance programs to reduce the cost burden on carbon-intensive industries are required. However, such programs may increase economy-wide abatement costs. In this paper, we focus on three forms of abatement policies: carbon tax exemptions; the refund of carbon taxes; and grandfathering emission permits. By using an original multi sectoral computable general equilibrium model of Japan, we investigate the possibility of limiting the negative impacts on carbon-intensive industries and reducing the adverse effects on carbon prices and social welfare. Our results indicate that assistance to carbon-intensive industries would raise marginal abatement costs by between 45% and 66%. We suggest that granting grandfathering emission permits is the most cost efficient and effective program for mitigating the effects on carbon-intensive industries. In addition, our results imply that, relative to having 50% exemptions, implementing two assistance programs under which economy-wide marginal CO₂ abatement costs are equal is more efficient and can substantially reduce the adverse impacts on the prices of carbon-intensive goods.

Key words: Carbon-intensive industries, carbon tax, emission trading, CGE model.

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概要

現在、京都議定書の遵守のための国内制度の整備が急がれている。費用効率的な排出削減を行うための有効な政策手段として、炭素税や排出権取引制度などが検討されてきた。しかし、制度の導入そのものは、産業界、とりわけ鉄鋼や電力の炭素集約産業の根強い反対によって先送りされてきた。炭素税や排出量取引制度は、CO₂ 排出に対して費用負担を求めることで排出削減を誘引する制度であり、日本全体としての削減費用が最小となるような削減量の個別配分が達成されるものである。しかし問題は、CO₂ 排出に対して一律の費用負担を求めると、炭素集約産業に削減費用負担が集中してしまうことにあり、このことが産業界の制度導入に反対する理由となっている。かといって、こうした産業に対して税率軽減などの負担軽減措置を設定することは、日本全体としての費用効率性を損ない、国民の負担増を招く可能性がある。そこで本稿では炭素集約産業への負担軽減をともなう CO₂ 排出削減制度の導入によって、日本全体としての排出削減費用や GDP、個別産業の生産活動、家計の消費活動にどのような影響が及ぶのかを、CGE モデルによって定量的に示した。検討対象とする制度は、炭素税率の差別化・炭素税の負担に応じた還付・無償配布型の排出量取引制度の3種類とした。分析の結果から、炭素集約産業への負担軽減をともなう措置によって、全体としての限界削減費用は45－60%程度増加することが示された。また、炭素集約産業への負担軽減の効果が大きく、費用効率的な削減制度は、無償配布型の排出量取引制度であることが示された。炭素集約産業に対し50%の炭素税率軽減を行う炭素税制度に比べて、無償配布型排出量取引制度下で削減費用が抑えられる理由は、限界削減費用が均等化されていることにあると考えられる。

注)本稿は、同著者による『炭素集約産業の負担軽減をともなう国内排出削減政策』(計画行政, 第31巻2号, pp.72-78, 2008年)のフルバージョンの論文であり、非日本人研究者への配布を目的とするものである。

1. Introduction

The first period of the Kyoto Protocol begins in 2008. However, as yet, Japan has no policy for meeting its Kyoto targets. Implementing a CO₂ abatement policy is difficult because of strong opposition from Nippon Keidanren (the Japan Business Federation). This is because a CO₂ abatement policy will increase their production costs, particularly for carbon-intensive industries. Table 1 shows the effects of abatement policy on the Japanese economy predicted by a number of models. This table shows that the CO₂ reductions required to meet the Kyoto target would cost the Japanese economy between 5,300 and 45,000 yen per ton of carbon (t-C). These abatement costs would mainly be borne by large emitters such as the electricity, transport, iron and steel and clay industries, as is shown in Figure 1. Therefore, it will be difficult to get these industries to support a CO₂ abatement policy.

Nippon Keidanren has a great deal of political power, and carbon-intensive industries have a big influence within this federation. The group published the Voluntary Action Plan on the Environment in 1997.¹ Under this plan, industries set their respective achievable environmental targets for reductions of emission amounts, levels of environmental investment, carbon intensity levels, and so on. The group's own assessment of its plan indicates that industries have succeeded in achieving their environmental targets.² However, the problem is that their original targets, even if fulfilled, are not sufficient to achieve Japan's Kyoto target. Moreover, the industries have adopted their own approaches to reducing CO₂ emissions instead of adopting government controls. Hence, they developed their own plan before the government developed its emission abatement policies. Although their efforts should be commended and their achievements acknowledged, their actions are a diversion and hinder the introduction of an emissions reduction policy in Japan.

Therefore, given the desirability of a CO₂ abatement policy, it is necessary for the Japanese government to design a policy that at least mitigates the negative impacts on carbon-intensive industries. It is suggested that if assistance programs for carbon-intensive industries, such as

¹ Nippon Keidanren (1997).

² Nippon Keidanren (2006).

exemptions and the refund of carbon taxes, were introduced, a CO₂ abatement policy could be implemented immediately. These programs may increase economy-wide abatement costs because assisting carbon-intensive industries increases the burden on other industries and incurs more welfare costs than would the introduction of a uniform carbon tax. However, such programs may be reasonable because workers in carbon-intensive industries have the right to be protected from salary cuts and unemployment, for example. The best and fairest way for Japan to achieve the Kyoto target would be to implement a uniform carbon tax or to auction emission permits. However, considering the distribution of emission abatement costs among agents, it would be difficult to identify what is fair for whom, particularly in the short term. This is the motivation for our research. Our main purpose is to determine the additional costs of assistance programs. In this way, given time to adapt over the long term, assisted industries could be persuaded to support abatement programs that are more cost effective than those implemented as a first step.

There are few quantitative studies of the effect of assistance programs for carbon-intensive industries in Japan. However, many studies have been conducted for European countries and the U.S. Boehringer and Rutherford (1996) analyze carbon tax exemptions for energy intensive industries and export industries in Germany. They conclude that tax exemptions limit the range of emission abatement and raise marginal abatement costs in the German economy. Jensen (1998) quantifies the distortions caused by tax exemptions and the initial allocation of emission permits, which amounts to a production subsidy, by using a computable general equilibrium (CGE) model of the Danish economy. For tax exemptions, he shows that a 20% abatement target causes a welfare loss of 1.9%. He also shows that marginal abatement costs are lower under tax exemptions. However, distortions are more significant under tax exemptions than under free allocation of emission permits based on past emission levels (grandfathering). Jensen and Rasmussen (2000) analyze the effects of the initial allocation of emission permits and the recycling of permit revenues. They find that the free allocation of permits raises wages, which increases total production costs. By using a CGE model of the U.S., Goulder (2002) analyzes compensation and the effects of recycling carbon tax revenue. He

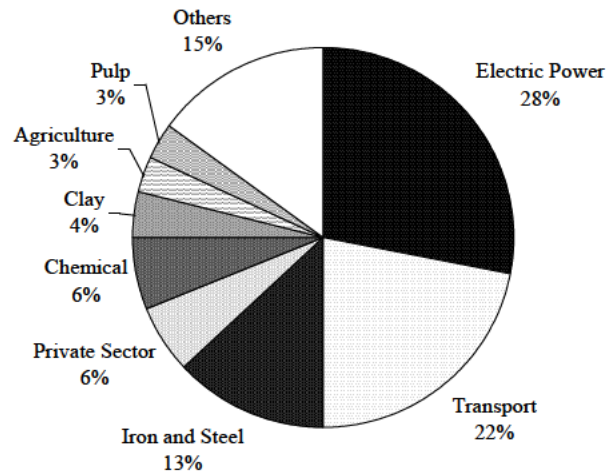
Table 1. The Effects of CO₂ Abatement Policy Predicted by Existing Studies

	Abatement rate (%) *	Carbon price (Yen/t-C)	GDP (%)**	Model
Okagawa and Hamasaki (2005)	22	13,212***	-0.36	GTAP-E
Our study	13	18,722	-1.71	yet unnamed
	20	35,431	-1.28	yet unnamed
Ministry of Environment (2001)				
AIM Enduse	17	30,000	NA	AIM Enduse
GDMEEM	18	34,560	-0.72	GDMEEM
MARIA	20	13,148	-0.40	MARIA
SGM	21	20,424	-0.30	SGM
AIM/Material	17	15,587	-0.54	AIM/Material
Ministry of Environment (2003)	10	45,000	-0.16	AIM Enduse
Park (2002)	20	14,100	-1.00	yet unnamed
Park (2004)	16	5,332***	-0.33	GTAP-E
Washida (2004)	14	20,000	NA	EPAM
Hamasaki and Truong (2000)	22	9,012***	NA	GTAP-E

* Abatement by 1990 level in 2008; ** % change from the business-as-usual case; *** 1US\$ = 120 yen.

Note: All results except those of Park (2002) are based on normal carbon taxes. Park (2002) shows results for labor tax reductions.

Figure 1. CO₂ Emission Shares in 2000



Data Source: National Institute for Environmental Studies, 'The GHGs Emissions Data of Japan (2004)'.

investigates policies designed to achieve equity-value neutrality. To maintain constant equity values following the introduction of industry-specific corporate tax credits, around 13% of permits must be allocated freely. Fischer and Fox (2004) quantify the impact of the output-based allocation of emissions permits on industries in the U.S. Although they find that auctioning that incorporates revenue recycling is better for the aggregate economy, historical output-based allocation is the most effective way of mitigating the negative impacts on energy intensive sectors and of carbon leakage.

These studies indicate that emission reduction policies that incorporate assistance for particular industries raise marginal abatement costs and social welfare costs. Furthermore, most of them show that the policies under which marginal abatement costs are not uniform lower social welfare by more than do policies under which these costs are uniform.

We focus on three forms of program; 50% exemptions; carbon tax refunds; and the grandfathering allocation of emission permits. We quantify the impacts of these programs by using a multisectoral CGE model of Japan. Our results show that refunding carbon tax and grandfathering emission permits mitigate the adverse impacts on carbon-intensive industries by more than does

granting 50% exemptions. This is consistent with the results of previous studies. However, in the case of carbon tax refunds, social welfare costs and the rate of carbon tax required to achieve the Kyoto target are relatively sensitive to the abatement rate and the parameters of our model. This is because carbon tax refunds generate large distortions.

In Section 2, we describe three policies that provide assistance to carbon-intensive industries. In Section 3, we provide an overview of our CGE model. In Section 4, we describe simulation scenarios and report our results. In the final section, we offer concluding remarks.

2. Assistance programs

The objective of Japan's CO₂ abatement policy is to reduce CO₂ emissions to 2.1% below the 1990 level to meet the Kyoto target. We focus on two types of assistance program. The first type involves using the scarcity rent caused by emission constraints. The second grants exemptions from carbon tax.

2.1 Using the scarcity rent

Total emissions are given by equation (1) below. The relationship between CO₂ emissions and the price of emissions is represented by a complementarity problem, which is given by equation (2). In these expressions, CO₂, $\overline{CO_2}$, and P_{CO₂} denote CO₂ emissions, the target for CO₂ emission reductions, and the shadow price of the constraint on CO₂ emissions, which represents the carbon price, respectively.

$$CO_2 = \sum_{industry} CO_2(industry) + CO_2(household) + CO_2(government) \quad (1)$$

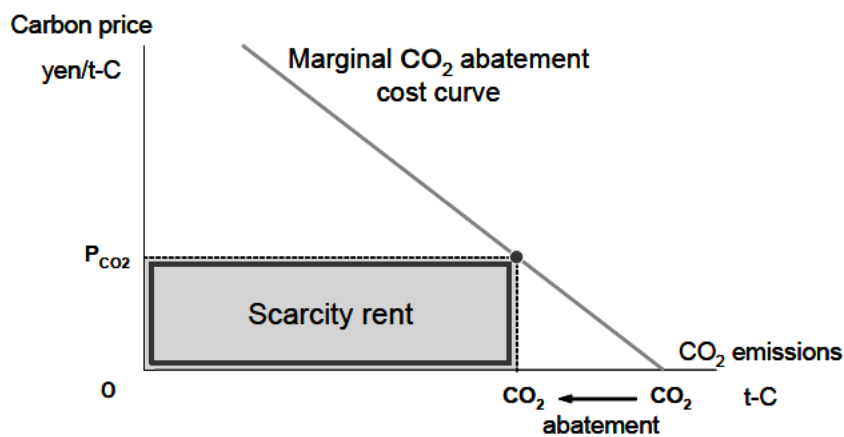
$$P_{CO_2}(CO_2 - \overline{CO_2}) \leq 0$$

$$\begin{cases} \text{CO}_2 - \overline{\text{CO}_2} < 0 & P_{\text{CO}_2} = 0 \\ \text{CO}_2 - \overline{\text{CO}_2} = 0 & P_{\text{CO}_2} > 0 \end{cases} \quad (2)$$

Unless CO₂ emissions are restricted, CO₂ emissions are free goods and the carbon price P_{CO₂} is zero. If CO₂ emissions are limited by a CO₂ abatement policy, P_{CO₂} is positive; this price is the cost of each additional unit of emissions. The marginal benefits of additional emissions equal their marginal costs at the emission level $\overline{\text{CO}_2}$.

Restricting CO₂ emissions induces a scarcity rent of $P_{\text{CO}_2} \times \overline{\text{CO}_2}$, which is represented by the trapezoid in Figure 2. Although carbon tax policies and emission permit trading policies are based on different systems, both can exploit the scarcity rent to assist carbon-intensive industries. Under a carbon tax policy, the government collects carbon tax revenue of P_{CO₂} per unit of CO₂ emissions to achieve the emission reduction target $\overline{\text{CO}_2}$; total carbon tax revenue is $P_{\text{CO}_2} \times \overline{\text{CO}_2}$. Revenue is the same when the government implements an auctioned emission permit policy, under which it issues emission permits worth $\overline{\text{CO}_2}$. Under a grandfathering emission permit policy, to provide an incentive for emissions to be abated to a level of $\overline{\text{CO}_2}$, the government imposes an opportunity cost

Figure 2. Potential Revenue from Carbon Tax



Note: The Japanese government can assist carbon-intensive industries by using the scarcity rent that is generated by restricting CO₂ emissions.

of P_{CO_2} per additional unit of CO_2 emissions. Under this policy, energy intensive industries bear a uniform marginal cost of P_{CO_2} , and receive assistance through the allocation of the scarcity rent.³ We analyze two examples of this type of program below.⁴

(1) The refund of carbon tax

The government imposes a uniform carbon tax on all agents, and refunds it to particular industries. Under this policy, all firms have the same incentive to substitute less carbon-intensive fuels for carbon-intensive fuels because all firms pay the same carbon price.

(2) Grandfathering

The government introduces an emission trading system and grants to carbon-intensive industries emission permits in proportion to their emissions shares in the benchmark year. This means that industries receive scarcity rents at no cost through the initial permit allocation. Under this policy, all firms have the same incentive to reduce emissions. This is because the allocated permits are tradable at the market price.

2.2 Tax exemptions

Carbon tax exemption (or reducing the carbon tax rate) is another effective way of assisting energy intensive industries. The mechanism underlying this policy differs from those described above. Under this policy, energy intensive industries pay a lower carbon tax rate than do other industries. Therefore, to meet a given target, nonexempted industries (NEIs) bear a greater tax burden than do exempted industries (EIs) in terms of the marginal costs of additional emissions. The

³ However, the issue of how the government secures revenue sources for subsidies is controversial.

⁴ Although subsidies are an important source of assistance to energy intensive industries, we ignore this policy in this paper for two reasons. First, carbon tax or emission trading is considered to be the main way of achieving the Kyoto target; the subsidy system is supplementary. It is difficult to secure revenue from subsidies to reduce CO_2 emissions sufficiently. Second, it is difficult to deal with subsidies in our top-down CGE model.

relationship between CO₂ emissions and their prices for exempted and nonexempted industries are represented by the complementarity problems expressed by equations (3) and (4) below.

$$P_{CO_2}^E (CO_2^E - \overline{CO_2^E}) \leq 0$$

$$\begin{cases} CO_2^E - \overline{CO_2^E} < 0 & P_{CO_2}^E = 0 \\ CO_2^E - \overline{CO_2^E} = 0 & P_{CO_2}^E > 0 \end{cases} \quad (3)$$

$$P_{CO_2}^{NE} (CO_2^{NE} - \overline{CO_2^{NE}}) \leq 0$$

$$\begin{cases} CO_2^{NE} - \overline{CO_2^{NE}} < 0 & P_{CO_2}^{NE} = 0 \\ CO_2^{NE} - \overline{CO_2^{NE}} = 0 & P_{CO_2}^{NE} > 0 \end{cases} \quad (4)$$

$$\overline{CO_2^E} + \overline{CO_2^{NE}} \leq \overline{CO_2} \quad (5)$$

Under this policy, some industries pay lower carbon tax rates than do other industries. To achieve the 13% abatement target met by the aggregate economy, nonexempted agents must generate greater abatement because emission reductions by energy intensive industries are relatively small. Hence, the program introduces a distortion.

When simulating the free allocation of emission permits in a CGE model, one must incorporate the scarcity rent into the appropriate part of the model. For example, Goulder (2002) considers the free allocation of emission permits to be equivalent to granting tax exemptions. Jensen and Rasmussen (2000) consider the grandfathering policy to be equivalent to making lump-sum transfers to households (who own firms) because, in their dynamic framework, future behavior does not affect permit allocations.

Following Jensen (1998), we deal with free allocations of emission permits by using output subsidies differentiated between industries in our CGE model. We do this for two reasons. First, the carbon price is unique when there is a free allocation of permits under grandfathering, but not when there are exemptions. Second, free allocations would reduce average production costs in each

industry, and we cannot identify the owners of energy intensive firms because there is only one representative household in our model.

Thus, the grandfathering policy is similar to the carbon tax refund policy. Industries have incentives to increase their output levels to obtain higher scarcity rents under both policies.⁵ However, under the grandfathering policy, incentives to increase output levels are restricted by the benchmark emissions. When there are tax refunds, incentives are less limited. Thus, some industries could get as much output subsidy as they wish. Hence, carbon tax refunds are more likely to induce distortions.

3. The model

3.1 The model structure

In this section, we provide an overview of our static CGE model. The model is developed for convenience, but incorporates energy substitutions. The three agents in the model are industries, the representative household, and the government.

3.1.1 Production

Industries produce goods and services by using primary factors and intermediate inputs. Production processes exhibit constant returns to scale and are represented by nested CES functions following the GREEN model.⁶ Our model incorporates energy substitutions. Figures 2 and 3 show the nesting structures for the production of all goods. Table 2 shows the elasticities of substitution. Firms select each input level to minimize the production cost given the output level. The goods and services produced by domestic industries are purchased as intermediate inputs by industries and as final goods by the household, the government, and foreign countries. We aggregated the input–output table to 33 industries. There are seven energy industries and 26 nonenergy industries.

⁵ This topic is discussed by Fischer and Fox (2004).

⁶ OECD (1994).

Figure 3. The Model Structure

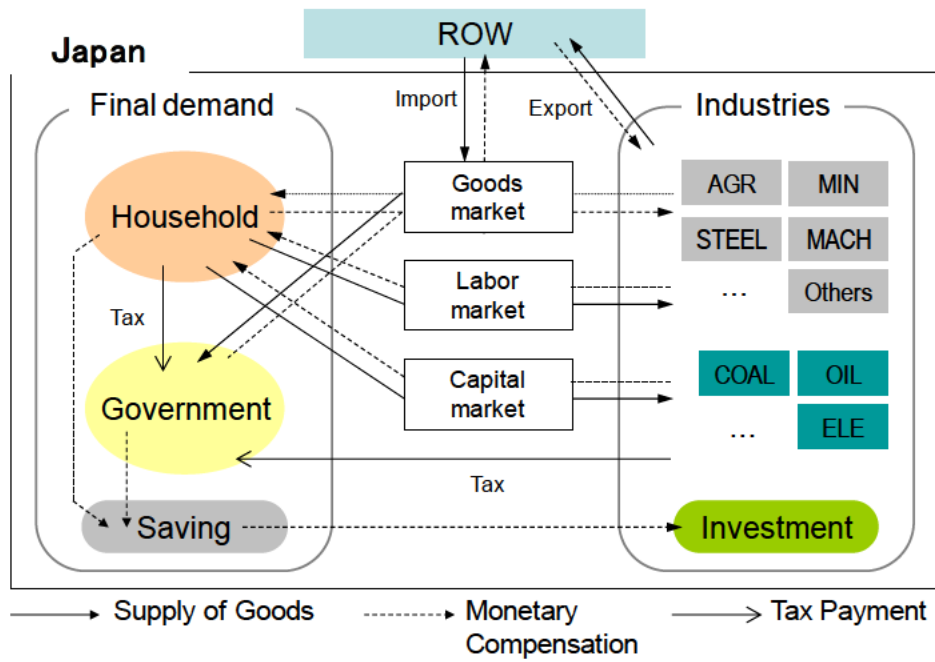


Table 2. Industries

Fossil fuel	Manufacturing		Services	
Coal	Agriculture	<i>Iron and steel</i>	Construction	Telecoms
Oil	Mining	Metal products	Water	Public services
Gas	Foods	Machinery	Waste	Private services
<i>Coal products</i>	Textiles	Electrical machinery	Commerce	Business services
Oil products	Pulp	Transport equipment	Financial services	Other
Gas distribution	Chemicals	<i>Recycling</i>	Real estate	
<i>Electric power</i>	<i>Clay</i>	Other manufacturing	<i>Transportation</i>	

Note: The six industries written in italics are carbon intensive.

3.1.2 The household

As shown in Figure 4, the representative household has a Cobb–Douglas utility function that implies a trade-off between leisure and consumption. The household owns factors of production, and uses its factor income to purchase goods and services from domestic industries and foreign countries to maximize utility. The 12 hours of the day not spent working constitutes leisure. The price of leisure is defined as the opportunity cost of labor supply. Household savings are exogenous.

3.1.3 The government

The government collects labor taxes, capital taxes, excise taxes, import taxes, and carbon taxes from industries and the household. The government purchases goods and services to maximize a Cobb–Douglas utility function. Government savings are exogenous.

3.1.4 Factor markets

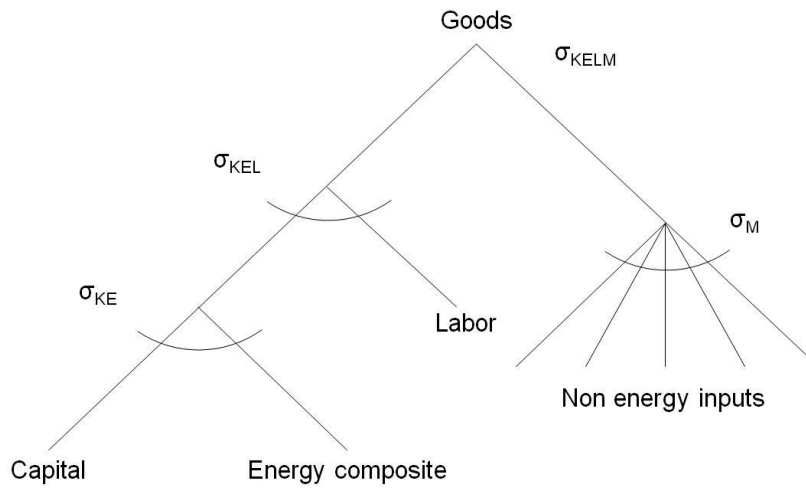
Primary factors include labor and capital, which are used in conjunction with energy goods and nonenergy intermediate goods to produce domestic goods. Having been determined by a choice between labor and leisure, labor supply depends on real wages. The level of capital is constant and the rate of return on capital is endogenous. We assume that both labor and capital markets are perfectly competitive, and that both factors are perfectly mobile between sectors.

3.1.5 International trade

Our model is an open economy model. Imports and exports are endogenously determined by domestic goods and services prices relative to world prices. Foreign countries are treated as one region termed the ‘rest of the world. World goods and services prices are constant. We use the Armington assumption for explaining trade in identical goods and services.⁷ This means that domestic goods and foreign goods are imperfect substitutes. The exchange rate adjusts to balance the current account.

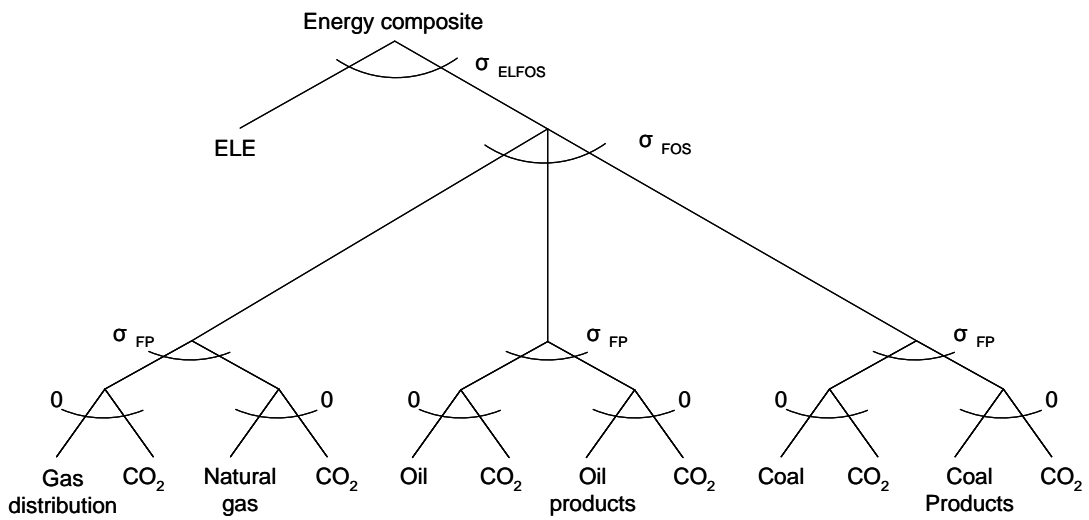
⁷ Armington (1969)

Figure 4. The Production Structure



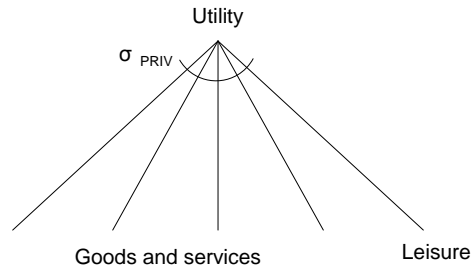
Sigmas stand for substitution elasticities between inputs.

Figure 5. The Production Structure (Energy Composite)



Sigmas stand for substitution elasticities between inputs.

Figure 6. Household Welfare Functions



Sigmams stand for substitution elasticities between goods and services.

3.1.6 CO₂ abatement and marginal abatement costs

As shown in Figure 3, we assume that CO₂ emissions are proportional to fossil fuel inputs in each industry. This means that demand for fossil fuels is synonymous with demand for CO₂ emissions. By restricting CO₂ emissions, the household, industries, and the government incur emission costs when using fossil fuel inputs. These additional emission costs are collected by the government in the form of carbon tax revenues.

In our model, CO₂ abatement is essentially achieved through three types of substitution.⁸ When the introduction of a carbon tax raises energy costs, agents substitute less CO₂ intensive fuels, such as natural gas, for CO₂ intensive fuels such as coal. (This represents interfuel substitution.) Agents also substitute energy-composites goods for capital and labor. (This represents interfactor substitution.) Depending on CO₂ intensity, rises in the relative prices of CO₂ intensive goods and services lower the relative demand for CO₂ intensive goods. (This represents intergoods substitution.)

3.2 The software and database

We constructed our model by using GAMS/MPSGE. The database used is the input–output table for 2000,⁹ which is the most recent one. To calculate the CO₂ emissions coefficient, we used the Energy Balance table and ‘Energy and the GHGs Emissions Data of Japan’.^{10, 11}

⁸ If it is impossible to reduce CO₂ sufficiently by using substitutions, the economy would contract.

⁹ Ministry of Internal Affairs and Communications. 2000 Input-Output Tables for Japan

Japan's Kyoto target is to reduce CO₂ emissions to 2.1% below the 1990 level, taking into account carbon sinks. According to 'Outlook on Energy Demand and Supply in 2030', Japan's total CO₂ emissions were 286 million t-C in 1990,¹² and are expected to increase by 322 million t-C in 2010. This implies that Japan has to reduce CO₂ emissions to 13% below the 2010 level.

Table 3. Elasticities of Substitution

Index		Notes
σ_{KEL-M}	0.0	–
σ_M	0.2	–
σ_{KE-L}	0.8	–
σ_{K-E}	0.2	0.1 in Electricity, Clay, Iron and steel, Transport
σ_{EL-FOS}	0.2	0.1 in Clay, Iron and steel, Transport
σ_{FOS}	0.5	0.1 in Electricity, Clay, Iron and steel, Transport
σ_{F-P}	0.0	–
σ_{PRIV}	1.0	(Cobb–Douglas utility function of the household)
σ_{DM}	0.4	0.1 between fossil fuels (Armington)

¹⁰ Agency for Natural Resources and Energy.

¹¹ National Institute for Environmental Studies.

¹² Agency for Natural Resources and Energy (2005).

4. Scenarios and results

4.1 Simulation scenarios

The objective on which of all the simulations are based is to reduce emissions by 13% to meet the Kyoto target. The government puts carbon tax on the combustion of all fossil fuels in proportion to their carbon content. We simulated four different policy experiments to analyze the policies outlined in Section 2.

4.1.1 Lump-sum transfers to households

Under this scenario, there is no assistance case to carbon-intensive industries, and thus it is the reference case. The government puts a uniform carbon tax on all industries and households. Carbon tax revenues are transferred to households in the form of a lump sum. The carbon tax raises marginal production costs and output prices relative to household income. However, under this policy, private-sector demand might not fall significantly.

4.1.2 Government revenue

The government puts a uniform carbon tax on all industries and households, and spends the revenues on government consumption. In this case, there is no assistance.

4.1.3 Fifty percent exemptions

The government differentiates carbon taxes between industries. The tax rate imposed on the six carbon-intensive industries is half that of the rate imposed on other industries and households. This is done to assist carbon-intensive industries. This means that carbon-intensive industries have less of an incentive to lower emissions.

The top six carbon-intensive industries to receive assistance are chosen as those whose output prices increased considerably (by between 1% and 14%) following the transfer of lump-sum payments to households, according to the results from the first simulation. These are: electricity;

recycling; iron and steel; coal production; clay; and transportation.¹³ These six industries combined produce 70% of Japan's emissions.

4.1.4 Refund of carbon tax

In our model, the government collects a uniform carbon tax from all agents, and refunds it to the six carbon-intensive industries listed in Table 2 in the form of an output subsidy. This program generates two inverse incentives for the six industries; one incentive is to reduce emissions by using carbon pricing, and the second is to increase output levels and, therefore, emissions through subsidies.

4.1.5 Grandfathering

Under this policy, the government grants emission permits to the six carbon-intensive industries based on their CO₂ emission shares in 2000. Permits representing 97% of the 1990 emission level are granted. In our model, each industry receives an emission permit equal to the value of its output subsidy. This program also provides two inverse incentives for the six industries. However, each industry's incentive to increase output and emissions is limited by its past share of CO₂ emissions.

4.2 Simulation results

When there is assistance, carbon prices are higher than when there is not. These qualitative results are the same as those from previous studies (see Table 4). In the 50% exemption case, nonexempted industries reduce emissions by more than do exempted industries, whose marginal abatement costs are lower. This is why carbon prices are higher when there are 50% exemptions. Under tax refunds and grandfathering, industries do not reduce their output levels (see Figure 8). Thus, increased demand for emissions increases the carbon tax rate. Factor prices fall except under tax refunds and grandfathering. In these two cases, carbon-intensive industries substitute energy-capital composite goods for labor. This result is similar to that of Jensen and Rasmussen (2000).

¹³ In Japan, the share of coal-fired electricity is high.

In the two cases under which there is no assistance, output prices increase and output quantities decrease mainly in carbon-intensive industries (see Figures 7 and 8). On the other hand, reduced factor prices increase the output levels of other industries. Refunding carbon tax and allocating grandfathered permits mitigate the negative impacts on carbon-intensive industries by more than does granting 50% exemptions. This is because output subsidies reduce price increases in both cases, as has been found in previous studies. In these two cases, results are similar, but under grandfathering, the mitigating effects on the prices of electricity, iron and steel, and clay are relatively small. In addition, the welfare loss and the carbon price are also lower. This is because industries' incentives to increase output are limited by past CO₂ emissions under grandfathering.

Carbon pricing induces the emission abatement by all industries (see Figure 9). In the 50% exemption case, the burden of abatement moves from exempted industries to nonexempted industries. This introduces distortions into the aggregate economy. In the tax refund case and grandfathering case, carbon-intensive industries reduce their emissions primarily by substituting energy for the labor rather than reducing output.

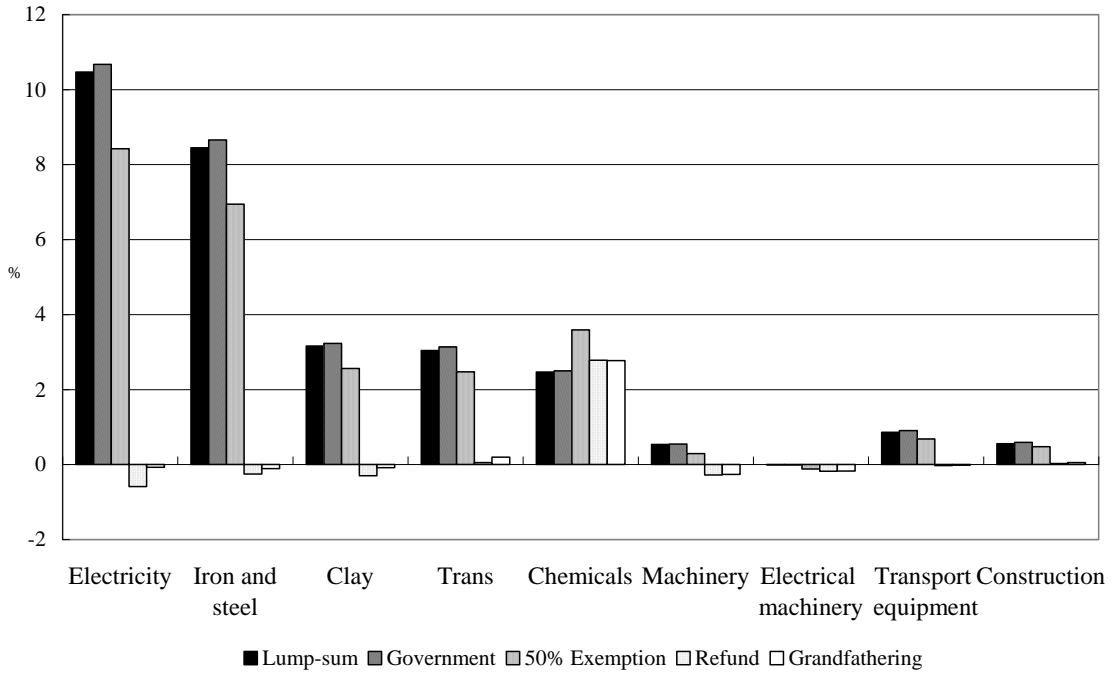
Table 4. Aggregate Results

Scenario	Private consumption	Government consumption	Wage	Capital price	GDP	EV*	Carbon price
Lump-sum	0.02	-0.91	-0.30	-2.20	-1.07	-0.19	18,157
Government	-1.17	3.40	-0.10	-2.50	-1.71	-0.17	18,722
50% Exemption	-1.23	3.54	-0.10	-2.70	-0.77	-0.18	30,180
Refund of carbon tax	-0.49	1.00	0.20	-1.80	-0.35	-0.17	26,653
Grandfathering	-0.52	1.11	0.20	-1.80	-0.37	-0.16	26,283

Note: Change (%) from the business-as-usual case following change in carbon tax rate (yen / t-C).

* EV is defined as the sum of utilities of the household and the government.

Figure 7. Output Price



Note: Change (%) from the business-as-usual case.

Figure 8. Quantity of Output

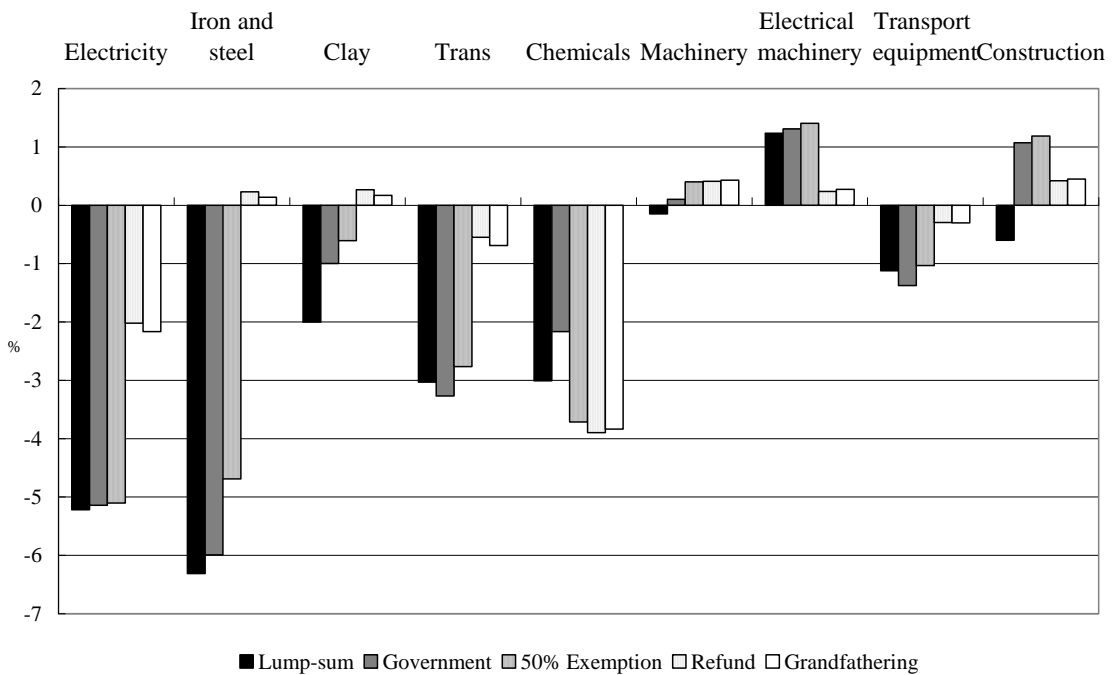
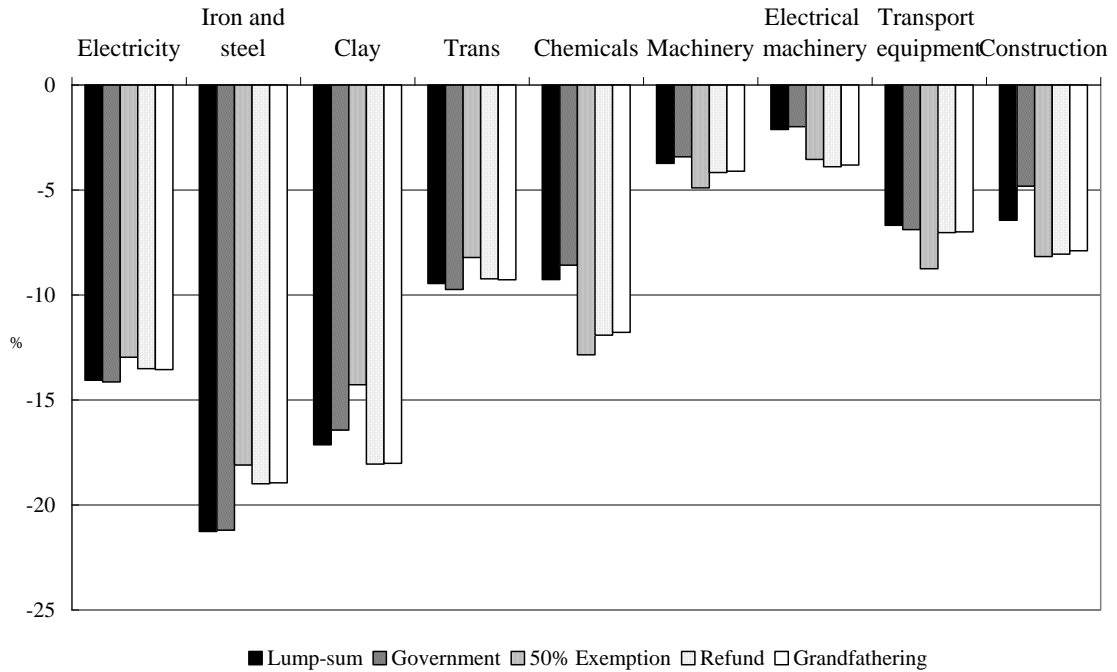


Figure 9. CO₂ Emissions



4.3 Sensitivity analysis

Table 5 shows the results of sensitivity analysis. We investigated the range of compensation, the abatement rate of CO₂ emissions, and substitution elasticities between productive factors and intermediate goods. An expansion of the compensation range improves welfare by raising carbon tax revenue. The stricter is the abatement target, the greater is the difference between the refund of carbon tax and grandfathering. Carbon tax refunds can increase distortions in relative prices. A reduction in substitutability between fossil fuels and electricity-based energy raises carbon prices, but improves welfare when there are carbon tax refunds. The effect of refunding carbon tax is sensitive to the CO₂ abatement target and to the degree of substitutability between energy-related production factors. This is because there are two inverse incentives.

Table 5. Results of Sensitivity Analysis

		Private consumption	Government consumption	Wage	Capital price	GDP	Carbon tax	EV
Compensation range (share of CO2)								
50%	50% Exemption	-1.25	3.59	-0.20	-2.70	-0.80	26213	-0.19
	Refund	-0.80	2.06	-0.10	-2.00	-0.56	24464	-0.18
	Grandfathering	-0.82	2.12	-0.10	-2.00	-0.57	24174	-0.17
70%	50% Exemption	-1.23	3.54	-0.10	-2.70	-0.77	30180	-0.18
	Refund	-0.49	1.00	0.20	-1.80	-0.35	26653	-0.17
	Grandfathering	-0.52	1.11	0.20	-1.80	-0.36	26283	-0.16
80%	50% Exemption	-1.24	3.59	-0.20	-2.70	-0.78	33169	-0.18
	Refund	-0.33	0.44	0.30	-1.60	-0.25	28303	-0.16
	Grandfathering	-0.37	0.58	0.20	-1.60	-0.28	27735	-0.16
Abatement rate								
10%	Lump-sum	0.03	-0.66	-0.20	-1.60	-0.76	12712	-0.12
	Government	-0.83	2.46	-0.10	-1.80	-0.50	13079	-0.11
	50% Exemption	-0.87	2.56	-0.10	-1.90	-0.55	21050	-0.12
	Refund	-0.33	0.72	0.10	-1.20	-0.24	18058	-0.10
	Grandfathering	-0.35	0.78	0.10	-1.20	-0.25	17871	-0.10
20%	Lump-sum	-0.04	-1.59	-0.50	-3.90	-1.89	34195	-0.38
	Government	-2.11	5.90	-0.20	-4.50	-1.28	35431	-0.36
	50% Exemption	-2.21	6.15	-0.30	-4.80	-1.39	57134	-0.38
	Refund	-1.14	1.30	0.10	-3.00	-0.71	42042	-0.60
	Grandfathering	-1.04	2.01	0.20	-3.40	-0.72	52543	-0.37
Substitution elasticities								
FF*0.5	Lump-sum	0.02	-0.97	-0.30	-2.30	-1.14	19455	-0.20
	Government	-1.26	3.66	-0.10	-2.70	-0.76	20101	-0.18
	50% Exemption	-1.32	3.84	-0.20	-2.90	-0.83	32542	-0.19
	Refund	-0.34	1.37	0.20	-1.80	-0.38	30492	0.04
	Grandfathering	-0.57	1.23	0.20	-2.00	-0.40	28754	-0.18
E_EL*0.5	Lump-sum	0.02	-0.97	-0.30	-2.40	-1.15	19554	-0.20
	Government	-1.26	3.68	-0.10	-2.80	-0.76	20214	-0.18
	50% Exemption	-1.33	3.87	-0.20	-2.90	-0.84	32751	-0.19
	Refund	-0.31	1.36	0.20	-1.80	-0.38	30400	0.06
	Grandfathering	-0.58	1.27	0.20	-2.00	-0.41	29597	-0.18
All*0.5	Lump-sum	0.02	-1.33	-0.60	-3.50	-1.93	32681	-0.28
	Government	-2.16	6.57	-0.30	-4.50	-1.31	34562	-0.25
	50% Exemption	-2.26	6.85	-0.30	-4.80	-1.42	55587	-0.26
	Refund	-0.95	3.10	0.20	-3.50	-0.82	62564	-0.06
	Grandfathering	-1.25	3.20	0.20	-3.80	-0.87	63408	-0.28
All*2	Lump-sum	0.01	-0.63	-0.10	-1.20	-0.53	9046	-0.13
	Government	-0.57	1.50	0.00	-1.30	-0.35	9181	-0.12
	50% Exemption	-0.60	1.56	-0.10	-1.30	-0.38	14865	-0.13
	Refund	-0.20	0.22	0.10	-0.80	-0.14	11198	-0.11
	Grandfathering	-0.22	0.28	0.10	-0.80	-0.15	11092	-0.11

5. Conclusion

In this paper, we analyzed CO₂ abatement policies that incorporate assistance to carbon-intensive industries by using an original computable general equilibrium model of the Japanese economy.

The results show that assisting carbon-intensive industries raises marginal abatement costs by between 45% and 66%. Such assistance lowers welfare by between 0.01% and 0.07%. Our analysis suggests that the free allocation of emission permits based on benchmark-year CO₂ emissions is the

most cost efficient and effective way of mitigating the negative impact of abatement on carbon-intensive industries. In addition, implementing two assistance programs under which marginal CO₂ abatement costs are equal in the aggregate economy is more efficient than granting 50% exemptions in terms of social welfare losses and CO₂ abatement costs, and substantially mitigates the adverse effects of abatement on the prices of carbon-intensive goods. However, the effect of refunding carbon tax seems sensitive to the severity of the CO₂ abatement target and to some of the model's parameters.

In the short term, granting tax exemptions and freely allocating emission permits for carbon-intensive industries would spread the burden of reducing CO₂ emissions. However, in the long term, when carbon-intensive industries have had sufficient time to adapt, these industries must be persuaded to accept a cost effective way of reducing aggregate emissions. Thus, in future, we aim to develop a dynamic model to evaluate the processes involved in adjusting to the development of environmentally friendly production structures.

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