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Measurement of social net benefit of climate stabilization policy

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Abstract

To evaluate the social welfare of climate stabilization policy from perspectives of cost–benefit analysis in a optimal economic growth framework based on macroeconomic theory, the purposes of this study are to show theoretically that the equivalent variation is divisible into a public-welfare effect, an income-change effect, and changes in investment in consideration of non-market effects of temperature change on utility. Then each effect of climate stabilization policy must be measured using simulation analysis. Consequently, it is concluded that the framework that this study has adopted is theoretically consistent with traditional cost-benefit framework and can measure each effect of climate stabilization policy.

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1. Introduction

In recent years, numerous studies including those of the IPCC (2007) have undertaken quantitative evaluation of dangerous levels of greenhouse gases (GHGs), which are likely to exacerbate climate change and affect atmospheric stability. Matsuoka (2005) reported that "compared to the preindustrial temperatures, an increase in global mean temperature over 2.0°C would have some severe impacts" through his review of the level of dangerous climate change and climate stabilization of GHG concentrations. Hijioka *et al.* (2006) reported that, to avoid a global mean temperature increase of greater than 2.0°C, a stabilization target for GHG concentrations of less than 500 ppm by volume is needed. Furthermore, Stern (2006) reported that a stabilization range of from 450 ppm – 550 ppm necessitates urgent, sharp reductions in GHG emissions. As described above, strict climate stabilization actions and considerable burdens in each country or each region are necessary to stabilize atmospheric GHG concentrations at a lower level.

Although numerous attempts have been undertaken by researchers to evaluate climate change countermeasures quantitatively, little effort has been made to perform a cost–benefit analysis of policies that have been pursued since the 1990s, when numerous studies, such as those of Cline (1992), Nordhaus (1993), Nordhaus and Boyer (2000), were conducted using cost–benefit analyses of global warming countermeasures. Cost–benefit analysis was developed as a benefit evaluation theory using general equilibrium analysis based on macroeconomics (e.g. McKenzie (1983), Ray (1984), Layard and Glaister (1994), Morisugi (1997), Boardman *et al.* (2006)); the analysis has been applied many times. Additionally, it has been practically applied to public works projects and environmental assessments. In Japan, for example, Morisugi and Hayashiyama (1997) showed, using a simple dynamic general equilibrium model, that the national benefits of railway network formation during the Meiji and Taisho era are measurable by their GNP contribution effects and the welfare effects. A great deal of effort has been made for policy evaluation of climate change countermeasures, such as a carbon tax and emissions trading, using a computable general equilibrium model and a dynamic optimization model that are designated as an integrated assessment model (e.g. Jorgenson and Wilcoxen (1993), Manne and Richels (1993), Amano (1996), Weyant (1999a), Weyant (1999b), Kainuma *et al.* (2003), Stern (2006)).

As described above, however, what is apparently lacking is evaluation of global warming countermeasures using cost–benefit analysis. One reason is that it necessitates further theoretical discussion of cost–benefit analysis using an optimal economic growth model based on macroeconomic theory. It is likely that ambiguous definitions of benefits and costs have made cost–benefit analysis of global warming countermeasures inconsistent with macroeconomic theory. Although Nordhaus and Boyer (2000) have conducted detailed regional cost–benefit analyses of some alternative policies, the definition and formulation of carbon dioxide (CO2) emissions reduction costs in their analysis are ambiguous, and their cost–benefit analysis is not theoretically well-supported. Additionally, although Nakajima *et al.* (2008) has formulated CO2 emissions reduction costs that are defined as differences between a net benefit of policy implementation and a benefit of reduction in global warming damage by policy, their cost–benefit analysis measures only direct effects of policy and are therefore theoretically insufficient.

To evaluate the social welfare of climate stabilization policy from perspectives of cost–benefit analysis in a optimal economic growth framework based on macroeconomic theory, the purposes of this study are to show theoretically that the equivalent variation is divisible into a public-welfare effect, an income-change effect, and changes in investment in consideration of non-market effects of temperature change on utility. Then each effect of climate stabilization policy must be measured using simulation analysis. Consequently, this study is part of a cost–benefit analysis using a macroeconomic framework that has received little attention.

The structure of this study is the following. Chapter 2 presents a theoretical means to divide equivalent variation into three effects and to measure these effects. Chapter 3 explains outlines of the model and scenario that this study adopts. Chapter 4 measures equivalent variation and three effects derived in Chapter 2 by simulation analysis with climate stabilization scenarios; it describes an examination of these results of simulation analysis. Finally, Chapter 5 presents concluding remarks and topics for future study.

2. Definition of Social Benefit Using Equivalent Welfare Measure

This study extends the way of describing money welfare measures by Morisugi and Hayashiyama (1997); it also shows theoretically that the equivalent variation by alternative scenarios is divisible into public-welfare effects, income-change effects, and changes in investment.

First, to evaluate various climate stabilization scenarios macro-economically, social cost, social benefit, and social net benefit are defined as shown below. For our purposes, $C^i(t)$ denotes the consumption in period t, $Q^i(t)$ signifies production, $I^i(t)$ represents investment, and r denotes the discount rate. Index i is represented as a with or without indicator, for which the Business-as-Usual (BaU) scenario corresponds to index $i=0$, and for which other climate stabilization scenarios correspond to index $i=1$. Furthermore, each variable in (1) is defined as the present value of the benchmark year in $t=0$. (2) is rewritten as variable converted by the presented value.

$$\sum_{t=0}^{T}\frac{C^i(t)}{\left(1+r\right)^t}=\sum_{t=0}^{T}\frac{Q^i(t)}{\left(1+r\right)^t}-\sum_{t=0}^{T}\frac{I^i(t)}{\left(1+r\right)^t}\quad (i=0,1) \tag{1}$$

$$C^i=Q^i-I^i\quad (i=0,1) \tag{2}$$

Output with temperature change Q^i is assumed as the product of output without temperature change Y^i and the impact of its changes Ω^i; it is given by (3).

$$Q^i=\Omega^iY^i\quad (i=0,1) \tag{3}$$

Considering (3), consumption in the BaU scenario and the climate stabilization scenario is given as (4) from (2) and (3).

$$C^i=\Omega^iY^i-I^i\quad (i=0,1) \tag{4}$$

Social net benefit SNB is defined as differences between consumption with a climate stabilization scenario and consumption with BaU scenario, and is shown in (5).

$$SNB=C^1-C^0=\left(\Omega^1Y^1-\Omega^0Y^0\right)-\left(I^1-I^0\right)=SB-SC \tag{5}$$

Regarding the second equality sign in (5), the first term of the right-hand side (RHS) represents social net benefit by climate stabilization policy and the changes in production by policy implementation. The second term of the RHS represents social costs of the policy and differences of investment needed because of policy implementation. Therefore, the social net benefit in (5) can be written with social benefit SB and social cost SC. If the change in output by policy implementation is positive, i.e. $\Omega^1 Y^1 - \Omega^0 Y^0 > 0$, then it represents the social benefit. If the change in output is negative ($\Omega^1 Y^1 - \Omega^0 Y^0 < 0$), then it indicates a social cost. However, if the difference in investment needed by policy implementation is positive, i.e. $I^1 - I^0 > 0$, then it represents the social cost. If the difference in investment is negative ($I^1 - I^0 < 0$), then it indicates the social benefit.

Secondly, we show the relation between social net benefit defined above and the equivalent variation to divide the equivalent variation by scenarios into the public-welfare effect, the income-change effect, and change in investment. In addition, the equivalent variation is defined as the amount of income paid or received that leaves the person at the final level of well-being (Haab and McConnell (2002)). Therefore, the equivalent variation EV by policy implementation is defined in (6) by utility u^i and the impact of temperature changes D^i.

$$EV = E_c\left(D^0, u^1\right) - E_c\left(D^0, u^0\right) = E_c\left(D^0, u^1\right) - E_c\left(D^1, u^1\right) + E_c\left(D^1, u^1\right) - E_c\left(D^0, u^0\right) \quad (6)$$

Therein, $E_c(\bullet)$ is the equivalent consumption of utility function. Now, utility u^i is assumed to be determined by consumption C^i and the impact of temperature changes D^i and by the product of the logarithm of consumption and the temperature impact; the utility function is given by (7). Additionally, if the impact of temperature changes decreases after policy implementation, it is assumed as $D^0 < D^1$. On the other hand, if the impact increases, it is assumed as $D^0 > D^1$.

$$u^i = u\left(D^i, C^i\right) = D^i \ln C^i \quad (i = 0,1) \quad (7)$$

From (6) and (7), although the equivalent consumption is represented in utility and the damage with or without policy implementation, it is readily apparent that it included in economic activities such as production and consumption, by dependence of utility on consumption. To clarify non-market damage or non-market benefits attributable to temperature increases, any x is assumed to satisfy $D^1 \ln C^1 = u = D^0 \ln x$. Then, any x can be written in (8). In addition, $E_c\left(D^i, u^i\right) = C^i$ from (7).

$$x = C^{1\frac{D^1}{D^0}} \quad (8)$$

Therefore, the equivalent variation represented in (6) can be rewritten in detail in (9) using social net benefit, as defined in (5).

$$EV = \left(C^{1\frac{D^1}{D^0}} - C^1\right) + SNB = \left(C^{1\frac{D^1}{D^0}} - C^1\right) + \left(\Omega^1 Y^1 - \Omega^0 Y^0\right) - \left(I^1 - I^0\right) \quad (9)$$

The second equality sign in (9), the first term of the RHS, is the public-welfare effect that is evaluated as the monetary expression of the public welfare changes because of the damage decrease attributable to policy implementation. The second term is the income-change effect attributable to changes in output. The third term represents changes in investment that means social cost, respectively. Economic activity changes is expressed as the term of $\left(C^1 - C^0\right)$, which is shown by differences in consumption with or without policy, the public-welfare effect is expressed as the damage change attributable to temperature change in the consumption level C^1 by policy implementation. Figure.1 presents the relation among utility, damage improvement, equivalent consumption and equivalent variation, as represented above. In this figure, the vertical axis shows consumption; the horizontal axis shows damage improvement. As the figure shows, the public-welfare effect in this study is shown as [1] in Figure.1, and the sum of the income-change effect and change in investment is portrayed as [2] in Figure.1.

It follows from the explanation so far that the method of measurement of social net benefit in this study is consistent with the theoretical framework of traditional cost-benefit analysis using the relation between the social net benefit that is defined as differences in consumption, output and investment with or without policy, and the equivalent variation that is defined as the consumption level needed to maintain the utility level after policy implementation under the condition of no implemented policy. Additionally, because the economic impact of the temperature change on utility means a non-market impact of temperature change, it follows that this study can divide the equivalent variation into a public-welfare effect, an income-change effect, and a change in investment, and that these analyses can measure the public-welfare that is evaluated in monetary terms both theoretically and quantitatively.

3. Summary for Model and Scenarios

3.1 Outline of Model

To measure each effect of climate stabilization policy as described above, this study employs a dynamic optimization model, which extends the Regional dynamic Integrated model of Climate and the Economy (RICE) developed by Nordhaus and Boyer (2000). This model consists of an economic model described in economic activities and CO_2 emissions and a climate model represented in atmospheric CO_2 concentrations, temperature increases and negative feedbacks of temperature increases on economic activities. Although the RICE model divides the world into eight regions (the United States (USA), high-income regions including OECD countries and Japan (OHI), the OECD Europe (EUR), Russia and eastern Europe including the formerly centrally planned economies (EE), middle-income (MI), lower-income (LMI), low-income (LI), and China (CHN)), the model used for the present analyses incorporates nine regions, separating Japan (JPN) from the eight RICE regions.

The damage inflicted by climate change is assumed to differ among regions. The damage function $d_j(t)$ in region j is given by (10) as a quadratic function of temperature increase $T(t)$. The damage coefficient $\Omega_j(t)$ in region j attributable to temperature change is given by (11); the damage to economic activities is represented as a fall in output as shown in (3), by multiplying the production function by the climate-change damage coefficient represented in (11). In addition, the damage coefficient used from (6) to (9) is the same as $D_j(t)$ in (11).

$$d_j(t) = \lambda_{1j} T(t) + \lambda_{2j} T(t)^2 \tag{10}$$

$$\Omega_j(t) = D_j(t) = \frac{1}{1 + d_j(t)} \tag{11}$$

Therein, λ_{1j} and λ_{2j} are locally characteristic parameters in the damage function. Although parameters for the damage function need further improvements and although parameter estimation is important, this study uses values that were incorporated into the RICE model. Additionally, those parameters for the damage function are shown in Table.1. For details related to the climate model and settings for other parameters in this study, those of Nordhaus and Boyer (2000) and Nakajima *et al*. (2008) were used.

3.2 Setting for Scenarios

To examine each effect of climate stabilization scenarios described above, scenarios in this study are assumed as described below. Furthermore, noting that the concentration unit used for this study is not the CO_2 equivalent concentration, but the CO_2 concentration.

a) Base scenario (BASE)
   This scenario is the baseline scenario in this study: no policies are taken to slow climate change.
b) 450 ppm stabilization of CO_2 concentrations (C450)
   Stabilization of atmospheric CO_2 concentrations at 450 ppm is pursued. This scenario implies a temperature increase of about 2.0 °C.
c) 550 ppm stabilization of CO_2 concentrations (C550)
   Stabilizing atmospheric CO_2 concentrations at 550 ppm is taken. This scenario is about twice preindustrial levels, which corresponds to a CO_2-doubling scenario used in some studies that have evaluated countermeasures against global warming economically in the early 1990s: Cline (1992), Nordhaus (1994), and Fankhauser (1995).

Additionally, this study examines effects of temperature change on utility. The RICE model by Nordhaus and Boyer (2000) did not consider these effects. Although numerous studies have been made of effects of climate change on production, few have assessed effects on utility. Therefore, along with scenarios presented without consideration of effects on utility, this study treats effects of temperature change on utility using the same damage function form as that used to assess effects on production. To consider the effects on utility necessitates discussion of non-market damage and benefits attributable to temperature change; we can develop the expression for (8) to measure the public-welfare effects of policy implementation.The effects on utility that this study adopts have no scientific basis; damage to utility becomes greater than that to production.

4. Measurement of Social Net Benefit by Simulation Analysis

4.1 Scenarios WITHOUT Impacts of Temperature Change on Utility Function

Table.2 shows each effect of social net benefit by implementing climate stabilization policies without effects of temperature change on utility. As sketched here, public-welfare effects in each region and the world as a whole are zero. One reason for these results is that improvement effects by climate stabilization cannot be shown to elucidate effects of temperature change on utility, which is also clear on the grounds that the first term of the RHS in the second equality sign in (9) is zero. However, because the income-change effects in the C450 and the C550 scenario are negative in all regions and the world, these results indicate social costs from (5).

Similarly, because changes in investment in the two scenarios are negative in all regions and world, they indicate social benefits from (5). Consequently, although there exist regions like EUR and JPN for which the equivalent variation in the C550 scenario is positive, most regions have negative equivalent variations in two scenarios. The reason for these results is that to impose stabilizing constraints in this model decreases economic activity compared with the BASE scenario because the model used for this study has no mechanism for which economic growth is prompted with a policy constraint like environmental investment satisfied. Furthermore, it is apparent that, because $EV = SNB$ in (9) is negative, $C^0 > C^1$ indicates decreasing production and investment and a shrinking scale of the economy after imposition of a policy constraint. Therefore, because a stricter policy reduces the scale of economy in most regions, it is difficult to support such a policy in terms of economic efficiency. Moreover, in settings of the model analysis used for this study, because the imposition of policy constraints causes decreases in the scale of economy, it is implied that it is of significant importance and indispensable factor for a mechanism that encourages economic growth by achieving policy targets to implement a climate stabilization policy.

4.2 Scenarios WITH Impacts of Temperature Change on Utility Function

Table.3 presents each effect of social net benefit by implementing climate stabilization policies with effects of temperature change on utility. It is apparent that the public-welfare effects in all regions and the world are positive. One reason for these results is that, because implementation of a climate-stabilization policy mitigates a rise in temperature, damage with or without policy indicates $D^0 < D^1$ and the first term of the RHS in the second equality sign in (9). Furthermore, it is apparent that the public-welfare effect depends on the impact of temperature change because some regions such as EUR, LMI and LI that the public-welfare effects are large have a significant decrease in damage by policy implementation. However, as shown in Table.3, equivalent variations in almost all regions except for LI in two scenarios are negative. The reason for these results is that, in addition to the decreasing scale of the economy in the case of imposing of policy constraint such as scenario with impact on utility, it indicates $((C^1)^{D^1/D^0} - C^0) + (C^1 - C^0) < 0$ from (9). Furthermore, the second term that shows a decrease in scale of economy as negative, of the RHS in the second equality sign in (9) is larger than the first term that shows the public-welfare effect. Additionally, it is likely that positive equivalent variations of LI in two scenarios result from a stronger public-welfare effect than the decrease in the scale of the economy. For reasons described above, even if the public-welfare effect in a region is positive, because negative equivalent variations of more strict policy in almost all regions means a decrease in the scale of the economy, it is likely that it is difficult to support such a policy in terms of economic efficiency. In case of scenario with effects of temperature change on utility, however, because a stricter climate stabilization policy tends to produce increasing equivalent variations in developed countries and decreasing variations in developing countries, further discussion is necessary for policy makers. They should consider not only policy evaluation with equivalent variation but also that with interregional equity.

5. Concluding Remarks

This study makes two contributions to measurement of social net benefit of climate stabilization policy from the viewpoint of cost-benefit analysis. It proposes a theoretical means to divide the equivalent variation into a public-welfare effect, an income-change effect, and a change in investment. It also measures these effects through simulation analysis with a policy scenario. The framework that this study has adopted is theoretically consistent with traditional cost-benefit framework and can measure each effect of climate stabilization policy above. Consequently, it is concluded that it is of significant importance to evaluate climate stabilization policy using a cost-benefit framework in this study. The findings in this study are shown below.

1) From the relation between the social net benefit and equivalent variation in cost-benefit analysis, this study has described division of equivalent variation into a public-welfare effect that is evaluated as the monetary expression of the public welfare change attributable to the decrease in damage attributable to the policy implementation, an income-change effect by changes in output, and a change in investment that represents a social cost. Consequently, this study has demonstrated that its framework is theoretically consistent with that of traditional cost-benefit analysis and that it is applicable in a case of a scenario showing effects of temperature change on utility.
2) For all scenarios with effects of temperature change on utility, this study has obtained positive public-welfare effects in all regions from simulation analysis. Even if the public-welfare effects are positive, however, negative equivalent variations that almost all regions have in implementing stricter policy indicate a decrease in the scale of the economy, irrespective of scenarios with or without effects on utility. Therefore, this study revealed that it is difficult to support stricter stabilization policies from the viewpoint of economic efficiency.
3) Irrespective of whether a scenario is one with or without effects of temperature change on utility, results of this study suggested that it is indispensable to have a mechanism such as environmental investment that encourages economic growth with policy target achievement to implement a climate stabilization policy.

Further consideration must be made of two kinds of equity that were not discussed herein. Intergenerational equity of the present and future generations must be addressed. Interregional equity of more-developed countries and less-developed countries must also be examined. Although neither shows agreement theoretically, each type of equity warrants inclusion in the discussion of long-term and irreversible climate change effects and their mitigation.

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Appendix

A.1 Figures and Tables

Figure 1: Relation among utility, consumption, damage, equivalent consumption and equivalent variation.

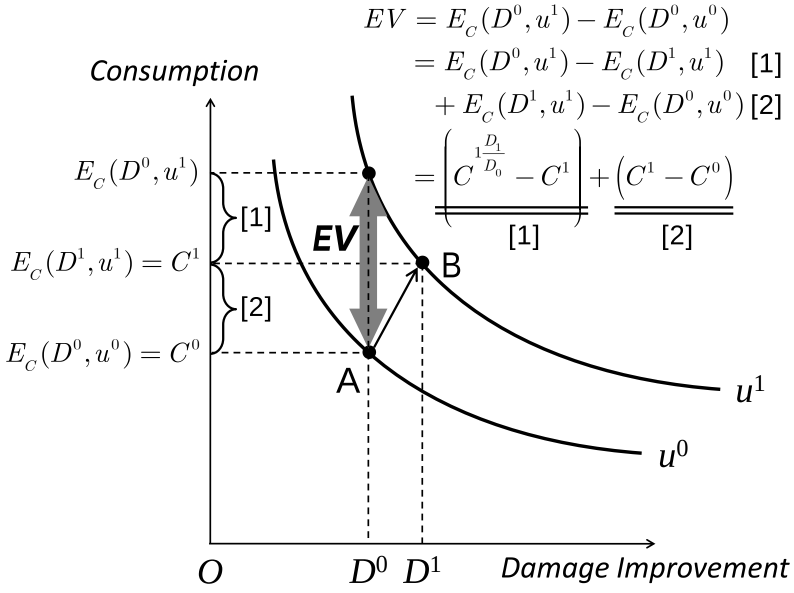

Table 1: Settings for damage function parameters

Regions	λ_{1i}	λ_{2i}
United States (USA)	-0.0026	0.0017
Other high income (OHI)	-0.007	0.003
OECD Europe (EUR)	-0.001	0.0049
Russian and Eastern Europe (EE)	-0.0076	0.0025
Middle income (MI)	0.0039	0.0013
Lower income (LMI)	0.0022	0.0026
Low income (LI)	0.01	0.0027
China (CHN)	-0.0041	0.002
Japan (JPN)	-0.0042	0.0025

Table 2: Social net benefit of climate stabilization WITHOUT effects of temperature change on utility

		USA	OHI	EUR	EE	MI	LMI	CHN	LI	JPN	WORLD
C450	PWE a)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	ICE b)	-437.91	-64.21	-148.94	-193.87	-261.58	-322.08	-388.91	-557.80	-58.80	-2434.11
	INV c)	-305.14	-48.43	-137.94	-109.33	-174.37	-180.76	-213.74	-313.44	-49.44	-1532.60
	EV d)	-132.76	-15.78	-11.00	-84.54	-87.22	-141.32	-175.16	-244.36	-9.36	-901.51
C550	PWE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	ICE	-150.31	-24.81	-65.81	-63.18	-87.13	-110.30	-126.68	-191.39	-27.29	-846.91
	INV	-131.64	-23.74	-74.79	-46.20	-74.47	-81.71	-89.76	-138.69	-27.34	-688.36
	EV	-18.67	-1.07	8.98	-16.97	-12.66	-28.59	-36.92	-52.70	0.05	-158.55

(2005US million dollars)

a) Public-welfare effect b) Income-change effect c) Change in investment d) Equivalent variation

Table 3: Social net benefit of climate stabilization WITH effects of temperature change on utility

		USA	OHI	EUR	EE	MI	LMI	CHN	LI	JPN	WORLD
C450	PWE a)	19.54	4.36	66.19	3.64	25.16	47.37	12.58	135.50	4.58	318.93
	ICE b)	-1323.69	-226.56	-630.56	-192.72	-448.87	-342.48	-216.60	-244.78	-233.23	-3859.49
	INV c)	-622.87	-116.98	-384.28	-91.47	-233.09	-170.58	-113.90	-164.66	-140.94	-2038.78
	EV d)	-681.28	-105.22	-180.08	-97.60	-190.62	-124.53	-90.12	55.38	-87.71	-1501.78
C550	PWE	22.05	4.72	68.96	4.00	27.27	49.37	13.42	136.90	4.92	331.61
	ICE	-1066.90	-169.24	-450.53	-89.39	-219.90	-197.03	-111.36	-214.63	-168.59	-2687.57
	INV	51.55	-19.47	-142.01	-38.98	-119.87	-101.44	-67.49	-132.25	-41.56	-611.52
	EV	-1096.39	-145.06	-239.57	-46.41	-72.76	-46.22	-30.45	54.52	-122.10	-1744.44

(2005US million dollars)

a) Public-welfare effect b) Income-change effect c) Change in investment d) Equivalent variation