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ANALYZING ECONOMIC IMPACTS OF CO_2 ABATEMENT AND R&D PROMOTION IN JAPAN APPLYING A DYNAMIC CGE MODEL WITH ENDOGENOUS TECHNOLOGICAL CHANGE

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This study proposes to develop a dynamic general equilibrium model that considers endogenous technological change and to analyze the economic impacts of a climate change measure using it. In order to focus on the relationships between the measure and its impacts in Japan, it is a single country model targeting the Japanese economy. Endogenous technological change is modeled as the accumulation of knowledge capital which is derived from research and development (R&D) investment.

As a result, negative effects on GDP and household consumption are observed when only abatement of CO_2 emissions is implemented and the effects become more severe according to the amount of abatement, despite technological change being promoted. However, when emission abatement and subsidies on R&D investment are implemented simultaneously, it is indicated that there is a possibility of positive effects on both GDP and household consumption compared to the base case through further acceleration of R&D investment and the accumulation of knowledge capital. Similar tendencies are observed in sensitivity analysis for some key parameters.

Key Words: *dynamic CGE model, endogenous technological change, knowledge capital, R&D investment, climate change policy, subsidy, economic impact*

1. INTRODUCTION

Climate change is one of the most significant global environmental issues for the present society and policy discussions from mid- to long-term perspectives are continuing all over the world including in Japan and the international arena such as in UNFCCC. Although the expected new protocol for the Post Kyoto Protocol beyond 2013 was not established at COP15 held in Copenhagen in December, 2009, the Copenhagen Accord was made. Based on the accord, the Annex I countries of UNFCCC and some major non-Annex I countries (55 countries and 78% of the world emissions in total) submitted their pledge on GHG emission abatement by the end of January, 2010$^{1)}$. As former Prime Minister 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. The Hatoyama 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$^{2)}$. In addition, the cabinet established a target to raise the research and development (R&D) investment of the total of private and governmental sectors to 4% of GDP by 2020FY following the New Growth Strategy (Framework) determined at the extraordinary cabinet meeting on December 30, 2009. The New Growth Strategy was then decided by the Kan cabinet on June 18, 2010.

International actions considering the relationships between climate change measures, R&D investment, technological development, and economy preceded such movements. On July 21, 2008, the Green New Deal Group published "A Green New Deal"$^{3)}$ and UNEP put out a press release on "Global Green New Deal" on October 22, 2008$^{4)}$. Along with the speech on such topics given by US President Obama, similar movements have spread to many countries.

In order to address the additional costs and economic impacts that accompany climate change mitigation measures, importance of technological development and its diffusion is being particularly emphasized globally in recent years. Technological change can be understood as the increase in outputs possible from a given level of inputs through the processes of invention, innovation, and diffusion[5]. In other words, inputs such as natural resources necessary to produce a certain amount of outputs are reduced. Especially, a decline in inputs from fossil fuels can be connected directly to mitigation in climate change. Thus, handling endogenous technological change in economic models would be of much significance for analyzing such relationships between climate change and its measures, technology, and economy. This is because endogenous technological change implies incorporating a feedback mechanism by which policy can direct technological change toward carbon-saving technology[5]. However, computable general equilibrium (CGE) models, which have been frequently used for economic analysis of climate change issues and its measures, in previous studies have treated technological change exogenously[5]-[8] and those with endogenous technological change are rare[5], [9]-[14]. There have been no such models targeting the Japanese economy. In addition, the methodology of modeling endogenous technological change has not yet been consolidated and several methods have been proposed. When modeling endogenous technological change, mainly two methods can be considered, namely knowledge capital accumulation through R&D investment and technology learning. The latter is generally used in bottom-up models and the former is more appropriate for CGE models considering structure[14].

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]-[20]. Especially, it has been applied to economic analysis in the environmental and energy fields which are closely related to climate change issues[9]-[14]. This is due to growing importance of climate change as one of the most significant social issues and the relevant policies are closely related to R&D investment, resulting in technological changes.

Concerning studies on climate change polices applying CGE models that consider endogenous technological change, first, Goulder and Schneider[9] analyzes impacts of carbon tax and an R&D subsidy on CO_2 emissions and economy using an optimum growth dynamic CGE model targeting the US economy. However, there are some issues for analyzing climate change policies such as the assumption that knowledge capital stock is 20% of physical capital stock and coarse aggregation of industrial sectors, especially energy sectors. Besides, knowledge capital is assumed not to be depreciated. Otto, et al.[11] studies energy bias in technological change also using an optimum growth dynamic CGE model, but the fictitious data are used in this study. Otto, et al.[12] analyzes effects of differentiated CO_2 emission abatement between CO_2 intensive and non-CO_2 intensive sectors and R&D subsidies using an optimum growth CGE model of the Netherlands considering technology externalities, and Löschel and Otto[10] analyzes effects of CO_2 emission abatement policy using the same model but considering uncertainty in CO_2 backstop technology. These models use more disaggregated sector classification than Goulder and Schneider, but energy sectors are aggregated to electricity and non-electricity sectors (electricity is separated into CO_2 intensive and non-CO_2 intensive electricity). Therefore, substitution effects between energy when introducing climate change policies are not reflected. In addition, although R&D investment and knowledge are estimated using the method also used in this study (see section 2.4 below), the former is estimated based on investment in information and communication infrastructure and the latter is based on expenditure on R&D and education. Thus, there is no consistency in these estimates. Wang, et al.[14] analyzes economic impacts of CO_2 emission abatement and R&D subsidies using a dynamic CGE model targeting the Chinese economy and consisting of more detailed sector classification. Although it is a dynamic model, recursive dynamic structure is applied unlike the above studies. However, since modeling to look into the future is significant to determine the amount of investment, optimum growth models (also called forward-looking models) are appropriate[21]. Especially, this approach is appropriate when technological change realized through R&D investment is the core of analysis like this study and the above studies.

Based on the above background, this study proposes to develop a CGE model targeting the Japanese economy and to introduce endogenous technological change through R&D investment in it. Economic impacts of abatement of CO_2 emissions as a climate change measure are then analyzed considering technological change. The structure of the developed model is based on the above studies, but some problems and shortages seen in these studies are modified, that is detailed classification of energy sectors, use of consistent data to estimate R&D investment and knowledge capital, and dynamic structure based on the optimum growth approach.

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. The model is a single-country model focusing on Japan and consisting of 33 industrial sectors (Table 1). Also, energy and environmental modules have been combined in the economic model. Knowledge capital appears in the production and dynamics as shown below.

Table 1 Classification of industrial sectors

	Classification		Classification
1	Agriculture, forestry, fisheries	18	Information equipment
2	Mining	19	Electronic components
3	Coal	20	Transportation equipment
4	Crude oil	21	Precision instruments
5	Natural gas	22	Other manufacturing
6	Foods	23	Construction
7	Textile	24	Electricity
8	Pulp, paper, wood	25	Gas & heat supply
9	Chemical	26	Water supply
10	Petroleum products	27	Waste management
11	Coal products	28	Commerce
12	Ceramic, stone, clay	29	Finance
13	Ferrous metal	30	Real estate
14	Non-ferrous metal	31	Transportation
15	Metal products	32	Communication
16	General machinery	33	Other services
17	Electric machinery		

(1) Data

The social accounting matrix (SAM) is the most frequently used data form for CGE models, in which industry, households, government, and abroad are considered as economic entities. In this model, only one sector exists for households, government, and abroad, respectively. The household sector possesses labor and capital (both knowledge capital and physical capital) and supplies the labor and capital to the industrial sectors. Taxes are imposed on the income and the remainder is used for consumption and saving. This household saving links to investment (both R&D investment and physical capital investment).

Industrial sectors produce goods using domestic and imported intermediate goods and production factors owned by the household sector described above. The produced goods are distributed to those for domestic use and export. They pay production tax to government.

Government uses the tax revenue, tariffs, and emission permit revenue (in this study it is assumed that government allocates emission permits by auction when implementing CO_2 emission abatement) for its expenditure. The budget deficit and current-account surplus are imposed on the household sector.

In this study, SAM is developed based on the 2005 Input-Output Table for Japan. As described above, the industrial sectors are aggregated into 33 sectors, but the energy sectors are described in detail with seven sectors (i.e. coal, crude oil, natural gas, coal products, petroleum products, gas and heat supply, and electricity) to analyze a climate change measure. The data on knowledge capital and R&D 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. Since emission data by energy and sector (including households) are shown in the Carbon Balance Statistics Table in it, the data are aggregated into the energy and sectors of this study. Direct CO_2 emissions are taken into account, thus CO_2 is taken as emitted in all energy consumption except electricity.

(2) Production structure

Each industrial sector performs production activities using production factors and intermediate inputs. Although each sector produces single goods, export-manufacturing industries produce goods for domestic use and export as joint products. The intermediate inputs are input as Armington aggregations of domestic and imported goods. When consuming energy goods, CO_2 emission permits corresponding to the amount of emissions from energy consumption are required. The model uses nested CES (constant elasticity of substitution) production functions, which are frequently used in CGE models. The substitution relationship of knowledge capital is considered at the top level of the functions as seen in existing studies[9)-10), 12)-14)] (Fig.1). Since inputs necessary to produce a certain amount of goods are reduced because of technological change, the substitution relationship between knowledge capital and other aggregated inputs as in Fig.1 is considered appropriate.

(3) Household and government consumption 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 supply, and consumes goods as Armington aggregations subject to the income. It is also required to hold emission permits for energy use just as the industrial sectors are. The household utility function is also a nested CES function (Fig.2).

Government determines its expenditure of Armington aggregations subject to the budget obtained from labor income tax, capital income tax, production tax, tariffs, and emission permit revenue. The government expenditure is also based on a nested CES function (Fig.3).

(4) Endogenous technological change

One characteristic of this model is to handle knowledge capital as one type of capital. Knowledge capital is used as a production factor and modeled to demonstrate the link between the knowledge capital accumulation in the economy and technological change based on the concept of endogenous growth theory[13), 22)-23)]. It is accumulated due to R&D investment, the scale of which is determined endogenously in dynamic structure. In other words, the level of R&D investment is determined based on its relative price and this links to technological change (accumulation of knowledge capital). This technological change affects economic growth and CO_2 emissions. Knowledge capital is assumed to be distributed throughout the economy as well as physical capital.

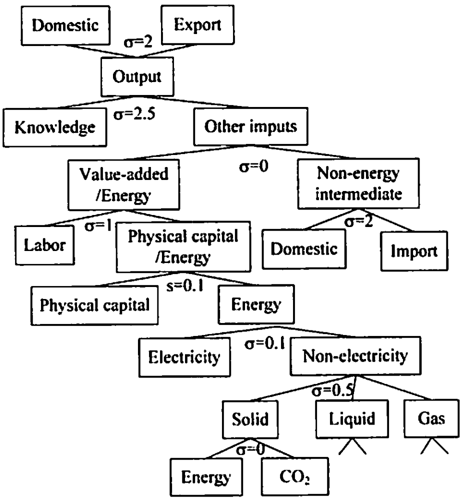

Fig.1 Production structure of industrial sectors

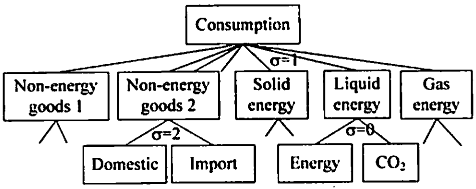

Fig.2 Structure of household consumption

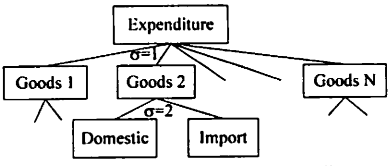

Fig.3 Structure of government expenditure

As mentioned in the previous section, both R&D investment and knowledge capital are not disaggregated in the Input-Output Table for Japan. Therefore, they are estimated using the method of Terleckyj[24)-25)], also used in Löschel and Otto[10)], Otto, et al.[12)], and Wang, et al.[14)]. When R&D investment (and knowledge capital) is handled like in this study, it should be obtained by sector and constructed in the same framework with the components of existing SAM such as consumption and investment. Furthermore, when using a CGE model, SAM must be balanced even when R&D investment is considered. The method of Terleckyj is useful because it considers that factors of R&D investment and knowledge capital are included in intermediate inputs of SAM and it is possible to satisfy the above conditions just using a simple approach. 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. The row sum and column sum correspond to R&D investment and knowledge capital, respectively. This method can be summarized in the following equations (1a)-(1d).

$$KC_{i,j} = \frac{INP_{i,j}}{\sum_j INP_{i,j}} RDV_i \tag{1a}$$

$$RD_i = \sum_j KC_{i,j} \tag{1b}$$

$$KN_j = \sum_i KC_{i,j} \tag{1c}$$

$$INPX_{i,j} = INP_{i,j} - KC_{i,j} \tag{1d}$$

$INP_{i,j}$: original intermediate input matrix by sector, $INPX_{i,j}$: modified intermediate input matrix by sector, $RDV_{i,j}$: R&D investment by sector, $KC_{i,j}$: knowledge factors in intermediate input, RD_i: row sum of knowledge factors (R&D investment by sector), KN_j: column sum of knowledge factors (knowledge capital by sector)

Although the data on R&D investment are obtained from the above method, the initial values are adjusted for the reason described in the next section.

(5) Dynamic structure

Consideration of the temporal aspect is indispensable for analyzing the changes in environment and economy as in this study. Moreover, the determination of the investment amount is an important issue for this analysis. Therefore, dynamic structure based on the Ramsey growth model is applied in the model. In the Ramsey growth model, households maximize the present discounted value of the utility based on their consumption as shown in the equations (2a)-(2e). Although only physical capital is generally considered as capital, knowledge capital (and R&D investment) is also considered in these equations.

$$\max \sum_{t=0}^{\infty} \left(\frac{1}{1+\rho}\right)^{t} U(C_t) \tag{2a}$$

$$Y_t = F(K_t, KN_t, L_t) = C_t + I_t + RD_t \tag{2b}$$

$$K_{t+1} = (1-\delta)K_t + I_t \tag{2c}$$

$$KN_{t+1} = (1-\mu)KN_t + RD_t \tag{2d}$$

$$L_{t+1} = (1+g)L_t \tag{2e}$$

$U(\cdot)$: utility function, $f(\cdot)$: production function, C_t: consumption, Y_t: income, K_t: physical capital, KN_t: knowledge capital, L_t: labor, I_t: physical capital investment, RD_t: R&D investment, ρ: discount rate, δ: depreciation rate of physical capital, μ: depreciation rate of knowledge capital, g: increase rate of labor

Here, the optimum condition below must be satisfied. The detail of the elicitation process is described in for example Paltsev[26)].

$$P_t = \left(\frac{1}{1+\rho}\right)^{t} \frac{\partial U(\cdot)}{\partial C_t} \tag{3a}$$

$$PK_t = (1-\delta)PK_{t+1} + P_t \frac{\partial F(\cdot)}{\partial K_t} \tag{3b}$$

$$PN_t = (1-\mu)PN_{t+1} + P_t \frac{\partial F(\cdot)}{\partial KN_t} \tag{3c}$$

$$P_t = PK_t = PN_t \tag{3d}$$

P_t: production price, PK_t: physical capital price, PN_t: knowledge capital price

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 (e.g. the developed SAM in this study) 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[21),26)-27)]. The amount of investment is adjusted following these examples. To be more precise, if the investment amounts from SAM are higher (lower) than the theoretical values estimated from the capital amounts in the base year, growth rate, and depreciation rate, the difference is added to (subtracted from) the household consumption.

In this type of dynamic CGE 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, based on the method proposed by Lau, et al.[28)], the condition under which increases in investment become equal to the economic growth rate at the terminal point is given. This method has an advantage that there is no need to specify the rising rate of investment ahead. In addition, the increase rate of labor in efficiency units is assumed to be equal to the growth rate to confirm the dynamic stable equilibrium condition from the initial to terminal points[21),26)].

3. BASELINE AND SCENARIOS

(1) Baseline settings

SAM described in the previous section is used for the base year (2005) data, and dynamic analysis is then implemented from that year to 2020 (interest rate: 5%/yr). The economic growth depends on labor increase (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. It can be considered that knowledge capital is not depreciated if it is accumulated very gradually, otherwise it is reasonable to consider that knowledge is depreciated[11)-12)]. Since rapid technological change (industrial growth) is expected in the environmental field and also the same method is used in recent studies[10)-14),29)], knowledge capital is considered to be depreciated as well as physical capital in this study. The range of the depreciation rate is broad such as 9-15% according to Sue Wing[13)] and 18-35% according to Otto, et al.[12)]. Thus, the above value is used in this study and the analysis is complemented by sensitivity analysis.

(2) Scenario cases

In order to analyze the impacts on CO_2 emissions and economy when considering endogenous technological change, scenario cases against the baseline are set. One is for the amount of CO_2 emission abatement. In this study, six cases from 0% (no abatement) to 50% compared to the baseline are prepared and the same rate is abated in each year for each. The other is subsidies on R&D investment. It is expected that R&D investment is promoted due to the subsidies and technological change occurs as a result. The subsidy rates from 0% (no subsidies) to 50% compared to the baseline are prepared and the rates are constant in each year.

36 cases, the combination of the above two settings, are analyzed using the dynamic CGE model, and each scenario is then compared with the baseline.

4. RESULTS

(1) Marginal abatement costs

Marginal abatement cost (MAC) of CO_2 emissions represents the cost to abate one unit of CO_2 emission incrementally and is frequently used to show the economic severity of the abatement. Fig.4 shows MAC curves for each year when only CO_2 emission abatement is implemented. As it shows, MAC increases with increases in the abatement rate and the curves can be approximated by quadratic functions as seen in similar studies[14]. In addition, it is indicated that MAC in each year except for the base year declines with subsidies on R&D investment (Fig.5). This means that the economic burdens from abating CO_2 emissions are reduced by introducing subsidies.

(2) Impacts on investments

Fig.6 shows the impacts of CO_2 emission abatement on R&D investment and physical capital investment. As this figure shows the changes compared to the baseline, the higher the emission abatement rate, the higher the R&D investment will be. The difference is larger in the earlier years than in the later years. Such increases in R&D investment accelerate the accumulation of knowledge capital and bring technological change along with CO_2 emission abatement.

Observing the changes in physical capital investment, on the other hand, the higher the emission abatement rate, the lower the investment will be contrary to R&D investment. The difference is larger in the earlier years than in the later years.

It is considered that the reason for such relationships between R&D investment and physical capital investment is due to the substitution relationships in the production structure shown in Fig.1. Although knowledge capital, accumulated through R&D investment, has a substitution relationship at the top level of the function, physical capital has a relationship at the lower level. Thus, considering the optimum resource allocation to maximize household utility under the constraints on CO_2 emissions, increase in allocations toward R&D investment is regarded as efficient.

Next, Fig.7 shows the impacts of subsidies on investment compared to the no-subsidy case. R&D investment increases by introducing the subsidies and the amount of increase is larger in the earlier years and shrinks over time. On the other hand, physical capital investment decreases by introducing the subsidies and the amount of decrease is larger in the earlier years and shrinks over time.

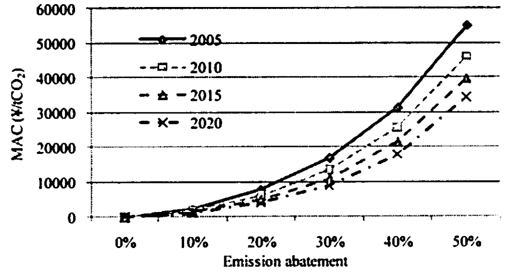

Fig.4 MAC curves

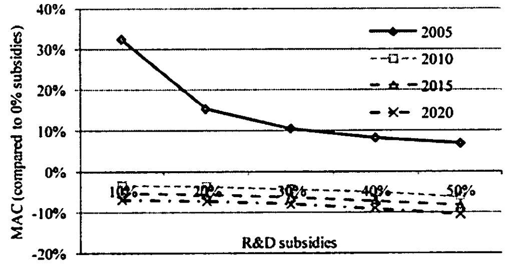

Fig.5 Change in MAC with subsidies

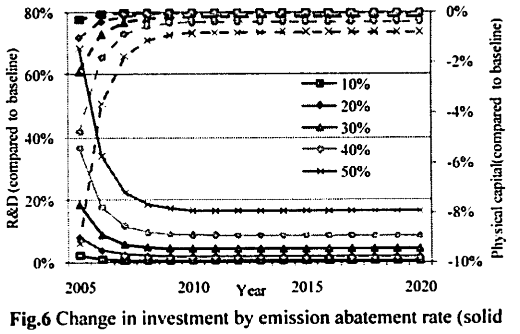

Fig.6 Change in investment by emission abatement rate (solid line: R&D, dashed line: physical capital)

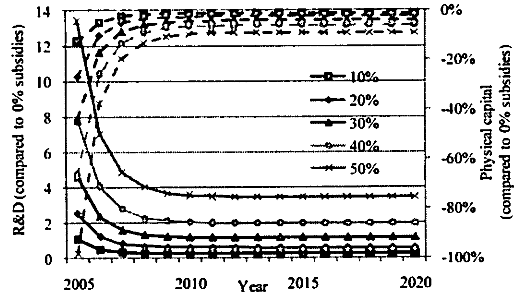

Fig.7 Change in investment with subsidies (10% abatement cases; solid line: R&D, dashed line: physical capital)

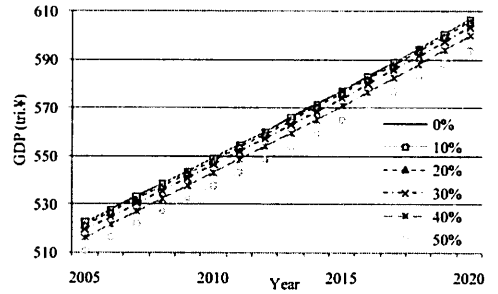

Fig.8 Change in GDP by emission abatement rate

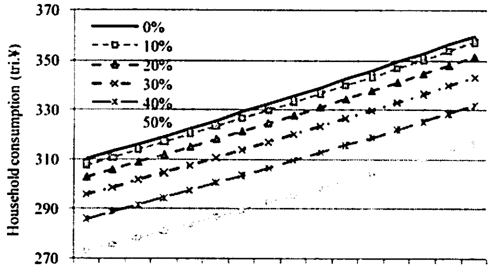

Fig.9 Change in household consumption by emission abatement rate

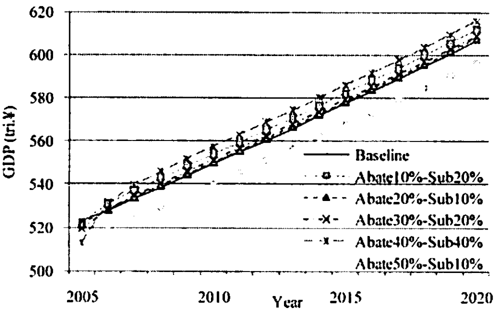

Fig.10 Change in GDP due to combination of emission abatement and subsidies

(3) Economic impacts

Observing the economic impacts other than investment, GDP decreases compared to the baseline when emissions are abated (Fig.8). The decrease rates are from 0.05% for the 10% abatement case to 2% for the 50% case, and there are almost no year-by-year differences for each case. Decreases in household consumption are the most significant factor both in the amount and rate for decreases in GDP (Fig.9). As the figure shows, the decrease rates are from 0.7% for the 10% case to 12% for the 50% case, and there are almost no year-by-year differences for each case as well as GDP. In these cases, although technological change occurs as described in the previous section, it is not possible to improve the economy only through such change.

What will happen if R&D investment is subsidized? Fig.10 shows some results on GDP for scenarios compared to the baseline. As the figure shows, there is a possibility of increasing GDP, except for the base year, by introducing subsidies on R&D investment even when CO_2 emissions are abated. According to the analysis, such a tendency is observed when the combinations of abatement-subsidies are 10-10%, 20-10%, 30-20%, 40-30%, 50-40%, and higher subsidy cases than these. Among these cases, government expenditure also increases for low subsidy cases, which means that increase in GDP is achieved through the subsidies without sacrifice of government expenditure. In addition, household consumption increases compared to the baseline when the combinations of abatement-subsides are 10-20%, 20-40%, 30-50%, and higher subsidy cases than these.

5. SENSITIVITY ANALYSIS

The simulation results can be affected by the parameter values used in the model. Thus, sensitivity analysis for the discount rate and depreciation rate of knowledge capital is implemented. In this study, analysis when they are halved or doubled, respectively, has been implemented (four cases in total).

The results of the sensitivity analysis for the terms also shown in the previous section are summarized in Table 2. From this analysis, it is indicated that the tendencies in the results are almost the same as in the original results. That is, R&D investment increases with emission abatement and subsidies on R&D investment, but physical capital investment decreases. GDP and household consumption decrease with emission abatement, and the economy is not improved only with technological change promoted by the abatement. However, there is a possibility to improve the economy when subsidies on R&D investment are introduced even though emissions are abated. Although MAC increases with emission abatement as well, it tends to decline with introduction of subsidies.

What affected by the parameter values are the amount of increase or decrease in the results compared to the baseline. When the discount rate is halved, the amount of increase in R&D investment and the amount of decrease in physical capital investment decline (increase in the amount of investment declines overall), and the amount of decrease in household consumption expands from the original results. As a result, the amount of decrease in GDP also expands. The same consequence is obtained when the depreciation rate

Table 2 Sensitivity analysis

	MAC		R&D investment		Physical capital investment		GDP		Utility	
	A	S	A	S	A	S	A	S (number of increasing cases^f)	A	S (number of increasing cases^f)
Original	Inc	Dec^a	Inc	Inc	Dec	Dec	Dec	(19)	Dec	7
Discount rate (half)	E	D	D	E	D	D	E	E(19)	E	E(7)
Discount rate (double)	E	E	E	D	E	E	D^c	D(18)	D	D(6)
Depreciation rate (half)	E(2005), D(2006-)	E	E	E	E	E	E	D(12)	D	D(7)
Depreciation rate (double)	D(2005), E(2006-)	D^b	D^c	D	D^d	D	E	E(21)	E	E^g(7)

*E (D) in the table indicates expansion (decline) in the amount of increase or decrease for each term compared to the original result. A indicates cases of emission abatement and S indicates cases in which subsidies are introduced. Inc (Dec) means increase (decrease) compared to the baseline.

a: an increase is observed for all the cases in the earlier years. b: it tends to increase for low abatement cases. c: the investment slightly decreases for low abatement cases. d: the investment slightly increases for low abatement cases. e: the decrease amount slightly expands (E) for 50% case. f: excluding 0% abatement case. g: the increase amount declines for 30% abatement case.

of knowledge capital is doubled. The reason for such results is that household consumption is the most significant factor influencing GDP change, and the changes in the discount rate and depreciation rate have a tremendous impact on the determination of household consumption and saving in the dynamic process. On the other hand, the amount of increase in household utility and GDP expands for the cases in which they increase, and also the number of such cases increases.

When the discount rate is doubled, the opposite results to those of when it is halved are obtained. The amount of increase in R&D investment and the amount of decrease in physical capital investment expand (increase in the amount of investment declines overall), and the amount of decrease in household consumption declines compared to the original results. Consequently, the amount of decrease in GDP also declines. However, when the depreciation rate is halved, almost the opposite results from those for the doubled case are obtained, yet the amount of decrease in GDP expands. It is considered that such a result is obtained because the differences in the changes in the components of GDP (i.e. household consumption, government expenditure, investment, and import and export) compared to the baseline are smaller than those of the original result, hence the balance among them affects the obtained results. On the other hand, the amount of increase in the household utility and GDP declines for the cases in which they increase, and also the number of such cases decreases.

6. CONCLUDING REMARKS

In this study, a dynamic CGE model considering endogenous technological change was developed and the impacts of CO_2 emission abatement as a climate change measure and subsidies on R&D investment were analyzed using the model. Endogenous technological change was defined as the relationship with the accumulation of knowledge capital through R&D investment. As a result, negative economic impacts such as increases in MAC and decreases in household consumption and GDP were observed when CO_2 emissions were abated as in existing studies. In these cases, although technological change was accelerated depending on the abatement amount, the effect could not offset the negative impacts because of the abatement. However, even in such a situation, it was suggested that positive economic effects could occur due to acceleration in the accumulation of knowledge capital through R&D investment by introducing subsidies on it. This tendency was confirmed in the range of the sensitivity analysis of this study.

As mentioned in the previous sections, most of the CGE models in existing studies considered technological change exogenously. Therefore, it was difficult to analyze the effects of technological change corresponding to policies and measures unlike this study. Even in such models, one possibility is to set parameters related to technological change in advance for each policy or measure, and use them accordingly. However, the relationship between policies and measures and technological change is assumed arbitrarily even though there is background information to some extent. Thus, the method used in this study, that is technological change is determined according to changes in policies and measures (CO_2 emission abatement and subsidies on R&D investment for this study) in the dynamic structure while considering the relationships with other factors, is considered better than the above one.

In this study, revenue from emission permits accompanied by CO_2 emission constraints is considered as the general income of government, and the subsidy rates on R&D investment are set independently of it. Therefore, analysis taking account of the relationship between the revenue and subsidies, and also policy-oriented analysis considering more broadly about climate change measures and environmental investment will be implemented for the future works. Furthermore, studies on modeling methodology of knowledge capital such as the spill-over effects of knowledge and sector-specific knowledge (technology) will be implemented.

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