Article

Mid-term Dynamic Effects of Carbon Tax Based on the Imputed Price of Carbon

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Abstract

A carbon tax based on the imputed price of carbon (ICT) is an international tax with tax rates that differ among countries according to their economic levels. Although the effects were analyzed from the short-term perspective in the previous study, understanding the longer-term effects of ICT is significant considering the characteristics and urgent necessity of future climate change policies. This study purposes to analyze the mid-term (until 2050) impacts on environment and economy by applying a dynamic CGE model, and comparing ICT with an internationally common carbon tax (CCT).

As a result, a tradeoff between economic equity and CO_2 emissions abatement occurs between ICT and CCT. From the emissions abatement aspect, CCT is superior to ICT. However, considering the economic aspects simultaneously, the suitability of CCT diminishes. While the negative influence on GDP is smaller in developing countries than in developed countries under ICT, it is larger in developing countries under CCT. Furthermore, disparities of per capita GDP among the regions are narrowed more under ICT, meaning that economic equity progresses further. In the light of significance of the 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.

Key Words: International carbon tax, Imputed price of carbon, Economic equity, Dynamic CGE model, Mid-term analysis

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 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). In addition, necessity of drastic GHG emissions abatement has been stated by some countries and regions[1, 2], and also by IPCC[3]. 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[4]. 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, international policies for the future are necessary urgently to sustain the international efforts against climate change. There have been a number of proposals for future climate change policies such

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as the multi-stage approach[5, 6], the Brazilian proposal[7], the triptych approach[8, 9], contraction and convergence[10], the carbon intensity target[11], and so on[12, 13] [i]. However, conclusions on the methodology of the 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[4, 14]. In these studies, the availability of carbon taxes as an international climate change policy[ii] was advocated by pointing out some problems and defects of the Kyoto Protocol and Kyoto-type international climate change policies[iii]. 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[15]. ICT and CCT were then analyzed and compared from environmental and economic (economic equity) perspectives. As a result, 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 due to the model structure, although understanding the dynamic effects is important considering the features of the tax[iv]. Matsumoto and Masui[16] then analyzed from the short-term dynamic perspective. The framework of the analysis was similar to the static studies. Consequently, it was found that economic disparities between developed and developing countries became narrower with time due to introduction of ICT, and feasibility of ICT was indicated again when considering the viewpoint of economic equity simultaneously. In the middle term, since there will be large differences in economic situations, GHG emissions, and technology from the present and shorter-term future, especially in developing countries, the impacts of ICT could be different in the longer-term perspective. Therefore, in order to tackle climate change issues further cooperatively throughout the world, it is significant to clarify the longer-term impacts on environment and economy.

The purpose of this study is to analyze the mid-term (until 2050) 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. As shown in detail in the next section, the ICT rates are determined according to some dynamic factors such as economic situations and CO_2 stock, hence analyzing by a dynamic model is significant. In addition, while it is required to abate GHG emissions internationally from mid- and long-term perspectives, 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, to some extent, the potential future outlooks 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, and the two carbon taxes 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

i Carbon tax is of course another example.

ii The post-Kyoto Protocol is considered there.

iii 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.

iv The features are explained in the sections below.

brief discussion on the possibility of a policy mix with ICT and the introduction of some additional climate change measures.

2. Methods

2.1 The AIM/CGE [Global] Model and Assumptions

In this study, the AIM/CGE [Global] model, also applied in Matsumoto and Masui[16), is applied for the analysis[v]. This model is a recursive dynamic CGE model[vi] in a global scale with 21 industrial sectors (Table 1) and 24 regions (Table 2).

The very basic mechanism of this model is similar to the GTAP model[20)] and GTAP-E model[21)]. 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, and hydro are considered; bio-energy production and consumption are included; and international markets are modeled for international trade of

Table 1 Structure of Industrial Sectors

Code	Including Sectors	Code	Including Sectors
COA	Coal	OMN	Other mineral mining
OIL	Crude oil	M_M	Metals & manufacture
GAS	Natural gas	FOD	Food processing
P_C	Petroleum & coal products	OMF	Other manufacture
GDT	Gas manufacture & distribution	CNS	Construction
ELY	Electricity	TRT	Transportation
AGR	Agriculture	CMN	Communication
LVK	Livestock	WTR	Water
FRS	Forestry	OSG	Governmental services
FSH	Fishery	SER	Other services
EIS	Energy intensive industries		

Table 2 Structure of Regions

Code	Including Countries	Code	Including Countries
AUS	Australia	XRA	Rest of Asia-pacific
NZL	New Zealand	IDN	Indonesia
JPN	Japan	THA	Thailand
KOR	Korea	XSE	Rest of Southeast Asia
CAN	Canada	IND	India
USA	USA	XSA	Rest of South Asia
MEX	Mexico	ARG	Argentina
XE15	Western EU countries	BRA	Brazil
RUS	Russia	XLM	Rest of Latin America
XE10	Eastern EU countries	XME	Rest of Middle East
XRE	Rest of Europe	ZAF	South Africa
CHN	China & Hong Kong	XAF	Rest of Africa

＊ We call the first eight regions “developed countries” and the others “developing countries” though including economies in transition.

[v] See also Masui[17)], Fujino, et al.[18)], and APEIS[19)] about the model.

[vi] CGE models are the multi-sector market equilibrium models focusing on the interrelation among economic entities and markets, and prices and supply and demand in goods and primary factors markets are determined simultaneously through the price mechanism.

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.

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

In this study, the base year is 2001. A simulation analysis is then implemented until 2050 with 5-year time steps except the period from 2001 to 2005, which is calculated with a 4-year time step. The data used in the analysis are based on the GTAP 6[22] for economy, the Energy Balances[23] for energy, the EDGAR 3.2 Fast Track 2000[24] for emissions, and the FAOSTAT[25] for land use.

2.2 Carbon Tax

The concept of the imputed price of carbon 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[4, 14]. This equation is identical with that used in Matsumoto and Masui[16].

$$ICT_{r,t} = \frac{\beta}{V - D_{t-1}} \left[\sum_r \frac{N_{r,t-1} y_{r,t-1}^{1-\sigma}}{1-\sigma}\right] y_{r,t-1}^{\sigma} \quad (1)$$

r: region, t: time period, $ICT_{r,t}$: 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 Eq. (1) indicates, the ICT rate of each region is proportional to per capita GDP exponentiated by elasticity parameter σ. Hence, the tax rates become higher in the developed countries and lower in the developing countries in the base year. Since the tax rates are determined (updated) every time period, the changes in the economic situations of the regions are reflected appropriately in the next step.

The values of the parameters independent of time in Eq. (1) are $\beta = 0.1$, $\sigma = 0.93$, and $V = 4.4$ trillion (t-CO_2)[4, 14, 26]. Table 3 shows GDP and population in 2005 which is one step before the tax introduction year (2010). Also, the ICT rates in 2010 calculated from Eq. (1) are shown. Although

Table 3 GDP, Population (in 2005), and ICT Rate (in 2010) of Each Region

Regions	GDP (Bil \$)	Population (Mil)	ICT (\$/t-CO_2)	Regions	GDP (Bil \$)	Population (Mil)	ICT (\$/t-CO_2)
AUS	377.9	20.1	97.3	XRA	329.5	56.9	32.8
NZL	51.7	3.9	70.1	IDN	163.4	226.0	4.8
JPN	4138.0	128.7	160.4	THA	134.5	63.7	12.9
KOR	485.1	48.2	54.6	XSE	391.3	266.3	9.2
CAN	712.9	32.1	114.0	IND	549.7	1086.3	3.4
USA	10706.9	299.8	176.8	XSA	162.6	381.6	2.9
MEX	728.9	106.5	38.2	ARG	254.7	39.3	36.3
XE15	7578.5	382.5	102.4	BRA	494.4	182.5	16.2
RUS	890.8	142.9	35.1	XLM	645.4	228.5	16.8
XE10	346.7	74.8	26.6	XME	713.8	191.1	21.8
XRE	675.1	277.4	14.7	ZAF	106.6	46.2	14.0
CHN	1570.5	1334.3	7.5	XAF	487.4	843.2	3.9

the ICT rates in most of the developed countries are higher than $50/t-CO_2$ [vii], 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), then they are compared as implemented in the previous studies[4, 14, 16]. For the CCT rate, it is set to attain an equal change in global GDP (comparing to the BAU case) to the case of ICT in the final year as a result of the analysis. The CCT rate corresponding to the ICT rates is $95.7/t-CO_2$. 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.

3. 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 2050 respectively.

A CO_2 emissions abatement of 69.4% is realized in the case of ICT and that of 73.3% is realized in the case of CCT globally in 2050 (Fig. 1). In other words, CCT contributes 5.5% more to CO_2 emissions abatement than ICT. This result is quite different from the results shown in Matsumoto[4, 14] in which CCT contributes about 1.5 times more to CO_2 emissions abatement than ICT. Furthermore, the difference becomes smaller than the short-term perspective where the difference is 16.3%[16]. The reason for this is that economic disparities among the regions become narrower over time in the case of ICT than that of CCT [viii]. Consequently, more efficient CO_2 emissions abatement is realized in 2050 than the earlier years by ICT.

Comparing the changes in GDP (Fig. 2), those by ICT and CCT are equivalent, –12.8% on average worldwide in 2050, 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 (–17.1% in the case of ICT and –10.6% in the case of CCT). For the developing countries, on the other hand, the damage is smaller in the case of ICT than that of CCT (–9.8% in the case of ICT and –14.3% in the case of CCT). In addition, the negative changes tend to be larger in the richer regions in the case of ICT (▲ and the dashed line in Fig. 3). This tendency is opposite to the case of CCT in which the negative changes tend to be larger in the poorer regions (■ and the solid line in Fig. 3). Comparing the two taxes, introducing ICT instead of CCT contributes more to the narrowing of economic disparities among the regions. For example, the percentage of GDP of developing countries in the world increases as time passes and it is larger in the case of ICT (26.2% in the case of ICT and 23.3% in the case of CCT in 2010, and 61.1% and 58.0% respectively in 2050). Moreover, the difference in per capita GDP among regions is narrowed more

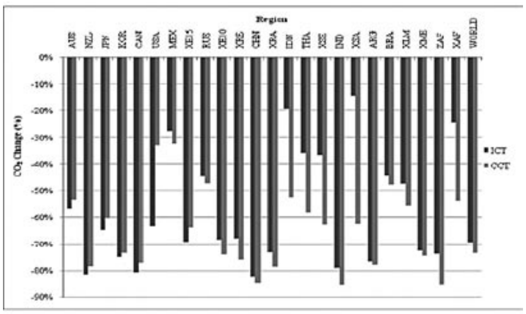

Fig. 1 Percentage Changes in CO_2 Emissions in 2050 (%).

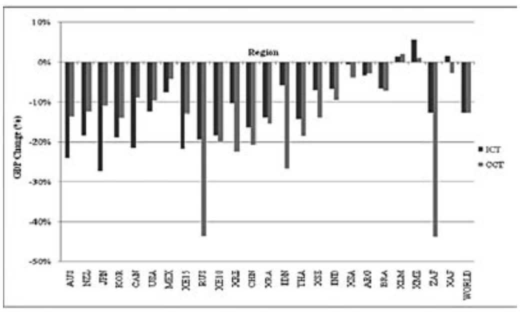

Fig. 2 Percentage Changes in GDP in 2050 (%)

[vii] 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.

[viii] The difference of the model structure with Matsumoto[4, 14] is also considered one of the reasons.

in the case of ICT than that of CCT (Fig. 4). In the case of CCT, the difference is larger than that of BAU. Also, increases in the ICT rates are higher in the developing countries than in the developed countries as a whole (Fig. 5[ix]). The tax rates increase is largest in IND, CHN, XSE, THA, and BRA. As a result, further reduction of the economic disparities is realized.

Comparing the above results with the static analysis[4, 14] and the short-term dynamic analysis[16], the effectiveness of ICT increases from the mid-term perspective. From the economic aspect, the effect on economic equity is enhanced. In addition, from the environmental aspect, the difference in CO_2 emissions abatement amount between the two taxes decreases compared to the previous studies.

Because CCT imposes excessive economic burdens on the developing countries, it conflicts with the principle 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 that this principle is essential[27].

In contrast, the negative economic influence is smaller in the developing countries totally in the case of ICT than that of CCT and it is also smaller than that in the developed countries (Fig. 6), hence there is economic equity among the developed and developing countries regarding their states

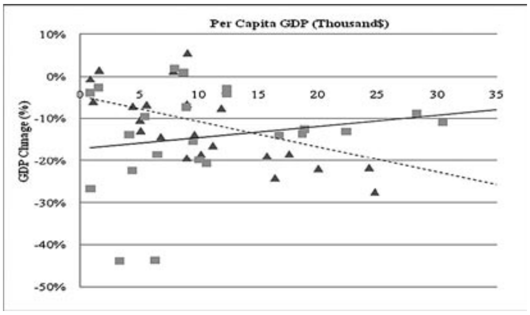

Fig. 3 Correlation between Per Capita GDP and GDP Changes (sannkaku ▲ : ICT, ■ : CCT)

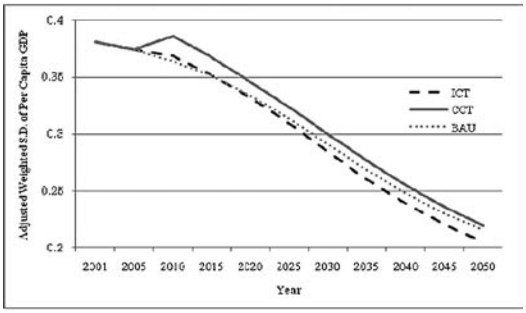

Fig. 4 Difference in Per Capita GDP

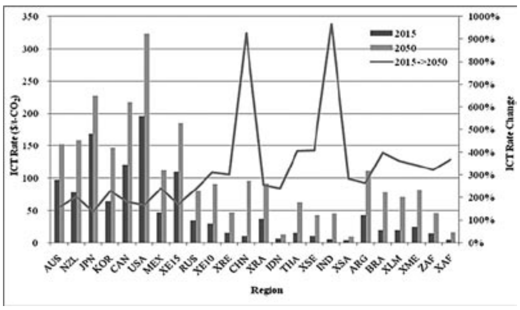

Fig. 5 ICT Rates and the Changes

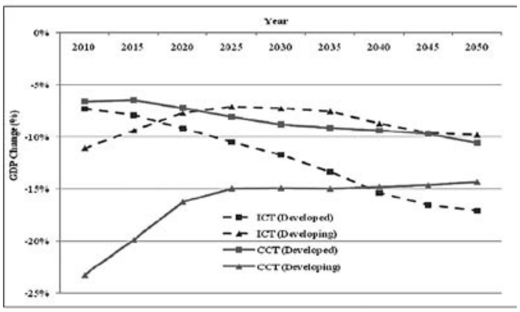

Fig. 6 Percentage Changes in GDP in Developed and Developing Countries (%)

[ix] Because ICT (and also CCT) is not introduced in 2005, there is no influence of the tax on the rates in 2010. On the other hand, there is the influence of the tax imposed in the previous period from 2015. Therefore, the ICT rates in 2050 are compared with those in 2015, not in 2010, in Fig. 5.

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[28], 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[29]. Consequently, the above results and discussions suggest that ICT is more appropriate as a carbon tax policy than CCT from the mid-term perspective.

4. Concluding Remarks

In this study, the mid-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[4, 14] and in a short-term dynamic basis[16], mid-term dynamic analysis was implemented in this study considering the further efforts against climate change and 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[4, 14]. Observing the result 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 if ICT was introduced (Fig. 4). It is essential to take into account economic aspects, which are crucial matters especially for developing countries, 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, carbon leakage occurs and the CO_2 emissions abatement amount becomes much smaller in the case of CCT without the participation of developing countries than in the case of ICT[4, 14, 30]. 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[x]. In addition to this, since the tax rates are determined objectively by the equation, it is expected that such a tool can facilitate 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 sorts 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[4, 31~33]. Furthermore, additional climate change measures such as technology transfer and financial aid for developing countries as implemented under the Kyoto Protocol and UNFCCC, must be introduced simultaneously.

In order to apply this tax system to the actual policy, it would be most appropriate and realistic to utilize and discuss under the UNFCCC, which is the only existing global framework for climate change policies. Also, the global participation contributes to formulation of the more effective system. Once the method is determined internationally, only thing each country should do is to legislate the tax internally and basically free reins should be given to the market forces so that GHG emissions are abated through the price mechanism. However, if the international competitiveness of a certain industry is extremely weakened, it will be possible to address the influence to some extent, for example by recycling the tax revenue. Even in such case, careful consideration, whether such

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

measures are necessary, is indispensable in order not to distort the international commitment. At the stage of the enforcement, some compliance mechanism such as penalties would be essential to ensure the achievement since noncompliance can occur without it, though it will not be easy to institutionalize such mechanism thoroughly considering the characteristics of international treaties. Although the legally binding force of the Kyoto Protocol is weak, it will be possible to introduce it even for international climate change policies looking at an example of WTO, which has the Dispute Settlement Body. In addition, some measures to help developing countries and promote further emissions abatement should be introduced as discussed above. It is expected to have urgent discussions and make efforts to realize the tax to obtain the effect as early as possible.

It will be important for future studies to analyze the longer-term dynamic effects of ICT because the influence of climate change will appear in the longer term and economic circumstances of some developing countries will approach those of developed countries. Also, it will be necessary to analyze the effects of policy mixes combining ICT with project-based abatement methods, technology transfer, and financial aid.

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帰属炭素税の中期的動学効果に関する分析

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摘　　要

国際炭素税は CO_2 排出削減を効率的に達成するための一手段である。しかし，各国で共通の税率を導入すると貧困国の経済的負担は大きくなる。炭素の帰属価格に基づく炭素税（ICT）は，各国の経済レベルに応じた差異のある税率を賦課する国際炭素税である。これまでの研究では ICT の効果を短期的観点から分析してきたが，本税の性質や将来の気候変動政策の構築が急務であることを踏まえると，より長期的な効果を分析することが非常に重要となる。本研究の目的は, ICT が環境と経済に与える中期的な（2050 年までの）影響を分析することである。本分析には動学的応用一般均衡モデルを用い，ICT による影響を国際共通炭素税（CCT）による影響と比較する。各地域の ICT の税率は公式に従って決定され，毎期更新される。一方，CCT の税率は ICT ケースと世界の GDP 変化（BAU 比）が同率となるように決定される。

分析の結果，世界全体の CO_2 排出削減量は ICT ケースの方が CCT ケースよりも小さいことが示された。この点では，CCT がより適切な炭素税であると言える。しかし，経済的側面も同時に考慮すると，両者で地域的な GDP 変化のパターンが大きく異なるために CCT の優位性は低下する。ICT ケースでは GDP のマイナス影響が途上国で先進国よりも小さいが，CCT ケースではその逆に途上国でマイナス影響が大きくなる。さらに，ICT ケースの方が世界全体の GDP に占める途上国の割合が高くなり，地域間の一人あたり GDP の格差が縮小する。この結果は，両者の経済的公平性が進展することを意味する。そのため，ICT と CCT には経済的公平性と CO_2 削減効果にトレードオフが見られる。世界全体で CO_2 排出削減政策を導入することと途上国に対する過度な経済的負担を回避することの重要性を踏まえると，中期的に見て ICT の方がより政策的実効性の高い炭素税政策と言える。

キーワード：国際的炭素税，炭素の帰属価格，経済的公平性，動学的応用一般均衡モデル，中期分析