Journal of Environmental Science and Engineering B 1 (2012) 945-956
Formerly part of Journal of Environmental Science and Engineering, ISSN 1934-8932

Economic Implications of CO_2 Emission Reduction in Japan Applying a Dynamic CGE Model with Endogenous Technological Change: Use of Emission Permit Revenue

Ken'ichi Matsumoto

School of Environmental Science, The University of Shiga Prefecture, Hikone 5228533, Japan

Received: August 4, 2012 / Accepted: August 18, 2012 / Published: August 20, 2012.

Abstract: This study analyzes the economic and environmental impacts of a climate change measure in Japan using a single-country dynamic computable general equilibrium model with technological change as an endogenous variable. In this way, a comprehensive analysis of the relationships between climate change and its measures, technology, and economy has been done. The model uses technological change as the accumulation of knowledge capital that is derived from research and development investment. The study investigates the impacts of a climate change measure considering the use of emission permit revenue and technological change induced by the policy implementation in the Japanese economy. Simulation results show that there is compatibility between CO_2 emission reduction and positive effects on GDP that depends on the ways of the revenue use and technological change induced by emission reduction. However, it is not possible to find the ways to realize positive effects on both GDP and welfare simultaneously in the study. The sensitivity analysis for the elasticity of substitution between knowledge capital and other inputs also confirms the obtained results.

Key words: Dynamic CGE model, endogenous technological change, R&D investment, climate change policy, revenue recycling.

1. Introduction

Since climate change is one of the most significant environmental issues for the present society, policy discussions from mid- to long-term perspectives are continuing all over the world including in Japan and the international arena such as in the UNFCCC (United Nations Framework Convention on Climate Change). Although the expected new protocol for the Post Kyoto Protocol beyond 2013 was not established, the Copenhagen Accord was made at the fifteenth COP (Conference of the Parties) of UNFCCC in 2009. Based on the accord, the Annex the author countries of UNFCCC and some major non-Annex I countries such as China submitted their pledge on GHG (greenhouse gas) emission reduction by the end of January 2010 [1]. As former Prime Minister of Japan, Yukio Hatoyama, stated at the United Nations Summit on Climate Change in 2009, the target Japanese government submitted was a 25% reduction compared to the 1990 level. His cabinet had also submitted the Basic Act on Global Warming Countermeasures to the ordinary Diet session in 2010, which was later scrapped off. Promotion of innovative technological development has been one of the fundamental measures and policies in it. Furthermore, a target was set to raise the R&D (research and development) investment of the total private and governmental sectors to 4% of GDP by 2020 FY following the New Growth Strategy (Framework) determined at the extraordinary cabinet meeting on December 30, 2009. The Kan cabinet on June 18, 2010 then decided the New Growth Strategy. International actions considering the relationships between climate change measures, R&D investment, technological

Corresponding author: Ken'ichi Matsumoto, Ph.D., assistant professor, main research fields: environmental economics and policy and energy policy. E-mail: matsumoto.k@ses.usp.ac.jp.

development, and economy preceded such movements [2, 3].

In order to address the additional costs and economic impacts that accompany the climate change mitigation measures, importance of technological development and its diffusion is being particularly emphasized globally in the recent years. Technological change can be understood as an increase in outputs possible from a given level of inputs through the process of invention, innovation, and diffusion [4]. In other words, inputs such as natural resources necessary to produce a certain amount of outputs are reduced. Especially, a decline in fossil fuel requirement can be connected directly to mitigation in climate change. Thus, handling endogenous technological change in the economic models would be of much significance for analyzing the relationships between climate change and its measures, technology, and economy as the endogenous technological change implies incorporating a feedback mechanism by which policy can direct technological change towards carbon-saving technology [4]. However, CGE (computable general equilibrium) models that have been frequently used for economic analysis of climate change issues and its measures in the previous studies have considered the technological change as exogenous [4-7] and those with endogenous technological change are rare [4, 8-13]. In addition, several methods have been proposed for modeling endogenous technological change and no consolidation of the methods has been postulated [14]. When modeling endogenous technological change, mainly two methods have been suggested, the first is R&D investment and the second is technology learning. The latter is generally used in bottom-up models and the former is more appropriate for CGE models considering structure [13].

One of the most important studies of recent years on technological change and knowledge capital carried by Romer [15] examines the relationship between knowledge accumulation and technological change considering knowledge as one of input factors. This framework has been used for policy analysis such as regional and economic policies to analyze policy-induced technological change [16, 17]. At the same time, it has also been used for policy analysis such as trade and public policies applying CGE models [18, 19]. Especially, it has been applied to economic analysis in the environmental and energy fields that are closely related to climate change issues [8-13]. This is due to growing importance of climate change as one of the most significant social issues and the relevant policies are closely knitted to R&D investment, resulting in technological changes.

In authors' previous study [20], a single-country dynamic CGE model with endogenous technological change targeting the Japanese economy had been developed. In the model, endogenous technological change is expressed as the accumulation of knowledge capital through R&D investment. The study analyzes economic impacts of CO_2 emission reduction as a climate change measure and subsidies on R&D investment, and finds that there is a possibility to have positive effects on economy when CO_2 emissions are reduced. However, it is assumed that government collects emission permit revenue for the emission reduction cases and the subsidy rates are determined arbitrarily. In addition, constant emission reduction rates (compared to the baseline case) during the entire period are assumed for the scenario cases. Although such analysis is also meaningful to understand the economic consequences, it is better to consider more realistic emission reduction pathways since some revenue is obtained from emission permits. Moreover, considering the ways to use emission permit revenue is an equally important issue. Therefore, CO_2 emission pathways different from the earlier study are used and several ways of the revenue use are taken into account. In this study, economic and environmental impacts are analyzed using the dynamic CGE model.

2. Model

In order to analyze the economic impacts when CO_2 emissions are reduced and technology is changed, a dynamic CGE model installing R&D investment and knowledge capital has been developed. The model is a single-country (Japan) model consisting of 33 industrial sectors (including seven energy sectors). In addition, energy and environmental modules have been combined in the economic model. Knowledge capital appears in the production and dynamics. This model is originally developed by Matsumoto [20], and also used in Ref. [21]. The model can be summarized as follows (see Refs. [20, 21] for the details):

- The data are based on the 2005 Input-Output Table for Japan (general economy), the System of National Accounts of Japan (tax), the Survey of Research and Development for Japan 2005 (knowledge capital and R&D investment), and the Energy Balance Table for Japan 2005 (CO_2 emissions);
- Nested CES (constant elasticity of substitution) functions are used for production, household consumption, and government expenditure;
- Endogenous technological change is expressed by knowledge capital, which is accumulated through R&D investment, based on the concept of endogenous growth theory [12, 22, 23]. The level of R&D investment is determined endogenously;
- Dynamic structure based on the Ramsey growth model (an intertemporal optimization) is applied.

3. Baseline and Scenarios

3.1 Baseline Settings

The 2005 Input-Output Table for Japan is used for the base year (2005) data, and dynamic analysis is then implemented from year 2005 to 2020 (interest rate: 5%/yr). Economic growth depends on labor (growth rate: 1%/yr) and capital accumulation. Physical capital and knowledge capital are accumulated through investment on each and assumed to be depreciated at 5% and 15% per annum, respectively. The range of the depreciation rate of knowledge capital is broad such as 9%-15% according to Sue Wing [12] and 18%-35% according to Otto et al. [11]. Thus, the above value, being approximately the central value, is adopted in this study. It has been proved that the difference of the depreciation rate does not largely affect the overall results according to authors' previous analysis [20], thus sensitivity analysis is not conducted for the depreciation rate in this paper.

CO_2 emission reduction is not implemented in the baseline case.

3.2 Scenario Cases

3.2.1 No Subsidies on R&D Investment

In order to analyze the impacts of CO_2 emission reduction on economy when considering endogenous technological change, scenario cases against the baseline case are set. In this study, the cases in which emissions are reduced from 1% to 50% in 2020 compared to the baseline case are analyzed. The 25% target that Japanese government has declared corresponds to the 43% reduction case if the target is achieved without relying on emission permits. This means that this study covers not only the target of Japan but also the emission levels when more/less reduction than the target are achieved. In each case, emission reduction starts in 2011 and is implemented at the same reduction rate every year between 2011 and 2020 to achieve the reduction target.

When CO_2 emissions are reduced, emission permit revenue is obtained. The revenue is first collected by government. At first, the revenue is used for government expenditure ("no-subsidy cases"), that is to say government obtains the additional budget. In addition, the effects of lump-sum payments of the revenue to households and also the cases when it is allocated to both government and households are analyzed (Section 4.1.2).

3.2.2 Subsidies on R&D Investment

In the above-mentioned cases, the revenue is recycled directly for some sort of consumption. However, it is also justifiable to utilize the revenue to further promote climate change efforts along with technological changes. Since technological change is expressed as the accumulation of knowledge capital through R&D investment in this study, cases in which the revenue is used for subsidizing R&D investment are also analyzed ("subsidy cases"). In this case, the subsidy rate, which is identical among sectors, is determined to balance the permit revenue with the total amount of the subsidies.

The scenario and model settings of the subsidy cases are same as the no-subsidy cases except for the way of the revenue use.

4. Results and Discussion

4.1 Original Results

4.1.1 No-subsidy Cases vs. Subsidy Cases

First, the no-subsidy cases are compared with the subsidy cases. Since the subsidy rates are determined endogenously from emission permit revenue derived from emission reduction, there is just one subsidy case for each emission reduction rate unlike Matsumoto [20].

Observing the overall economic impacts, GDP increases compared to the baseline case for the no-subsidy cases (3.5% in 2020 for 50% reduction) and larger reduction cases tend to bring higher GDP (Fig. 1). The difference between the two is first widened and then narrowed through time. On the other hand, GDP decreases compared to the baseline case by introducing the subsidies (-2.4% in 2020 for 50% reduction) and larger reduction cases tend to bring lower GDP.

GDP consists of private (household) consumption, government expenditure, investment, and net exports (i.e. exports minus imports). Examining these changes, the two scenario cases show different tendencies for household consumption, government expenditure, and investment (Fig. 2). For the no-subsidy cases, while household consumption decreases compared to the baseline case (-0.7% in 2020), investment and government expenditure increase (0.9% and 2.7%, respectively, in 2020), and GDP increases due to the latter effects as a result. The model used in this study is an intertemporal optimization model, thus not only the present status but also the future status is considered for the decision-making. Thus, when the direction of a policy is determined (i.e. the amount and period of CO_2 emission reduction in this study), the economy responds to the policy before it actually begins. Increasing investment instead of household consumption, although the decreases are small, is evaluated optimum in the model consequently. Furthermore, additional R&D investment indicates additional technological change, which accelerates

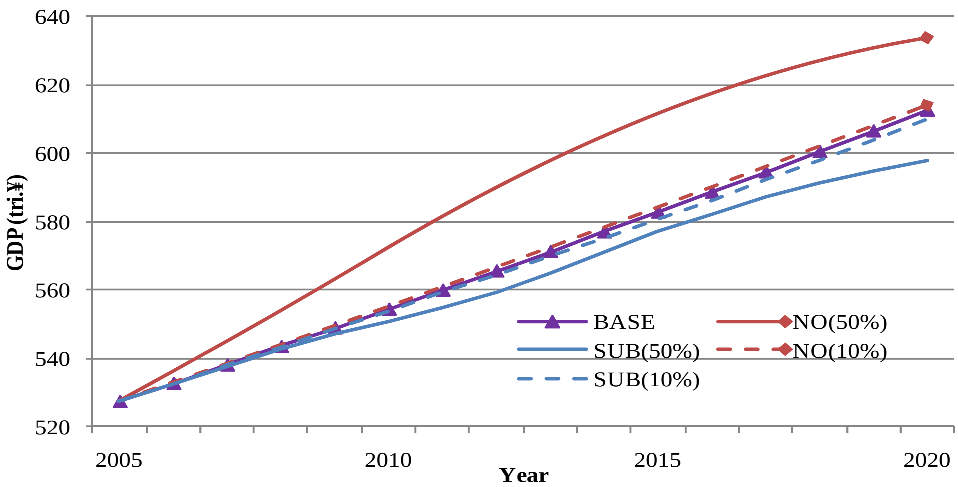

Fig. 1 GDP (with and without subsidies: 10% and 50% reduction cases). "BASE" indicates the baseline case, "NO" indicates the no-subsidy cases, and "SUB" indicates the subsidy cases (same for Fig. 2).

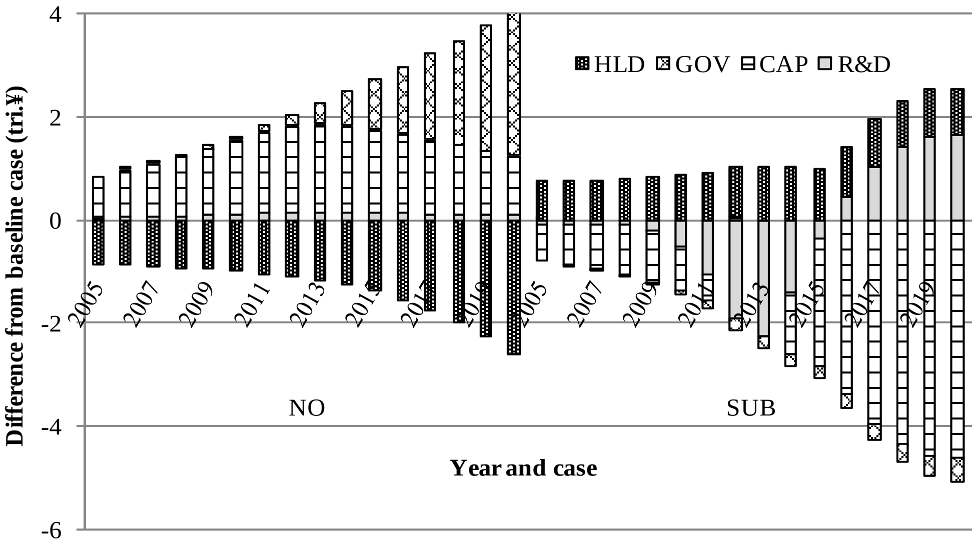

Fig. 2 Components of GDP (with and without subsidies: 10% reduction cases). "HLD" indicates household consumption, "GOV" indicates government expenditure, "CAP" indicates physical capital investment, and "R&D" indicates R&D investment (same for the figures below). In this study, net exports are identical for all the cases (see also Refs. [20, 21]).

economic growth. This effect is induced by CO_2 emission constraints. In these cases, increase in government expenditure is due to the emission permit revenue. This mechanism can be interpreted as follows. First, the economy considers increasing investment (including investment for technological change) and decreasing household consumption instead are more reasonable to realize the low-carbon economy. Here, household consumption is just replaced by investment. This increase in investment links to additional capital accumulation, which expands the economy (increase in supply) as a result. Besides, the additional capital accumulation is returned to households as capital income. Allocation of emission permit revenue is considered to affect increase and decrease in government and household consumption (see also Section 4.1.2).

For the subsidy cases, on the other hand, the tendencies are more or less opposite to those of the no-subsidy cases. While household consumption increases compared to the baseline case (0.3% in 2020), physical capital investment and government expenditure decrease (-3.7% and -0.5%, respectively, in 2020). R&D investment decreases in the earlier years, but increases in the later years owing to the subsidies on it, the rates of which increase year by year with increase in the reduction amount. In these cases, economic distortion occurs due to the subsidies and consequently, physical capital investment, which is a driver for future economic growth, decreases. Since the model solves the entire period at one time considering the future scenarios (e.g. CO_2 emission reduction and subsidies on R&D investment), economic impacts appear before CO_2 emissions are actually reduced.

Although increase in GDP compared to the baseline case is observed even for the subsidy cases in Matsumoto [20], it would be due to the assumption that CO_2 emission reduction and introduction of the subsidies started from the base year. To be more precise, technological change is accelerated from the beginning and economic growth is further promoted as a result. Moreover, difference in the way to determine the subsidy rates would also be a reason.

Another important indicator to understand economic impacts of emission reduction is MAC (marginal abatement cost), which also represents the emission permit price. It represents the cost or economic difficulty to reduce one unit of CO_2 emission incrementally and is frequently used to show the economic severity of the reduction. Fig. 3 shows MAC curves for the two scenario cases in 2015 and 2020. As shown in the figure, MAC increases nonlinearly with increase in the reduction rate as seen in similar studies [13, 20]. MAC is higher in the later years because of the larger reduction rate. In addition, it is indicated that MAC in each year is smaller for the subsidy cases. As shown in Fig. 1, GDP is higher for the no-subsidy cases than for the subsidy cases. Therefore, this result can be interpreted that the higher the GDP (economy), the more economically difficult CO_2 emission reduction would be.

As for environmental aspects, emission intensity (CO_2 emissions per unit of GDP) improves compared to the baseline case for the no-subsidy cases, since GDP increases and CO_2 emissions decrease simultaneously. Decomposing it to carbon intensity (CO_2 emissions per unit of energy use) and energy intensity (energy use per unit of GDP), both of them improve. The former indicates a fuel switch to low-carbon energy and the latter indicates less energy use. The larger the emission reduction rate, the lower these intensities will be. The same holds for the subsidy cases, although the emission intensity is slightly higher than the no-subsidy cases.

In order to achieve such low-carbon economy, industrial structure has changed. For example, the percentage of production from tertiary industry increases about 2.7% and that from secondary industry decreases about 2.8% in 2020 compared to the 2005 levels (50% reduction without the subsidies). Especially, decreases in the percentages of production from energy intensive sectors such as steel industry are large. These tendencies are similar for the subsidy cases.

4.1.2 Other Ways of Revenue Use

As discussed in Section 3.2, there are several ways to use emission permit revenue and using it for subsidizing R&D investment analyzed in the previous section is one of the ways. According to the above analysis, although increase in GDP, which means economic expansion, was realized, household consumption declined, which relates to a welfare loss. Thus, it is meaningful to seek possibilities of realizing increase in GDP and household consumption at the same time. The simplest and most straight way to increase household consumption would be lump-sum payments of the revenue to households. Here, the following five allocation combinations are analyzed: 100% for government and 0% for households (G100/H0; same as the no-subsidy cases in the previous section); 75% for government and 25% for households (G75/H25); 50% for government and 50% for households (G50/H50); 25% for government and

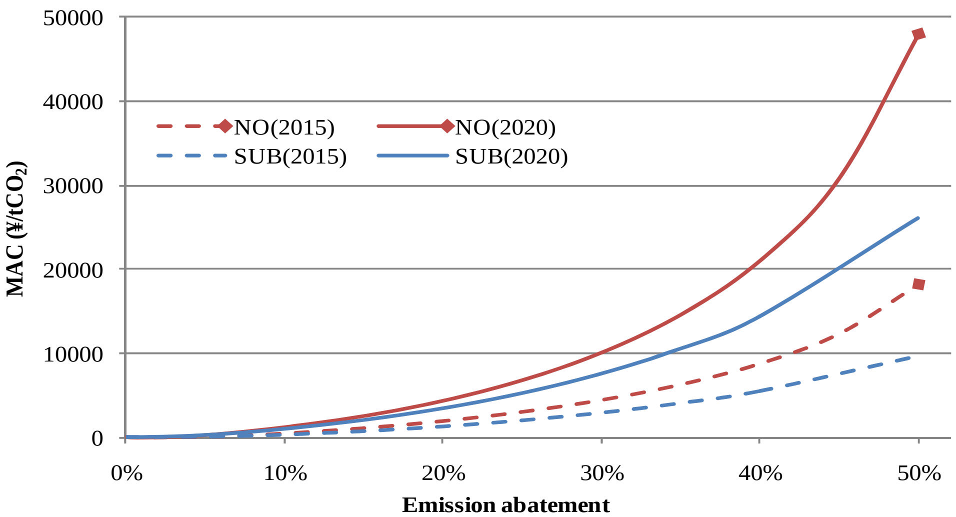

Fig. 3 MAC curves (with and without subsidies).

75% for households (G25/H75); and 0% for government and 100% for households (G0/H100). In this analysis, the revenue use for subsidizing R&D investment has not been considered.

While considering the overall economic impacts independently of the emission reduction rate, GDP increases when more than half of the revenue is allocated to government (Fig. 4). When the revenue is bisected, namely the G50/H50 cases, while GDP is almost at the same level with the baseline case for lower reduction cases, it tends to be higher than the baseline case for larger reduction cases except for the later years.

Decomposing GDP to its components (Fig. 5), their tendencies gradually change as the allocation to households increases. Although household consumption is lower than the baseline case when more revenue is allocated to government as in the previous section, it becomes higher than the baseline case by increasing the allocation to households (from -0.7% (G100/H0) to 0.1% (G0/H100) in 2020). Opposite to it, government expenditure and investment become lower than the baseline case by increasing the allocation to households (from 2.7%

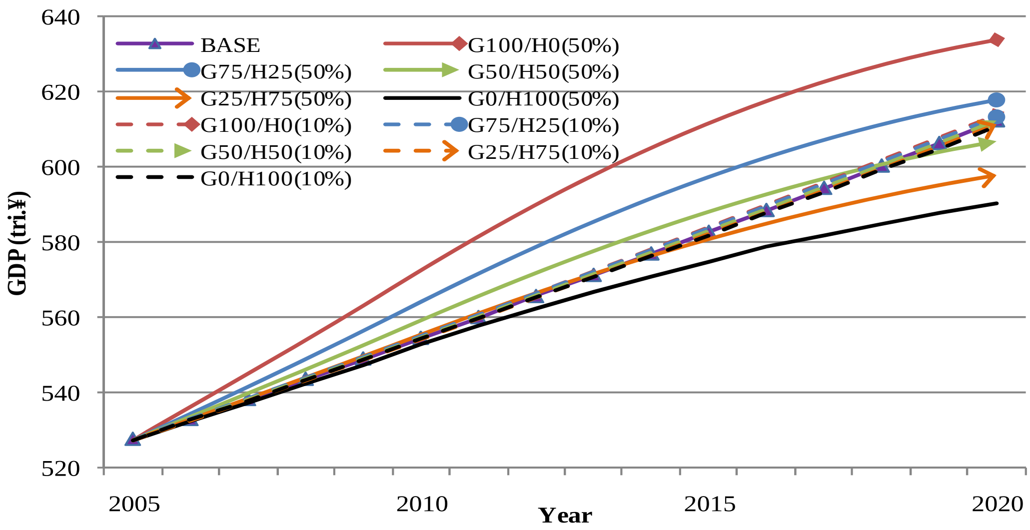

Fig. 4 MAC curves (with and without subsidies).

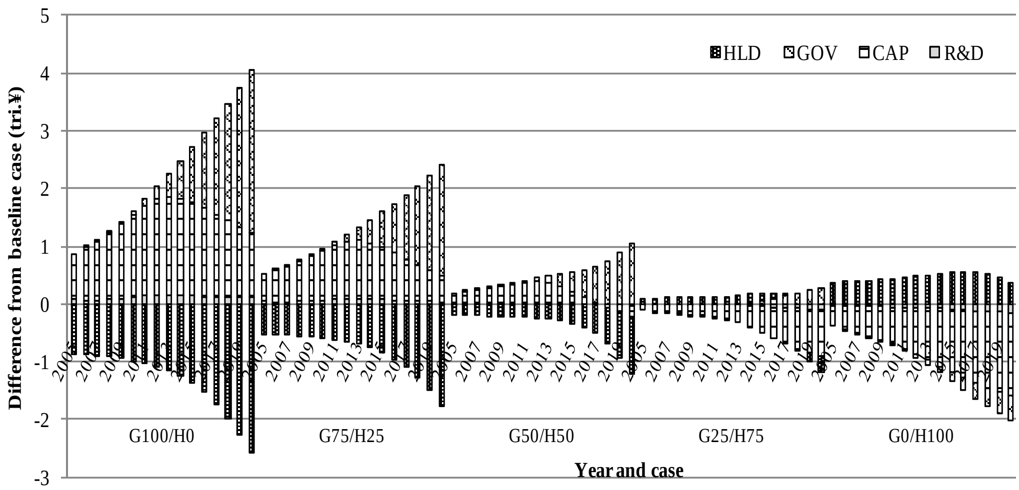

Fig. 5 Components of GDP (allocation to government and households: 10% reduction cases).

(G100/H0) to -0.4% (G0/H100) and from 0.9% (G100/H0) to -1.1% (G0/H100), respectively, in 2020). These positive and negative impacts balance when the revenue is allocated evenly (G50/H50), but the impacts of government expenditure and investment become larger when the allocation to either government or households is larger and determine the direction of GDP. The larger amount of R&D investment in these scenarios than that in the baseline case links to acceleration in technological change.

Although there are some cases in which the amount of R&D investment is lower than the baseline case, technology is improved even for such cases year by year, just the improvement slows down a little.

From this analysis, it was not possible to find cases in which both GDP and household consumption increase simultaneously. Thus, it is necessary to clarify where to give priority when determining an allocation scheme if it is selected from these simple ways.

Similar to Fig. 3, MAC increases nonlinearly with increase in the reduction rate and it is higher in the later years because of the larger reduction rate (Fig. 6). Comparing the five cases, the larger the allocation to government, the higher MAC will be. As in Fig. 4, GDP is higher as the revenue is allocated more to government. Thus, this result also can be interpreted that the higher the GDP (economy), the more costly CO_2 emission reduction will be.

As for environmental aspects, emission intensity improves compared to the baseline case for all the cases. Furthermore, both carbon intensity and energy intensity also improve, however, the larger the emission reduction rate, the lower these intensities will be. Comparing the five cases, the more the revenue is allocated to government, the lower the emission intensity will be. It is due to higher GDP for such cases.

While evaluating the industrial structure, the changes are similar to those described in the previous section. The structure in 2020 is almost the same for all the cases.

4.2 Sensitivity Analysis

The simulation results can be affected by the parameter values used in the model. Thus, sensitivity analysis for the elasticity of substitution between knowledge capital and other inputs, which is the most influential parameter to model endogenous technological change, is implemented. In this study, the cases when the values are 0.5 (lower than the original) and 2.0 (higher than that) are analyzed. This analysis corresponds to the no-subsidy cases in Section 4.1.1. Figs. 7-9 are the results.

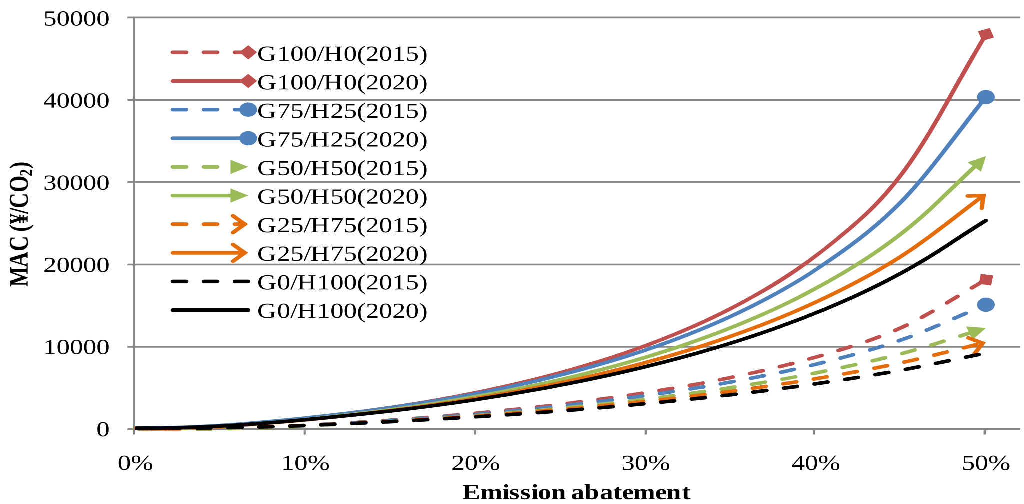

Fig. 6 MAC curves (allocation to government and households).

Although GDP increases compared to the baseline case regardless of the elasticity, the low-elasticity cases show the highest GDP (5.3% increase compared to the baseline case in 2020 for 50% reduction, Fig. 7). However, since the elasticity is low, the technological change effects are supposed to be smaller than the higher-elasticity cases.

The components of GDP also indicate similar tendencies regardless of the elasticity (Fig. 8). That is to say, while household consumption decreases (-26.7%-15.0% in 2020), investment and government expenditure increase (42.6%-19.2% and 65.1%-41.8%, respectively, in 2020), and GDP increases due to the decrease expands for the low-elasticity cases and contracts for the high-elasticity cases. The R&D investment moves to the opposite directions. This is because the lower elasticity makes the substitution between knowledge capital, which is accumulated

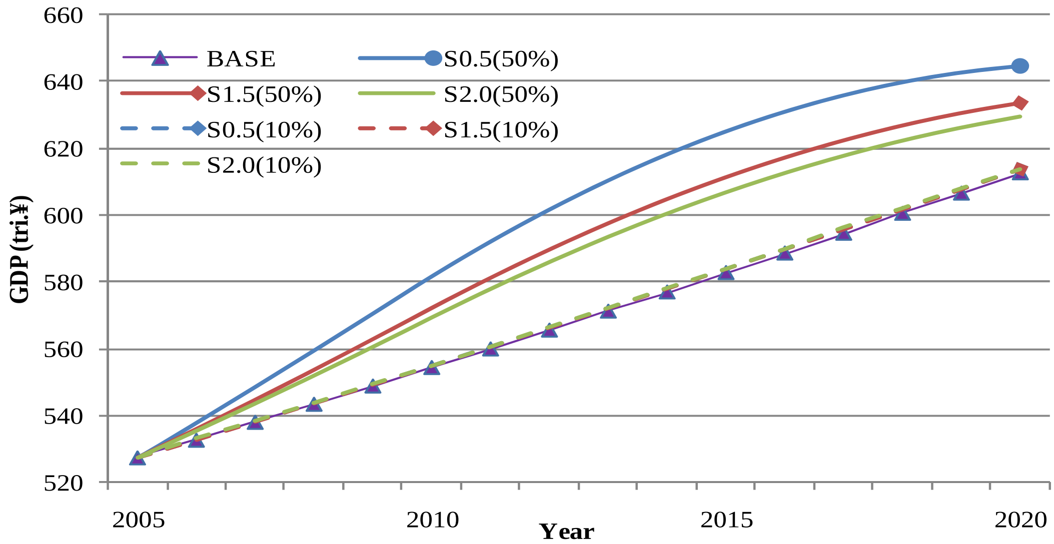

Fig. 7 GDP (sensitivity analysis: 10% and 50% reduction cases). "S 0.5" indicates the low elasticity cases, "S 1.5" indicates the original cases, and "S 2.0" indicates the high elasticity cases.

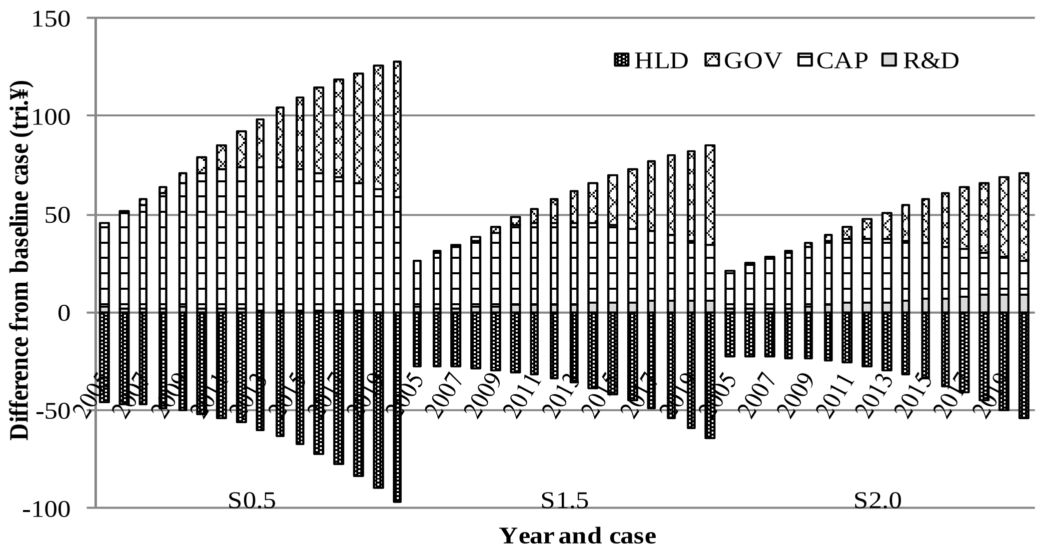

Fig. 8 Components of GDP (sensitivity analysis: 50% reduction cases). In this figure, 50% reduction cases are shown, because the differences for 10% reduction cases are too small to clearly examine the results.

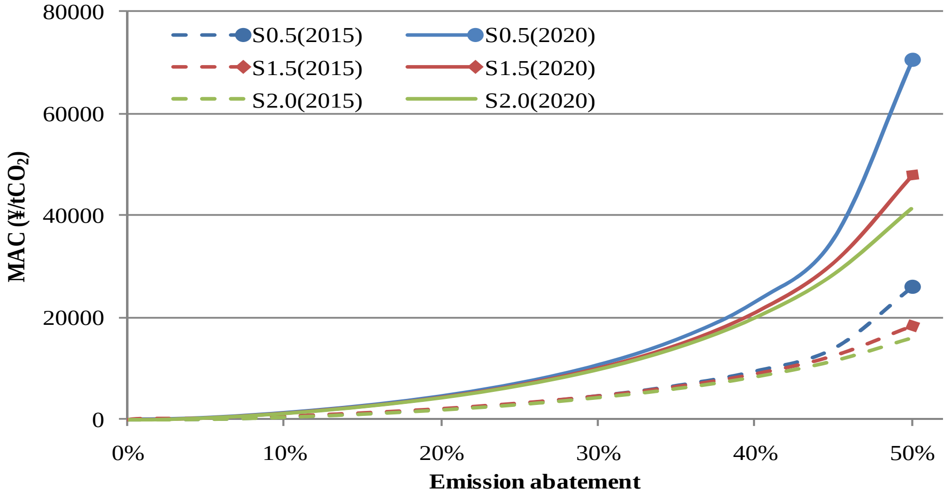

Fig. 9 MAC curves (sensitivity analysis).

through R&D investment, and other inputs difficult and costly. Since R&D investment accounts for a small percentage of GDP, the effects of the other factors outweigh those of R&D investment.

As Fig. 9 indicates, regardless of the elasticity, MAC rises and remains higher in later years with increase in the reduction rate. These tendencies are similar to the results in Section 4.1. The elasticity also affects the level of MAC. The lower the elasticity, the higher the MAC will be. One reason would be their higher GDP as well as the reason described in Section 4.1. In addition, since the low value means difficulty to substitute other inputs with knowledge capital, technological change does not progress compared to the higher-elasticity cases. Consequently, the economic burdens from abating CO_2 emissions become heavier.

As for environmental aspects, emission intensity improves compared to the baseline case regardless of the elasticity, since GDP increases and CO_2 emissions decrease simultaneously. In addition, both carbon intensity and energy intensity improve, too. Emission intensity tends to be low as the elasticity is smaller mainly because of low carbon intensity.

Examining industrial structure, it changes as described in the previous section (i.e. the percentage of tertiary industry increases, while that of secondary industry decreases) regardless of the elasticity. The difference between the cases is marginal.

5. Conclusions

In this paper, the impacts of CO_2 emission reduction as a climate change measure in Japan have been analyzed using a dynamic CGE model considering endogenous technological change developed by Matsumoto [20]. By applying this mechanism, it was possible to analyze the effects of technological change corresponding to policies and measures unlike most of existing CGE models, in which technological change was handled exogenously. First, the two scenario cases, namely the CO_2 emission reduction with and without subsidies on R&D investment, were compared. Next, in order to understand more broadly about the effects of the use of emission permit revenue and to seek the possibilities to increase GDP and welfare simultaneously, analysis on the revenue allocation was conducted. In addition, sensitivity analysis was implemented with regard to the elasticity of substitution between knowledge capital and other inputs. In this study, CO_2 emission reduction from 1%-50% in 2020 compared to the baseline case was simulated for the scenario cases. The higher reduction levels correspond to the emission reduction target of Japan in 2020 if the emissions are reduced purely in the country.

As a result of the first analysis, while positive effects on GDP were observed for the no-subsidy cases, the negative effects were observed for the subsidy cases. The former would be due to additional capital accumulation derived from increase in investment to address the emission reduction policy, while the latter would be due to economic distortion brought by the subsidies. On the other hand, the latter cases brought increase in household consumption even in this short-term analysis opposite to the former cases. These tendencies were confirmed in the range of the sensitivity analysis of this study.

The second analysis showed that the larger the allocation to government, the higher would be the GDP, and more allocation to government could realize higher GDP comparing to the baseline case. On the other hand, the larger allocation to households had effects of increasing household consumption.

Concerning technological change, it could be promoted depending on the revenue use. Even though no subsidies were given on R&D investment, technological improvement could be accelerated, which is induced by CO_2 emission reduction. This effect partly contributed to economic growth. Although subsidies on R&D investment further accelerated technological change especially in the later years since more subsidies were provided, decrease in GDP compared to the baseline case were observed owing to the impacts of the other components.

In regard to the environmental aspects, emission intensity, carbon intensity, and energy intensity were improved for all the scenario cases, and the higher the reduction rate, the lower the intensities. Conversely, it suggests that improving these indicators simultaneously was indispensable to achieve CO_2 emission reduction targets.

To summarize, this study showed that there was compatibility between economic growth and CO_2 emission reduction. Although technological change was one of the important factors for economic growth, other factors such as physical capital investment were also important. In addition, it was found that determining how to use emission permit revenue was a significant issue to realize both economic and environmental effects.

Although larger investment is founded on the sacrifices of the present (short-term) consumption as mentioned above, it contributes to future economic growth. It means a potential to increase consumption in the future. Since this study focused on analysis until 2020 and CO_2 emission reduction was assumed to start from 2011, such possible effects in the future would not appear in such a short time period. Since longer term is considered for CO_2 emission reduction in Ref. [20], it would be one reason to realize increase in both GDP and consumption. Thus, analysis taking account of the longer future in the model would be a work for future. Furthermore, studies on modeling methodology of knowledge capital such as spillover effects of knowledge and sector-specific knowledge (technology) will be implemented.

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