Analyzing long-term impacts of carbon tax based on the imputed price, applying the AIM/CGE model

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Abstract

Purpose – The purpose of this study is to analyze long-term (up to 2100) impacts of carbon tax based on the imputed price of carbon (ICT) from environmental and economic perspectives.

Design/methodology/approach – ICT is an international tax with tax rates that differ among countries according to their economic levels. It is evaluated by comparing it with an internationally common carbon tax (CCT), applying the AIM/CGE [Global] model, a dynamic computable general equilibrium model. The ICT rates are determined from a certain formula and the CCT rates are set to achieve global GDP changes equal to the case of ICT.

Findings – According to the results, the world CO_2 abatement amount is almost the same between the two taxes. However, the economic impact on each country is different. Although the negative influence is smaller in the case of CCT in developed countries, it is smaller in the case of ICT in developing countries. Moreover, ICT narrows economic disparities among developed and developing countries further. In the light of significance of the worldwide introduction of CO_2 abatement policies and avoidance of excessive economic burdens on developing countries, it is concluded that ICT is a more feasible carbon tax policy than CCT.

Originality/value – Although the impacts of ICT have been analyzed from static and mid-term perspectives, understanding the long-term dynamic impacts is still essential, considering the features of the tax and possible socioeconomic and technological changes, especially in developing countries. This study proposes a new policy method that will contribute to efforts to combat climate change in the long run.

Keywords Carbon, Taxes, Prices

Paper type Research paper

1. Introduction

The first commitment period of the Kyoto Protocol started in 2008 and some discussions on the post-Kyoto Protocol are underway at the international level, such as at the Conference of Parties to the United Nations Framework Convention on Climate Change (COP) and the *Ad Hoc* Working Group on Further Commitments for Annex I Parties

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under the Kyoto Protocol (AWG-KP)[1]. However, climate change measures have made little progress globally, and realizing the greenhouse gases (GHG) emissions abatement targets under the Kyoto Protocol is still far for most of the Annex B countries of the Kyoto Protocol (Matsumoto, 2007a). Furthermore, it is indispensable to establish international climate change policies for the post-Kyoto Protocol era and achieve further commitments as soon as possible in order to sustain international efforts. There have been a number of proposals for future climate change policies, such as the multi-stage approach (Criqui *et al.*, 2003; Den Elzen and Lucas, 2003), the Brazilian proposal (Brazil, 1997; La Rovere *et al.*, 2002), the sector-based CDM (Samaniego and Figueres, 2002), the triptych approach (Groenenberg *et al.*, 2001; Groenenberg *et al.*, 2004), contraction and convergence (Meyer, 2000), multi-sector convergence (Sijm *et al.*, 2001), sustainable development policies and measures (Winkler *et al.*, 2002), the carbon intensity target (Baumert *et al.*, 1999), the dual track approach (Kameyama, 2003), standard-setting (e.g. on emissions, efficiency, and technology) (Cooper, 1998; Ninomiya, 2003), and so on (Baumert *et al.*, 2002; Den Elzen, 2002)[2]. However, the related discussions have not been developed concretely and conclusions on the methodology of future measures have not yet been provided. Therefore, appropriate policies for the future must be established immediately. When developing the future measures, systems in which not only developed countries but also developing countries participate on the basis of "common but differentiated responsibilities" (economic equity) will be necessary. This point is also emphasized in the above proposals.

Considering these perspectives, the effects of a carbon tax based on the imputed price of carbon (ICT) were analyzed by comparing it with an internationally common carbon tax (CCT) applying a static computable general equilibrium (CGE) model (Matsumoto, 2007a, 2008). In these studies, the availability of carbon taxes as an international climate change policy (the post-Kyoto Protocol) was advocated by pointing out some problems and defects of the Kyoto Protocol and Kyoto-type international climate change policies, namely assignment of emissions caps, no emissions abatement commitments on developing countries, monopolistic power in the international emissions trading market, negotiations for the future commitments, and the Weitzman theorem (Weitzman, 1974). ICT and CCT were then analyzed and compared from environmental and economic (economic equity) perspectives. As a result of the analyses, it was concluded that ICT would be a more feasible policy as an international climate change policy when considering economic equity. However, it was not possible to deduce from these studies what might happen in the future due to the model structure, although understanding the dynamic effects is important considering the features of the tax that climatic and socioeconomic factors contribute to determine the tax rates. Matsumoto and Masui (2009) then analyzed the impacts from the mid-term (until 2050) dynamic perspective. The framework of the study was similar to the static studies. Consequently, it was indicated that economic disparities between developed and developing countries became narrower with time due to introduction of ICT, and feasibility of ICT was shown again when considering the viewpoint of economic equity simultaneously. In the longer term, since there will be large differences in socioeconomic situations, GHG emissions, and technology, especially in developing countries such as China and India, the impacts of ICT could be different in the long-term perspective. Thus, it is significant to clarify the long-term impacts of ICT on environment and economy in order to tackle climate change issues further in the global scale.

The purpose of this study is to analyze the long-term (until 2100) dynamic impacts of ICT on environment and economy. Moreover, how the economic discrepancy changes with time will be clarified by observing the changes in per capita GDP and the tax rates among countries. Since it is required to abate GHG emissions internationally by seeing the long-term future, it is expected that this study contributes to the provision of a clear vision for the consideration of future international climate change policies. This is because it is possible to incorporate the potential future outlook regarding factors such as the economic, social, and technological growth of countries. As in the previous studies, ICT is compared with CCT, which is the most efficient carbon tax system in theory.

The rest of this paper is organized as follows. The methods and assumptions of the analysis are described in the second section. The results of the analysis are shown and discussed in the third section. Finally, the fourth section includes some concluding remarks with a brief discussion on the possibility of a policy mix with ICT and the introduction of some additional climate change measures.

2. Methodology

In this section, first, the model and assumptions of this study are described. Then, the meaning of ICT is described and the tax rates of both ICT and CCT used in the analysis are shown.

2.1 The model and assumptions

In this study, the AIM/CGE [Global] model is applied for the analysis (see for example Fujino *et al.* (2006), Kainuma *et al.* (1999, 2003), Masui (2005), Matsumoto and Masui (2009), and Shukla *et al.* (2004) about the AIM/CGE models)[3]. This model is a recursive dynamic CGE model in a global scale with 21 industrial sectors (commodities), 24 regions, and 4 production factors. Tables I to III show the structure of industrial sectors, regions, and production factors, respectively. This model is almost identical with that used in Matsumoto and Masui (2009).

The basic mechanism of this model is similar to the GTAP model (Hertel, 1996) and GTAP-E model (Burniaux and Truong, 2002). However, the structure is quite different from these models. Some important differences can be summarized as follows: dynamic analysis is possible; not only CO_2 emissions but also other GHG emissions are incorporated; power generation by various resources such as fossil fuels, nuclear, hydro, and other renewables are considered; bio-energy production and consumption are considered; and international markets are modeled for international trade of some fossil fuels. Considering the dynamics in the model, the acceleration principle is applied to determine the investment and autonomous energy efficiency improvement is applied for the technology progress.

As described above, some kinds of GHG emissions are considered in the model. However, since the subject of this study is to analyze the effects of "carbon taxes," ICT and CCT are imposed only on CO_2 emissions.

With regard to the data used in the analysis, economic data are based on the GTAP 6 database of the Center for Global Trade Analysis (Dimaranan, 2006)[4], energy data are based on the Energy Balances of the International Energy Agency (IEA)[5], emissions data are based on the EDGAR 3.2 Fast Track 2000 database of The

Table I.
Structure of industrial sectors

Code	Including sectors
Energy sectors	
COA	Coal
OIL	Crude oil
GAS	Natural gas
P_C	Petroleum and coal products
GDT	Gas manufacture and distribution
ELY	Electricity
Non-energy sectors	
AGR	Agriculture (e.g. rice)
LVK	Livestock (e.g. bovine cattle)
FRS	Forestry
FSH	Fishery
EIS	Energy-intensive industries (e.g. chemical products)
OMN	Other mineral mining
M_M	Metals and manufacture (e.g. motor vehicles)
FOD	Food processing (e.g. food products)
OMF	Other manufacture (e.g. textiles)
CNS	Construction
TRT	Transportation (e.g. air transportation)
CMN	Communication
WTR	Water
OSG	Governmental services (e.g. education)
SER	Other services (e.g. insurance)

Netherlands Environmental Assessment Agency (PBL)[6], and land-use data are based on the FAOSTAT of the Food and Agriculture Organization (FAO)[7].

In this study, the base year is 2001 in line with the GTAP database. A simulation analysis is then implemented until 2100 with five-year time steps except for the first four years.

2.2 Carbon tax

The concept of the imputed price of carbon (in other words, atmospheric CO_2 stock) in this study is to evaluate the value of carbon that is not traded and also not priced in the market by the shadow price. It can be applied as a climate change policy method and is derived from a global optimization problem. Unlike huge physical models that describe causal relationships of climate change in detail, this method describes the causal relationships simplistically for policy discussions. ICT is the carbon tax based on this concept and calculated from equation (1). The optimization problem and derivation process of equation (1) are described in Matsumoto (2007a, 2008). This equation is also applied in Matsumoto and Masui (2009):

$$ICT_{r,t} = \frac{\beta}{V - D_{t-1}} \left[\sum_{r} \frac{N_{r,t-1} y_{r,t-1}^{1-\sigma}}{1 - \sigma} \right] y_{r,t-1}^{\sigma} \tag{1}$$

where:

- r: region.
- t: time period.

Code	Including countries
Developed countries	
AUS	Australia
NZL	New Zealand
JPN	Japan
KOR	Korea
CAN	Canada
USA	United States of America
MEX	Mexico
XE15	15 Western EU countries
Economies in transition	
RUS	Russia
XE10	10 Eastern EU countries
XRE	Rest of Europe (e.g. Bulgaria)
Developing countries	
CHN	China and Hong Kong
XRA	Rest of Asia-pacific (e.g. Mongolia)
IDN	Indonesia
THA	Thailand
XSE	Rest of Southeast Asia (e.g. Malaysia)
IND	India
XSA	Rest of South Asia (e.g. Bangladesh)
ARG	Argentina
BRA	Brazil
XLM	Rest of Latin America (e.g. Chile)
XME	Rest of Middle East (e.g. Saudi Arabia)
ZAF	South Africa
XAF	Rest of Africa (e.g. Egypt)

Note: *The above three categories of the regions are based on the base year situation. We call developing countries and economies in transition "developing countries" hereinafter

Table II. Structure of regions

Code	Explanations
Mobile	
LAB	Labor
CAP*	Capital
Sluggish	
LND	Land
RES	Natural resources

Note: *In the model, capitals are mobile if newly introduced but sluggish if they have already existed through the dynamic process

Table III. Structure of production factors

- $ICT_{r,t}$: ICT rate in region r in time t (\$/t-CO_2).
- $N_{r,t}$: population in region r in time t.
- $y_{r,t}$: per capita GDP in region r in time t (\$).
- V: critical level of global atmospheric CO_2 stock (t-CO_2).
- D_t: global atmospheric CO_2 stock in time t (t-CO_2).
- σ: elasticity parameter ($0 < \sigma < 1$).
- β: sensitivity parameter of utility against global atmospheric CO_2 stock ($0 < \beta < 1$).

As equation (1) indicates, the ICT rate of each region is proportional to per capita GDP exponentiated by elasticity parameter σ. Hence, the tax rates might become higher in the richer regions (developed countries) and lower in the poorer regions (developing countries) in the base year.

The values of the parameters independent of time in equation (1) are $\beta = 0.1$, $\sigma = 0.927$, and $V = 4.4$ trillion (t-CO_2) (Matsumoto, 2007a, 2008; Uzawa, 1991). Table IV shows GDP, population, and per capita GDP of each region in 2005 which is one step before the tax introduction year (2010). Also, the ICT rates in 2010 calculated from equation (1) are shown in Table IV. As shown in the table (the rightmost column), while the ICT rates in most of the developed countries are higher than \$50/t-CO_2, those in most of the developing countries are lower than \$35/t-CO_2 and the rates in the developed countries are higher than those in the developing countries.

Table IV.
GDP, population, per capita GDP (in 2005), and ICT rate (in 2010) of each region

Regions	GDP (Bil\$)	Population (Mil)	Per capita GDP (\$)	ICT rates (\$/t-CO_2)
AUS	377.9	20.2	18,757.0	97.3
NZL	51.7	3.9	13,160.0	70.1
JPN	4,138.0	128.7	32,152.0	160.4
KOR	485.1	48.2	10,058.0	54.6
CAN	712.9	32.1	22,237.0	114.0
USA	10,706.9	299.8	35,714.0	176.8
MEX	728.9	106.5	6,844.0	38.2
XE15	7,578.5	382.5	19,815.0	102.4
RUS	890.8	142.9	6,234.0	35.1
XE10	346.7	74.8	4,635.0	26.6
XRE	675.1	277.3	2,434.0	14.7
CHN	1,570.5	1,334.0	1,177.0	7.5
XRA	329.5	56.9	5,792.0	32.8
IDN	163.4	225.9	723.0	4.8
THA	134.5	63.7	2,111.0	12.9
XSE	391.3	266.3	1,469.0	9.2
IND	549.7	1,087.0	506.0	3.4
XSA	162.6	381.6	426.0	2.9
ARG	254.7	39.4	6,473.0	36.3
BRA	494.4	182.5	2,709.0	16.2
XLM	645.4	228.5	2,824.0	16.8
XME	713.8	191.1	3,735.0	21.8
ZAF	106.6	46.2	2,308.0	14.0
XAF	487.4	843.9	578.0	3.9

In this study, ICT and CCT are evaluated from the viewpoints of changes in CO_2 emissions and GDP (environmental and economic impacts, respectively), and then they are compared as in the previous studies (Matsumoto, 2007a, 2008; Matsumoto and Masui, 2009). Concerning the CCT rate, it is set to make the model attain an equal change in global GDP to the case of ICT in 2050 and 2100 as a result of the analysis. The CCT rates corresponding to the ICT rates are \$95.7/t-CO_2 until 2050 and \$55.8/t-CO_2 until 2100. Comparing the two taxes, since the ICT rates (in the first year of the tax introduction) are smaller than the CCT rate in the developing countries, it is considered that the CCT rate is extremely high for these countries.

3. Results and discussions

Figures 1 and 2 show the changes in CO_2 emissions and GDP in each region and the world from the business as usual (BAU) case in 2100 respectively as a result of the analysis. As Figure 1 indicates, a CO_2 emissions abatement of 72.2 percent is realized in the case of ICT and of 73.0 percent in the case of CCT globally. In other words, there is little difference in emissions abatement amount between the two taxes. This result is quite different from the previous studies (Matsumoto, 2007a, 2008) in which CCT contributes about 1.5 times more to CO_2 emissions abatement than ICT. Furthermore, the difference becomes smaller than the mid-term perspective (Matsumoto and Masui, 2009). It is considered that the reason for this is that economic disparities among the regions are narrowed further as time passes by introducing ICT and the difference in the ICT rates among them is narrowed as a result. Actually, the adjusted weighted standard deviation of the ICT rates (the weighted standard deviation divided by the weighted average) decreases to 0.12 in 2100 from 0.27 in 2010. Consequently, CO_2 emissions are abated more efficiently in 2100 than in the earlier years. Although there is an advantage with CCT in the abating of CO_2 emissions at earlier dates, which means that the impacts of climate change are expected to be smaller, the difference in the total CO_2 emissions abatement amount for the entire period (relative to the BAU

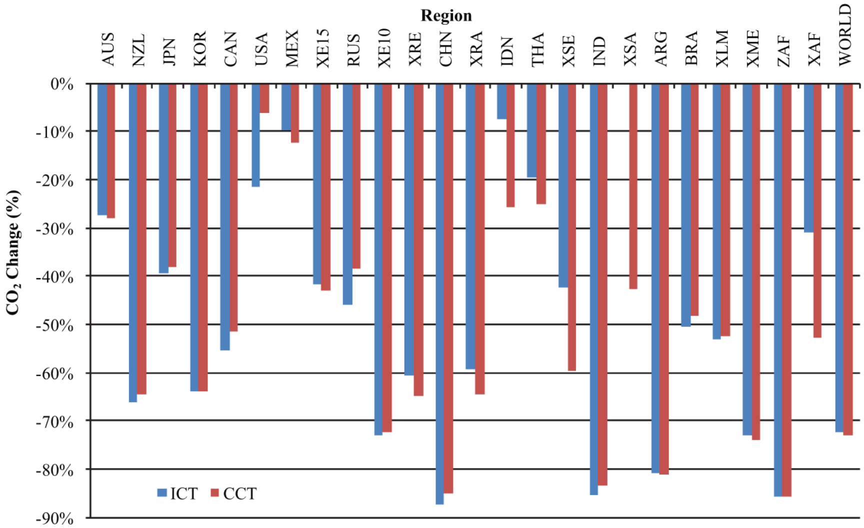

Figure 1.
Percentage changes in CO_2 emissions in each region in 2100

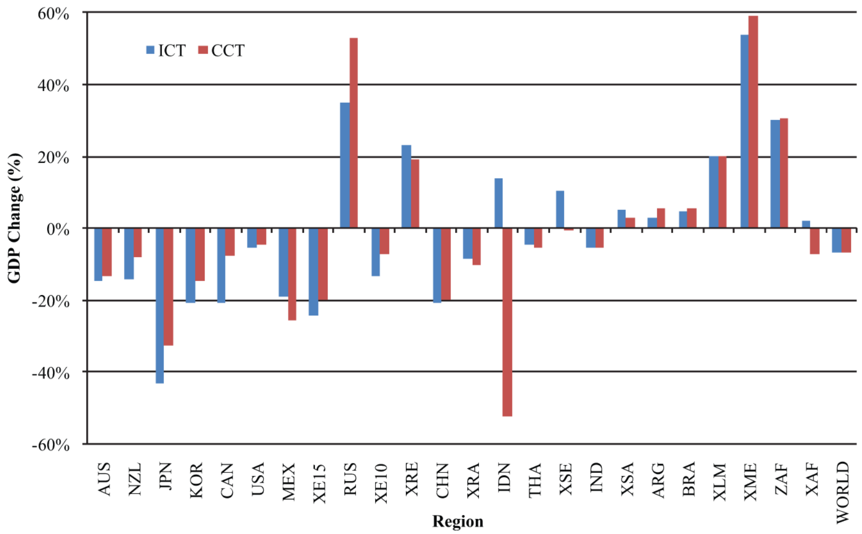

Figure 2.
Percentage changes in GDP in each region in 2100

case) is only 2.9 points and the abatement level becomes almost the same from 2050 (Figure 3).

Comparing the changes in GDP shown in Figure 2, those by ICT and CCT are equivalent, −6.8 percent on average worldwide, according to the assumption of this study. However, observing the changes regionally, they show different tendencies. For the developed countries, the economic damage is smaller in the case of CCT than that of ICT (−13.5 percent in the case of ICT and −10.9 percent in the case of CCT averagely). For the developing countries, on the other hand, the damage is smaller in the case of ICT than that of CCT (−5.3 percent in the case of ICT and −5.9 percent in the case of CCT averagely). In addition, the negative changes tend to be smaller in the poorer regions than in the richer regions in the case of ICT as shown in Figure 4 (the

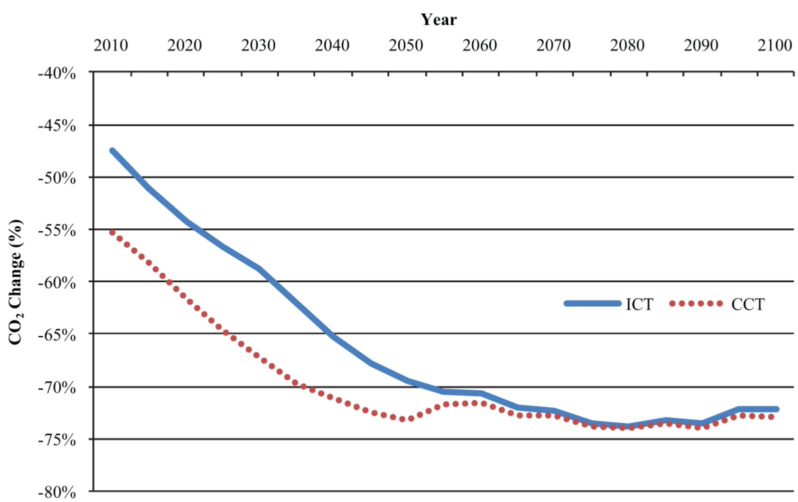

Figure 3.
World CO_2 emissions abatement amount from 2010 to 2100 (%)

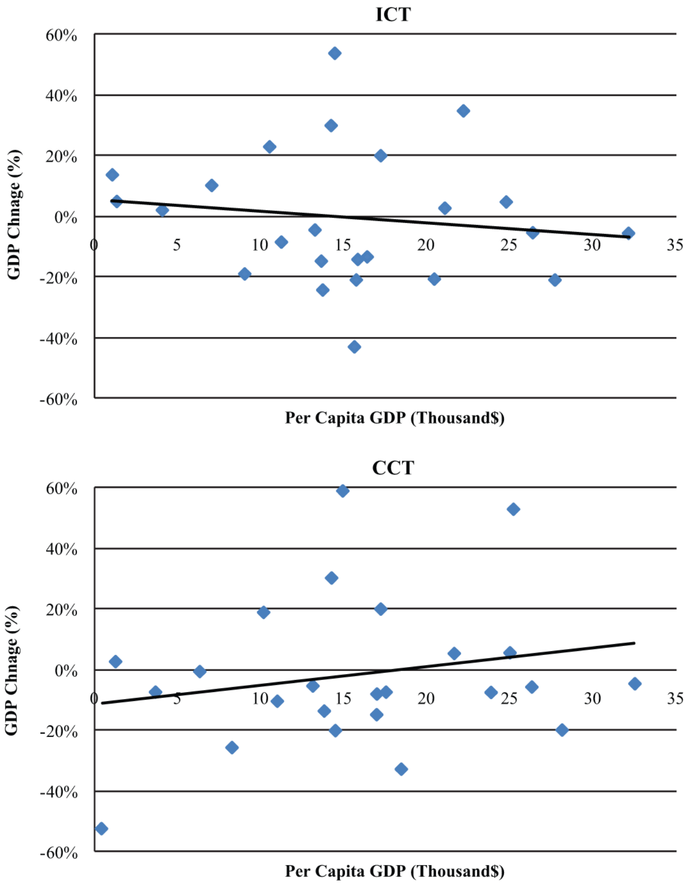

Figure 4.
Correlation between per capita GDP and GDP changes

upper side). This tendency is contrary to the case of CCT (the lower side of Figure 4). That is to say, introducing ICT instead of CCT contributes more to narrowing economic disparities among the regions. For example, the percentage of GDP developing countries occupy in the world increases further in the case of ICT as shown in Figure 5. Likewise, as Figure 6 shows, the difference in per capita GDP is narrowed faster in the case of ICT than that of CCT. In the case of CCT, the difference is larger than that of BAU until the middle of the century. Besides, as Figure 7 indicates, increase in the ICT rates is remarkably higher in the developing countries, which means that increase in per capita GDP is also much higher in these countries. Especially in China, India, Brazil, and Argentina, the tax rates reach the same levels as the developed countries. As a result, the economic disparities are narrowed as described above.

Comparing the above results with the previous studies (Matsumoto, 2007a, 2008; Matsumoto and Masui, 2009) shows that the effectiveness of ICT increases from the longer-term perspective. From the economic aspect, the effect of economic equity is attained and further promoted. From the environmental aspect, the difference in CO_2

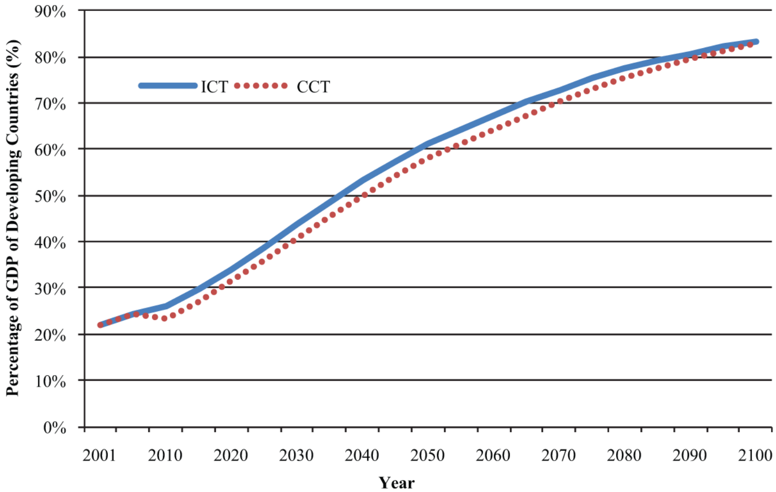

Figure 5.
Percentage of GDP of developing countries

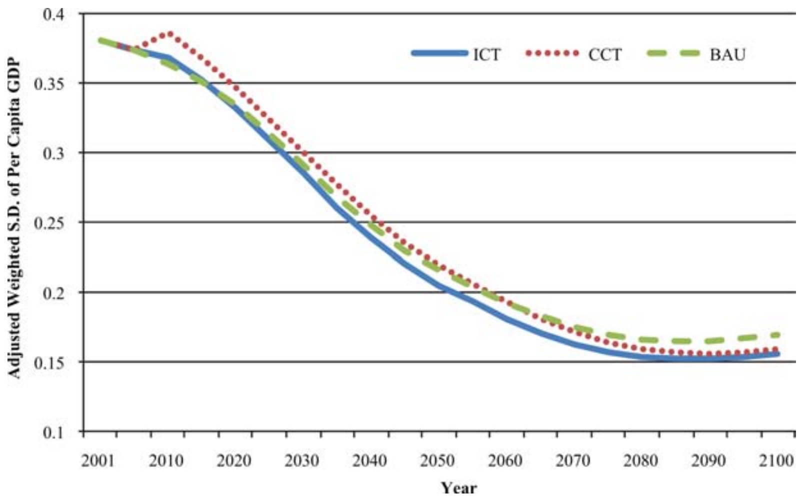

Figure 6.
Difference in per capita GDP

emissions abatement amount between the two taxes decreases tremendously as time passes (Figure 3).

Because CCT imposes excessive economic burdens on the developing countries especially in earlier years, it conflicts with the Principles of the UNFCCC (Article 3), which says that "the Parties should protect the climate system . . . on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities." Looking at the recent discussions on international climate change policies such as COP and the related sessions, it seems that both developed and developing countries recognize and agree that this principle is essential.

In contrast, the negative influence on economy is relatively small for the developing countries totally in the case of ICT as shown in Figure 8, hence there is economic equity

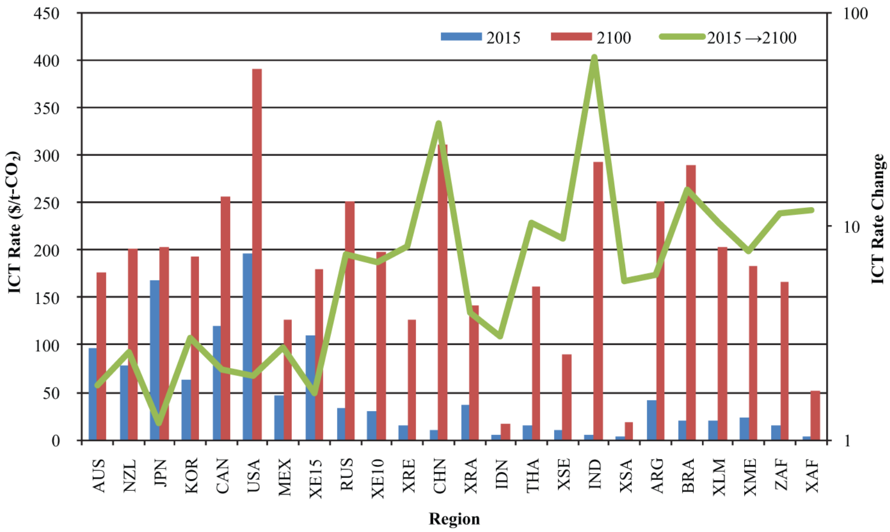

Figure 7.
ICT rates and the changes in each region

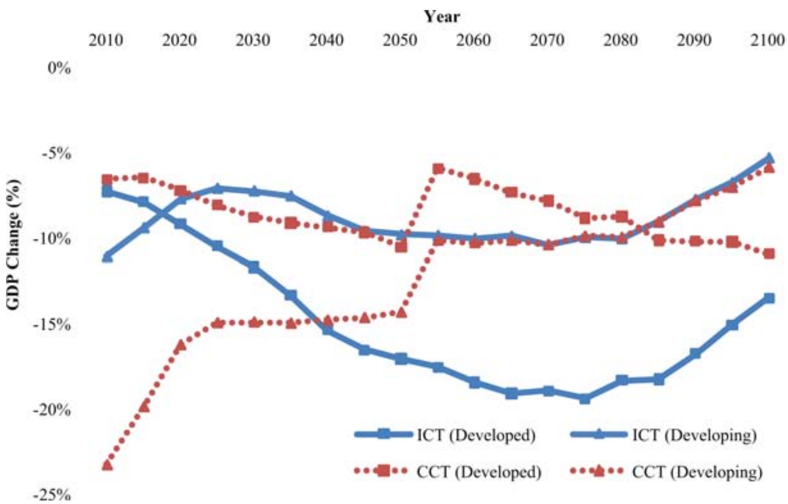

Figure 8.
Percentage changes in GDP in developed and developing countries

among the developed and developing countries regarding their states of development. In addition, it is also possible to update the tax rates without arbitrariness according to the economic levels by introducing ICT applying equation (1) and the equation can function as a basis for future negotiations, and improve the likelihood that they will progress more smoothly. Because economic issues are especially crucial for less developed countries, and it is possible to raise the policy feasibility by keeping the costs as low as possible (Tol, 1999), policy methods which will reduce economic burdens on these countries must be considered. Furthermore, concerning climate change decision-making, deliberation of both environmental and economic consequences is extremely important (IPCC, 2001). Consequently, the above results and discussions suggest that ICT is more appropriate as a carbon tax policy than CCT from the long-term perspective.

4. Concluding remarks

In this study, long-term dynamic impacts of ICT were analyzed from the viewpoints of the changes in CO_2 emissions and GDP by comparing it with CCT applying the AIM/CGE [Global] model. Although the effects of ICT had so far been analyzed in a static basis in Matsumoto (2007a, 2008) and in a mid-term basis in Matsumoto and Masui (2009), longer-term dynamic analysis was implemented in this study considering the important features of the tax and possible socioeconomic changes. As a result, it was found that ICT could realize more economically equal conditions than CCT, while there was a little difference in the world CO_2 emissions abatement effects. This result is quite different from the results of the previous studies where a tradeoff between economic equity and CO_2 emissions abatement was observed between the two taxes. Observing the result more in detail, it was shown that economic equity among the regions progressed with time. In addition, compared with CCT, the adjustment speed was faster. It is essential to take into account economic aspects further for the sake of future climate change policies. Because economic burdens on the developing countries were larger in the case of CCT, there is possibility that these countries might back away from such a severe policy. As a result, the CO_2 emissions abatement amount would become much smaller if CCT is introduced without the participation of developing countries than the case of ICT (Matsumoto, 2006, 2007a, 2008). This therefore suggests that ICT is a more feasible carbon tax policy among future climate change measures considering the economic condition of each country and the significance of the worldwide introduction of CO_2 abatement policies (the significance, in other words, of avoiding a situation in which developing countries withdraw from the policy framework). One of the most interesting results of this study, different from the static and mid-term perspectives, was that some developing countries such as China, Argentina, and brazil responded to the carbon taxes as the developed countries did in the later years since their economic levels became on par with the developed countries. Thus, it might not be appropriate to count them as "developing countries" any more.

The findings of this study mainly suggest for this kind of studies that observing economic aspects, especially from the standpoint of equity, are indispensable; long-term analysis is crucial considering socioeconomic and technological changes and the nature of climate; designing systems related to climate change issues from the long-term perspective is essential; and the proposed methodology will be continually effective and justified toward the long-term future to tackle climate change issues globally.

In the above discussions, it is assumed that ICT is introduced as the sole international climate change policy. However, it would be possible to introduce it in tandem with other policy methods in a "policy mix" to realize additional CO_2 emissions abatement. For example, by introducing project-based CO_2 emissions abatement methods, a system like the CDM in the Kyoto mechanism, further abatement could be anticipated especially in developing countries where the potential to abate CO_2 emissions is high (Criqui *et al.*, 1999; Matsumoto, 2006, 2007a, b; Morris *et al.*, 2008). Furthermore, additional climate change measures such as technology transfer and financial aid, especially for developing countries as implemented under the Kyoto

Protocol and UNFCCC must be introduced simultaneously. Consequently, expeditious institutional design, taking the principles of UNFCCC into account, is required as a comprehensive package of the policies and measures since we can afford no further delay to tackle this difficult issue.

It will be important for future studies to analyze the effects of policy mixes combining ICT with project-based abatement methods, technology transfer, financial aid, and so on.

Notes

1. For further information, see the website of the UNFCCC, available at: http://unfccc.int/
2. See also Future International Action on Climate Change Network, available at: www.fiacc.net/
3. See also Integrated Environmental Assessment prepared by Asia-Pacific Environmental Innovation Strategy Project (APEIS), available at: www.env.go.jp/en/earth/ecoasia/APEIS/iea/index.html
4. See also the Global Trade Analysis Project of the Center for Global Trade Analysis, available at: www.gtap.agecon.purdue.edu/
5. The data are from the IEA Statistics, available at: www.iea.org/Textbase/stats/index.asp
6. The data are available at: www.mnp.nl/edgar/
7. The data are available at: http://faostat.fao.org/

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