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Short-term Dynamic Effects of

Carbon Tax Based on the Imputed Price of Carbon

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ABSTRACT

Although an international carbon tax is a method to efficiently abate CO_2 emissions, it might be a heavy economic burden for poorer countries if the tax rate is unified among countries. A carbon tax based on the imputed price of carbon (ICT) is an international carbon tax with tax rates that differ among countries according to their economic levels. Although the effects were analyzed statically in the previous studies, understanding the dynamic effects is important considering the characteristics of the tax. The purpose of this study is to analyze the short-term dynamic influence of ICT on environment and economy by applying a dynamic computable general equilibrium model, and comparing ICT with an internationally common carbon tax (CCT). The ICT rate of each region is calculated based on a certain formula and updated every year. In contrast, the CCT rate is fixed and set to achieve an equal change in world GDP in the final year to the case of ICT.

As a result, the world CO_2 emissions abatement amount is smaller in the case of ICT than in that of CCT. From this point of view, CCT is considered a better approach. However, considering the economic aspects simultaneously, the suitability of CCT diminishes. The patterns of the GDP changes among the regions are quite different between the two taxes. For developed countries, the negative influence is smaller in the case of CCT. On the other hand, it is smaller in the case of ICT for developing countries. Furthermore, the percentage of GDP of the developing countries in the world increases and disparities of per capita GDP among the regions become narrower in the case of ICT. This means that economic disparities between the developed and developing countries are narrowed. Also, since the tax rates imposed on the developing countries are not merely low but are updated according to their economic levels, the difference of the rates among the regions is expected to become smaller as the growth rates of the developing countries become higher. Actually, it is observed that increase rates of ICT are higher in the developing countries. As a result, a tradeoff between economic equity and CO_2 emissions abatement occurs between ICT and CCT. Further consideration of economic aspects is indispensable for future climate change policies. In the light of the importance of worldwide introduction of CO_2 abatement policies and avoidance of excessive burdens on developing countries, ICT is regarded as a highly feasible carbon tax policy.

Keywords: international climate change policy, carbon tax, imputed price of carbon, economic equity, dynamic computable general equilibrium model

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 under the Kyoto Protocol (AWG-KP). However, climate change measures have made little progress globally, and realizing the greenhouse gases (GHG) emissions abatement targets under the Kyoto Protocol is still very far for most of the Annex B countries of the Kyoto Protocol (Matsumoto, 2007a). Furthermore, while it is essential to establish international climate change policies for the post-Kyoto Protocol and further commitments as soon as possible in order to abate GHG emissions and stabilize the climate, the related discussions regarding the above have not made any concrete advances. Therefore, policies for the future, especially in the near term, are necessary urgently to sustain the international efforts against climate change. 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, de Macedo, and Baumert, 2002), the sector-based CDM

(Samaniego and Figueres, 2002), the triptych approach (Groenenberg, Blok, and van der Sluijs, 2004; Groenenberg, Phylipsen, and Blok, 2001), contraction and convergence (Mayer, 2000), multi-sector convergence (Sijm, Jansen, and Torvanger, 2001), sustainable development policies and measures (Winkler, 2002), the carbon intensity target (Baumert, Bhandari, and Kete, 1999), the dual track approach (Kameyama, 2003), standard-setting[i] (Cooper, 1998; Ninomiya, 2003), and so on[ii] (Baumert, et al., 2002; Den Elzen, 2002; Ecofys, 2008). However, conclusions on the methodology of future measures have not yet been provided, and appropriate policy methods must therefore be determined as soon as possible. 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 indispensable. 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 the static computable general equilibrium (CGE) model in Matsumoto (2007a, 2008). In these studies, the availability of carbon taxes as an international climate change policy[iii] was advocated by pointing out some problems and defects of the Kyoto Protocol and Kyoto-type international climate change policies[iv]. The problems and defects are summarized as follows: 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). Then, ICT and CCT were analyzed and compared from environmental and economic (economic equity) perspectives. As a result of the analysis, it was concluded that ICT would be a more feasible policy as an international climate change policy when considering the viewpoint of economic equity simultaneously. However, it was not possible to deduce from these studies what might happen in the future by introducing ICT or CCT due to the model structure, although understanding the dynamic effects is important considering the features of the tax[v].

The purpose of this study is to analyze the short-term dynamic impacts of ICT on environment and economy as in the previous studies. Moreover, how the economic discrepancies change with time will be clarified by observing the changes in the tax rates among countries. As shown in detail afterward, the ICT rates are determined according to some dynamic factors such as economic situations and

CO_2 stock, hence analyzing by using a dynamic model is significant. In addition, unlike static analysis, it is expected that this study contributes to the provision of a clear vision for the consideration of future international climate change policies through dynamic analysis. This is because it is possible to incorporate, to some extent, potential future outlooks such as the economic 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, and the carbon taxes applied in this study 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.

METHODS

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.

The Model and Assumptions

In this study, the AIM/CGE [Global] model (APEIS, 2008; Fujino, et al., 2006; Kainuma, Matsuoka, and Morita, 1999, 2003; Masui, 2005; Shukla, et al., 2004) is applied for the analysis. This model is a dynamic CGE model in a global scale with 21 industrial sectors (commodities), 24 regions, and 4 production factors. Table 1, Table 2, and Table 3 show the structure of industrial sectors, regions, and production factors, respectively. This model is a revised version of the previous ones.

Table 1. Structure of Industrial Sectors

Table 2. Structure of Regions

Table 3. Structure of Production Factors

The very 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 from fossil fuels consumption but also CO_2 and other GHG emissions from industrial activities are incorporated; power generation by various resources such as fossil fuels, nuclear, and hydro are included; bio-energy production and consumption are considered; and international markets are modeled for international trade of some fossil fuels.

As described above, some kinds of GHG emissions are considered in the model, but GHG emissions except CO_2 emissions are based on industrial activities. Since the subject of this study is to analyze the effects of “carbon taxes,” ICT and CCT are imposed only on CO_2 emissions from fossil fuels consumption.

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 (Center for Global Trade Analysis, 2008; Dimaranan, 2006), energy data are based on the Energy Balances of International Energy Agency (IEA, 2008), emissions data are based on the EDGAR 3.2 Fast Track 2000 database of Netherlands Environmental Assessment Agency (PBL, 2008), and land-use data are based on the FAOSTAT of Food and Agriculture Organization (FAO, 2008).

In this study, the base year is 2001. A simulation analysis is then implemented until 2012 with a 1-year time step.

Carbon Tax

The concept of the imputed price of carbon (or atmospheric CO_2 stock) in this study is to evaluate the value of carbon which 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 which describe causal relationships of climate change in detail, this method can describe the causal relationships simplistically for policy discussions. ICT is the carbon tax based on this concept and calculated from Eq. (1). The optimization problem and derivation process of Eq. (1) are described in Matsumoto (2007a, 2008).

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

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

The equation without subscripts t was applied to calculate ICT in Matsumoto (2007a, 2008) because they were based on static analysis. Conversely, Eq. (1) is formed by just putting subscripts t on some variables expressed in the equation in the previous studies even though it was derived from the static optimization problem. However, since the AIM/CGE [Global] model is a recursive dynamic CGE model, namely the economy attains the equilibrium condition in every year, there is no problem in simply putting subscripts t on the corresponding variables and apply for the analysis. Because of the calculation limitation, GDP is employed instead of net national income in this study for $y_{r,t}$ unlike Matsumoto (2007a, 2008).

As Eq. (1) indicates, the ICT rate of each region is proportional to per capita GDP exponentiated by elasticity parameter σ. Hence, the tax rates will become higher in the richer regions (developed countries) and lower in the poorer regions (developing countries) in the base year. Since the tax rates are determined in every year, the changes in economic situations of the regions are reflected appropriately in the next year.

The values of the parameters independent of time in Eq. (1) are $\beta = 0.1$, $\sigma = 0.927$, and $\bar{V}$= 4.4 trillion (t-CO_2) (Matsumoto, 2007a, 2008; Uzawa, 1991). Table 4 shows GDP, population, and per capita GDP of each region in 2007 which is one year before the tax introduction year (2008). Also, the ICT rates in 2008 calculated from Eq. (1) are shown in Table 4.

Table 4. GDP, population, per capita GDP (in 2007), and ICT rate (in 2008) of each region

As shown in Table 4 (the rightmost column), although the ICT rates in most of the developed countries are higher than \$50/t-CO_2[vi], those in most of the developing countries are lower than \$35/t-CO_2.

In this study, ICT and CCT are evaluated from the viewpoints of the changes in CO_2 emissions and GDP (environmental and economic impacts, respectively), and then they are compared as implemented in Matsumoto (2007a, 2008). Concerning the CCT rate, it is set to attain an equal change in global GDP to the case of ICT in the final year as a result of the analysis. The CCT rate corresponding to the ICT rates is \$46.9/t-CO_2. 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, the CCT rate is extremely high for these countries.

RESULTS AND DISCUSSIONS

Fig. 1 and Fig. 2 show the changes in CO_2 emissions and GDP in each region and the world from the BAU case in 2012 respectively.

Fig. 1. Percentage Changes in CO_2 Emissions in Each Region in 2012 (%)

Fig. 2. Percentage Changes in GDP in Each Region in 2012 (%)

As Fig. 1 indicates, a CO_2 emissions abatement of 41.6% is realized in the case of ICT and of 48.4% in the case of CCT globally. In other words, CCT contributes 16.3% more to CO_2 emissions abatement than ICT. This result is very different from the results shown in Matsumoto (2007a, 2008) in which CCT contributes about 1.5 times more to CO_2 emissions abatement than ICT. It is considered that the reason for this is that economic disparities among the regions become narrower over time in the case of ICT than in the case of CCT[vii] [viii].

Comparing the changes in GDP shown in Fig. 2, those by ICT and CCT are equivalent, −13.0% on average worldwide in 2012, 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 (−12.4% in the case of ICT and −7.7% in the case of CCT averagely in 2012). For the developing countries, on the other hand, the damage is smaller in the case of ICT than that of CCT (−14.7% in the case of ICT and −28.8% in the case of CCT averagely in 2012). In addition, the negative changes are independent of the economic levels or tend to be very slightly larger in the richer regions in the case of ICT as shown in Fig. 3 (the upper graph). This tendency is different from the case of CCT in which the negative changes tend to be larger in the poorer regions (the lower graph of Fig. 3). Comparing the two taxes, introducing ICT instead of CCT contributes more to the narrowing of economic disparities among the regions. As Fig. 4 shows, for example, the percentage of GDP of developing countries in the world increases as time passes in the case of ICT. In the case of CCT, on the other hand, the percentage decreases with time. Moreover, as Fig. 5 shows, the difference in per capita GDP is narrowed more in the case of ICT than that of CCT. Also, as Fig. 6 indicates[ix], increases in the ICT rates are higher in the developing countries than in the developed countries as a whole, although a rate decrease is observed in XME[x]. Among the developing countries, the tax rates increase is largest in CHN, IND, and THA. As a result, the economic disparities are narrowed as described above.

Fig. 3. Correlation between Per Capita GDP and GDP Changes (Upper: ICT, Lower: CCT)

Fig. 4. Percentage of GDP of Developing Countries

Fig. 5. Difference in Per Capita GDP

Fig. 6. ICT Rates and the Changes in Each Region

Comparing the above results with Matsumoto (2007a, 2008) (and also with the base year results in this study) shows that the effectiveness of ICT increases from the short-term dynamic perspective. From the economic aspect, the effect of economic equity is attained. In addition, from the environmental aspect, the difference in CO_2 emissions abatement amount between the two taxes decreases comparing to Matsumoto (2007a, 2008).

Because CCT imposes excessive economic burdens on the developing countries, 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.

Fig. 7. Percentage Changes in GDP in Developed and Developing Countries (%)

In contrast, the negative economic influence is smaller for the developing countries totally in the case of ICT than that of CCT, as Fig. 7 shows, hence there is economic equity 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 Eq. (1), and the equation can also 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 be able to reduce economic burdens on these countries must be introduced. Moreover, concerning climate change decision-making, deliberation of both environmental and economic consequences is extremely important (Watson and the Core Writing Team, 2001). Consequently, the above results and discussions suggest that ICT is more appropriate as a carbon tax policy than CCT from the dynamic analysis perspective.

CONCLUDING REMARKS

In this study, the short-term dynamic effects 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 been analyzed in a static basis in Matsumoto (2007a, 2008), short-term dynamic analysis was implemented in this study considering the features of the tax. As a result, it was found that ICT could realize more economically equal conditions than CCT, while there was a small difference in the world CO_2 emissions abatement effects. This result is quite different from the results of the previous studies where a significant tradeoff between economic equity and CO_2 emissions abatement was observed between the two taxes (Matsumoto, 2007a, 2008). Observing the results in more detail, it was shown that economic equity among the regions progressed with time. In addition, compared with CCT, the adjustment speed was faster (see Fig. 5). 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 are larger in the case of CCT, there is a 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 amongst future climate change measures considering the economic condition of each country and the significance of the worldwide introduction of CO_2 abatement policies[xi]. In addition to this, since the tax rates are determined objectively by the equation, it is expected that such a tool facilitates future international negotiations.

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 (and other kinds of GHG) emissions abatement as in the Kyoto Protocol. 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, Mima, and Viguier, 1999; Matsumoto, 2007a, 2007b; Morris, Paltsev, and Reilly, 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.

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

Footnotes

i. The standard-setting means to coordinate in establishing standards such as the GHG emissions of countries, the fuel consumption of cars, the energy efficiency of equipment, and technology levels of countries.

ii. Carbon tax is of course another example.

iii. The post-Kyoto Protocol is considered there.

iv. In these studies, the Kyoto-type international climate change policy is defined as a policy to abate GHG emissions by assigning a GHG emissions cap on each country and utilizing flexible mechanisms for efficiency like the Kyoto Protocol.

v. The features are explained in the sections below.

vi. Although the tax rate in MEX is lower than \$50/t-CO_2 and the lowest in the developed countries, the level is higher than any of the developing countries as shown in Table 4.

vii. The details are described below.

viii. The difference of the model structure is also considered one of the reasons.

ix. Because ICT is not introduced in 2007, no influence of the tax on the rates appears in 2008. On the other hand, the influence of the tax imposed in the previous year appears from 2009. Therefore, the ICT rates in 2012 are compared with those in 2009, not in 2008, in Fig. 6.

x. It is considered that the rate in XME decreases because it is a large oil-exporting region so that the economy is affected due to decreases in the oil demand in the other regions.

xi. In other words, it is significant to avoid the withdrawal of developing countries from the policy framework.

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Table 1. Structure of Industrial Sectors

Code	Including Sectors
Energy Sectors	
COA	Coal
OIL	Crude oil
GAS	Natural gas
P_C	Petroleum & coal products
GDT	Gas manufacture & 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 & 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)

Table 2. Structure of Regions

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 & 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)

*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 except in special cases.

Table 3. Structure of Production Factors

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

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

Table 4. GDP, Population, Per Capita GDP (in 2007), and ICT Rate (in 2008) of Each Region

Regions	GDP (Bil$)	Population (Mil)	Per capita GDP ($)	ICT Rates ($/t-$CO_2$)
AUS	383.4	20.6	18649.0	95.4
NZL	52.1	4.0	13081.0	68.6
JPN	4151.6	129.1	32158.0	158.0
KOR	484.9	48.7	9955.0	53.3
CAN	713.7	32.6	21913.0	110.7
USA	11057.9	305.4	36208.0	176.4
MEX	765.4	109.3	7003.0	38.5
XE15	7603.8	383.9	19809.0	100.8
RUS	846.3	142.0	5960.0	33.1
XE10	351.9	74.8	4705.0	26.6
XRE	653.3	279.6	2337.0	13.9
CHN	1659.0	1347.7	1231.0	7.7
XRA	357.4	57.8	6181.0	34.3
IDN	159.9	231.1	692.0	4.5
THA	135.7	64.7	2096.0	12.6
XSE	408.0	273.8	1490.0	9.2
IND	593.9	1114.2	533.0	3.5
XSA	170.0	396.4	429.0	2.9
ARG	261.1	40.2	6492.0	35.9
BRA	501.7	186.5	2690.0	15.8
XLM	649.9	235.5	2759.0	16.2
XME	668.4	198.9	3361.0	19.5
ZAF	105.8	46.9	2257.0	13.5
XAF	485.4	884.1	549.0	3.6

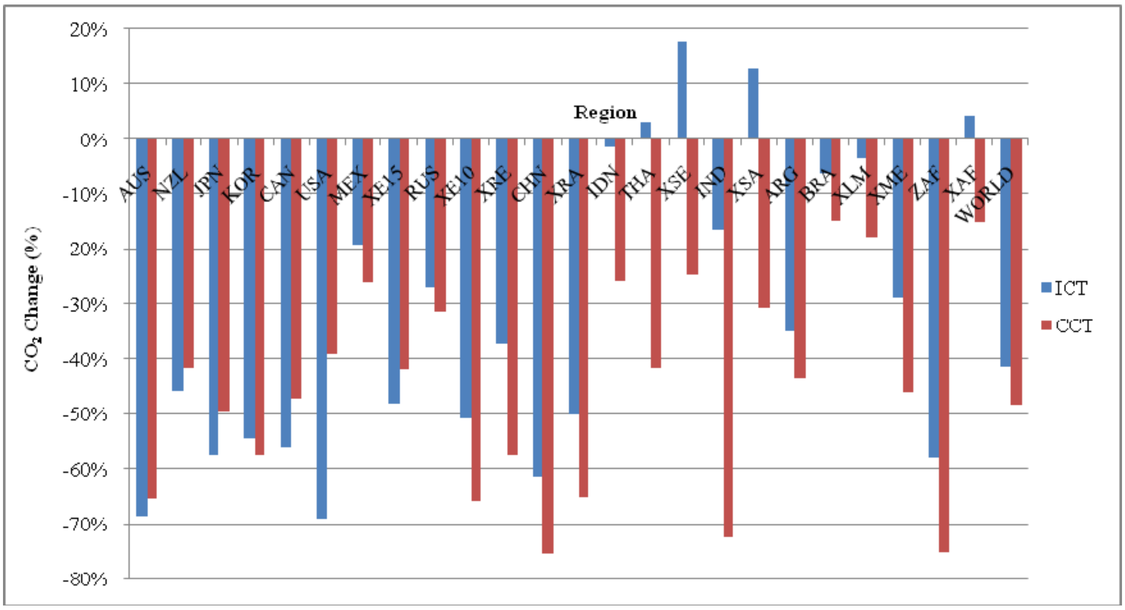


Fig. 1. Percentage Changes in CO_2 Emissions in Each Region in 2012 (%)

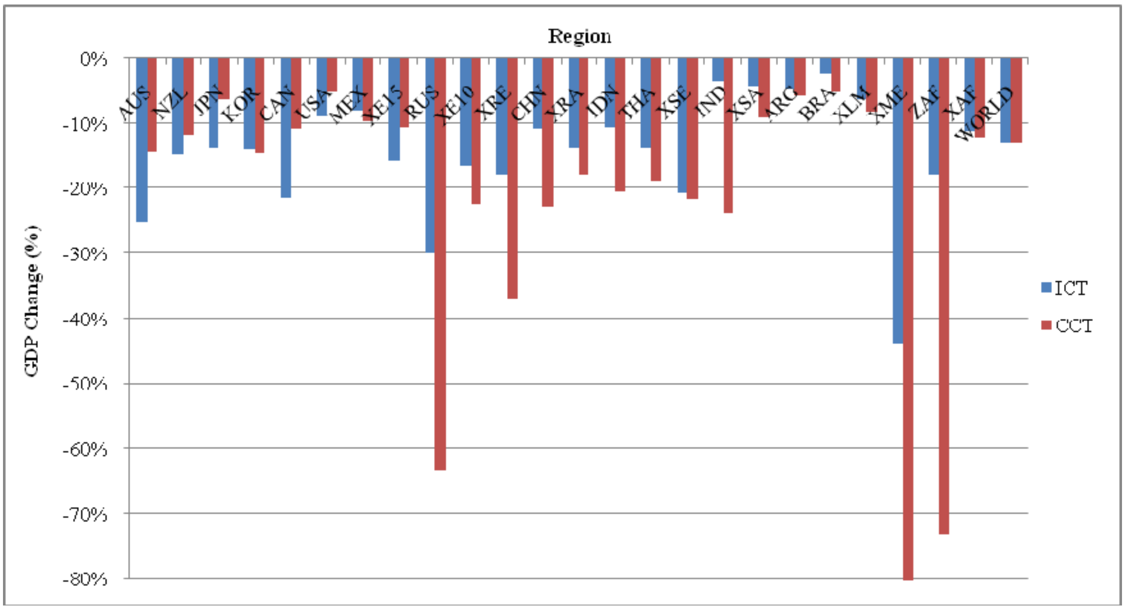
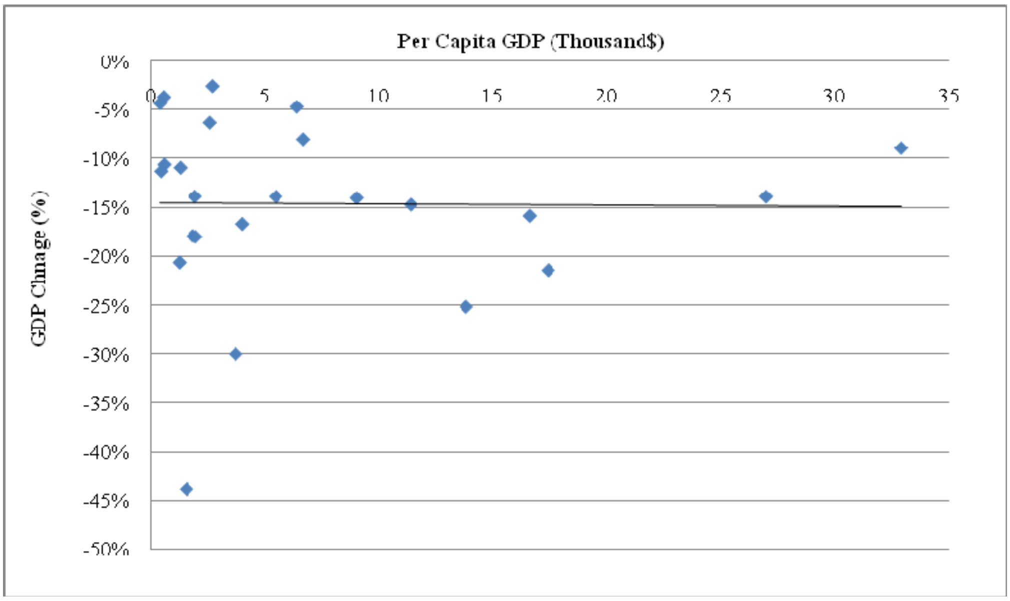


Fig. 2. Percentage Changes in GDP in Each Region in 2012 (%)



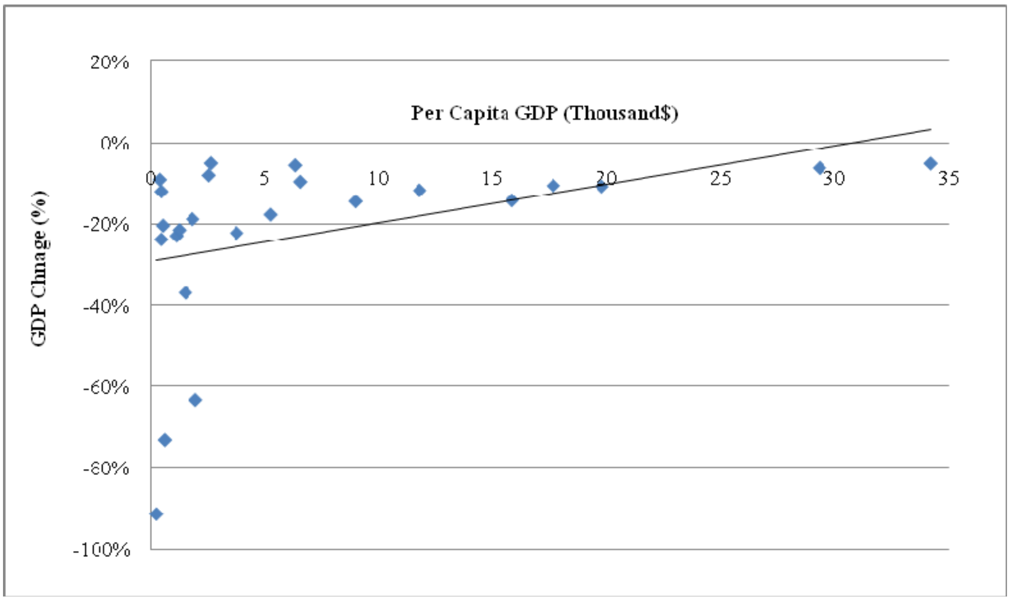


Fig. 3. Correlation between Per Capita GDP and GDP Changes

(Upper: ICT, Lower: CCT)

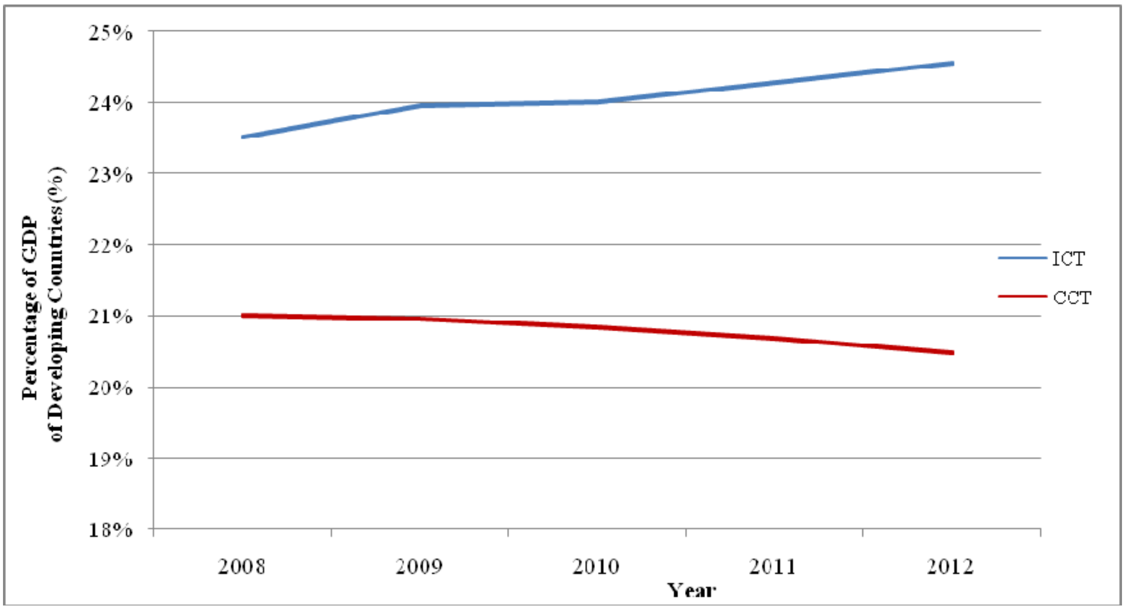


Fig. 4. Percentage of GDP of Developing Countries

Fig. 5. Difference in Per Capita GDP

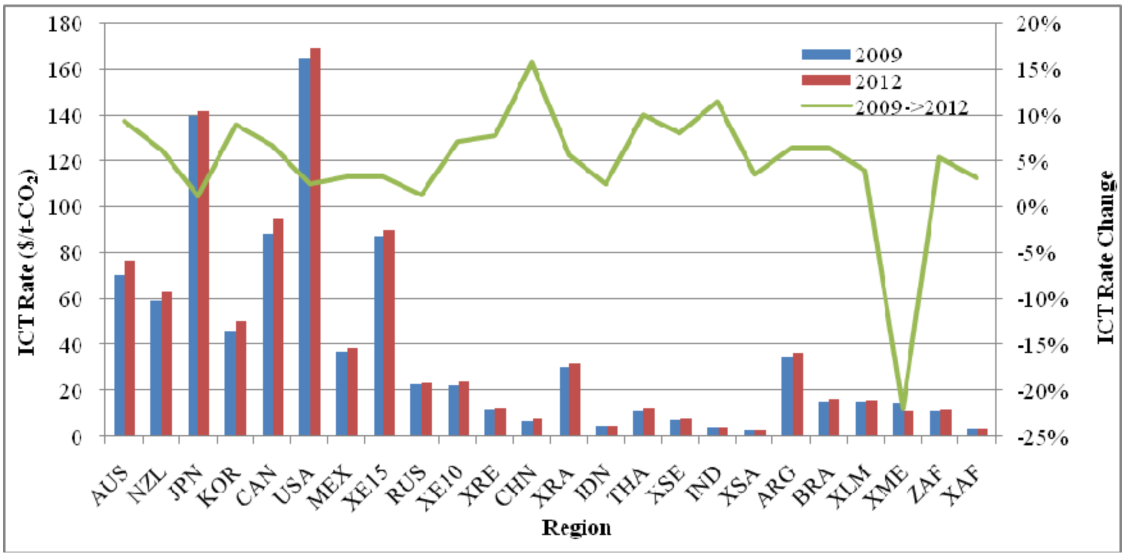


Fig. 6. ICT Rates and the Changes in Each Region

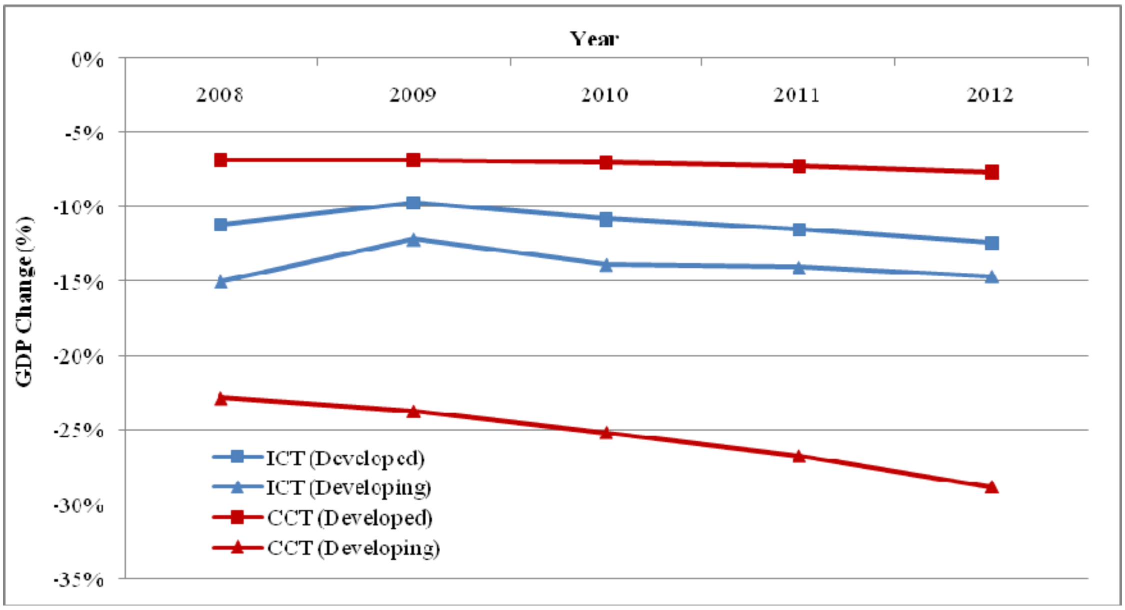


Fig. 7. Percentage Changes in GDP in Developed and Developing Countries (%)