The Double Dividend from Carbon Regulations in Japan

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Abstract

Using a multisector dynamic CGE model, this paper examines the double dividend from carbon regulations in Japan. The model has 27 sectors and goods (eight goods generate carbon emissions) and covers 100 years (from 1995 to 2095). When carbon regulations are introduced, pre-existing taxes are reduced, keeping government's revenue constant. Our main findings are summarized as follows. First, the weak double dividend arises in all scenarios. This means that by using revenues from carbon tax to finance reductions in pre-existing distortionary taxes, one can achieve cost savings relative to the case where the tax revenues are returne to households in lump-sum fashion. Second, the strong double dividend does not arise from reductions in labor and consumption taxes, but it does from reductions in capital tax. The second result is attributable to the nature of the pre-existing tax system in Japan where capital taxes are more distortionary than labor and consumption taxes.

Keywords: The double dividend; carbon regulation; CGE analysis.

JEL Classification: C1000.

Contents

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1 Introduction

Various policy instruments for reducing GHG emissions have already been designed, and in particular, *economic measures* such as emission taxes and emission permit trading have attracted much attention. For example, the Kyoto Protocol allows for emission permit trading, and European countries have already introduced carbon taxes. In Japan, it is recognized that conventional voluntary energy saving is not sufficient to achieve the Kyoto targets, and the Japanese government has begun to consider carbon taxes.

In economics, much research on emission taxes and emission permit trading has already accumulated. In particular, the *double dividend hypothesis* has attracted much attention. The idea of the double dividend hypothesis is summarized as follows.[1] The principal aims of emission regulations are to reduce emissions and to improve environmental quality. However, if economic regulations such as emission taxes and permit trading are introduced, the government can collect additional revenues. With these additional revenues, the government could reduce existing tax levels without reducing

[1]For details of the double dividend hypothesis, see surveys such as Goulder (1995b) and Bovenberg and Goulder (2002).

revenue. Since most existing taxes such as corporate income and labor income taxes are considered distortionary, it is likely that reducing these taxes will remove some distortions from the economy and thereby improve the efficiency of the tax system. If the government can indeed improve efficiency by replacing distortionary taxes by emission regulations, the introduction of emission regulations not only improves environmental quality (the first dividend) but also increases the efficiency of the tax system (the second dividend). The double dividend refers to a situation in which emission regulations yield the second dividend as well as the first dividend.

The notion of the double dividend is especially appealing to environmental protectionists and policy makers who try to promote environmental protection. Although it is widely recognized that emission regulations can have desirable effects on the environment, they usually attract strong opposition because they are likely to impose further burdens on economies. However, policymakers who can achieve the "double dividend" can introduce emission regulations at no cost.[2] If emission regulations are costless, policymakers and environmental protectionists can promote environmental protection without friction. In this sense, the information on the possibility of the double dividend is very important for policy making.

Reflecting this importance of the double dividend hypothesis, Park (2002, 2004), and Kawase et al. (2003) try to analyze the double dividend hypothesis from carbon emission regulations in Japan, using CGE model analyses. Park (2002, 2004) construct the model with involuntary unemployment and examine the swap of carbon tax for existing labor and income taxes. On the other hand, Kawase et al. (2003) examines the double dividend from not only labor tax reduction but also reduction of consumption and capital taxes. Although these studies use elaborate models and data and provide excellent analyses, they have one important drawback, that is, both of them employ a static model. Because of this drawback, dynamic effects from emission regulations and tax reform are eliminated from their analyses. Moreover, they cannot analyze capital and asset taxes appropriately. Since Park (2002, 2004) assume that capital stock is exogenously constant, distortions in capital market are excluded from their models and thus they cannot analyze swap of emission regulations and capital taxes. On the other hand, Kawase et al. (2003) examines capital and asset taxes. However, they realize it by making a peculiar assumption on a static model.

To overcome these limitations in previous studies, this paper empirically examines the double dividend from carbon regulations in Japan, using a dynamic CGE model. A dynamic model enables us to capture dynamic effects from carbon regulations and tax reform. In particular, in a dynamic model, we can introduce capital taxes appropriately and thus analyze distortions resulted from capital taxes. Moreover, a dynamic model enables us not only to analyze capital tax itself but also analyze interaction between capital tax and other taxations.

There are already several analyses which try to examine the double dividend hypothesis from carbon regulations with dynamic CGE models. For example, Shackleton et al. (1996), Goulder

[2]Strictly speaking, it is called the *strong* double dividend.

(1995a), Bovenberg and Goulder (1996, 1997), and Böhringer et al. (1997). These studies analyze not only labor taxes but also capital taxes. However, all of these studies focus on carbon regulations in US and European economies and do not analyze regulations in Japan. This paper tries to add new analysis to these studies. Needless to say, an analysis on carbon regulations in Japan is quite useful for Japanese policy maker. However, it has another implication.

The possibility of the double dividend depends crucially on pre-existing tax system and types of carbon regulations and tax reform, and thus it can vary across regions. However, since most of the previous studies listed above reached the conclusion that the double dividend does not occur, the idea that the double dividend is not likely to arise is dominant in the literature. However, it is not appropriate to evaluate the relevance of the double dividend hypothesis only from studies which focus on US and Europe. In particular, Japan is a region with substantial carbon emissions following US, EU, China, and Russia and thus is one of the most important regions in terms of prevention of global warming. Without analyzing such an important region, we should not reach the conclusion on the double dividend hypothesis. In fact, our analysis on emission regulations in Japan may be able to reverse the idea dominant in the previous literature. Even if our analysis reaches the same conclusion as the previous studies, it leads to the improvement of the undesirable situation where researches on the double dividend hypothesis focus extremely on US and Europe. Based on the reasons listed above, the analysis on emission regulations in Japan can be an important contribution to researches on the double dividend hypothesis.

To do the analysis, we employ a CGE approach using a multisector dynamic general equilibrium model. The model has 27 sectors and goods (eight goods generate carbon emissions) and covers 100 years (from 1995 to 2095). In the baseline equilibrium where no emission regulations are introduced, we incorporate various taxes that apply in Japan, such as taxes on labor, capital, and consumption. We assume that these taxes are reduced when emission regulations are introduced. Emission regulations take the form of carbon tax whose level is determined so that total volume of carbon emissions is reduced to the targe level.

Based on the model and assumptions above, we examined the validity of the double dividend hypothesis and obtained the following results. First, the weak double dividend arises in all cases. This means that by using revenues from carbon tax to finance reductions in pre-existing distortionary taxes, one can achieve cost savings relative to the case where the tax revenues are returne to households in lump-sum fashion. Second, the strong double dividend does not arise from reductions in labor and consumption taxes, but it does from reductions in capital tax. The result that the double dividend does not arise from reductions in taxes on labor and consumption is the same as the previous studies on US and Europe and thus reinforces the previous results. On the other hand, the result that the double dividend is possible in the case of reductions in capital tax has not been derived in the previous studies except for Jorgenson-Wilcoxen model in Shackleton et al. (1996) and thus noteworthy. This result is attributable to the nature of the pre-existing tax system where capital taxes are more distortionary than labor and consumption taxes. We also showed that the strong double dividend following the cut in capital tax is generated by the following two effects. First, the capital tax cut increases leisure significantly in the long run. Second, the capital tax cut increases consumption in the medium run and keeps the highest consumption level among all cases in the long run. We conducted several sensitivity analyses and found that the above results remain the same.

This paper is organized as follows. In the next section, we review the key aspects of the double dividend hypothesis. We provide a precise definition of the double dividend and consider the possible effects of swapping existing taxes. Section 3 describes the benchmark data set for the simulations, and Section 4 presents the model. In Section 5, determination of parameters and derivation of baseline equilibrium are explained. Section 6 explains the scenarios for simulation, and Section 7 presents the results of the computations. Finally, concluding remarks are provided in Section 8.

2 The double dividend hypothesis

In this section, we review the key arguments on the double dividend issue. First, let us ascertain the precise definition of the double dividend. From a cost–benefit point of view, an emission regulation is justified if it generates a positive net benefit:

$$\text{The net benefit} = \text{the gross benefit} - \text{the gross cost}$$

The gross benefit refers to the welfare gains associated with improvements in environmental quality due to emission regulations. This gross benefit (environmental benefit) refers to the "first dividend" in the context of the double dividend issue. On the other hand, the gross cost represents all effects other than the environmental quality change. When we analyze the double dividend hypothesis, it is assumed that new revenues from environmental regulations are used to finance reductions in pre-existing distortionary taxes. So, effects on the efficiency of the tax system are included in the gross cost. Using this gross cost, two types of the double dividend are defined:

The strong double dividend: This is the case where the gross cost of environmental regulations becomes negative.

The weak double dividend: This is the case where allocating new revenues from environmental regulations to reduce pre-existing distortionary taxes generates smaller costs than returning revenues directly to households in lump-sum fashion.

In the case of the strong double dividend, emission regulation brings about negative gross cost and thus improves welfare regardless of the size of its gross benefit. On the other hand, in the case of the weak double dividend, the gross cost of environmental regulations is positive. However, it means that using revenues to cut pre-existing distortionary taxes is more desirable than returning revenues to households in lump-sum fashion. Among two notions of the double dividend, the strong double dividend is more important, but this paper examines both of them.

The double dividend hypothesis is particularly worth considering in the context of the global climate change problem. In general, to do a cost–benefit analysis, it is necessary to evaluate both gross benefits and gross costs. However, it is widely recognized that quantifying the gross benefits of GHG abatement is extremely difficult.[3] Although the possible adverse effects of global climate change have already been well documented, most remain subject to significant uncertainties, and furthermore, even if such effects are identified, it is still difficult to quantify them. Given our current knowledge, evaluating the gross benefit of emission regulations accurately is quite difficult.

However, if it turns out that carbon emission regulations generate the second dividend — that is, if the gross cost of emission regulations is negative — the burden on policymakers is much lighter because they can justify the regulations without quantifying the magnitude of the gross benefit. Moreover, the double dividend means that emission regulations can be introduced without any additional burden. Because of this attractiveness to policymakers, the double dividend hypothesis has attracted much attention and its validity has been investigated by many researchers.

Since the possibility of the double dividend depends on the gross cost of emission regulations, factors which constitute the gross cost matter. The first factor is the ordinary abatement cost — that is, the cost resulting from the reduction in economic activities. This first factor is called the *primary cost*. The second factor is the change in efficiency resulting from a tax swap. The additional revenues generated from emission regulations can be used to reduce existing distortionary taxes. This tax swap alleviates distortions and improves the efficiency of the tax system. Namely, this effect makes the gross cost of emission regulations negative. This effect of the tax swap is called the *revenue-recycling effect*.

When the double dividend issue was first investigated, it was thought that the possibility of the double dividend was fairly high (for example, Pearce, 1991), and in fact, some researchers have shown that the double dividend does arise from emission regulations (for example, Reppetto et al., 1992). However, research beginning with Bovenberg and Mooij (1994) showed that previous studies had overlooked important effects associated with tax swaps.[4] What is pointed out by these studies is the effect of emission regulations on distortions caused by pre-existing taxes. This effect is called *tax-interaction effect*.[5]

The gross cost is derived by summing these three factors. As explained already, the primary cost raises the gross cost, and the revenue-recycling effect lowers it. On the other hand, the tax-interaction

[3] The one difficulty is the controversy over the discount rate. Second is the difficulty of incorporating the small possibility of catastrophic climate change due to possible non-linear responses within the climate system. Third is that the most climate sensitive countries tend to be in the developing world; therefore damage estimates are sensitive to distributional weights attached to poor countries.

[4] This research includes Bovenberg and Ploeg (1994), Goulder (1995b), Parry (1995), and Bovenberg and Goulder (2002).

[5] In some theoretical papers, the tax-interaction effect refers exactly to the effect that the carbon tax has on labor supply. However, in this paper, the term tax-interaction effect is defined more broadly, and all effects that operate between markets are regarded as tax-interaction effects. For example, the effect of a carbon tax on the labor market, the effect of a labor income tax reduction on the energy market, and the effect of a labor income tax reduction on the capital market are all classified as tax-interaction effects.

effect can work in either direction. So, whether the double dividend occurs or not depends on the direction of tax-interaction effect and the size of three effects. Since researchers before Bovenberg and Mooij (1994) neglected the tax-interaction effect, they suggested that the possibility of the double dividend was fairly high. However, the theoretical studies after Bovenberg have shown that the tax-interaction effect is likely to be positive, and thus the possibility of the double dividend is not so high. Moreover, most of empirical studies such as Shackleton et al. (1996), Goulder (1995a), Bovenberg and Goulder (1996, 1997), and Böhringer et al. (1997) have reached the conclusion that the double dividend does not arise.

However, the theoretical studies have also showed that the double dividend is possible under the following cases (Bovenberg and Goulder, 2002). First, in models where labor is the only primary factor, the double dividend can occur (1) if improvements in environmental quality have feedback effects that raise the marginal value of work time relative to leisure time; (2) if improvements in environmental quality raise labor productivity; (3) if, compared to dirty goods, clean goods are better substitute for leisure (or, if dirty goods are complements with leisure); (4) if polluting activities are subsidized; (5) if pre-existing commodity taxes are highly distortionary; (6) if there is involuntary unemployment because of imperfection in labor markets. In addition to these cases, in models with capital, the double dividend is possible (7) if pre-existing factor taxes are highly distortionary and if the tax swap shifts the burden of taxation from a factor with large distortion and onto a factor with small distortion.

To make clear mechanism which works behind the model in this paper, let us examine the relevance between our model and seven cases listed above. First, case (1) and (2) are not applied to our model because our model, like previous studies, does not include environmental quality (carbon emissions) into utility function (see Section 4). Moreover, since the utility function in our model assumes that dirty goods (goods that generate carbon emissions) and leisure are substitutes (not complements) and that elasticity of substitution between dirty goods and leisure is equal to that between clean goods and leisure, case (3) is eliminated from our model.

Case (4) is not relevant here because subsidies to energy-related industries are very small in Japan although they are not zero. Case (5) is important in the US context where there are large tax deductions for housing and health care and therefore cutting taxes reduces a distortion in the allocation of household spending in addition to improving efficiency in factor markets. Parry and Bento (2000) took account of this effect and showed the possibility of the double dividend can rise significantly. Also in Japan, a large amount of subsidies are paid to several goods such as health care and there may be large distortions in the allocation of consumer expenditure and therefore the reform of these subsidies may raise the possibility of the double dividend. However, since these subsidies are usually paid on equity grounds and thus it is politically difficult to reduce them, this paper does not consider such policy reform.

Case (6) is important in the European context where there is persistent high unemployment. Due to long-lasting economic recession since 90's, Japan also has experienced high rate of unemployment and the importance of unemployment problem is increasing. However, compared to European regions, rate of unemployment in Japan is still much lower and unemployment is not as serious as in Europe. So, this paper does not consider involuntary unemployment and case (6) is eliminated from our analysis. Other simulations with dynamic models make the same assumption. Since this paper uses a dynamic model and analyzes not only distortions caused by labor taxes but also distortions by capital taxes, case (7) is quite important. The effect of case (7) is called *tax-shifting effect*. In the previous studies, Jorgenson-Wilcoxen model in Shackleton et al. (1996) derived the result that the double dividend arises from reduction in capital taxes. It is thought that this result is due to the tax-shifting effect which works from capital with high distortion to labor with low distortion.

These are the main results derived from the previous theoretical studies. Since case (1) to (6) are not applicable to our model presented later, whether the double dividend is possible or not depends mainly on whether case (7) does hold or not, that is, whether tax-shifting effect does work in desirable direction or not. In the analysis below, we examine this point carefully. However, note that the above arguments do not imply that case (1) to (7) are only reasons for the double dividend to occur. Since we use a large-scale complicated dynamic CGE model with intermediate inputs, investment, and international trade and consider many pre-existing taxations, effects overlooked in theoretical studies can work in our model.[6] So, there could be another factors in our model that yield the double dividend and case (7) may not be the only factor.

3 Data

In this section, we briefly describe benchmark dataset. The benchmark data comprise three main parts: (1) economic data, (2) quantity data of carbon emission sources, (3) tax data. "Economic data" are value data of outputs, intermediate inputs, primary factors, and final demand. "Quantity data of carbon emission sources" are quantity data of inputs and the consumption of goods from which carbon is emitted. "Tax data" record the pre-existing taxes in Japan in the benchmark year. All data refer to 1995, which is the benchmark year for the simulation.

3.1 Economic data

For value data of outputs, intermediate inputs, final consumption, investment, government expenditure, exports and imports, we mainly use the data of "Japanese 1995 Input-Output Table" (MCAG 1999, IO table hereafter) and "2003 Annual Report on National Accounts" (ESRI, 2003). Since we assume the 27 sectors listed in Table 1 for the simulation, the original 519×403 IO table is aggregated

[6] Most theoretical studies use highly simplified models where one sector, one factor, no intermediate input, no investment, closed economy, and static structure are assumed. Moreover, they usually consider only one or at most two pre-existing taxes.

into 27 sectors. We adjusted the data so that the number of goods is equal to the number of sectors. Thus, the number of goods is also 27.

Table 1: Sector identifiers (27 sectors)

Identifier	Sector description
AGR	Agriculture, forestry and fishery
LIM	Limestone (Materials for ceramics)
COC	Coking coal
SLA	Steam coal, lignite and anthracite
CRU	Crude petroleum
NAT	Natural gas
OMI	Other minings
FOO	Foods
TET	Textile products
PPP	Pulp, paper and wooden products
CHM	Chemical products
PET	Petroleum refinery products
OPP	Other petroleum products (naphtha and others)
COK	Coke (Coal products)
CSC	Ceramic, stone and clay products
IAM	Iron and metal
MAC	Machinery
OIP	Other industrial products
CON	Construction
ELE	Electricity
GAS	Gas supply
SWW	Steam, and hot water supply, water supply and waste disposal services
COM	Commerce
RES	Real estate
TCB	Transport, communication and broadcasting
PUB	Public administration
SER	Services

3.2 Quantity data of carbon emission sources

Table 2: Carbon emission sources and energy goods

Classification	Goods
Emission sources (ESs)	COC, SLA, CRU, NAT, PET, COK, GAS, LIM
Energy goods	COC, SLA, CRU, NAT, PET, GAS, ELE

Since our main purpose is to investigate the effect of carbon emission regulations, we need to calculate the volume of carbon emissions. To do this, it is necessary to prepare a data set on goods whose input and consumption involves carbon emissions. We refer to these goods as *carbon emission sources* (ESs hereafter). The list of eight ESs that we consider in the simulation is displayed in Table 2. In addition, we define *energy goods*, which are treated differently from other goods in the production and utility functions. For input and consumption data of ESs, quantity data as well as value data are necessary to derive carbon emissions. For this, we use the data provided by 3EID

(Embodied Energy and Emission Intensity Data for Japan Using Input-Output Table, Nansai et al. 2002). 3EID is the data in which intermediate inputs and final consumption of emission sources are recorded. We aggregated 399 sectors of data from 3EID into 27 sectors.

3.3 Tax data

At the benchmark year of the simulation, there were various taxes in Japan. For example, there were corporation tax, corporation inhabitant tax, and corporation enterprise tax as taxes on firms, and income tax and inhabitant tax as taxes on households. In addition, we had consumption tax, import tariff, fixed asset tax, liquor tax, and various energy taxes such as gasoline tax and local road tax.

Of course, it is desirable to introduce these taxes into the model. However, it is extremely difficult to incorporate all existing taxes into a general equilibrium model which tries to capture the Japanese economy as a whole. Thus, to simply the model, we divide existing taxes in Japan to the following eight taxes: (1) labor income tax, (2) capital income tax, (3) consumption tax, (4) capital tax, (5) labor tax, (6) indirect tax on production, (7) import tariff, and (8) subsidies for consumption. Note that labor tax and labor income tax have the same tax base, that is, labor. However, they are distinguished because labor tax is imposed on production sectors and labor income tax is imposed on the household. Similarly, capital tax and capital income tax are distinguished because the former is imposed on production sectors and the latter is imposed on the household. Moreover, labor and capital taxes are imposed at different rates across sectors. Among eight taxes and subsides above, taxes swapped for emission regulation in the simulation are the following five taxes: labor income tax, capital income tax, consumption tax, capital tax, labor tax.

4 Model

In this section, we present the structure of the model used for the simulation. The model is based on a multisector dynamic general equilibrium model used in Böhringer et al. (1997) and Rutherford et al. (2002). Here only the main features of the model is described and detailed explanation is offered in the supplement of this paper.[7] The flows of goods, factors, and taxes are summarized graphically in Figure 1.

4.1 Production side

Using intermediate inputs and primary factors (labor and capital), firms produce goods under constant returns to scale (CRS) technology to maximize profits. All markets are assumed to be perfectly competitive and thus all producers are price takers.[8] In the production function, inputs are catego-

[7] A detailed supplementary paper which documents the structure of model, data, and simulation is available from the author upon request.

[8] Scale economies are often observed in various manufacturing industries. In addition, electric power industries in Japan have not only scale economies but also regional monopoly power, and they are administered under regulations. Thus, it is clear that the assumption of CRS technology and perfect competition does not reflect reality. However, it is quite difficult to introduce scale economies and imperfection competition into a large scale dynamic CGE model.

Flows of goods, factor, taxes, and emissions

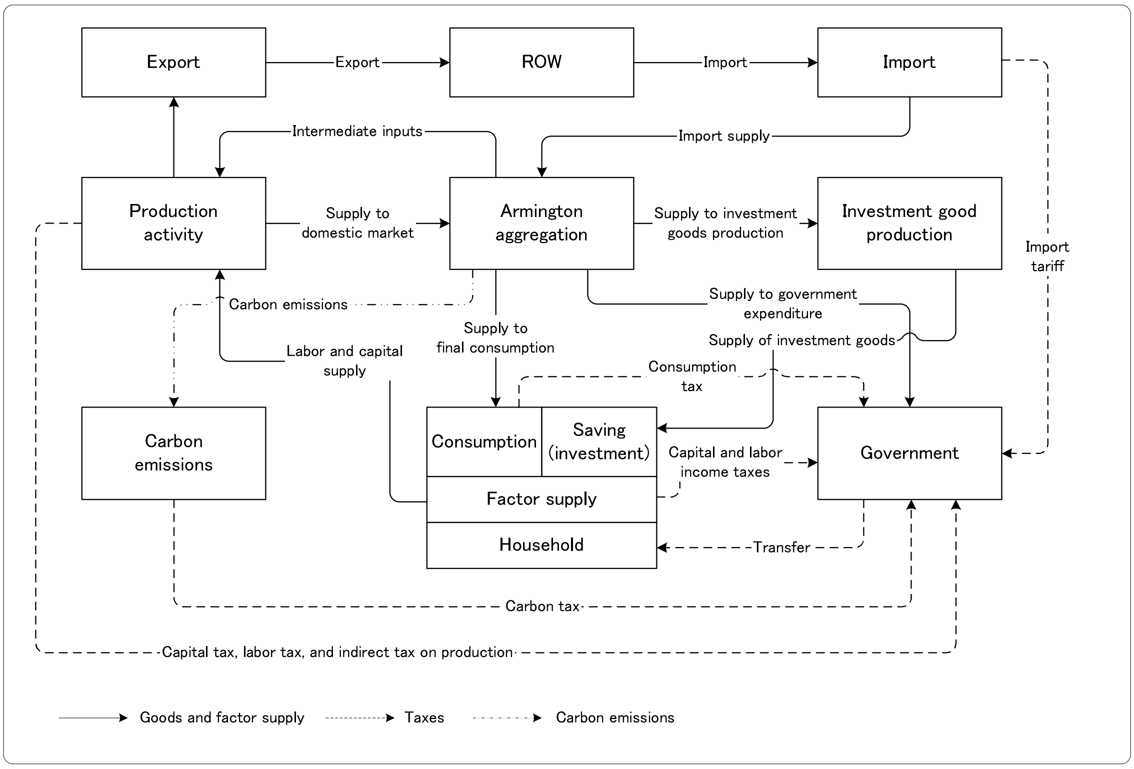

Figure 1: Flow of goods, factors, taxes and emissions.

rized into the following four types: (1) non-energy goods, (2) energy goods for combustion purpose, (3) energy goods for non-combustion purpose, and (4) primary factor (capital and labor).

Energy goods include COC, SLA, CRU, NAT, PET, GAS, and ELE in Table 2, and non-energy goods are all other goods. Note that although LIM and COK are sources of carbon emissions, they are not included among energy goods because they are treated as ordinary materials in the production function. Moreover, inputs of energy goods for non-combustion purpose such as CRU inputs to sector PET and NAT inputs to sector GAS are treated in the same way as non-energy intermediate goods.

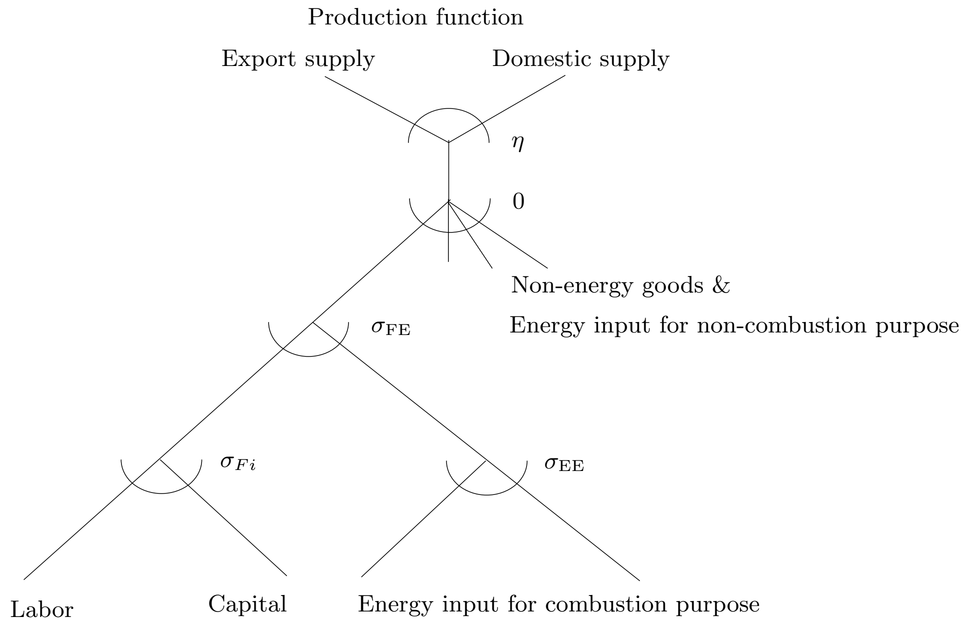

Figure 2: Production function

The production function is a nested CES function represented by Figure 2. The numerical values (of the sigmas) in the figure represent elasticities of substitution between inputs (see Table 3). Output is produced with fixed coefficient aggregation of non-energy intermediates, energy intermediates for non-combustion purpose, COL and LIM inputs for combustion purpose, and primary factor-energy composite. The primary factor-energy composite is a CES aggregation of primary factor composite and energy composite with elasticity σ_{FE}. The primary factor composite is a CES aggregation of labor and the capital stock with elasticity $\sigma_{F,i}$, and the energy composite is a CES aggregation of energy goods with elasticity σ_{EE}.

With regard to the output side, following Böhringer et al. (1997), we assume that goods produced for domestic market and goods produced for export are differentiated, and that they are allocated through a CET (constant elasticity of transformation) function with elasticity η. In the simulation, we assume $\eta = 4$ for all sectors.

Thus, we assume CRS technology and perfect competition as many previous studies do.

We adopt the neoclassical assumption that capital stock is owned by households and rented to industries. This assumption means that investment is also done by households, not by industries. As explained in section 3.3, we assume that taxes are imposed on employment of capital and labor and we call them capital tax and labor tax. Moreover, each sector is imposed ad-valorem tax on his output (indirect tax on production).

4.2 Household

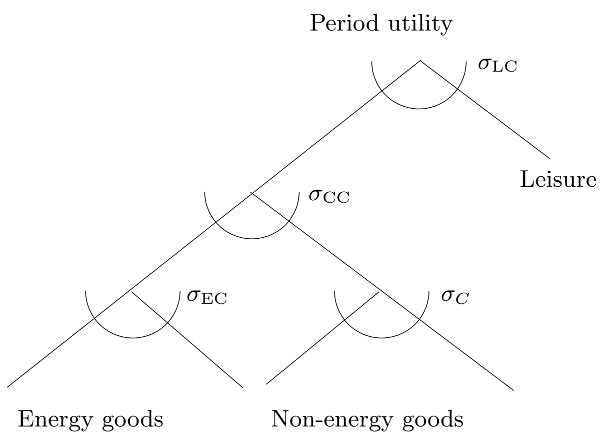

Figure 3: Period utility

To represent the demand side, we assume an infinitely lived representative household.[9] Final consumption, savings, and labor supply are derived from the optimizing behavior of this representative household. The period utility for the household is a nested CES function in Figure 3, which depends on leisure and aggregate consumption. Aggregate consumption is a CES aggregation of an energy composite and a non-energy composite with elasticity σ_{CC}. The energy composite is a CES aggregation of energy goods with elasticity σ_{EC}, and the non-energy composite is a CES aggregation of non-energy goods with elasticity σ_C. As in other empirical studies on the double dividend, we assume that environmental quality and public goods are not included in the utility function. The values of the elasticities of substitution in the utility function are given in Table 3. Lifetime utility is assumed to be a CES function of period utility:

$$U = \left[\sum_{t}^{\infty} \alpha_t^U (W_t)^{\frac{\sigma_U - 1}{\sigma_U}} \right]^{\frac{\sigma_U}{\sigma_U - 1}} \tag{1}$$

where W_t is period utility in period t, and σ_U is the intertemporal elasticity of substitution. The representative household chooses consumption, savings and labor supply subject to its lifetime budget constraint so as to maximize this lifetime utility.

[9] In reality, households differ both in energy consumption and taxations according to their types. Thus, it is desirable to households according to their types. However, it is quite difficult to introduce multi-households into a large-scale dynamic CGE model in terms of both data construction and model building. So, we assume a single representative household as most studies do.

The representative household derives revenue from the following four sources: (1) labor income, (2) capital income, (3) transfer from government, and (4) borrowing. The household owns labor and capital stock, and earns income by supplying them to industries. As already explained in section 3.3, the household is imposed labor and capital income taxes. Moreover, the household pays consumption tax on his consumption.

4.3 Investment (capital accumulation)

In addition to its role as a consumer, the household plays the role of investor by using its savings to purchase an investment good, thereby accumulating capital. The level of investment (savings) is determined so that the marginal benefit of the capital stock is equal to its marginal cost. An investment good is a fixed coefficient composite of 27 Armington goods.

We assume that this investment requires adjustment cost. To incorporate adjustment cost, we employ the standard quadratic adjustment cost. Namely, net investment J and gross investment I have the following relation:

$$I = J \left[1 + \phi \frac{J}{2K} \right]$$

where ϕ is adjustment cost parameter. The larger value of ϕ means the higher adjustment cost. In the simulation later, we assume $\phi = 0.5$.[10]

4.4 Government

The government activity consists of the following three: (1) taxation, (2) government expenditure, and (3) transfer to the household. The government obtains revenue by collecting taxes, which funds government expenditure and transfer. Government expenditure is spent on a good, which is a fixed coefficient composite of 27 Armington goods. The time path of government expenditure is exogenously given. Like other simulations on the double dividend issue, we assume that government expenditure does not enter into the household's utility function.

In the subsequent simulation, we assume that government budget is balanced intertemporally. Thus, government budget may not be balanced at each period. In addition, we assume that the path of government expenditure is held constant at the baseline equilibrium level and the additional revenues from emission regulations are used to cut pre-existing distortionary taxes. The taxes replaced are (1) capital income tax, (2) labor income tax, (3) consumption tax, (4) labor tax, and (5) capital tax. The rates of other taxes (import tariff and indirect tax on production) are held constant at their benchmark levels in all scenarios.

4.5 International trade

We assume that both goods and services can be traded internationally, although they are restricted by import tariff. All regions other than Japan are labeled as "rest of the world" and treated as

[10] In Section 7.3, we conduct sensitivity analysis for the adjustment parameter ϕ.

one region. Moreover, we assume that Japan is a small country and thus world prices are held constant. Like other CGE analyses, we use the Armington assumption to explain cross-hauling in trade (Armington, 1969). The Armington assumption implies that domestically produced goods and imported goods are imperfect substitutes. Domestic goods and imported goods are aggregated through a CES function with the Armington elasticities given in Table 4. These Armington elasticities are taken from the GTAP version 5 data set (GTAP, 2001). The produced Armington composite is used for intermediate inputs, final consumption, investment, and government expenditure (Figure 1). In the simulation, we assume intertemporally balanced current accounts. Thus, current accounts may not be balanced at each period. This assumption means that Japan can lend and borrow money with the rest of the world.

5 Parameters, exogenous variables, and the baseline equilibrium

In this section, we explain the determination of parameters and exogenous variables and the derivation of a baseline equilibrium without emission regulations. In addition, the way to calibrate the benchmark value of interest rate, capital stock, and rental price are presented. Parameters determined here are elasticities of substitution and depreciation rate, and exogenous variables determined here are government expenditure, technology parameters, and total labor endowment.

5.1 Elasticity of substitution

Table 3 presents exogenously determined elasticity of substitution. Actually, these values should be based on empirical estimates for Japan, but reasonable estimates for these parameters are not available. So, we determine them by using values in Böhringer et al. (1997) and Rutherford et al. (2002). Similarly, since reasonable estimates for elasticity of substitution of capital-labor and Armington elasticity for Japan are not available, we use values in GTAP data (Table 4 and Table 5).

Table 3: Value of elasticity parameters

Notation	Description	Value
η	Elasticity of transformation between domestic supply and export supply	4
σ_{FE}	Elasticity of substitution between primary factor composite and energy composite	0.5
σ_{Fi}	Elasticity of substitution between capital and labor in sector i	Table 5
σ_{EE}	Elasticity of substitution between energy intermediate inputs	0.5
σ_{Ai}	Armington elasticity of good i	Table 4
σ_{CC}	Elasticity of substitution between energy composite and non-energy composite in utility function	0.3
σ_{EC}	Elasticity of substitution between energy consumption goods	2
σ_{C}	Elasticity of substitution between non-energy consumption goods	1
σ_{U}	Intertemporal elasticity	0.5

Table 4: The values of Armington elasticity ($\sigma_{A,i}$)

Goods	Value
AGR, FOO, TET	2.2
OMI, LIM, COC, SLA, CRU, NAT, IAM, MAC, OIP, ELE, GAS, SWW	2.8
PPP	1.8
CHM, PET, OPP, COK, CSC, CON, COM, RES, TCB, CAB, PUB, SER	1.9

Source: GTAP version 5 data.

Table 5: The values of elasticity of substitution between capital and labor ($\sigma_{F,i}$)

Sector	Value
AGR, FOO	0.237
OMI, LIM, COC, SLA, CRU, NAT	0.2
TET, PPP, CHM, PET, OPP, COK, CSC, IAM, MAC, OIP	1.26
ELE, GAS, SWW, RES, TCB, PUB, CON, SER,	1.4
COM	1.68

Source: GTAP version 5 data.

In contrast to other elasticity parameters, elasticity of substitution between leisure and consumption in the utility function (σ_{LC}) is calibrated by providing a value of uncompensated wage elasticity of labor supply (ε_L) exogenously. Following Bessho et al. (2003), we assume $\varepsilon_L = 0.19$ for this calibration.[11]

5.2 Derivation of the baseline equilibrium

Simulation in a dynamic model usually compares the baseline equilibrium and after-shock equilibrium. Also in this paper, we first derive the baseline equilibrium without any emission regulations and then analyze what effects emission regulations have on the baseline equilibrium.

A frequently used approach for deriving a baseline equilibrium in a dynamic CGE analysis is to assume that the economy in the benchmark year is in steady state. For example, Böhringer et al. (1997) and Rutherford et al. (2002) adopt this approach for deriving a baseline equilibrium.

This approach has the following advantages: (1) it is easy to derive the baseline equilibrium because path of all variables can be predicted only from benchmark data and exogenously determined steady state growth rate;[12] (2) By using the assumption of steady state, we can calibrate parameters and variables.[13] On the other hand, this approach has a disadvantage that it is necessary to impose

[11] However, Hayashi and Bessho (2004) offer another estimate of ε_L, that is, 0.018. As this shows, empirical estimates of ε_L for Japan exhibit a wide range. So, we conduct sensitivity analysis for ε_L.

[12] For example, assume that a quantity variable x has a benchmark value of x_0 and that the steady state growth rate is $100 \times n$ %. Then, the value of x at period t is derived as $x_t = (1+n)^t x_0$. Moreover, since all price variables must be constant in steady state, the values of price variables at any point of time are equal to the benchmark values.

[13] The assumption of steady state implies that several conditions on parameters and variables must be satisfied.

strict conditions on the path of exogenous variables in order to assume steady state. For example, the only technology improvement consistent with steady state is labor-augmented technology improvement. The restriction that we cannot consider capital-augmented and energy-augmented technology growth is a significant limitation. In addition, we must assume that growth rates of exogenous variables such as government expenditure and total labor endowment is uniform and constant. This is also an annoying limitation.

The alternative approach for deriving the baseline equilibrium is to assume that the economy in the benchmark year is not in steady state. If this approach is employed, it is possible to determine paths of exogenous variables more freely. However, under this approach, one cannot do calibration of parameters and variables by using the steady state assumption. More serious problem is that values of endogenous variables in the benchmark year derived by this approach do not coincide with the benchmark data. In deriving a baseline equilibrium, it is desirable that the following two conditions are simultaneously satisfied; (1) values of endogenous variables in the benchmark year coincide with the benchmark data; (2) the baseline equilibrium is not in steady state. In fact, an approach for derivation of a baseline equilibrium in a dynamic CGE model, which satisfies above two conditions, are provided by Wendner (1999). However, the approach of Wendner (1999) is not applicable to a large scale CGE model with numerous endogenous variables like ours. Thus, it is difficult to satisfy two conditions simultaneously in our model.

As the above arguments show, both approaches have advantages and disadvantages and therefore we employ the alternative approach that combines two approaches above. In this paper, the baseline equilibrium is derived according to the following steps:

Step 1: First, we assume the steady state equilibrium with zero growth rate and calibrate parameters and variables.

Step 2: The values of total labor endowment, which is set to be constant in Step 1, are changed to desired levels.

Step 3: Finally, we calibrate technology growth rates so that rates of growth in GDP and carbon emissions derived from the model equilibrium coincide with exogenously given target growth rates. At the same time, we determine the path of government expenditure so that the benchmark level of government expenditure-GDP ratio is kept constant.

What is calibrated in Step 1 is discount factor in lifetime utility function (α_s^U), capital depreciation rate, benchmark values of interest rate, capital stock, and rental price. Under Step 1, it is assumed that total labor endowment, technology level, and government expenditure are constant over time so as to ensure a steady state equilibrium.

The path of total labor endowment specified under Step 2 is derived from the benchmark total labor endowment and projected labor growth rates. The value of projected labor growth rates from

Using these conditions, we can calibrate parameters and variables.

1995 to 2050 are taken from Yashiro et al. (1997). Since the value of projected labor growth rates after 2051 are not available, we use projected growth rate of population (16–50 years) as a substitute for it. Projected growth rate of population is taken from NIPSSR (2002).

As technology improvement introduced in Step 3, we consider primary-factor augmented technology growth and energy-augmented technology growth and assume that two types of technology growth have different growth rates. Target growth rates of GDP and carbon emissions used to calibrated two technology growth rates are derived from AIM/Trend model (AIM Project Team, 2002). Note that technology improvements calibrated here are exogenous and therefore common for both the baseline equilibrium and the dynamic equilibrium with emission regulations.[14]

5.3 Restriction on Terminal Period

Although a representative household is assumed to live over an infinite horizon, it is necessary to determine a terminal period to solve the model numerically. In the subsequent simulation, we set the terminal period at 2095; thus, the time period covered by the model is 1995 to 2095. There is one problem in setting the terminal period for a dynamic model. That is, if no condition is imposed on the terminal adjustment, investment becomes very low as the terminal period approaches because capital stock existing after the terminal period is worthless. To avoid this problem, we adopt the approach used in Lau et al. (1997) and Böhringer et al. (1997) — that is, we impose the following restriction on investment in the terminal period:

$$\frac{J_T}{J_{T-1}} = \frac{W_T}{W_{T-1}}$$

where J_s is net investment in period s, W_s is period utility in period s, and T is the terminal period. This restriction means that the growth rate of investment in the terminal period must be equal to the growth rate of period utility in that period. By imposing this restriction, the model yields a path of investment that is similar to one in an infinite horizon model. For more details on this terminal condition, see Lau et al. (1997).

5.4 Software

Numerical computation is done with GAMS (general algebraic modeling system) and its solver PATH.[15] For details of GAMS, see the GAMS web site <http://www.gams.com/>.

6 Policy scenarios

In this section, we explain various scenarios in which the simulation in the next section is conducted.

[14] Although we assume exogenous technology growth as most previous studies do, there are papers which consider endogenous technology growth. For example, Buonannoa et al. (2003).

[15] To write programs for the simulation in this paper, the author has greatly benefited from various GAMS programs created by Thomas F. Rutherford and his coauthors. The author would like to express acknowledgment to them. GAMS codes for the simulation in this paper is available from the author upon request.

6.1 Emission regulations

As carbon emission regulations, we use carbon tax. We assume that the government determines the target emission level and sets carbon tax so that actual emissions coincide with the target level.[16] This policy seems realistic because the Japanese government, who aims to achieve the Kyoto targets, is currently examining the introduction of carbon tax. Carbon tax is imposed on emission sources according to their carbon content and the government obtains all tax revenues from carbon tax.

The government restricts carbon emissions as follows. Let $\bar{C}_t$ denote carbon emissions in the benchmark year, and $\bar{C}_s$ denote carbon emissions in period s in the baseline equilibrium. Then, carbon emissions in period s under the regulations are given by:

$$C_s = \bar{C}_s - \alpha(\bar{C}_s - \bar{C}_t)$$

where α denotes the rate of reduction. That is, a constant fraction of increased emissions from the benchmark year level is abated.

We consider the following four reduction scenarios: $\alpha = 0.25$ (C25), $\alpha = 0.5$ (C50), $\alpha = 0.75$ (C75), $\alpha = 1$ (C100). Note that C100 represents the situation where carbon emissions are stabilized at the benchmark year level. Since Kyoto Protocol requires Japan to reduce carbon emissions at 6% to below the 1990 level, it seems that C100 is the closest policy to the Kyoto Protocol. However, in order to compare results, we consider other three scenarios, too.

6.2 Tax reforms

As described in the previous section, the government obtains additional revenues by introducing emission regulations and uses them to reduce pre-existing taxes subject to the constraint that government expenditure in each period is held constant at the baseline level. The taxes swapped for emission regulations are labor income tax (LIN), capital income tax (CIN), consumption tax (CTX), capital tax (CAP), and labor tax (LAB). Moreover, in order to evaluate the weak double dividend, we consider the scenario in which the additional revenues are returned to households in the form of a lump sum (LUM).

Among these tax reforms, one may doubt the feasibility of capital tax reform (CIN and CAP cuts). That is, reduction in capital taxes is usually regarded as a policy that gives preferential treatment to the high income group and firms and therefore politically difficult to implement. Although this argument may hold true in many regions, it is not necessarily applicable to Japan. There are at least two reasons for this. First, Nippon Keidanren (Japan Business Federation) who is one of the most powerful pressure groups in Japan has consistently required reductions in corporate income and dividend income taxes on the ground of avoiding capital flight and reinforcing international

[16] In this model, the equivalence between carbon tax and permit trading holds under some conditions. That is, the dynamic equilibrium from the model with carbon tax is equivalent to the one with emission permit trading (1) if permits are traded in a competitive market and (2) if the government acquires all revenues from permits. Thus, if we assume the regulation by emission permit trading, we can get the exactly same results.

competitiveness of firms. Although the claim of Keidanren may not be approved, it is likely to influence policy in Japan. Second, Council on Economic and Fiscal Policy of Cabinet Office suggests a policy that gives preferential treatment to investment in stocks. Following this suggestion, the Japanese government indeed reduced dividend income taxes in 2003. As the above examples show, various actions supporting reductions in capital taxes are observed in Japan. It follows that reductions in capital taxes are not so politically difficult at least in Japan.

There are two ways of reducing a tax rate. For taxes with a single rate, such as labor income tax, capital income tax, and consumption tax, the single tax rate is reduced. As to taxes whose rates differ between industries such as capital tax and labor tax, their rates are multiplied in all sectors by a common value of less than unity. Let $\bar{t}_i$ denote the tax rate in sector i in baseline equilibrium, and let t_i denote the new tax rate. Then, for capital tax and labor tax, the following relation holds:

$$t_i = \xi \bar{t}_i$$

where $\xi < 1$. The value of ξ is determined endogenously so as to keep government's revenue constant.

7 Results of computations

7.1 Tax data and marginal excess burden

Whether the double dividend occurs or not depends heavily on the size of distortions caused by pre-existing taxes. So, before examining the possibility of the double dividend, let us see the data of pre-existing taxes. Table 6–8 report benchmark revenues and rates of five taxes.[17] CAP and LAB are taxes on production and their rates are differentiated across industries. The tables show that CAP, LAB, and LIN have relatively high tax rates. In particular, the rates of CAP are not only very high but also extremely uneven across industries. Since the standard tax theory suggests that an efficient tax system should have the same tax rates on the same tax base, this unevenness of tax rates of CAP can lead to large distortion. In order to check if this is true, let us compare the size of distortions caused by each tax.

Table 9 shows marginal excess burden (MEB) of five taxes. MEB here is calculated by the differential approach in Ballard (1990). For example, if MEB of CIN is 20%, 1% increment of tax revenue through CIN leads to 1.2% decrease in household real income. The high (low) value of MEB means the large (small) distortion. Table 9 shows that MEB varies widely across taxes. From the table, we can see, as was expected, that MEB of CAP is large relative to labor and consumption taxes. The high MEB of CAP implies that swap of CAP is most likely to generate the double dividend. Moreover, the fact that different taxes have quite different MEB means that the tax-shifting effect can play an important role.

[17] For the details of data, see the supplementary paper.

Table 6: Taxes on production by sector.

	CAP		LAB		Value Added (GDP)	
	Value	Rate (%)	Value	Rate (%)	Value	Share[a] (%)
AGR	21.7	0.3	73.0	3.8	8,853.3	1.8
OMI	40.3	15.4	18.6	8.5	600.4	0.1
LIM	5.3	15.4	5.0	10.1	100.4	0.0
SLA	2.0	15.4	3.2	10.5	38.8	0.0
NAT	5.3	15.4	1.1	10.5	55.7	0.0
FOO	627.9	17.6	368.5	7.6	13,548.7	2.8
TET	76.2	8.5	212.0	8.2	4,047.8	0.8
PPP	395.1	21.6	279.5	9.2	5,993.8	1.2
CHM	757.6	21.6	257.9	8.8	8,100.3	1.7
PET	84.0	21.6	15.0	8.1	4,361.0	0.9
OPP	10.6	21.6	1.9	8.1	551.2	0.1
COK	19.3	21.6	3.9	8.1	181.2	0.0
CSC	272.5	21.6	181.9	9.3	3,998.2	0.8
IAM	482.0	10.8	646.7	9.1	13,911.2	2.9
MAC	1,930.7	16.4	1,870.6	9.3	37,675.2	7.8
OIP	1,001.4	32.9	617.2	8.5	12,683.1	2.6
CON	2,189.3	40.8	2,342.1	8.7	38,954.5	8.0
ELE	521.4	9.6	126.7	8.4	8,747.5	1.8
GAS	47.9	9.6	39.4	9.7	1,073.0	0.2
SWW	209.1	9.6	179.8	7.8	4,949.8	1.0
COM	3,317.2	28.0	3,618.3	7.6	70,023.9	14.4
RES	631.4	1.3	158.1	6.6	55,637.6	11.5
TCB	905.7	9.6	2,043.0	10.4	33,905.2	7.0
PUB	0.0	0.0	2,307.5	16.0	17,584.9	3.6
SER	3,260.7	8.5	7,363.4	8.5	140,250.0	28.9
Sum	16,814.7	10.5[b]	22,734.4	8.9[b]	485,826.6	

Unit of value is billion yen.
[a] Share of value added of each sector in total value added (GDP).
[b] Average rate of each tax.

Table 7: Taxes on the household.

	Value (trillion yen)	Rate (%)
CTX	8.3	3.0
LIN	23.4	9.2
CIN	6.4	4.0
Total income of the household	417.4	

7.2 Is the double dividend possible?

Next, let us see the effects of swapping emission regulations and pre-existing taxes on welfare. Table 10 shows the percentage change in lifetime utility in each scenario. Here, we consider four reduction scenarios: C25, C50, C75, and C100, and consider reductions in lump-sum tax and five distortionary taxes: LUM, LIN, LAB, CIN, CAP, and CTX. A positive (negative) value of the percentage change in

Table 8: List of all taxes.

	Revenue (trillion yen)	Share (%)
CTX	8.3	7.4
CAP	16.8	14.9
LAB	22.7	20.2
LIN	23.4	20.8
CIN	6.4	5.7
Other taxes	35.0	31.1
Total	112.7	

Table 9: Marginal excess burden of taxes (%)

	LIN	LAB	CIN	CAP	CTX
MEB	9.514	9.715	35.135	64.605	7.699

lifetime utility means that lifetime utility increases (decreases) as a result of emission regulations.[18]

Table 10: Percentage change in lifetime utility from baseline value (%)

Reduction scenarios	LUM	LIN	LAB	CIN	CAP	CTX
C25	−0.0158	−0.0125	−0.0124	−0.0026	0.0093	−0.0131
C50	−0.0400	−0.0319	−0.0318	−0.0082	0.0208	−0.0335
C75	−0.0694	−0.0560	−0.0557	−0.0160	0.0326	−0.0586
C100	−0.1037	−0.0842	−0.0837	−0.0259	0.0447	−0.0879

Let us summarize the results derived from Table 10.

[1] The rate of decrease in lifetime utility in the LUM case is larger than in any other tax swaps for all reduction scenarios.

[2] Cuts in LIN and LAB generate similar results.

[3] The CTX cut also generates the similar result to cuts in LIN and LAB.

[4] The CAP cut generates positive effects in all reduction scenarios. All other cases lower the lifetime utility.

[5] The CIN cut generates negative effects but the rates of decrease in lifetime utility following the CIN cut are smaller than those following cuts in labor and consumption taxes.

Result [1] means that rebating additional revenues directly to the household through lump-sum transfers is a less efficient measure than swapping pre-existing taxes, that is, the weak double divided

[18] In CGE analyses, equivalent variations are often used to evaluate effects on welfare. By the specification of (1), the percentage change in utility is equal to the percentage change in real income (that is, equivalent variations divided by the benchmark lifetime income).

occurs in all cases. This weak double divided is predicted by the theoretical analysis (Goulder, 1995b) and is confirmed by most of the existing empirical studies (for example, Goulder 1995a, Böhringer et al. 1997).[19] The simulation in this paper shows that the same result also applies to carbon regulations in Japan.

The reason for result [2] is very simple. Since LIN and LAB have the same tax base (that is, labor), policies to cut these two taxes have similar effects. One difference is that LAB is imposed at the different rates for the different sectors and is slightly more distortionary than LIN (see Table 9).

On the other hand, the reason why taxes on labor and consumption tax have the similar effect is that most of household's income consists of labor income and most of household's expenditure consists of consumption expenditure. As is well known, if household's income consists of only labor income and if household's expenditure consists of only consumption expenditure, labor income tax and consumption tax have equivalent effects. In our model, household's income includes not only labor income but also capital income and transfer and household's expenditure includes not only consumption expenditure but also savings. However, capital income and transfer are relatively smaller than labor income, and savings are relatively smaller than consumption. Thus, consumption tax has a similar effect to taxes on labor.

Result [4] is the main finding in this paper. It means that lifetime utility increases as a result of the CAP cut, that is, the strong double dividend arises from the CAP cut. As explained in Section 2, since the sign of tax-interaction effect, and the size of primary cost, revenue-recycling effect, and tax-interaction effect are highly dependent on the nature of existing tax system and newly introduced emission regulations, we cannot determine them *a priori*. However, most of the previous empirical studies on European and US economies, except for Jorgenson-Wilcoxen model, derived the result that the sum of three effects (i.e. the gross cost) from emission regulations will be positive, that is, the strong double dividend is not likely to occur. In contrast, our analysis showed that the strong double dividend arises at least from reduction in capital taxes.

The reason why the CAP cut yields the strong double dividend seems to be that CAP is the most distortive among all existing taxes. A policy of swapping the most distortionary tax is likely to reduce gross cost through two channels. First, the more distortionary the preexisting tax, the larger the revenue-recycling effect from swapping that tax. Second, when the most distortionary tax is reduced, the tax-shifting effect is likely to work in the desired direction. By these two effects, tax swap shifts the burden of taxation from a factor with large distortion and onto a factor with small distortion and thus overall efficiency of tax system improves.

Result [5] also attributes to the difference in the size of distortions. First, in contrast to the CAP cut, welfare reduces following the CIN cut. This is because, as Table 9 shows, the distortion caused by CIN is not so large as that caused by CAP although both CAP and CIN are taxes on capital. On

[19]However, Gilbert E. Metcalf and Reilly (2004) and Mustafa H. Babiker and Reilly (2003) show that the weak double divided need not hold in a world with multiple distortions.

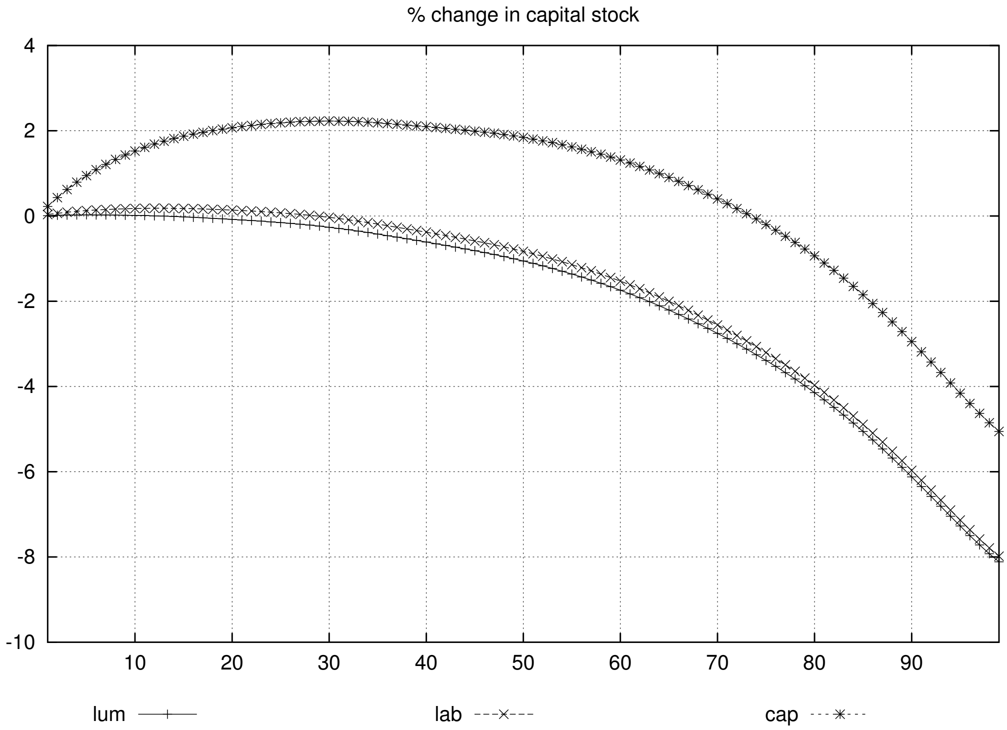

Figure 4: Percentage change in capital stock (%)

the other hand, the reason why the CIN cut generates smaller welfare losses than cuts in labor and consumption taxes is that CIN is more distortionary than labor and consumption taxes.

The main results of this paper are summarized above. However, just looking at welfare effects does not reveal the mechanism behind them. In the following, by examining the details of the effects from emission regulations, we try to check the logics that give rise to the results above, in particular, the strong double dividend from the CAP cut. As a reduction scenario, we only consider C100 case where carbon emissions are stabilized at the 1995 level because C100 seems to reflect actual emission regulations most precisely. As swapped taxes, we consider CAP cut where the strong double dividend arises. In addition, we also consider LUM and LAB cases for comparison. The effect on each variable is given by the percentage change from the baseline level. The percentage change of a variable in scenario SCN is given by:

$$100 \times \frac{x_t^{\mathrm{SCN}} - x_t^B}{x_t^B}$$

where x_t^B is the value of variable x in period t under baseline equilibrium, and x_t^{SCN} is the value of variable x in period t in scenario SCN.

Figures 4 reports the percentage changes in the capital stock. Following LIN and LUM cuts, the capital stock increases slightly in the short run, but decreases significantly in the long run. On the other hand, following the CAP cut, the capital stock increases significantly in the short and medium run although it decreases in the long run. In the baseline equilibrium, the capital stock is restrained

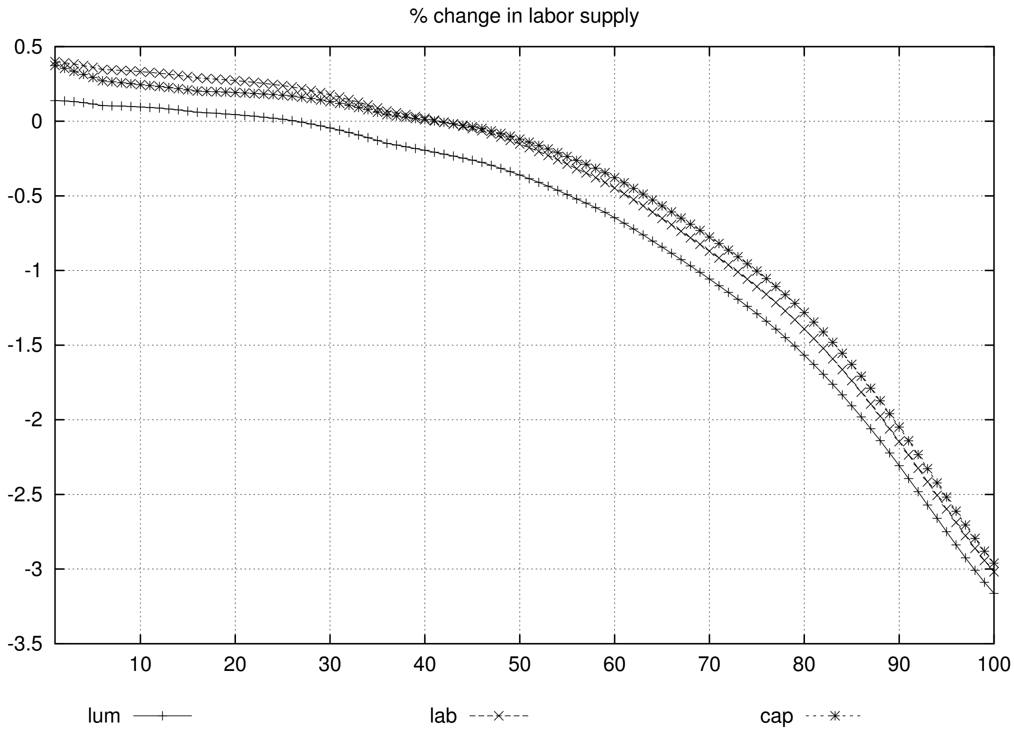

Figure 5: Percentage change in labor supply (%)

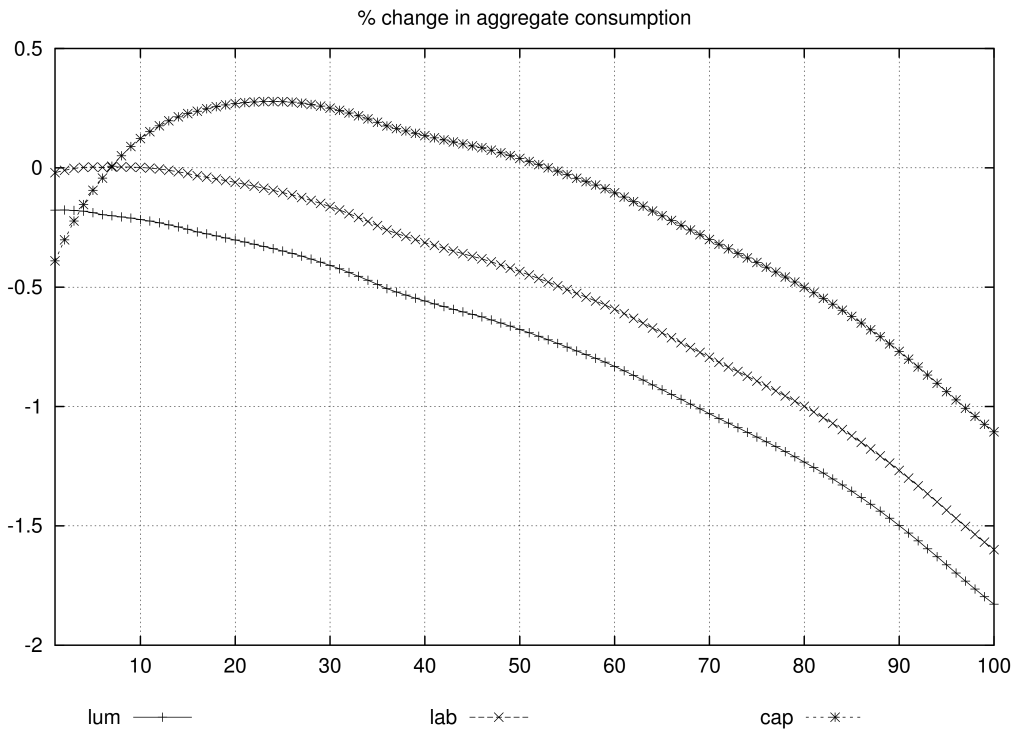

Figure 6: Percentage change in aggregate consumption (%)

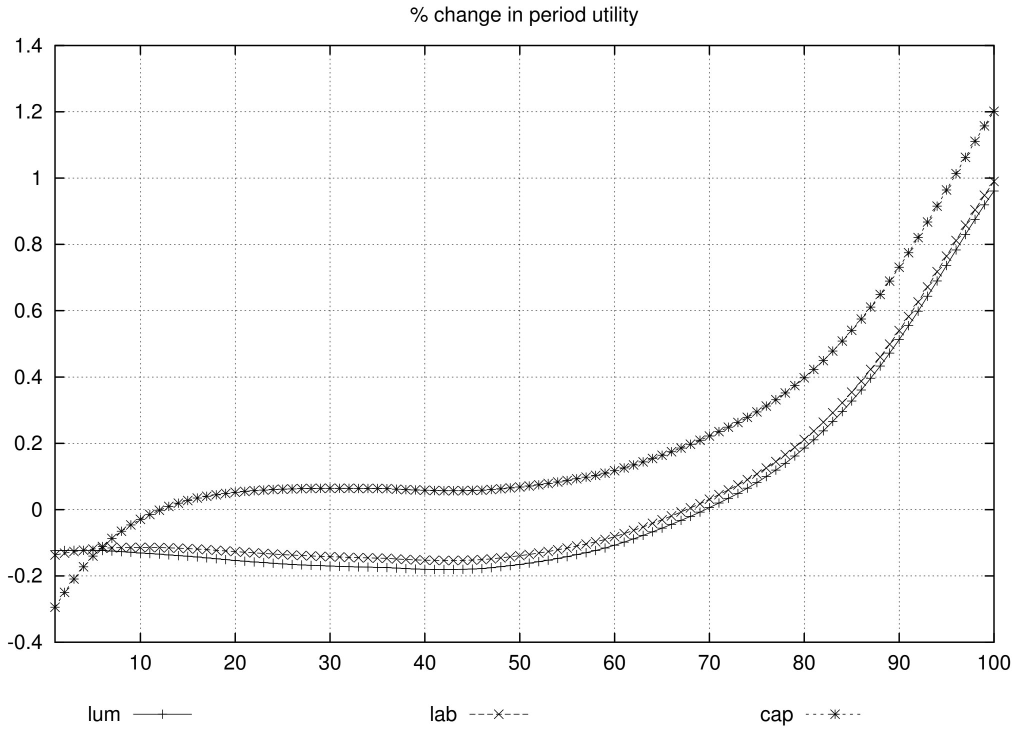

Figure 7: Percentage change in period utility (%)

by the existing capital tax and there are distortions in the capital market. However, following the CAP cut, the capital stock increases and therefore efficiency in the capital market improves.

As taxes on capital depress the capital stock, taxes on labor depress employment. Thus, if a tax swap increases employment, it improves efficiency in the labor market. Figure 5 shows the percentage change in labor supply. The LAB cut is expected to have the largest effect on labor supply. However, the figure shows that the effects of tax swap on labor supply are almost the same in all cases. That is, labor supply increases slightly in the short run and decreases significantly in the long run in all cases.

Since lifetime utility depends on period utility and period utility depends on consumption and leisure, it is necessary to examine the change in consumption and leisure in order to ascertain the cause of change in lifetime utility. The change in leisure can be seen from Figure 5 because leisure moves in the opposite direction to labor supply. From Figure 5, leisure decreases slightly in the short run but increases significantly in the long run. This increase in leisure in the long run is one of the reasons for improvement in lifetime utility. However, this occurs uniformly in all cases and is not specific to the CAP cut. Thus, the strong double dividend of the CAP cut attributes not to change in leisure but to change in consumption.

Figure 6 reports the percentage change in aggregate consumption. Following the CAP cut, aggregate consumption decreases most in the short run because more resources are allocated to investment in the short run. However, it increases in the medium run and keeps the highest level among three cases in the long run. This movement in aggregate consumption generates the result that the strong double dividend occurs only in the CAP cut. We can see this in Figure 7. Figure 7 reports the percentage change in period utility. The figure shows that period utility in the CAP cut keeps the highest level in all cases. The high level of period utility in the CAP cut is due to the high level of consumption in the CAP cut.

The reason for the strong double dividend following the CAP cut is summarized as follows. First, the CAP cut increases leisure significantly in the long run. Second, the CAP cut increases consumption in the medium run and keeps the highest consumption level among all cases in the long run. By these two effects, the net effect of emission regulation becomes positive in the case of the CAP cut.

7.3 Sensitivity analysis

In the previous sections, we have derived various results from tax swaps. In this section, we conduct sensitivity analysis to show the validity of the above results. In particular, we focus on the following six assumptions and parameters: (1) assumption on current accounts (2) adjustment cost of investment, (3) labor supply elasticity, (4) intertemporal elasticity, (5) Armington elasticity, and (6) Elasticity of substitution between energy goods. We change these assumptions and parameters and examine how the results in Table 10 are affected. We consider C100 as reduction scenario and CAP, LAB, and LUM as swapped taxes. Below, the assumptions and parameters up to this point are called the *base case*.

Table 11: Sensitivity analysis: Percentage change in lifetime utility (%)

			LUM	LAB	CAP
Case 0	Base case		−0.1037	−0.0837	0.0447
Case 1	CA constraint		−0.0775	−0.0631	0.0066
Case 2	Adjustment cost of investment	$\phi = 0$	−0.0993	−0.0797	0.0491
		$\phi = 1$	−0.1076	−0.0874	0.0407
Case 3	Uncompensated elasticity of labor	$\varepsilon_L = 0$	−0.1117	−0.0893	0.0843
	supply	$\varepsilon_L = 0.4$	−0.1016	−0.0814	0.0324
Case 4	Intertemporal elasticity	$\sigma_U = 0$	−0.0849	−0.0704	0.0074
		$\sigma_U = 2$	−0.2295	−0.1723	0.2253
Case 5	Armington elasticity	$\sigma_{Ai} \times 0.5$	−0.1079	−0.0860	0.0485
		$\sigma_{Ai} \times 2$	−0.0982	−0.0803	0.0427
Case 6	Elasticity of substitution between	$\sigma_{\mathrm{EE}}, \sigma_{\mathrm{EC}} \times 0.5$	−0.1424	−0.1113	0.1017
	energy goods	$\sigma_{\mathrm{EE}}, \sigma_{\mathrm{EC}} \times 2$	−0.0730	−0.0613	0.0109

Table 11 reports the results from sensitivity analysis. Case 0 indicates the base case. Case 1 is the case where the assumption on current accounts is changed. In the base case, current accounts are assumed to be balanced intertemporally, but case 1 assumes that current accounts are balanced at each period. Case 2 is the case where value of adjustment cost parameter is changed. In the base case, we assumed $\phi = 0.5$. Here we consider two other cases: $\phi = 0$ and 1. Note that $\phi = 0$ means no adjustment cost for investment. Case 3 is the sensitivity analysis on uncompensated elasticity of labor supply. While the base case assumed $\varepsilon_L = 0.19$, Case 3 assumes $\varepsilon_L = 0$ and 0.4. Case 4 the sensitivity analysis on intertemporal elasticity. While the base case assumed $\sigma_U = 0.5$, Case 4 assumes $\sigma_U = 0$ and 2. Case 5 is the case where value of Armington elasticity is changed. Since we assume that Armington elasticity is different across goods, we consider two cases, i.e., doubling and halving Armington elasticity of each good. Finally, Case 6 examines the sensitivity of elasticity of substitution between energy goods. We consider two cases other than the base case, i.e., doubling and halving elasticities of each good.

Results in Table 11 show that changes in assumption and parameters affect the size of welfare change. In particular, in the case of $\sigma_U = 2$ and in the case that elasticities of substitution between energy goods are halved, the size of welfare change becomes large. On the other hand, in the case that elasticities of substitution between energy goods are doubled and in the case that CA constraint is imposed, the size of welfare change becomes small. However, the results derived under the base case, that is, the CAP cut increases lifetime utility and lifetime utility following the LAB cut is higher than that following LUM cut, are obtained in all cases. From these sensitivity analyses, we can see that our results in the previous section are robust to some extent.

8 Concluding remarks

Using a CGE model analysis, this paper investigated the possibility of the double dividend from carbon regulation in Japan. The model is the dynamic general equilibrium one which allows for 27 sectors and 100 periods. As the pre-existing distortionary taxes, the model incorporates capital income tax, labor income tax, capital tax, labor tax, and consumption tax. We assume that when the emission regulation is introduced, these distortionary taxes are alleviated instead, keeping the government revenue constant.

Under these model and assumptions, we have explored the effects of swapping carbon emission regulations and distortionary taxes. The main results are summarized as follows. First, the weak double dividend occurs in all scenarios. This means that the policy that uses new revenues from emission regulations to finance reduction in pre-existing distortionary taxes is more beneficial than the policy that returns new revenues to households in lump-sum fashion. Second, the strong double dividend does not arise from reductions in labor and consumption taxes, but it arises from reductions in capital tax. The result that the double dividend does not arise from reductions in taxes on labor and consumption is the same as the previous studies on US and Europe and thus reinforces the previous results.

On the other hand, the result that the double dividend is possible in the case of reductions in capital tax has not been derived in the previous studies except for Jorgenson-Wilcoxen model in Shackleton et al. (1996) and thus noteworthy. This result is attributable to the nature of the pre-existing tax system where capital taxes are more distortionary than labor and consumption taxes. Our analysis also shows that the strong double dividend following the cut in capital tax is generated by the following two effects. First, the capital tax cut increases leisure significantly in the long run. Second, the capital tax cut increases consumption in the medium run and keeps the highest consumption level among all cases in the long run.

Emission regulations usually attract strong opposition because they are likely to impose further burdens on economies. However, our result that the strong double dividend can occur provides enough ground to justify emission regulations. In addition, we clarified which tax should be swapped for environmental regulations. This can be useful information for policy making. Moreover, the result that reductions in capital tax lead to the strong double dividend has an important policy implication because it means that the welfare-improving policy coincides with the policy demanded by industries. Industries in Japan are strongly opposed to emission regulations and thus they are not likely to accept pure emission regulations. However, at the same time, industries request reductions in capital taxes. Thus, if we combine environmental regulations with reductions in capital taxes, regulation could be implemented more smoothly. Our analysis shows that the combination of these two policies indeed improves welfare.

Finally, we make some comments on the limitation of our analysis. Since we have used a large scale simulation, there are plenty of points that should be mentioned. However, there is not enough space for that, thus we only comment on a few points especially important. The first problem is the way to treat existing tax system. Tax system in the real world is highly complicated and thus it is impossible to incorporate it into a CGE model analysis accurately. However, our analysis has made several strong assumptions in order to simplify the model. For example, in actual tax system, firms are imposed various taxes such as corporation tax, corporation inhabitant tax, corporation enterprise tax, and fixed asset tax. However, we aggregate various taxes on production into two taxes. Due to these simplifications, our analysis may misunderstand the effects of tax reforms.

The second problem is the assumption of a representative household. Households in the real world differ both in energy consumption and taxations according to their types, and thus the effects from emission regulations can vary substantially across households. However, our representative household model cannot deal with such distributional issues. The final problem is the assumption on technology growth. Technology growth in our model is highly simplified, for example, it assumes that rate of technology growth is constant over time and uniform across all sectors. To capture the effect of emission regulations more accurately, it is necessary to improve the way to incorporate technology growth.

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