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Economic Analysis of CO_2 Emission Abatement Applying a Dynamic CGE Model with Endogenous Technological Change: Impacts of the Time Horizon

K. Matsumoto

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

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Abstract: We evaluate economic and environmental impacts of climate change mitigation in a country scale considering various time horizons in the analysis applying a single-country dynamic computable general equilibrium model with endogenous technological change. Although there is a possibility that Gross Domestic Product (GDP) becomes larger for the abatement cases than the baseline case in the earlier years, it tends to be lower than that in the later years. The longer the time horizon and/or the more severe the abatement, the larger the negative impacts will be. When subsidizing R&D investment, increase in GDP compared to the baseline case is realized in the middle of the time horizon, and the larger increase tends to be observed for the longer-term cases. These results would be due to technological change induced by the subsidies and emission abatement. Environmental indicators are also improved. We showed that the results were influenced by the target time horizon when using an intertemporal dynamic model.

Key words: Endogenous technological change, intertemporal dynamic CGE, time horizon, economic impact, climate change policy.

1. Introduction

Climate change is one of the most significant environmental issues for the present society and policy discussions from mid- to long-term perspectives are continuing all over the world. Although the expected new protocol for the Post Kyoto Protocol was not established, the Copenhagen Accord was made at the fifteenth Conference of the Parties (COP) of the United Nations Framework Convention on Climate Change (UNFCCC) in 2009. Based on the accord, the Annex I countries of UNFCCC and some major non-Annex I countries such as China submitted their pledge on greenhouse gas (GHG) emission abatement [1]. As former Prime Minister of Japan, Yukio Hatoyama, stated at the United Nations Summit on Climate Change on September 22, 2009, the target Japanese government submitted was a 25% abatement 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 research and development (R&D) investment of the total private and governmental sectors to 4% of Gross Domestic Product (GDP) by 2020FY 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 development, and economy preceded such movements [2, 3].

In order to address the additional costs and economic impacts that accompany the climate change

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

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 (ETC) in the economic models would be of much significance for analyzing the relationships between climate change and its measures, technology, and economy as ETC implies incorporating a feedback mechanism by which policy can direct technological change towards carbon-saving technology [4]. However, computable general equilibrium (CGE) models that have been frequently used for economic analysis of climate change issues and its measures have considered the technological change as exogenous [4-7] and those with ETC are rare [4, 8-14]. In addition, several methods have been proposed for modeling ETC and no consolidation of the methods has been postulated [15]. When modeling ETC, mainly two methods have been suggested, the first being 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 [14].

One of the most important studies of recent years on technological change and knowledge capital carried by Romer [16] examines the relationship between knowledge accumulation and technological change considering knowledge as one of input factors. This framework has also been applied to economic analysis in the environmental and energy fields that are closely related to climate change issues [8-14]. 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 our previous study [17], a single-country dynamic CGE model with ETC targeting the Japanese economy had been developed. In the model, ETC is expressed as the accumulation of knowledge capital through R&D investment like the above studies. The study analyzes economic impacts of CO_2 emission abatement and subsidies on R&D investment, and finds that there is a possibility to have positive effects on economy when CO_2 emissions are abated. However, as it is assumed that the target period is between 2005 and 2020, such a short period would be insufficient for this kind of analysis, because climate change is a longer-term issue. Moreover, since the dynamic structure of the model is an intertemporal optimization type, the results can be affected by the time horizon. The purpose of this study is to analyze economic and environmental impacts of CO_2 emission abatement considering longer periods applying the abovementioned CGE model. We consider year 2020, 2030, 2050, and 2100, respectively, as the terminal points (i.e. planning periods).

2. Model

In order to analyze the economic impacts when CO_2 emissions are abated and technology is changed, a dynamic CGE model installing R&D investment and knowledge capital has been developed [17]. The model is a single-country (Japan) model and consists of 33 industrial sectors (Table 1). Knowledge capital appears in the production and dynamics. The summary of the model is described below (see Ref. [17] for the details).

2.1 General Structure and Data

In this study, the social accounting matrix (SAM) is developed based on the 2005 Input-Output Table for Japan. For households, government, and abroad, only one sector exists for each. The labor and capital tax data are from the System of National Accounts of Japan. The data on knowledge capital and R&D

Table 1 Classification of industrial sectors.

Code	Classification	Code	Classification
AGR	Agriculture, forestry, fisheries	ITQ	Information equipment
MIN	Mining	ECM	Electronic components
COA	Coal	TRQ	Transportation equipment
OIL	Crude oil	PRQ	Precision instruments
GAS	Natural gas	OMF	Other manufacturing
FOD	Foods	CNT	Construction
TEX	Textile	ELE	Electricity
PPP	Pulp, paper, wood	GSH	Gas & heat supply
CHE	Chemical	WTR	Water supply
PPR	Petroleum products	WST	Waste management
CPR	Coal products	COM	Commerce
CLY	Ceramic, stone, clay	FIN	Finance
STL	Ferrous metal	EST	Real estate
NFE	Non-ferrous metal	TRN	Transportation
MET	Metal products	ICT	Communication
MCH	General machinery	OSV	Other services
ELQ	Electric machinery		

investment are not represented in the Input-Output Table. The estimation method is described in section 2.4.

The data on CO_2 emissions are based on the Energy Balance Table for Japan 2005, in which emission data by energy and sector, including households, are shown. Direct CO_2 emissions are taken into account in the model.

2.2 Production Structure

Each industrial sector performs production activities using domestic and imported intermediate inputs and production factors owned by the household sector, and pays production tax to government. When energy goods are consumed, CO_2 emission permits corresponding to the amount of emissions from energy use are required. The model uses nested CES (constant elasticity of substitution) functions. The substitution relationship of knowledge capital is considered at the top level of the functions as in existing studies [8, 10, 12-14]. For the elasticity of substitution between knowledge capital and other inputs, several values are used in the literature. For example, Otto et al. [12], Sue Wing [13], and some other studies use 1.0, Wang et al. [14] use 2.5, and Sue Wing [18] suggests 0.5-2.0. Thus, we use 1.5 for the value, being approximately the central value. According to our previous study [19], the difference of the substitution parameter does not largely affect the overall results and only affect the degrees of the changes. Thus, we do not conduct sensitivity analysis for the substitution parameter.

2.3 Household Consumption and Government Structure

The household sector determines its consumption and saving to maximize the present discounted value of the utility based on its consumption. It earns its income from labor and capital (physical and knowledge capital) supply, pays taxes imposed on its income, and consumes goods as Armington aggregations. It is also required to hold emission permits for energy use just as the industrial sectors are. The household utility function is a nested CES function. The intertemporal elasticity of substitution is 0.5 in the model.

Government determines its expenditure subject to its budget obtained from taxes (minus subsidies) and emission permit revenue. In this study, it is assumed that government allocates emission permits by auction when implementing CO_2 emission abatement measures. The government expenditure is also a nested CES function.

2.4 Endogenous Technological Change

Knowledge capital is used as a production factor and modeled to demonstrate the link between the knowledge accumulation and technological change based on the concept of endogenous growth theory [13, 20, 21]. It is accumulated due to R&D investment, the scale of which is determined endogenously in dynamic structure. This technological change affects economic growth, energy use, and CO_2 emissions. Knowledge capital is assumed to be distributed throughout the economy as well as physical capital.

Since both R&D investment and knowledge capital are not disaggregated in the Input-Output Table for Japan, they are estimated using the method of Terleckyj [22, 23]. First, the amount of R&D investment by sector is estimated based on the total expenditure on R&D of the Survey of Research and Development for Japan 2005. Knowledge factors are then separated from the intermediate input matrix of SAM using the data.

2.5 Dynamic Structure

Consideration of the temporal aspect is indispensable for analyzing the changes in environment and economy. Furthermore, the determination of the investment amount is a significant issue for this analysis. Thus, dynamic structure based on the Ramsey growth model, an intertemporal optimization, is applied in the model. In the Ramsey model, households maximize the present discounted value of the utility based on their consumption as shown in the Eqs. (1-5):

$$\max \sum_{t=0}^{\infty} \left(\frac{1}{1+\rho}\right)^t U(C_t) \tag{1}$$

$$\text{s.t. } Y_t = F(K_t, KNC_t, L_t) = C_t + I_t + RDI_t \tag{2}$$

$$K_{t+1} = (1-\delta)K_t + I_t \tag{3}$$

$$KNC_{t+1} = (1-\mu)KNC_t + RDI_t \tag{4}$$

$$L_{t+1} = (1+g)L_t \tag{5}$$

Where, U(·): utility function, f(·): production function, C_t: consumption, Y_t: income, K_t: physical capital, KNC_t: knowledge capital, L_t: labor, I_t: physical capital investment, RDI_t: R&D investment, ρ: discount rate, δ: depreciation rate of physical capital, μ: depreciation rate of knowledge capital, g: increase rate of labor, t: time.

To solve such dynamic models, it must be ensured that a dynamic stable equilibrium exists and the solution converges to the stable equilibrium from the initial state. However, it is not certain that the arbitrary initial state satisfies such conditions. Thus, it is often assumed that the initial state is also a stable equilibrium for analysis using this kind of dynamic model [24-26]. The amount of investment is adjusted following these examples.

In this type of dynamic model, household sectors determine the optimum combination of their consumption and saving from the infinite horizon optimization problem. However, because it is not possible to consider infinite time in simulation analysis, a finite time is considered instead and the solution at the terminal point must be identical to that for infinite time. Thus, elaborating the condition under which rise in investment becomes equal to the economic growth rate at the terminal point is estimated [27]. In addition, the increase rates of labor in efficiency units, budget deficit, and current-account surplus are assumed to be equal to the growth rate (of the baseline case) to confirm the dynamic stable equilibrium condition from the initial to terminal points.

3. Baseline and Scenarios

3.1 Baseline Settings

Dynamic analysis is implemented from year 2005 (base year) to 2100 (interest rate: 5%/yr), because calculation until 2020, 2030, 2050, and 2100 brings identical results for the baseline case. Economic growth depends on labor (increase 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% [13] and 18-35% [12]. 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 our previous analysis [17], thus we do not conduct sensitivity analysis for the depreciation rate in this paper.

3.2 Scenario Cases

In this study, scenario cases in which emissions are abated from 10% to 50% at the terminal points compared to the baseline case are analyzed to understand the economic impacts. In addition, larger abatement cases are calculated for the longest one. In each case, emission abatement starts in 2011 and is implemented at the same abatement rate every year between 2011 and each terminal point to achieve the abatement target.

When CO_2 emissions are abated, emission permit revenue is obtained. At first, the revenue is considered to be used for government expenditure (“no-subsidy cases”). In addition, 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 through R&D investment in this study, we also analyze cases in which the revenue is used for subsidizing R&D investment (“subsidy cases”). The other assumptions are same as the no-subsidy cases.

4. Results and Discussions

4.1 No-Subsidy Cases

Observing the overall economic impacts, GDP increases compared to the baseline case for the 2020 cases (e.g. 3.5% in 2020 for 50% abatement) and larger abatement cases tend to bring higher GDP (Fig. 1). On the other hand, the other cases (i.e. 2030, 2050, and 2100 cases) tend to be different. In these cases, although GDP increases compared to the baseline case in earlier years, it decreases in later years. Depending on the abatement amount and terminal years, the turning points are around 2021-2035. The longer the time span, the smaller the increase in GDP and the larger the decrease in GDP will be. Moreover, the larger the abatement amount, the larger the decrease in GDP will be.

GDP consists of private (household) consumption, government expenditure, investment, and net exports. Examining these changes, household consumption and government expenditure show similar tendencies for all the cases (Fig. 2). Household consumption decreases compared to the baseline case and the decrease is larger as the abatement amount is large. Government expenditure is opposite to it owing to the emission permit revenue.

On the other hand, investment changes differently depending on the cases. For the shortest cases, both physical capital investment and R&D investment are larger than the baseline case. However, both increase in earlier years, but decrease in later years for the longer cases (the turning points are around 2020-2030). From these results, it is found that change in investment is most influential to increase or decrease GDP. The model is an intertemporal optimization model, thus not only the present status but also the future status is considered for the decision-making. In the shorter term, increasing investment instead of household consumption would

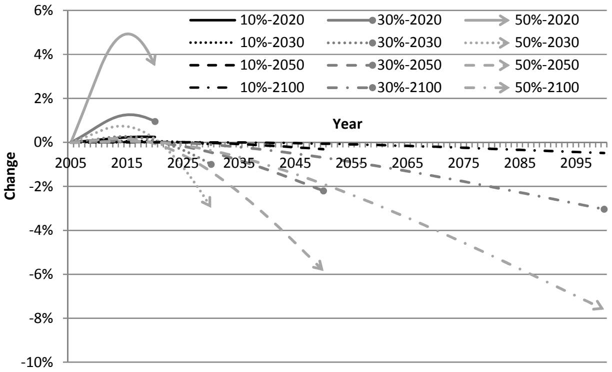

Fig. 1 Change in GDP for no-subsidy cases (e.g. 10%-2020: 10% abatement-2020 terminal point case).

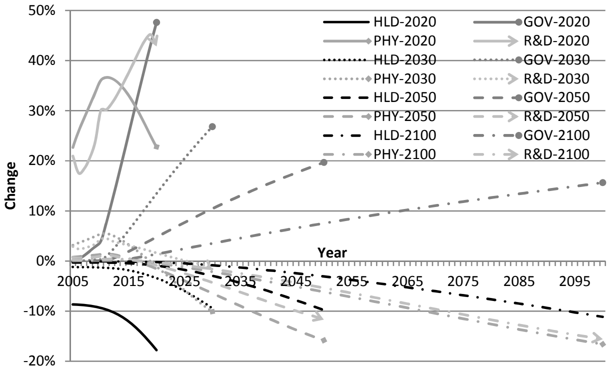

Fig. 2 Change in components of GDP for no-subsidy cases (50% abatement. HLD: household consumption; GOV: government expenditure; PHY: physical capital investment; R&D: R&D investment. e.g. HLD-2020: household consumption for the 2020 case).

be evaluated optimum in the model considering the present and future situations simultaneously. In addition, additional R&D investment indicates additional technological change, which accelerates economic growth. This effect is induced by CO_2 emission constraints. Considering the longer term, however, it is required to abate more CO_2 emissions because of continuous increase in the "amount" of CO_2 emissions in the baseline case. Consequently, both physical capital investment and R&D investment have to be reduced as well as household consumption. Since the model is an intertemporal optimization type, economic impacts appear before CO_2 emissions are actually abated.

Another important indicator to understand economic impacts of emission abatement is marginal abatement cost (MAC). MAC increases nonlinearly with increase in the abatement rate for the scenario cases (Fig. 3). Compared to the shorter cases, however, MAC does not increase exponentially over time for the longer cases and even decreases in later years for the longest cases because of the emission abatement pathways assumed in this study.

As for environmental aspects, emission intensity (CO_2 emissions/GDP) improves compared to the baseline case since decrease in CO_2 emissions is larger than that in GDP (Fig. 4). Decomposing it to carbon intensity (CO_2 emissions/energy use) and energy intensity (energy use/GDP), both of them improve. The former indicates a fuel switch to low-carbon energy and the latter indicates less energy use for economic growth. The larger the emission abatement rate, the lower these indicators will be.

In order to achieve such low carbon economy, industrial structure has changed. For example, the percentage of production from tertiary industry increases 2.7 percentage points and that from secondary industry decreases 2.8 percentage points in 2020 compared to the 2005 levels for the 2020 case (50% abatement). It is similar for the 2100 case, and the percentage of production from tertiary industry increases 2.5 percentage points and that from secondary industry decreases 2.5 percentage points in 2100 (50% abatement). Especially, decreases in the percentages of production from energy intensive sectors such as steel industry are large.

4.2 Subsidy Cases

When subsidies on R&D investment are introduced, the results tend to be different from the no-subsidy cases. Observing the overall economic impacts, GDP decreases compared to the baseline case for the 2020 cases (e.g.-2.4% in 2020 for 50% abatement) and larger abatement cases tend to bring lower GDP (Fig. 5). On the other hand, the other cases tend to be different from them. In these cases, change in GDP can be positive or negative depending on the year, and the larger the abatement rate, the more greatly GDP

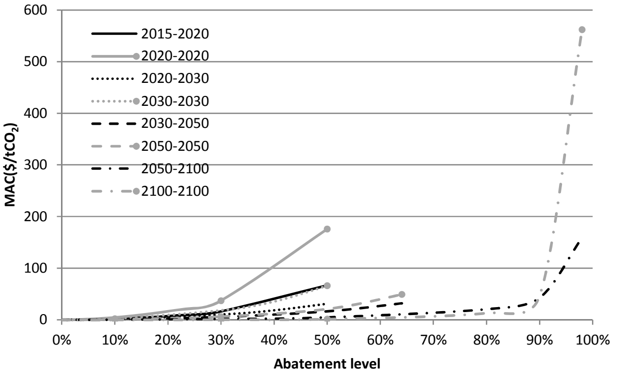

Fig. 3 MAC curves for no-subsidy cases (e.g. 2015-2020: MAC in 2015 for the 2020 cases).

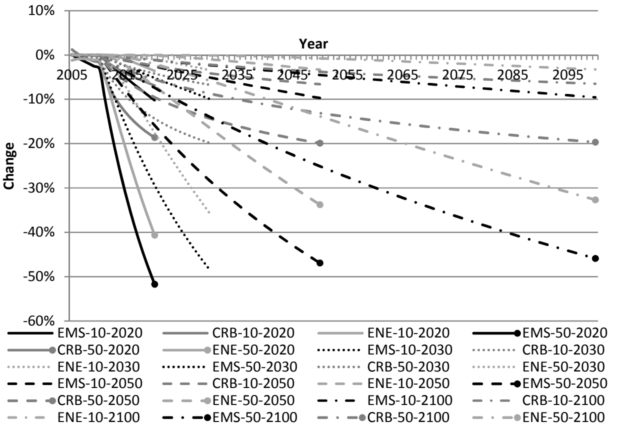

Fig. 4 Change in environmental indicators for no-subsidy cases (EMS: emission intensity; CRB: carbon intensity; ENE: energy intensity. e.g. EMS-10-2020: emission intensity for the 10% abatement-2020 terminal point case).

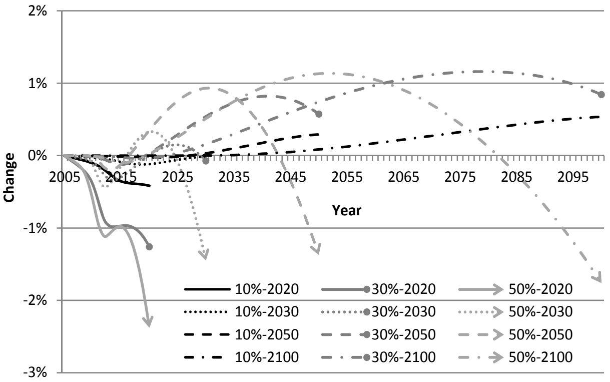

Fig. 5 Change in GDP for subsidy case.

changes.

In these cases, R&D investment plays an important role to raise GDP (Fig. 6). It is accelerated by CO_2 emission abatement and subsidies on it, especially the latter has the significant effect. This increase in R&D investment means technological improvement. The other components of GDP tend to decrease. Government expenditure decreases mainly because of subsidies on R&D investment. Decreases in consumption and physical capital investment are due to the substitution relationships. Increasing investment instead of household consumption would be evaluated optimum in the model. Furthermore, R&D investment is selected instead of physical capital investment, since the price of R&D investment becomes relatively cheaper by subsidizing R&D investment. Emission abatement constraints also contribute to these decreases.

The shapes of MAC for the subsidy cases are similar to those for the no-subsidy cases (Fig. 7). Comparing the two, there is a tendency that the larger the economy (GDP), the larger the MAC will be, and vice versa. This result can be interpreted that CO_2 emission abatement would be more economically difficult as the economy grows.

As for environmental aspects, all of the indicators improve as well as the no-subsidy cases (Fig. 8). Similar to the no-subsidy cases, industrial structure has changed to realize such the environmental improvement. For the 2020 case, the percentage of production from tertiary industry increases about 0.4 percentage points and that from secondary industry decreases about 0.5 percentage points in 2020 compared to the 2005 levels (50% abatement). As these changes are smaller than the no-subsidy cases, it would be due to the effects of technological change promoted by the subsidies. Because of the effects, secondary industry would be able to produce goods more energy-efficiently than the no-subsidy cases.

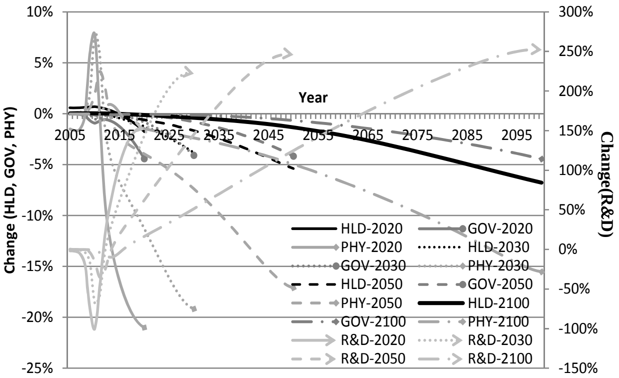

Fig. 6 Change in components of GDP for subsidy cases (50% abatement).

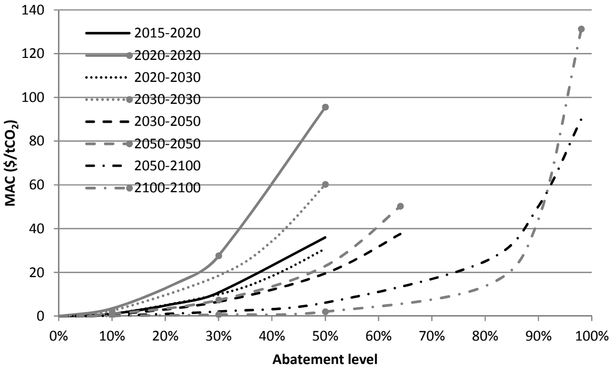

Fig. 7 MAC curves for subsidy cases.

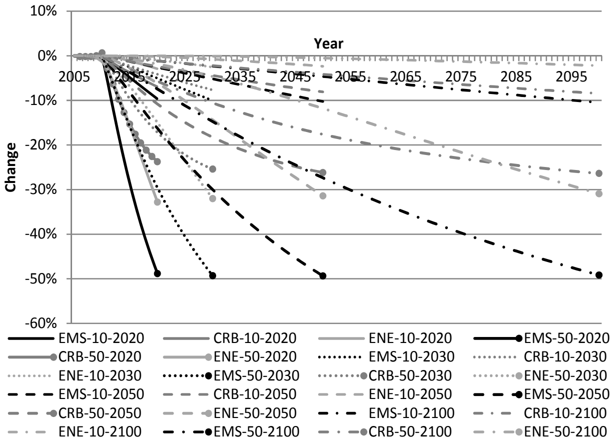

Fig. 8 Change in environmental indicators for subsidy cases.

Observing the 2100 case (50% abatement), to the contrary, the percentage of production from tertiary industry decreases 1.5 percentage points and that from secondary industry increases 1.6 percentage points in 2100. Since a possible trend toward service (or postindustrial) economy is not installed explicitly in the model, there is sufficient time for secondary industry to adapt to the emission abatement through technological change promoted by the subsidies.

4.3 Large Abatement Cases

In order to achieve low carbon economy, tremendous CO_2 emission abatement is required and understanding the economic consequences is important. Thus, we also analyze economic impacts of 90% emission abatement in 2100. The emission abatement pathway is determined as in the previous sections. In addition, we also analyze economic impacts considering the shorter terms using the same pathway to understand the impacts of the time horizon. The emission abatement rates compared to the baseline case are 22.6% in 2020, 40.1% in 2030, and 64.1% in 2050.

Overall, the relationships of changes in GDP between the cases are same with the previous comparisons (Fig. 9). For the no-subsidy cases, GDP increases compared to the baseline case in earlier years, but decreases in later years. In addition, the shorter-term cases show larger GDP if compared in the same year. For the subsidy cases, GDP decreases compared to the baseline case for the 2020 cases, but change in GDP can be positive or negative depending on the year in the other cases. Comparing these results with those for the lower abatement cases, the degrees of the changes are almost the same or slightly decline when increasing and expand when decreasing. The differences in the above results between the cases might be due to the way of handling the terminal condition. For the no-subsidy cases, since the amount of emission abatement is larger for the longer-term cases, the utility level is lowered more. Consequently, investment is affected more severely and decrease in GDP becomes larger.

The components of GDP change as explained in the previous sections for all the cases (Fig. 10). In addition, MAC and the environmental indicators, too, change as in the previous sections (Figs. 3 and 7, and Fig. 11). In these cases, industrial structure also has

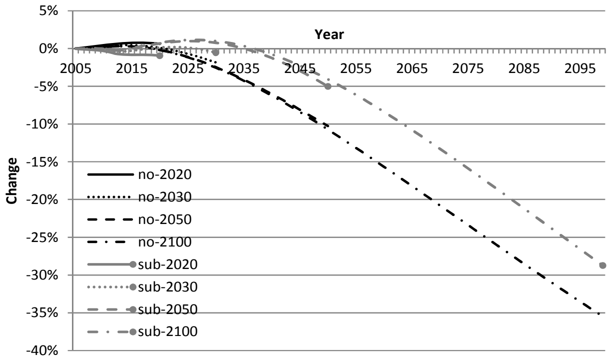

Fig. 9 Change in GDP for cases of 90% abatement in 2100 (no: no-subsidy case; sub: subsidy case. e.g. no-2020: no-subsidy-2020 terminal point case).

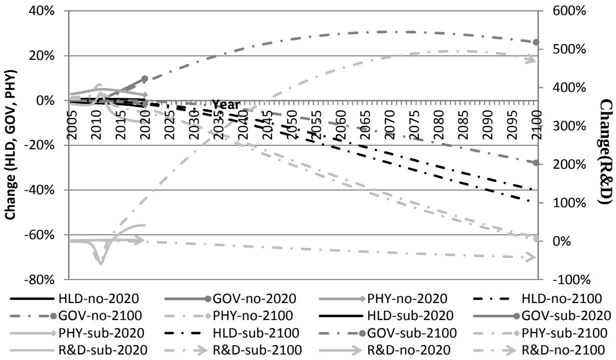

Fig. 10 Change in components of GDP for cases of 90% abatement in 2100 (e.g. HLD-no-2020: household consumption for the no-subsidy-2020 terminal point case).

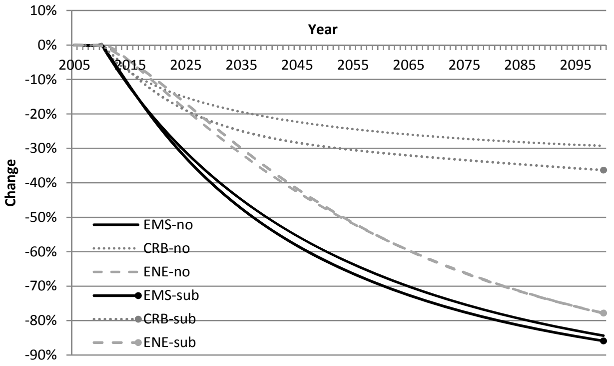

Fig. 11 Change in environmental indicators for cases of 90% abatement in 2100 (e.g. EMS-no: emission intensity for the no-subsidy case).

changed similar to the previous sections. For the 2100 without subsidies case, the percentage of production from tertiary industry increases 8.0 percentage points and that from secondary industry decreases 7.7 percentage points in 2100 compared to the 2005 levels, which are larger than the small abatement cases. For the 2100 with subsidies case, on the other hand, the percentage of production from tertiary industry decreases 4.0 percentage points and that from secondary industry increases 4.4 percentage points in 2100 because of the same reason mentioned in section 4.2.

5. Conclusions

In this paper, the authors have analyzed the impacts of CO_2 emission abatement as a climate change measure in Japan using a dynamic CGE model considering ETC developed by Matsumoto [17]. We compared the impacts by setting different terminal points in the model.

As a result, the authors found that the trends of GDP were different between the cases. For no-subsidy cases, while GDP increased compared to the baseline case when short periods were considered, it increased in earlier years and decreased in later years when longer periods were considered. The change in investment would determine increase or decrease in GDP in this analysis. For the subsidy cases, while GDP decreased compared to the baseline case for the 2020 cases, change in GDP could be positive or negative depending on the year for the other cases. In these cases, R&D investment or technological change, accelerated mainly by subsidies on R&D investment, played an important role to raise GDP. This effect was stronger in later years because of the larger subsidies.

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

To summarize, this study showed that although there was compatibility between economic growth and CO_2 emission abatement in the short term, the economic damage was observed in the long term. Because the amount of emission abatement becomes large in the far future, technological change and other factors could not cover the damage.

In this study, only one electricity sector (ELE) exists in the model. It means that although it is possible to consider the fossil fuel switches, it is not possible to consider the substitution effects between fossil fuels and renewables explicitly. However, such effects are significant to consider CO_2 emission abatement in the longer-term future. Thus, analysis taking account of multiple types of power generation 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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