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Reducing CO_2 Emissions and Long Run Growth of the Japanese Economy[1]

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Abstract

We outline the intertemporal general equilibrium model of the Japanese economy. Our model of the Japanese economy incorporates a submodel of consumer behavior and a submodel of producer behavior in which separate models of production has been econometrically estimated for seventeen industries. In our model of the Japanese economy, given that the economic production technology is characterized by constant returns to scale in each industry and all markets are perfectly competitive, the prices are determined so as to clear each market in each period. Further our intertemporal model incorporates backward-looking and forward-looking equations that determine time paths of capital stock, full consumption and price of investment goods. Under the perfect foresight assumption the prices which are determined in each period are solved to obtain a complete intertemporal equilibrium along these intertemporal equations. We tried to depict the long-run economic growth path of the Japanese economy during the period 1990–2100 as a basic scenario by using our general equilibrium model. In order to evaluate the stabilization policy of the CO_2 emissions in terms of the introduction of the carbon taxes to the Japanese economy, we tried to simulate the growth path of the economy by imposing the carbon taxes in the system as following two alternative scenarios:[Case I] Employ an endogenous carbon tax to stabilize per capita CO_2 emissions at the level of 1990, 2.14tC, from 1991. The carbon tax is levied as a indirect tax on secondary energies proportional to their carbon contents. The revenue from carbon tax is applied so as to hold government spending constant at its base case level and allow government transfer to the rest of the world to adjust to keep the government deficit constant. [Case II] Under the same stabilization program as case I, the rate of capital income tax is reduced by 10%. The application of revenue from carbon tax is the same as case I.

1. Introduction

The possibility that carbon dioxide emissions from fossil fuel combustion might lead to global warming through the greenhouse effect has emerged as a leading international environment concern. At the end of the year 1990, Japanese government proposed her action program in order to stabilize the CO_2 emissions in Japan, where their objective aims to stabilize the per-capita CO_2 emissions in the year 2000 at the 1990 level. Although it has continued to make an effort to achieve this target in the Japanese economy, we think that it is not so easy to guarantee the carrying out of the program at this stage. Moreover, according to our impression,

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the action program itself was not necessarily based upon the careful discussion deciding what the optimum target would be, what kinds of impacts on the economy would be expected, what kinds of policy instrument would be preferable and so on. Finding answers to these questions requires a robust analysis of observed relationships between economy and environment and an accurate assessment of the various policy instruments. In this paper, we present a multi-sectoral dynamic general equilibrium model, which is econometrically estimated by Japanese historical data. By using our model we try to simulate the dynamic growth path of the Japanese economy and propose alternative scenarios concerning the reduction of CO_2 emissions. As one of the policies for fighting the greenhouse effect, a tax on the carbon content of fossil fuels, so called a "carbon" tax could be an effective way to reduce CO_2 emissions. We would like to focus on an introduction of carbon taxes to reduce CO_2 emission and analyze the impacts of the introduction on the growth path and resource allocation of the Japanese economy.

Our developed model, which is similar to the model basically proposed by Cass(1965) and Koopmans(1967) and empirically developed by Jorgenson-Wilcoxen (1992, 1993a, 1993b) in the U.S. economy, has several appropriate features to simulate a long-term economic impacts such as reducing policy of CO_2 emissions. First, it is a multi-sectoral model in which the production sectors of our model are divided into seventeen industrial sectors. There are much differences in the energy intensity among industrial sectors. Impacts of the introduction of the carbon tax would be expected to be different among sectors because of the differences of the energy intensity. Second, in our model the rate of productivity growth and the bias of technical changes are endogenously determined consistently with the changes of the system of relative prices. Introduction of carbon tax would be expected to change the system of relative prices of the economy. It would be highly important that the model has to provide a tool to evaluate their impacts on the changes of the productivity. Third, one of our key features in our model is the dynamic properties, by which we can depict the dynamic path of the intertemporal optimum resource allocation of the economy. Finally, our model is not a so called computable general equilibrium model (CGE), but an empirically estimated econometric model based upon the historical data in Japan. In section 2, we will provide a brief summary of our model. We try to depict the dynamic path of the Japanese economy during the period 1990-2100 as a basic scenario under the assumption of the exogenous variables as shown in section 3.1. Comparing the results of the alternative policy concerning carbon tax with the basic scenario, we try to evaluate the impacts of the introduction of carbon tax reducing CO_2 emissions on the Japanese economy in section 3.2. Carbon tax assumes to be introduced as increasing the rate of indirect taxes of secondary energies such as coal, petroleum and gas products excluding electricity, proportioned to the carbon contents of each energy.

2. An Overview of the Model

In this section, we will give a brief summary of our intertemporal general equilibrium model of the Japanese economy. Our model incorporates a submodel of consumer behavior and a submodel of producer behavior. Models of production were econometrically estimated for seventeen industries, in which four energy conversion sectors and thirteen energy combustion sectors are included as shown in Table 1. Given the production technology characterized by constant returns to scale in each production sector and the assumption of the perfect competitiveness of all of the market, prices of goods and services, and factor prices are simultaneously determined so as to clear the market in every periods of time. In the market, each individual is assumed to behave rationally with perfect foresight in the future in order to determine the time paths of capital accumulation and full consumption in a forward looking way. On the other hand, behavior of each individual is constraint with the factor endowment such as the past accumulation of capital stock and the exogenously given human capital stock in a backward looking way. The

Table 1: The Classification of Industries

Number	Description (Abbreviation)
1	Coal products (Coal)
2	Petroleum refining products (Petro.)
3	Electric power generating(Elec.)
4	Gas supply (Gas)
5	Agriculture, forestry and fisheries (Agric.)
6	Mining (Mining)
7	Construction (Const.)
8	Foods and kindred products (Food)
9	Textile and apparel (Text.)
10	Paper and allied product (Paper)
11	Chemical (Chemic.)
12	Stone and clay (Stone)
13	Iron and steel (Iron)
14	Metal and machinery (Machine)
15	Miscellaneous manufacturing (Mfg.)
16	Transportation and communication (Transp.)
17	Services (Service)

results presented in this paper are based on simulations we conducted using this disaggregated, econometrically estimated intertemporal general equilibrium model of the Japanese economy. Before explaining our results, we will confine ourselves to outlining a few of its key features and discussing how we extended our model to simulate the impact of the stabilization of CO_2 emissions in this section.

2.1. System of National Accounts and Outline of the Model

The basic framework of our modeling is based upon the system of national accounts for the Japanese economy composed by Kuroda(1991) and Kuroda and Shimpo(1992).This system of national accounts integrates production accounts for each industry, input-output table, income-expenditure accounts, and capital accounts. In production accounts, the value of output is equal to the value of inputs for each industry which is expressed as the following identities for each j^{th} industry:

$$\begin{aligned} P_{O_j}Q_j &= \frac{P_{I_j}}{1+\tau_{I_j}}Q_j \\ &= \sum_i P_{S_i}X_{ij} + (1+\tau_{N_j})eP_{N_j}N_j + P_{K_j}K_j + P_{L_j}L_j, \end{aligned} \tag{1}$$

where the quantity of output from j^{th} industry is represented by Q_j and the j^{th} industry's quantities of inputs of i^{th} commodity, non-competitive imports, capital and labor are denoted by X_{ij}, N_j, K_j, and L_j. Similarly, we denote the net price of output excluding indirect tax levy in j^{th} industry by P_{O_j}, and the input prices of i^{th} commodity, non-competitive imports, capital, and labor by P_{S_i}, P_{N_j}, P_{K_j}, and P_{L_j} respectively. Input price, P_{S_i} is defined as composite price of domestic commodity price, P_{Ci} and imported commodity price, P_{IMi}, because the quantity of each input is a composite of products domestically produced and competitively imported. e denotes the exchange rate and τ_{N_j} denotes the rate of import tax for the non-competitive imports which is exogenously given in our model. τ_{I_j} stands for the rate of net indirect tax, which is also exogenously given in our model, so that P_{I_j} represents the supply price of output including net indirect tax levy in j^{th} industry[2]. Interdependence of the production sectors are depicted by the framework of the input-output tables. Our system of input-output tables are divided between a use table and a make table. The use table describes the inter-industry transactions of intermediate inputs and incorporates the production account identities among output and all of inputs by industries. On the other hand, since we allow for joint production, we have to describe the relationships between output by industry and output by commodity. Then the make table gives us information for the amount of each commodity produced by each industry, so that our production accounts include the following identity for the value of output produced by j^{th} industry:

$$P_{I_j}Q_j = \sum_i P_{C_i}x_{ji}, \tag{2}$$

where x_{ji} denotes the output of i^{th} commodity produced by j^{th} industry. The make table also links output prices to commodity prices and determines the allocation of the output of each industry among commodities in our model of producer behavior.

Given the prices of non-competitive imports, capital, and labor services, our model of producer behavior determines output prices and input demands simultaneously to maximize profit in each period as a function of prices of output and input. Factor demands for capital service and labor service meet their supplies in each market, and the rental price of capital, P_K, and the price of labor input, P_L will be determined so as to clear each market in each period:

$$\begin{aligned} K^S &= \sum_j K_j, && (3) \\ L^S &= \sum_j L_j. && (4) \end{aligned}$$

where K^S denotes supply of capital service at period t, which is predetermined proportionally to capital stock, K^{SK} at the beginning of the period. We assume that the amount of capital service is proportional to the amount of capital stock which is accumulated by all past investments and predetermined at the beginning of each period as discussed later. L^S denotes labor supply which is determined by the submodel of consumer behavior.

The input-output tables also depict the deliveries of commodities to domestic final demands and the rest of the world. In the input-output table, demand and supply identity holds for each i^{th} commodity:

$$\begin{aligned} P_{C_i}(X_i - EX_i) &+ (1+\tau_{IM_i})eP_{IM_i}IM_i \\ &= P_{S_i}(\sum_j X_{ij} + C_i + I_i + G_i). \end{aligned} \tag{5}$$

The left hand side of this identity shows total domestic supply of i^{th} commodity. We denote total output of i^{th} commodity domestically produced by X_i. EX_i is the exports of i^{th} commodity to the rest of the world. IM_i denotes competitive imports of i^{th} commodity from the rest of the world. We denote its price and the rate of tariff by P_{IM_i} and τ_{IM_i} respectively, which are

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[2] Net indirect tax implies that indirect tax minuses subcidies.

exogenously given in our model. On the other hand the right hand side of the identity shows total domestic demand of i^{th} commodity. It consists of intermediate demands, X_{ij}, household consumption demand, C_i, investment demand, I_i, and government demand, G_i. Assuming imperfect substitution among domestic goods and imported goods in consumer behavior, the shares of imported goods within each demand item are determined exogenously as a function of the relative prices, P_{C_i} / P_{IM_i}.

Aggregating these identities we can obtain the output-expenditure identity for the economy as a whole:

$$Y = P_{CC}C + P_{INV}I + G + EX - IM, \tag{6}$$

where

$$P_{CC}C = \sum_i P_{S_i}C_i, \quad P_{INV}I = \sum_i P_{S_i}I_i,$$

$$G = \sum_i P_{S_i}G_i, \quad EX = \sum_i P_{C_i}EX_i,$$

$$IM = \sum_i (1 + \tau_{IM_i})eP_{IM_i}IM_i + \sum_j (1 + \tau_{N_j})eP_{N_j}N_j,$$

P_{CC}, and C denote the aggregate price and quantity of goods-service consumption. P_{INV}, and I denote the acquisition price and the quantity of investment for the economy as a whole. G, EX, and IM represent the nominal value of the government expenditure, export and import in the aggregate level. From the viewpoint of expenditure account Y shows gross domestic expenditure. On the other hand, from the viewpoint of production account Y shows gross domestic product which is the sum of value added over all industries:

$$Y = \sum_j \left[P_{O_j}Q_j - \sum_i P_{S_i}X_{ij} - (1 + \tau_{N_j})eP_{N_j}N_j \right] \tag{7}$$

Furthermore, from the viewpoint of income distribution, Y is gross domestic products and it is also satisfied with the following identity:

$$Y = Y_K + Y_L, \tag{8}$$

where Y_K shows the income share should be paid to owners of capital in compensation for rental of capital. We refer this as pre-tax capital income. Y_L shows the value should be paid to workers in compensation for the supply of labor. We refer this as pre-tax labor income. They are defined as follows, respectively:

$$Y_K = \sum_j P_{K_j}K_j, \quad Y_L = \sum_j P_{L_j}L_j.$$

These identities described above are linked with the income-expenditure account in which income less tax payment is equal to the consumption expenditure plus saving:

$$Y - T = P_{CC}C + S. \tag{9}$$

Denoting saving by S and tax payment, equivalently government tax revenue by T:

$$\begin{aligned} T &= \sum_j \tau_{I_j} P_{O_j} Q_j + \sum_j \tau_{N_j} e P_{N_j} N_j + \sum_i \tau_{IM_i} e P_{IM_i} IM_i \\ &\quad + \tau_K Y_K + \tau_L Y_L + \tau_P P_{INV_{t-1}} K^S, \end{aligned} \tag{10}$$

where τ_K, τ_L, and τ_P denote the rates of capital income tax, labor income tax, and property tax, respectively.

To explain the income-expenditure accounts in greater detail, we must present some identities relating to the consumer behavior. We assume that a representative consumer owns the initial physical capital stock or claim on it. We also assume that he is endowed with a fixed amount of disposable life-time at the beginning of the period. We refer this endowment as time endowment or human capital. In our model the amount of human capital for each period is exogenously given. The claim on physical capital stock and the exogenously given amount of the human capital stock are assumed to make up his lifetime wealth, which is referred as full wealth. We assume that the representative consumer optimally allocates the lifetime wealth, in other words, income earned by his lifetime wealth, to consumption and saving over time by maximizing his intertemporal utility. Consumption defined here includes current consumption of goods and services and leisure consumption, which is called full consumption. Especially leisure consumption is corresponding to a consumption of time endowment of a human capital. Human capital can be consumed by leisure or by supplying labor service to the market, so that we can define the following identity for each period:

$$P_L H = P_L LEIS + P_L L^S, \tag{11}$$

where H denotes the time endowment or human capital, and $LEIS$ denotes the hours devoted to leisure. Next we must define full consumption which is an aggregate of leisure consumption and goods and service consumption. For full consumption, the following identity is required:

$$P_F F = P_{CC} C + P_L LEIS, \tag{12}$$

where P_F and F denote the price and quantity of full consumption. We assume that the representative consumer has his preference for the allocation of the full consumption between goods-service consumption and leisure consumption subject to the budget constraint(12). We can derive demands for goods-service and leisure as a function of these prices and the wealth allocated to the current period. This determines the supply of worked hours to labor market, i.e. labor supply from equation (11).

We return to the income-expenditure identity (9) again. The left hand side of this identity shows the current disposable income which is generated by wealth allocated to the current period. As a consequence this identity implicitly determines the saving in our model of consumer behavior. Then, we can summarize the identities discussed above as the following identity between saving and investment in the economy:

$$S - P_{INV} I = \Delta FA + \Delta GB. \tag{13}$$

This identity requires that the I-S balance in private sector be equal to the current account surplus minus the government budget deficit. We denote the current account surplus by $\Delta FA = EX - IM$ and the government budget deficit by $\Delta GB = G - T$.

One of the key features of our model is that the current account surplus and the government budget deficit can be treated as exogenous variables. This means that the exchange rate can be determined endogenously so as to satisfy the exogenously specified current account surplus, and simultaneously the government expenditure can be determined endogenously so as to satisfy the exogenously specified government budget deficit. As described above saving is determined by equation (9) reflecting the intertemporal allocation of lifetime wealth, so that the amount of capital formation can be determined so as to satisfy the I-S balance (13). While the identities discussed above characterize the static equilibrium as the I-S balance in each period, the capital accumulation also importantly characterizes an intertemporal feature as a dynamic path of the economy. In other words, the capital accounts incorporates a backward-looking accumulation equation for capital stock, linking the current flow of capital services to all past capital formations as an aspect:

$$K^{SK}_{t+1} = (1-\delta)K^{SK} + I, \tag{14}$$

where K^{SK}_{t+1} stands for capital stock at the beginning of the next period, t+1 and δ denotes the rate of economic depreciation of capital. The capital accumulation behavior also includes a forward-looking one such as asset pricing equations in which the acquisition price of new investment goods, P_{INV_t}, is equal to the present value of future capital services, weighted by the relative efficiency of capital goods, i.e. the rate of depreciation of capital in each future period. Thus the capital service price in each period is given by:

$$\begin{aligned} P_K &= \frac{1}{1-\tau_K}\cdot[P_{INV_{t-1}}r + P_{INV_t}\delta \\ &\quad -(P_{INV_t} - P_{INV_{t-1}}) + \tau_P P_{INV_{t-1}}], \end{aligned} \tag{15}$$

where r is the rates of return on capital in period t and δ is the rate of depreciation, while $\{\tau_K, \tau_P\}$ are the rates of tax on capital income and property income respectively. $\{P_{INV_t}\}$ are current prices of aggregate investment goods which are equal to the present discounted values of the returns expected on an extra unit of capital under the assumption of perfect foresight. This equation is forward-looking, so the current price of aggregate investment goods in every period will depend on the whole paths of future rental prices and interest rates.

2.2. Producer Behavior

We next present our submodel of producer behavior. Substitutability of energy for other factors of production and among energies, and price induced endogenous productivity growth give an important features of our submodel of producer behavior relating to the environmental policy. We divide the Japanese industries into seventeen industries as shown in Table 1.This is essential for analyzing the impact of introducing the carbon tax since these industries differ in energy intensity. Energy treated in our model is divided into two categories. The first one is *primary energies* including fossil fuels(coal, oil, and natural gas) and nuclear power. The primary energies, excluding nuclear power, are principally supplied by domestic mining industry and the rest of the world. However, the endowment of natural resources in Japan is so poor that Japan has historically obliged to depend upon imported sources of primary fossil fuels almost noncompetitively. It is one of the key features of the Japanese economy when it comes to consider energy and environment problem in Japan. On the other hand, a portion of electric power is also generated by nuclear power and its ratio will be expected to increase in the future. Although the perspectives of the ratio of the nuclear power is highly important in our concerns, the ratio of nuclear power generation in total electric power supply is treated as exogenous at this moment.

The second one is *secondary energies* including coal products, petroleum refining products, electric power and gas which are physically converted from primary energies. We refer these industries as *energy conversion industries.* The other thirteen industries combust the secondary energies supplied by energy conversion industries. We refer these industries as *energy combustion industries.*

Our submodel of producer behavior is based on a two-stage allocation. We assume that economic production technology in each industry is characterized by constant returns to scale without externality. We can summarize the representation of this production technology in terms of unit cost or price functions. The unit cost or output price from each industry is a function of input prices and state of technology. The functions must be homogeneous of degree one, non-decreasing and concave in the input prices. We assume that the energy input and the material input are homothetically separable in the price functions. P_{Ej}, and E_j denote the aggregate input price and quantity of energy for j^{th} industry respectively. Similarly, P_{Mj}, and M_j denote the aggregate input price and quantity of material for j^{th} industry. The functions $g_j(t)$ represent the state of technology for each industry and it is a function of time, t.

At the first stage, the value of output is allocated among four inputs, capital, labor, aggregate energy and aggregate material in each industry under the assumption of perfectly competitive markets of commodities and factors of production. This implies that the value of output is equal to the value of inputs:

$$P_{Oj}Q_j = P_{Kj}K_j + P_{Lj}L_j + P_{Ej}E_j + P_{Mj}M_j. \tag{16}$$

We define the value shares of inputs in the value of output, representing v_{Kj}, v_{Lj}, v_{Ej}, and v_{Mj} by:

$$v_{Kj} = \frac{P_{Kj}K_j}{P_{Oj}Q_j}, \quad v_{Lj} = \frac{P_{Lj}L_j}{P_{Oj}Q_j}, \quad v_{Ej} = \frac{P_{Ej}E_j}{P_{Oj}Q_j}, \quad v_{Mj} = \frac{P_{Mj}M_j}{P_{Oj}Q_j}. \tag{17}$$

At the second stage, the value of energy and material inputs are allocated among corresponding commodities. This implies that the values of energy and material inputs are equal to the sum of the values of corresponding commodities:

$$P_{Ej}E_j = P'_{EEj}X_{EEj}, \quad P_{Mj}M_j = P'_{MMj}X_{MMj}, \tag{18}$$

where X_{EEj} and X_{MMj} denote the vectors of quantities of individual commodities, each element of these vectors correspond to the price vectors P_{EEj} and P_{MMj}, respectively. We define the value shares of commodities and noncompetitive imports in the value of output, v_{ij} and v_{N_j} by:

$$v_{ij} = \frac{P_{Si}X_{ij}}{P_{Oj}Q_j}, \quad v_{Nj} = \frac{P_{Nj}X_{Nj}}{P_{Oj}Q_j}. \tag{19}$$

Further, we denote the vectors of value shares of individual commodities in output corresponding to the price and quantity bundles (P_{EEj}, X_{EEj}) and (P_{MMj}, X_{MMj}) as v_{EEj} and v_{MMj}, respectively.

We try to specify the production model of energy combustion industries in the following way. For simplicity we define the vector of logarithms of input prices faced by the industries as:

$$\ln P_j = (\ln P_{K_j}, \ln P_{L_j}, \ln P_{E_j}, \ln P_{M_j})'.$$

Similarly, we define the vector of value shares of inputs for j^{th} industry as:

$$v_j = (v_{K_j}, v_{L_j}, v_{E_j}, v_{M_j})'.$$

We assume that the j^{th} energy combustion industry allocates the value of its output among four inputs, capital, labor, energy and material at the first stage in accord with the translog price function:

$$\begin{aligned}\ln P_{Oj} &= \alpha^j_{P0} + \ln P'_j \alpha^j_P + \frac{1}{2} \ln P'_j B^j_{PP} \ln P_j \\ &\quad + \alpha^j_T g_j(t) + \ln P'_j \beta^j_{TP} g_j(t) + \frac{1}{2} \beta^j_{TT} g^2_j(t),\end{aligned} \tag{20}$$

The scalars α^j_{P0}, α^j_T, and β^j_{TT}, the vectors α^j_P, and β^j_{TP}, and the matrices B^j_{PP} are j^{th} industry's constant parameters that differ among industries, reflecting the differences in economic technology. All parameters should be constrained to integrability conditions. These conditions should be imposed on parameters, when they are estimated. Necessary conditions for producer equilibrium and the Shephard's lemma are given by equalities between the value shares of each input in the value of output and the elasticities of price of output with respect to price of that input:

$$v_j = \alpha^j_P + B^j_{PP} \ln P_j + \beta^j_{TP} g_j(t), \tag{21}$$

The parameters B^j_{PP} and β^j_{TP} give very important features to our model since these parameters capture the price induced improvements in the efficiency of utilization of energy and other inputs. The parameters B^j_{PP} are *share elasticities* and they measure the substitutability among inputs since they give the response of the value shares of energy and other inputs to proportional changes in the input prices. The parameters β^j_{TP} are *biases of productivity growth* [3]. The specification of function, $g_j(t)$, plays an important role in long run simulations. Usually, the state of technology was taken to be linear in time, $g_j(t) = t$. This linear formulation allows for an unlimited growth of productivity. Consequently, if an input has an input-saving bias of productivity growth, its value share will eventually become negative. Moreover, it should be noted that negative value share would be able to occur regardless to the integrability conditions of other parameters. Further, if productivity growth is unlimited, the existence of balanced growth equilibrium requires the rates of productivity growth become the same for all industries in the long run. Otherwise, the industry with the highest productivity growth rate would come to dominate the economy in the long run. In our model we assume that productivity growth is limited and converged in the long-run in order to avert the above unwilling possibilities. The functions $g_j(t)$ are given by;

$$g_j(t) = \frac{\mu_j t}{1 + \mu_j t}, \tag{22}$$

where the scalars μ_j are constant parameters that differ among industries. With our specification, each of the state of technology goes to unity in the limit, so that the value shares depend only on the input prices in the limit. We can express the endogenous rate of productivity growth in the j^{th} industry, say, $-v_{T_j}$, by differentiating the price function with respect to time:

$$- v_{T_j} = \left(\alpha^j_T + \ln P_j' \beta^j_{TP} + \beta^j_{TT} g_j(t)\right) \dot{g}_j(t). \tag{23}$$

With this specification the rate of growth of productivity approaches zero for all industries since the derivatives $\dot{g}_j(t)$ go to zero in the limit, so that the level of productivity in each industry goes to a constant. This specification yields long run behavior of the economy consistent with balanced growth equilibrium.

The parameters related to the productivity growth, α^j_T, β^j_{TP} and β^j_{TT} were estimated with a historical data set and these parameters reflect the knowledge about the state of technology in the sample periods. We assume that the rate of productivity growth built up with the knowledge accumulated during the sample periods will be decreased gradually to certain saturated level of the productivity in the future.

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[3] If a bias of productivity growth is positive, productivity growth is *input-using* since the corresponding value share increases with a change in the state of technology, alternatively the productivity decreases with the input price. If a bias of productivity growth is negative, productivity growth is *input-saving* since the corresponding value share decreases with a change in the state of technology, alternatively the productivity increases with the input price. Finally, if a bias of productivity growth is zero, productivity growth is *neutral* since the corresponding value share is independent of the state of technology, alternatively the productivity is independent of the input price.

In our model the producer behavior in the energy conversion sectors are not perfectly symmetric to the producer behavior for the energy combustion industries. In the energy conversion industries, we assume that primary energy requirement for producing unit of secondary energy is physically and chemically fixed, so we represent this feature in energy conversion industry production by means of fixed input coefficients. The fixed input coefficients are exogenous so that we can simulate an effect of increase in the energy conversion efficiency on the long run growth of the Japanese economy. Input coefficients are defined as an amount of the i^{th} commodity required to produce unit of output for the j^{th} industry;

$$a_{ij} = \frac{X_{ij}}{Q_j}, \qquad a_{Nj} = \frac{X_{Nj}}{Q_j}.$$

We first divide an unit cost in energy conversion industries into two parts, an unit cost of primary energy input, say, C_{PEj}, and an unit cost of other inputs, say, C_j:

$$P_{O_j} = C_{PE_j} + C_j \qquad (j = 1,2,3,4). \tag{24}$$

Since the primary energy sources are supplied by domestic mining industry and the rest of the world, the unit cost of primary energy for coal products, petroleum refining, and gas supply industries is defined as follows:

$$C_{PEj} = a_{6j} P_{S6} + a_{Nj} P_{Nj} \qquad (j = 1,2,4) \tag{25}$$

The unit cost of other inputs is defined so as to satisfy the cost-revenue identity for each industry:

$$C_j Q_j = P_{Kj} K_j + P_{Lj} L_j + P_{Ej} E_j + P_{Mj} M_j, \qquad (j = 1,2,4). \tag{26}$$

These industries allocate the value of output among capital, labor, energy and material in accordance with the translog unit cost functions for these four inputs:

$$\ln P_{Oj} = \alpha^j_{P0} + \ln P_j' \alpha^j_P + \frac{1}{2} \ln P_j' B^j_{PP} \ln P_j, \quad (j = 1,2,4). \tag{27}$$

Necessary conditions of producer equilibrium are given by the following equalities with respect to the value shares of four inputs in the value of output and the elasticities of output price with respect to price of that input adjusted by the unit cost C_j per output price:

$$v_j = \frac{C_j}{P_{Oj}} \left(\alpha^j_P + B^j_{PP} \ln P_j \right), \quad (j = 1,2,4), \tag{28}$$

while the value shares of primary energy in the value of output are given by:

$$v_{6j} = a_{6j} \frac{P_{S6}}{P_{Oj}}, \quad v_{Nj} = a_{Nj} \frac{P_{Nj}}{P_{Oj}}, \quad (j = 1,2,4). \tag{29}$$

For the electric power generation industry, the requirements for coal products, petroleum refining products and gas are also treated as fixed input coefficients, so that the unit cost of fuels is defined by:

$$C_{PE3} = \sum_{i=1}^{4} a_{i3} P_{Si} + a_{63} P_{S6} + a_{N3} P_{N3}. \tag{30}$$

The unit cost of other inputs is made up from the cost of capital, labor and non-energy material is given so as to satisfy cost-revenue identity by:

$$C_3Q_3 = P_{K3}K_3 + P_{L3}L_3 + P_{M3}M_3. \tag{31}$$

The electric power generating industry allocates the value of output among capital, labor, and non-energy material in accordance with the translog unit cost function for these three inputs. The value shares of these three inputs are derived by differentiating the translog unit cost function with respect to the logarithms of input prices and adjusted by the unit cost C_j per output price. Although the demands for primary energies and secondary energies producing unit of electric power are exogenously specified, their value shares are endogenously determined as functions of input and output prices.

We turn next to present the second stage of our model of producer behavior. At the second stage the j^{th} industry except electric power generating industry allocates the value of energy input among four individual energies with the translog energy price function:

$$\ln P_{Ej} = \alpha^j_{E0} + \ln P'_{EEj}\alpha^j_E + \frac{1}{2}\ln P'_{EEj}B^j_{EE}\ln P_{EEj}, \tag{32}$$

The scalars α^j_{E0}, the vectors α^j_E and the matrices B^j_{EE} denote constant parameters that differ among industries. Especially, the parameters B^j_{EE} are *share elasticities* and they measure the degree of substitutability among individual energies for each industry. Necessary conditions for producer equilibrium and the Shephard's lemma are given by equalities between the value shares of each individual energy in the value of aggregate energy and the elasticities of price of aggregate energy input with respect to price of that energy:

$$v_{EEj} = \left(\alpha^j_E + B^j_{EE}\ln P_{EEj}\right) v_{E_j} \tag{33}$$

Similarly, the j^{th} industry allocates the value of material input among the corresponding commodities and noncompetitive imports with the Cobb-Douglas material price function:

$$\ln P_{M_j} = \ln P'_{MM_j} + \alpha^j_{MM}, \tag{34}$$

The vectors α^j_{MM} are constant parameters that differ among industries and can be interpreted as the value shares of each commodity in the value of aggregate material input, so that the value shares of individual commodities are given by:

$$v_{MMj} = \alpha^j_{MM_i} v_{M_j}, \tag{35}$$

The outputs produced by each industry are supplied with net indirect taxes, so that j^{th} industry's sales price is given by:

$$P_{Ij} = (1 + \tau_{Ij})P_{Oj}, \tag{36}$$

where τ_{Ij} denote the rates of net indirect tax. We allow for joint production. We have seventeen commodity price functions which take in form Cobb-Douglas:

$$\ln P_{Ci} = \sum_j m_{ji}\ln P_{Ij}, \tag{37}$$

where m_{ji} are constant parameters and can be interpreted as the market share of j^{th} industry in the value of i^{th} commodity. The commodity price functions link industry output prices to commodity prices and determine the allocation of the output of each commodity among industries.

In summary, given all of the input prices, our model of producer behavior determines seventeen industry output prices, seventeen commodity prices, and value shares of seventeen commodities, capital, labor, and noncompetitive imports by each industry. Our model of producer behavior is consistent with the production accounts, so that it determines the input shares depicted by the use matrix endogenously. Further, the commodity price functions convert the industry output prices into commodity prices consistent with the make table.

2.3. Consumer Behavior

Let us explain our submodel of consumer behavior. We represent consumer preferences by means of an infinite lived representative consumer. The representative consumer owns the capital stock or the claim to the income streams created by its capital stock and is also endowed with the human capital, which is given exogenously by *time endowment*, that can be allocated to labor supply and leisure consumption. We assume that the representative consumer can capitalize its future income which can be earned from the supply of its physical and human capital with perfect foresight of all future prices and discount rates. We refer this capitalized income as *full wealth*. Thus, the full wealth is the present value of future earnings from the supply of capital and labor service and the imputed value of leisure time.

For the simplicity of manipulation, we divide our submodel of consumer behavior into three stages. The first stage is intertemporal. At the first stage a representative consumer optimally allocates its full wealth over time according to its rate of time preference and intertemporal elasticity of substitution, subject to an intertemporal budget constraint. This determines *full consumption* and saving in each period. The full consumption, here, is defined as an aggregate of goods-service and leisure. The second and the third stages are atemporal. At the second stage we assume that the representative consumer has preferences between goods-service and leisure. In accordance with the preference, the consumer demands for leisure time and goods-service and supply of labor service can be derived in each period. At the third stage, we also assume that the consumer has preferences among commodities. The consumer allocates the goods-service consumption among seventeen commodities and noncompetitive imports with a function of their prices and expenditure as a budget constraint.

At the first stage, the infinite lived representative consumer with perfect foresight of all future prices and discount rates maximizes an additively separable intertemporal utility function:

$$U = \sum_{t=0}^{\infty} \frac{N_t U_t}{(1+\rho)^t}. \tag{38}$$

U_t is an utilitarian atemporal utility function, where the utility per capita multiplied by number of population, N_t, which is exogenous variable in our model. ρ is the rate of time preference. The atemporal utility depends on the per capita full consumption, $fracF_tN_t$:

$$U_t = \left[\frac{F_t}{N_t}\right]^{1-1/\sigma}, \tag{39}$$

where σ denotes the intertemporal elasticity of substitution.

The representative consumer allocates the full wealth over time and chooses the time path of full consumption and saving to maximize the intertemporal utility, subject to an intertemporal budget constraint. This requires that the present value of future full consumption is no greater than full wealth. In our model, since the stream of time endowment is exogenously specified, under perfect foresight of all future prices and discount rates, the intertemporal budget constraint is given as follows:

$$W = P_{INV0}K_0 + \sum_{t=0}^{\infty} \frac{w_t H_t}{\prod_{s=0}^{t} 1+r_s} \geq \sum_{t=0}^{\infty} \frac{P_{Ft} F_t}{\prod_{s=0}^{t} 1+r_s}. \tag{40}$$

The equality gives the definition of full wealth, W. r_t represents the discount rate which is equal to the nominal rate of return after tax on physical capital in period t. w_t denotes the after tax wage rate, defined as, $w_t = (1 - \tau_{Lt})P_{Lt}$, where τ_{Lt} is the exogenously specified labor income tax rate. $P_{INV0}K_0$ shows the present value of income generated by initial holding of capital stock or its claim, since P_{INV0} is the present value of future capital service produced by K_0. H_t is the time endowment exogenously specified in period t, so that the second in the right hand side of this equality shows the present value of income earned by the supply of labor service and the imputation of leisure time. The inequality gives the intertemporal budget constraint. In equilibrium this is satisfied with equality.

The conditions for optimality, where the intertemporal utility, (38)is maximized subject to the budget constraint, (40), can be given in the form of Euler equation with respect to adjoining two periods of time, t and $t + 1$:

$$F_t = \left[\frac{P_{Ft}}{P_{Ft+1}} \frac{1 + r_{t+1}}{1 + \rho} \right]^{-\sigma} \frac{N_t}{N_{t+1}} F_{t+1} \tag{41}$$

We find that the current level of full consumption depends on the price, discount rate, population, and full consumption itself in next period. This relation is kept consecutively on all future level of full consumption. Thus, the current level of full consumption incorporates expectations about all future prices and discount rates, so that the Euler equation is *forward-looking*.

Once each period's full consumption has been determined, we proceed to the second stage of our submodel of consumer behavior. In this stage, the representative consumer allocates the expenditure of full consumption between the goods-service expenditure and the leisure in accordance with its preference. For convenience sake, we refer the expenditure of full consumption as *full expenditure*, M_{Ft}, defined as $M_{Ft} = P_{Ft}F_t$. We assume that the full expenditure is allocated by maximizing an indirect utility function(dropping time subscript):

$$V_{CL}(P_{CC}, w, M_F) = \max \quad U_{CL}(C, LEIS), \tag{42}$$

subject to the budget constraint:

$$M_F \geq P_{CC}C + w\ LEIS. \tag{43}$$

The indirect utility function is specified in the form of translog imposing homotheticity that means the allocation is independent of full expenditure.

$$-\ln \frac{V_{CL}}{M_F} = \alpha'_{CL} \ln P_{CL} + \frac{1}{2} \ln P'_{CL} B_{CL} \ln P_{CL}, \tag{44}$$

where $P_{CL} = (P_{CC}, w)'$. The vector α_{CL} and matrix B_{CL} are constant parameters. The parameters α_{CL} is normalized as $\alpha'_{CL}\ \iota = 1$, where ι is an unit vector. The homotheticity assumption allows the price of full consumption to be expressed as, $\ln P_F = -\ln \frac{V_{CL}}{M_F}$, so that the quantity of full consumption can be expressed as, $F = V_{CL}$.

Using Roy's identity, we can obtain the vector of share equations:

$$v_{CL} = \begin{bmatrix} v_{CC} \\ v_{LEIS} \end{bmatrix} = \begin{bmatrix} \frac{P_{CC}C}{M_F} \\ \frac{w\ LEIS}{M_F} \end{bmatrix} = \alpha_{CL} + B_{CL} \ln P_{CL}. \tag{45}$$

These share equations give us demands for goods-service and leisure, given their prices and full expenditure:

$$C = v_{CC}\frac{M_F}{P_{CC}}, \quad LEIS = v_{LEIS}\frac{M_F}{w}. \tag{46}$$

The difference between the leisure time and the time endowment determines the time for labor market, i.e. the supply of labor service:

$$L^S = H - LEIS. \tag{47}$$

The final stage of our submodel of consumer behavior allocates the expenditure of goods-service among seventeen commodities and noncompetitive imports. For the sake of convenience, we denote the expenditure of goods-service as $M_{CC} = P_{CC}C + w\ LEIS$, the vector of prices of seventeen commodities and noncompetitive imports as:

$$P_C = (P_{S1}, P_{S2}, ..., P_{S17}, P_{NC})',$$

and the vector of corresponding quantities as:

$$C_C = (C_1, C_2, ..., C_{17}, C_N)'.$$

We assume that the expenditure is allocated by maximizing an indirect utility function:

$$V_{CC}(P_C, M_{CC}) = \max \ U_{CC}(C_C), \tag{48}$$

subject to the budget constraint:

$$M_{CC} \geq P_C' C_C. \tag{49}$$

The indirect utility function is specified in the form of Cobb-Douglas, so that the value share of each commodity is independent of their prices and the total expenditure, M_{CC}:

$$-\ln\frac{V_{CC}}{M_{CC}} = \alpha_{CC}' \ln P_C. \tag{50}$$

The vector α_{CC} represents constant parameters and the value shares of commodities. With this specification, the price of goods-service consumption can be expressed as, $P_{CC} = -\ln\frac{V_{CC}}{M_{CC}}$, and its quantity as, $C = V_{CC}$. The demand for each commodity is given by:

$$C_C = \alpha_{CC}' P_C^{-1} M_{CC}. \tag{51}$$

2.4. Foreign Trade and Government

The two remaining components of the model are the foreign sector and government. Beginning with the foreign sector, it has two components: imports and exports. We assume that the prices and the income in the foreign market which are represented by P_{IMi} and Y^* are exogenous variables for the Japanese economy.

Concerning imports, we assume that the each import is an imperfect substitute of domestic product and the share of the imported goods in the total demand is the same for all purchasers including intermediate uses and final demand uses. The imports have to be principally distinguished by types of the domestic purchasers–intermediate users or end users. It is reasonable to treat the imports by different manners by types of purchasers, because the producers' demands have to be characterized by production technology and the consumers' demands have to be reflected by preferences. It is, however fairly difficult to treat separately import behavior by types of users. We assume that share of imported goods is not different among users.

We assume that the purchaser determines the value share of i^{th} commodity supplied to domestic market between domestic product and import in accordance with the translog price function:

$$\ln P_{Si} = \alpha'_{DMi} \ln P_{DMi} + \frac{1}{2} \ln P'_{DMi} B_{DMi} \ln P_{DMi}, \tag{52}$$

where $P_{DMi} = (P_{Ci}, (1+\tau_{IMi})eP_{IMi})'$. The vectors α_{DMi} and the matrices B_{DMi} are parameters which are estimated by commodities. The parameters B_{DMi} are ***share elasticities*** that represent the degree of substitution between domestic product and imports.

Differentiating the price functions with respect to prices, we can obtain the vector of share equations:

$$\begin{aligned} v_{DMi} &= \begin{bmatrix} v_{DOMi} \\ v_{IMi} \end{bmatrix} = \begin{bmatrix} \dfrac{P_{Ci}(X_i - EX_i)}{P_{Ci}(X_i - EX_i)) + (1+\tau_{IMi})eP_{IMi}IM_i} \\ \dfrac{(1+\tau_{IMi})eP_{IMi}IM_i}{P_{Ci}(X_i - EX_i) + (1+\tau_{IMi})eP_{IMi}IM_i} \end{bmatrix} \\ &= \alpha_{DMi} + B_{DMi} \ln P_{DMi}. \end{aligned} \tag{53}$$

The share equations give us the quantities of imports, given the prices and the values of total domestic supply:

$$IM_i = \frac{1}{P_{IMi}} \frac{v_{IMi}}{v_{DOMi}} P_{Ci}(X_i - EX_i). \tag{54}$$

On the other hand, the demands for Japanese goods in the rest of the world, i.e. exports are functions of the relative prices and income:

$$EX_i = \alpha_{EXi} \left[\frac{P_{Ci}}{eP_{IMi}}\right]^{\eta_{Pi}} Y^{*\eta_{Yi}}, \tag{55}$$

where α_{EXi}, η_{Pi}, and η_{Yi} denotes constant parameters that differ among commodities. The parameters η_{Pi} and η_{Yi} are the price and income elasticities, respectively.

Finally, the foreign trade submodel is completed by the explanation of the current accounts and the exchange rate. It is impossible to determine both the current account and the exchange rate simultaneously without an elaborate model of the international trade. Here, in the simulations reported below, we take the current account balance to be exogenous and the exchange rate to be endogenous.

Next we will explain briefly the treatment of government sector. We determined final demand for government consumption from the income-expenditure identity for the government sector. At first we can determine total tax revenue by applying exogenous tax rate to transactions in producers and consumers. After treating the non-tax government revenue exogenously, we can obtain total government revenue. Next, we make an important assumption about the government budget deficit; namely that it can be specified exogenously. We can finally determine government expenditure by adding the deficit to total revenue and adjusting other government expenditure such as interest paid and transfer. In the base case scenario reported below, we take the government budget to be exogenous and the government expenditure to be endogenous.

3. Computing Carbon Dioxide Emissions

There are several origins of CO_2 emissions, for example, fossil fuels, biomass, deforestation and so on. In our model of the Japanese economy we treat the CO_2 emissions originated by fossil fuels and assume that CO_2 is emitted by combusting fossil fuels and secondary energy in electric

Table 2: Unit prices of Energies

	Fossil Fuels	Secondary Energies
Coal	0.007635×10^9yen/10^3t	0.00709×10^9yen/10^3t
Oil	0.0048×10^9yen/10^3kl	0.0097×10^9yen/10^3kl
Gas	0.00757×10^9yen/10^{10}kcal	0.00883×10^9yen/10^{10}kcal

Table 3: Heat Contents and Emission Rate

	Heat Content	Emission Rate
Coal	0.3664×10^{-3}MTOE/10^3t	0.96MT-C/MTOE
Oil	0.920×10^{-3}MTOE/10^3kl	0.804MT-C/MTOE
Gas	0.1×10^{-2}MTOE/10^{10}kcal	0.574MT-C/MTOE

power industry, energy combustion industries and household. We also assume that these sectors use fossil fuels or secondary energy as fuel not as material but 66.517% of the petroleum input by chemical industry is treated as naphtha[4]. We measure CO_2 emissions in mega-tons of carbon content(MT-C).

We compute CO_2 emissions in the following way. In our model the equilibrium prices are indices normalized to unity at 1970, the corresponding equilibrium quantities are evaluated in 1970 constant prices and the values are evaluated in 10^9 yen for each fossil fuel and secondary energy. We first convert the value of fossil fuel and secondary energy inputs to physical unit quantities, say, coal origin in 10^3t, oil origin in 10^3kl, and natural gas origin in 10^{10}kcal, respectively. For this we prepare the unit prices at 1970 of each fossil fuel and secondary energy shown in Table 2.

We can obtain the fossil fuels and the secondary energies inputs by electric power industry, energy combustion industries and household in terms of each physical unit by dividing the value of these inputs with the above unit prices multiplied by the equilibrium prices.

Next, we calculate the heat contents of these figures. Finally, the carbon emissions are calculated from the heat contents. The average heat content per unit and the carbon emission rate per heat content are shown in Table 3.

4. Simulation Results

In order to solve the model, we have to provide values for all exogenous variables in all periods. First, we try to depict a basic scenario of the Japanese economy during the period 1990-2100 under a set of default assumption about values of each exogenous variable, in which government will not provide any policy reducing CO_2 emissions. Second, we try to introduce carbon taxes for secondary energies as an indirect tax in order to stabilize the CO_2 emissions, where the rates of carbon taxes are endogenously determined as optimal rates reducing CO_2 emissions by the targeting level. Scenarios depicted by the introduction of carbon taxes would be compared with the basic scenario in order to evaluate the impacts of the carbon tax on the economy.

Default assumptions about values of exogenous variables are as follows:

POPULATION

Estimates by the Welfare Ministry(September 1992). Until the year 2013, the Japanese pop-

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[4] This ratio of naphtha input is calculated from table on value and quantity of selected goods in *1985 INPUT-OUTPUT TABLES FOR JAPAN*(government of Japan).

ulation will continue to increase by 0.13 billion people. After the year 2013, it is expected to decrease gradually and in the year 2050, it will be 0.11 billion people.

GOVERNMENT DEFICIT

The values of government surplus are set at their historical value from 1985 to 1990(in 1990, 12.6 trillion yen). The government surplus gradually increases to the year 2000, where the values will be 2.83 trillion yen in the year 2000. After that government surplus gradually decline to the year 2050 and after 2050 government expenditure is assumed to balance constantly with government revenue.

CURRENT ACCOUNT

The values of current account surplus are set at their historical value from 1985 to 1990(in 1990, 10 trillion yen). After that current account surplus gradually decline to zero at the year 2050. After the year 2050 current accounts are assumed to be maintained in balance.

PRICES FOR IMPORTED GOODS

Annual Average Growth Rates to the year 2050	
Coal products	3.8%
Petroleum Refining	4.7%
Coal	3.7%
Crude Oil	4.7%
LNG	5.2%

Other import prices are constant in real term at the level of 1985.

WORLD TRADE

Annual average growth rates of real world trade is 1.4%(in nominal value, 4.4%).

4.1. Base Case Scenario

Under the default assumptions for various exogenous variables, we can solve the model during the period 1990–2100 as a basic scenario. Let us focus on the main variables and depict the dynamic path of the Japanese economy in the future. The annual growth rate of real GNP will reach 3.3%, 3.8%, 1.0% and 0.3% during the period 1985–1990, 1990–2000, 2000–2030 and 2030–2050 respectively. At the same time period, consumer price will increase by 2.4, 0.9, 2.6, and 2.8% annually. As shown in Figure 1 , CO_2 emissions is expected to expand from the level of 0.27 billion ton in terms of carbon in 1990 to that of 0.38 billion ton in 2000, 0.50 billion ton in 2030 and 0.53 billion ton in 2050. It implies that per-capita CO_2 emissions in terms of carbon will increase rapidly from 2.14 ton in 1990 to 3.01 ton in 2000. After the year 2011, per-capita emissions is expected to expand more rapidly due to the population decrease in Japan and reach 4.73 ton in 2050. While the growth rate of total emission of CO_2 in the economy will be 0.13% annually, that of per-capita emission will increase by 0.27% annually during the period 2030–2100.

4.2. Impacts of the carbon tax

We try to evaluate the impacts of the introduction of the carbon tax on the economy. In our simulations, as we mentioned previously, carbon tax will be imposed on prices of the secondary energies excluding electricity such as coal, petroleum and gas products as an indirect tax, where the tax rate would be proportional to the carbon contents of each energy sources. Imposing the carbon tax on the secondary energies, energy price increases will simultaneously reflect upon all of commodity markets and factor markets such as labor and capital, so that resource allocation in the economy will be changed and the growth path of the economy will be influenced dynamically. Due to the differences of the parameters of price functions among industrial sectors, impacts of the increases of the energy prices will make different substitution among inputs and

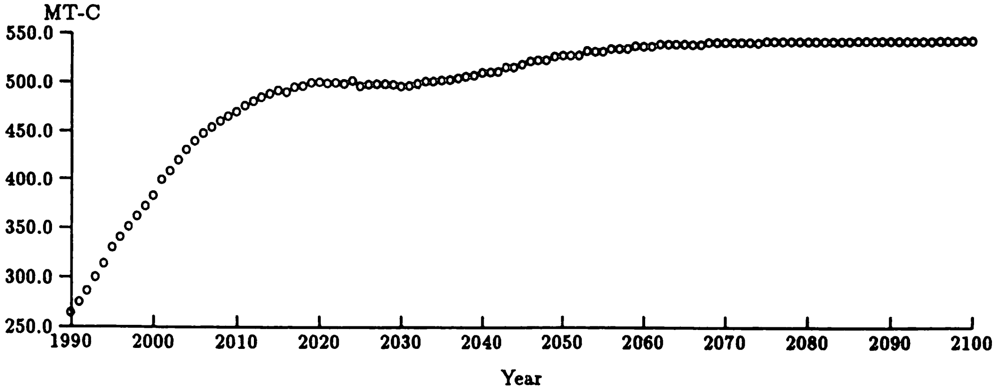


Figure 1: Trend of CO_2 Emission in Japan: 1990 - 2100

Table 4: Rates of Carbon Tax and Its Revenue (Case I)

Year	Rates of Carbon Tax	Carbon Tax per 1tC	Per Capita Revenue	GNP /Revenue
1991	1.6%	1730 yen	3702 yen	0.1%
2000	61.1%	62749 yen	134437 yen	3.8%
2030	78.9%	97997 yen	209822 yen	5.0%
2050	97.1%	134492 yen	289214 yen	6.2%
2100	99.4%	143769 yen	307737 yen	6.5%

non-homogeneous changes of the productivity among industries. Not only substitutions among energies and among inputs, but also the structural changes of resource allocation might promote the stabilization of the CO_2 emissions.

Here, in introducing carbon tax to the economy in order to reduce CO_2 emissions, we try to simulate two alternative scenarios and compare them to the basic scenario of the economy as follows:

Case I: Employ an endogenous carbon tax to stabilize per capita CO_2 emissions at the level of 1990, 2.14tC, after 1991. The carbon tax is levied as an indirect tax on secondary energies proportional to their carbon contents. The revenue from carbon tax is applied so as to hold government spending constant at its base case level and allow government transfer to the rest of the world to adjust to keep the government deficit constant.

Case II: Under the same stabilization program of carbon tax as Case I, the rate of capital income tax is simultaneously decreased by 10% in order to reduce the tax levy of the corporate sector. The application of revenue from carbon tax is the same as Case I, where government spending is held to be the same at its base case level and the increased amount of the government revenue more than deducted amount of the capital tax will be transferred to the rest of the world.

Table 4 and 5 are summaries of results concerning the rate of carbon tax for coal products and total amounts of carbon tax revenue in each case. According to the results in Table 4, the rate of carbon tax for coal products has to be imposed by 1.6% in 1991, 61.1% in 2000 and 99.4% in 2100 in order to stabilize the per-capita CO_2 emission at the level of that in 1990. It implies that the amount of carbon tax per one ton carbon emission will increase from 1730 yen in 1991 to 62,749 yen in 2000 and 97,997 yen in 2030 at the constant price of the year 1985. These levy of carbon tax will reach from 0.1% of GNP in 1991, through 3.8% in 2000 and 5.0%

Table 5: Rates of Carbon Tax and Its Revenue (Case II)

Year	Rates of Carbon Tax	Carbon Tax per 1tC	Per Capita Revenue	GNP /Revenue
1991	16.4%	16048 yen	34578 yen	1.2%
2000	74.0%	68806 yen	147355 yen	4.2%
2030	103.0%	120608 yen	258178 yen	6.0%
2050	120.2%	158357 yen	339105 yen	7.1%
2100	121.8%	166283 yen	356040 yen	7.3%

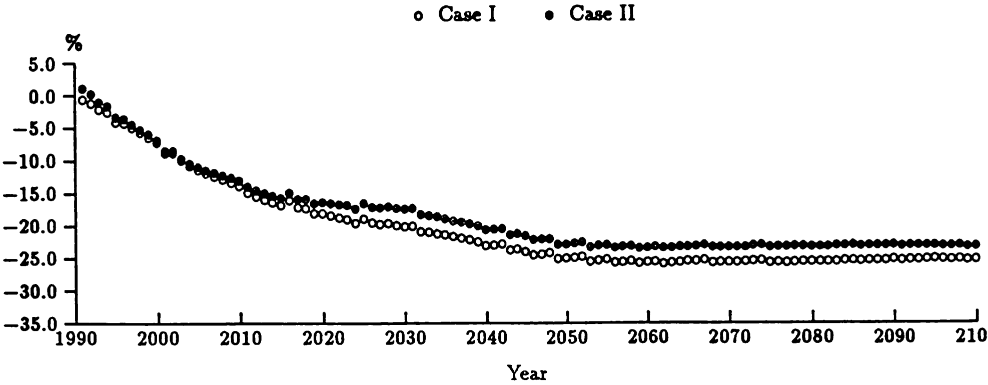


Figure 2: Percentage Changes in Real GNP

in 2030. It might be interesting to compare the results in Case I with those in Case II. In Case II capital accumulation is promoted rapidly as a result of the deduction of capital income tax and CO_2 emissions increased as compared to that in Case I. Consequently, carbon tax levy has to be increased in order to stabilize the emission at the targeting level as shown in Table 5. Focusing on the ratio of the tax burden to GNP, total government tax revenue reaches 22.3% and 24.3% of GNP including 3.8% and 6.2% carbon tax in the year 2000 and 2050 respectively in Case I, while those are 21.6% and 24.0% of GNP including 4.2% and 7.1% carbon tax in the year 2000 and 2050 in Case II. Comparing these results of both cases with the basic scenario, carbon tax due to the stabilization of CO_2 emissions seems to increase tax burden of the public by almost 3.0% in 2000 and 5.0% in 2050.

We will turn our focus to the dynamic changes of real GNP growth. Figure 2 presents the percentage changes of real GNP in Case I and Case II from that in the base case. In Case I, real GNP will decrease by 7.3%, 20.3%, 25.0% and 25.3% in the year 2000, 2030, 2050 and 2100 respectively, while in Case II, 7.0%, 17.4%, 22.7% and 23.3% decreases will be expected in the corresponding period. In the year 2000, we have to reduce CO_2 emissions from the per-capita emission level, 3.01 tC to the targeting level, 2.14 tC. As shown in Table 4, we have to impose additively the carbon tax which rate is 61.1% in order to achieve this target and it forces to decrease real GNP by 7.8%. While in Case II decreases of real GNP will be slightly smaller than that in Case I, due to the effect of the deduction of capital income tax, its rate of carbon tax is forced to increase more than 10% in comparison with that of Case I. Average annual growth rate of real GNP during the period 1991–2050 is 0.68% and 0.7% in Case I and II, while in the base scenario, it is 1.16%. It is reasonable that in Case I which all of the carbon tax revenue assume to transfer to the rest of the world without any deduction of other tax levies, the impact on the economy would be expected to be relatively serious in comparison with that in Case II, which a part of the carbon tax revenue assumes to be restored to the deduction of capital income tax.

Introduction of the carbon tax are expected to have different impacts on industries, because of the differences of the energy intensity by industries. In Figure 3, we try to depict the impact on the output prices by industry, which are shown by the percentage changes from the base case. Prices of secondary energy products such as coal, petroleum and gas increases directly due to the imposition of the carbon tax, where the impacts in Case II are finally larger than those in Case I. In the year 2030, output prices of secondary energies would be expected to increase by more than 220%, 200% and 130% for coal, petroleum and gas products respectively in Case II. Although carbon tax is not directly imposed on electricity, price of electricity will increase by almost 90% in comparison with that of the base case as an indirect effect due to increases of material input prices such as secondary energies and non-competitive energy imports. Output prices in the energy combustion sectors would be expected to increase due to the indirect effects. Their increases, however, will be within 50% because they would be mitigated by the structural changes of input compositions in industries due to the possibility of the substitutions among inputs. According to the estimated parameters on price functions by industry, complementarity between capital and energy are dominant in twelve of the thirteen industries, while substitutability between energy and labor, and energy and material are dominant in nine and eight of the thirteen industries respectively. Thus, we can expect that increases of prices of secondary energies by carbon tax levy force to save energies and simultaneously promote to save capital inputs instead of labor and material inputs. Finally such changes on inputs structure by industry would be expected to mitigate the impacts of the price increases due to the carbon tax levy. It is highly interesting that although price increases of secondary energies in Case II are expected to be larger than those in Case I due to the higher carbon tax levy, rates of increase of output prices in energy combustion sectors in Case II are relatively smaller than those in Case I. It implies that promoting the capital accumulation by the deduction of capital income tax has a preferable impact on the stabilization of the price increases.

Figure 4 presents the percentage changes of output level by industry. It shows that output level will decrease in all industries. Especially, in energy conversion sectors, where almost more than 60% decreases in coal, petroleum and gas products are inevitable, their impacts are remarkable. On the other hand, decreases of the output level in electricity are relatively small because of the promotion of the substitution from fuel energies to electricity. In energy combustion sectors carbon tax decreases the output level by 15–30%. Their impacts are completely different by industries, where high energy intensive industries such as stone & clay, iron & steel and paper & pulp are forced to have serious impacts relatively. It is highly important to see that the introduction of carbon tax has a completely different impact by industry. Furthermore, the introduction of carbon tax will be expected to weaken the international price competitiveness by industry because of the increases of output prices. According to our results, exchange rate will be depreciated slightly under the same assumption of the current accounts as that in the base case. Because of the decreases of real GNP and the depreciation of yen value, real import will decrease as shown in Figure 5.

Finally, we would like to focus on the impacts of the carbon tax on the input structures and resource allocation among industries. Figure 6 presents changes in input coefficients in the year 2030 after imposing carbon tax in Case I in comparison with those in the base case. In our model we can endogenously determine the input coefficients in terms of material inputs and factor inputs by using the price functions formulated by translog type, in which parameters of the price function by industry are characterized by the technological properties in each industry. In Figure 6 each cell in matrix represents the size of changes in input coefficients in Case I in comparison with those of the base case, where white and black boxes stand for changes of decrease and increase respectively. For example, second column, which is designated by industry number '6' in the top of the column, represents the changes of input coefficients in mining sector,

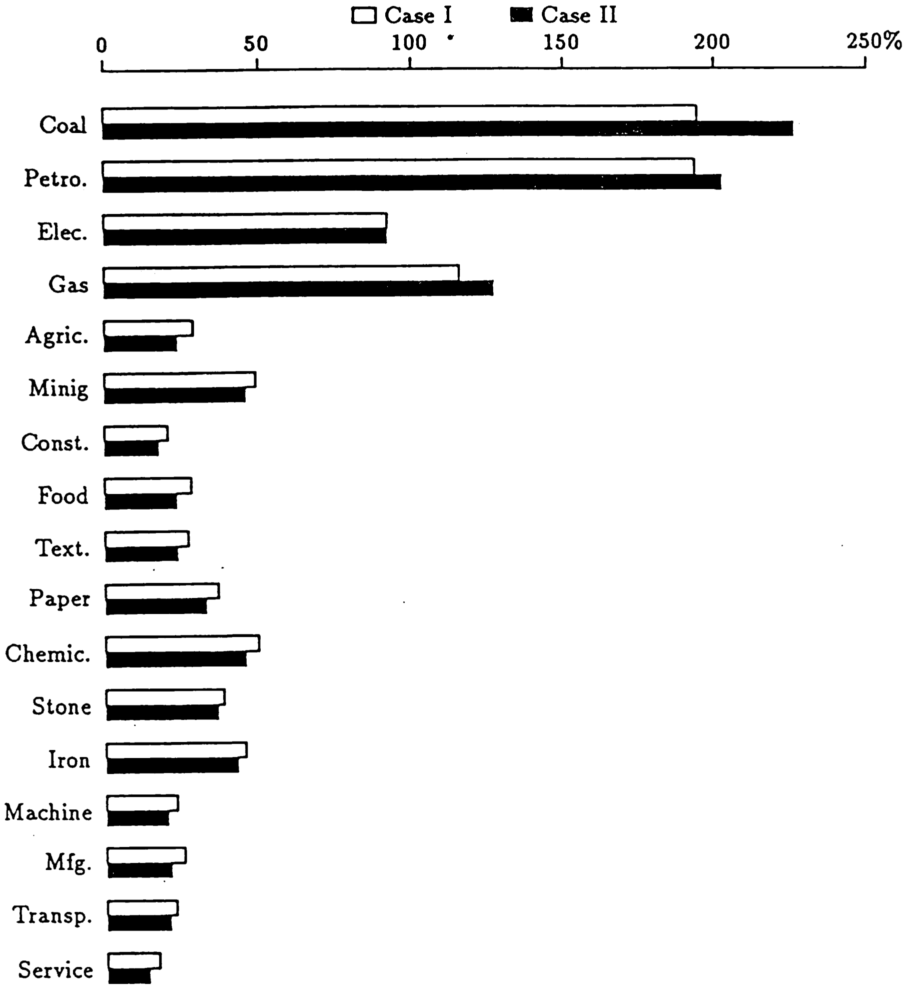


Figure 3: Percentage Changes in Industry Output Prices

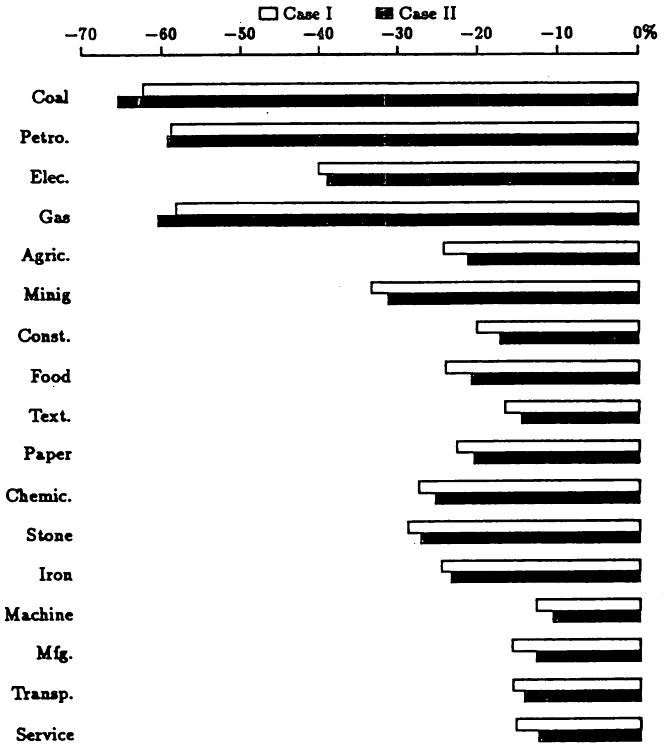


Figure 4: Percentage Changes in Industry Output

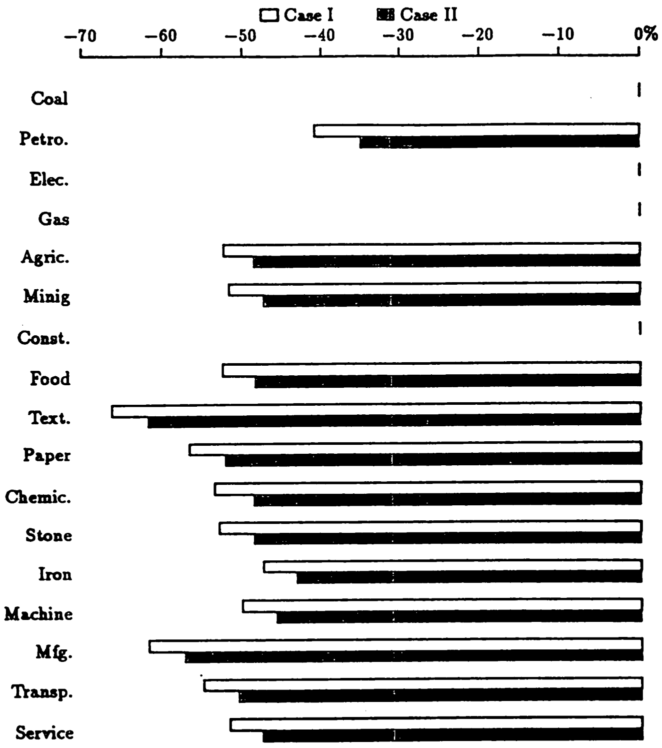


Figure 5: Percentage Changes in Industry Import(Real)

where the intermediate inputs from sector 1, sector 2 and non-competitive import such as coal, petroleum and other non-competitive import energy materials decreases remarkably and they are substituted by the intermediate inputs such as electricity and services and labor inputs. Broadly speaking, in almost all industries, input coefficients of energies such as coal, petroleum, electricity and gas decrease remarkably with the reduces of the input from the non-competitive imported intermediate commodity, while other material input coefficients are slightly increasing. On the other hand, in almost all industries, labor input shows substitutable relationships to the energy inputs, while capital input is mostly complements. It implies that changes of relative prices between energy and non-energy materials and energy and labor force to substitute from energy to others rapidly and input structure in each industry is obliged to move to labor and non-energy material using and energy and capital saving. Moreover, these changes of relative prices promote the structural changes of resource allocation among industries simultaneously. Figure 7 and 8 represent so called skyline maps in the base case and Case I, where resource allocation, especially, labor input allocation in this chart, among sectors is designated in the year 2030. Numbers of the bottom line represent industry number shown in Table 1. Vertical axis measures the degree of the self-sufficiency by industry. In the Figure, width of the square between the bottom line and the 100% degree line of the self-sufficiency in each industry represents the labor contents corresponding to the output which is enough to satisfy the domestic final demand. Width of the square more than the 100% degree of the self-sufficiency represents the labor contents contained in the export demand in each industry and finally the width shadowed by black represents the labor contents contained in the import demand. In other words, we can see the size of the labor contents in each industry and its allocation among industries in the year 2030, which contained in domestic demand, export and import respectively. Comparing the results in Figure 8 with those in Figure 7, we can recognize that the introduction of carbon tax has sizable impacts on the allocation of labor input among industries and the degree of self-sufficiency of the labor contents. As we have mentioned above, the introduction of the carbon tax increased prices of energy and capital service and price of labor input becomes relatively cheaper. Thus, relatively cheaper labor input will increase the contribution of the labor using industry such as construction and service sectors to the economy, while the share of energy using and capital using industry such as chemical and iron & steel will decrease gradually. Also, relatively cheaper labor input price will increase the degree of self-sufficiency in terms of labor contents in Japan in comparison with the base case.

5. Concluding Remarks

We would like to summarize our key results of our analysis and point out some comments for further research as our concluding remarks.

1. In order to stabilize per capita CO_2 emissions in the year 2000 at the level of the year 1990 by imposing carbon tax, the rate of carbon tax, which is levied proportionally to the carbon contents in the secondary energies such as coal, petroleum and gas, has to be around 60–70% in the year 2000, 80–100% in 2030 in terms of rate of indirect tax of coal products.

2. Total amount of carbon tax is almost 3-4% of GNP in 2000 and 6–5% in 2030.

3. Real GNP is forced to decrease by around 7% in 2000 and 17–20% in 2030 in comparison with that of the base case. Annual rate of growth in real GNP slows down by almost 0.4–0.5%.

4. Impacts on real GNP are fairly different by the cases in which there are alternative policies in terms of the usage of the carbon tax revenue. In Case I which all of the carbon tax

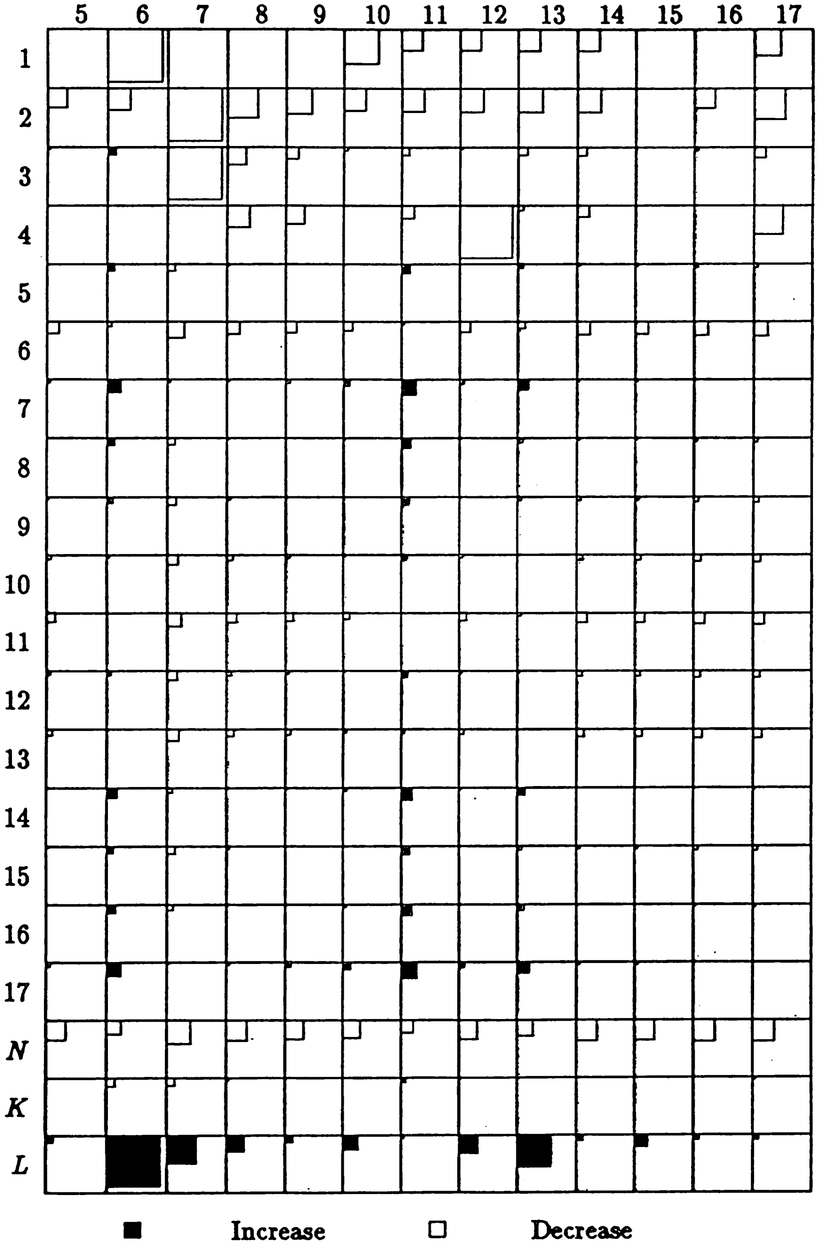
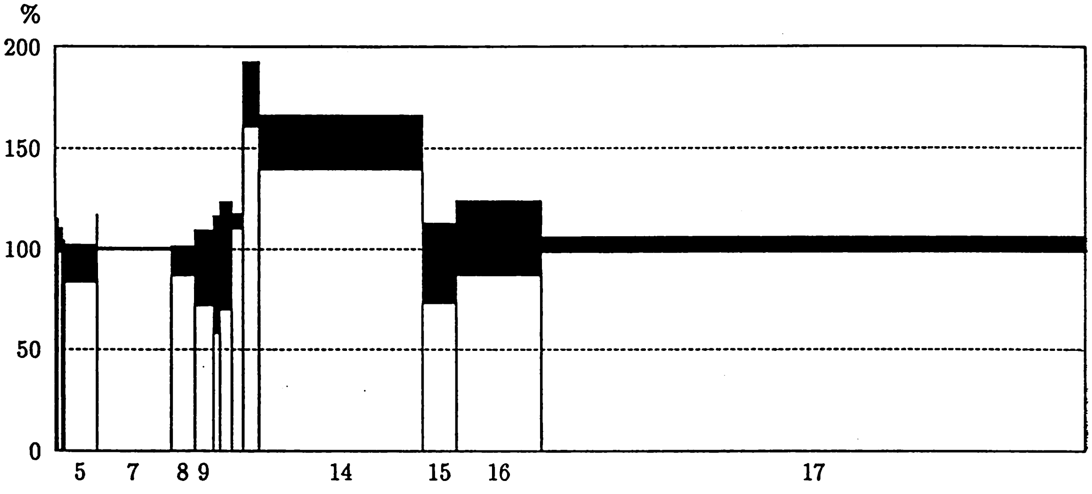


Figure 6: Changes in Input Coefficients in 2030:Case I

Skyline Map in 1990 (Base Case)



Skyline Map in 2030 (Base Case)

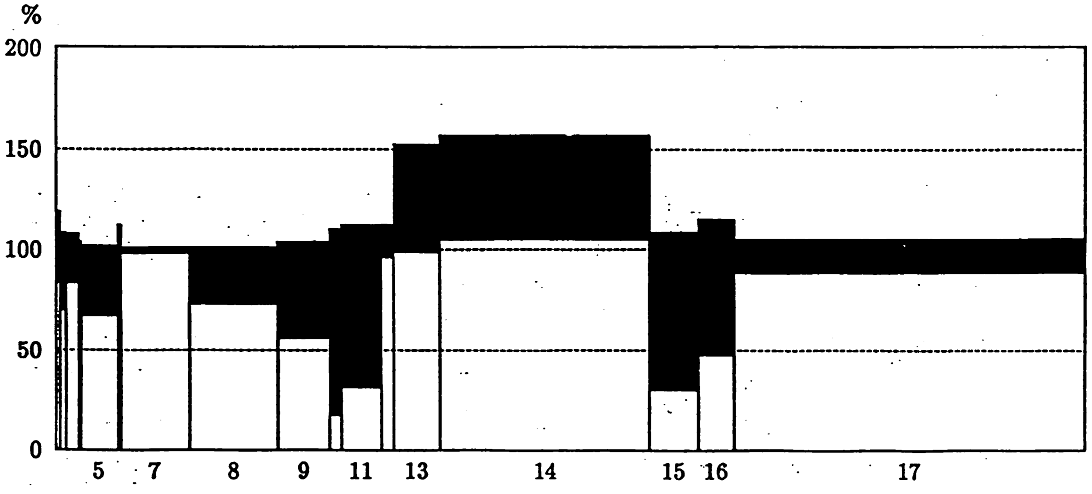
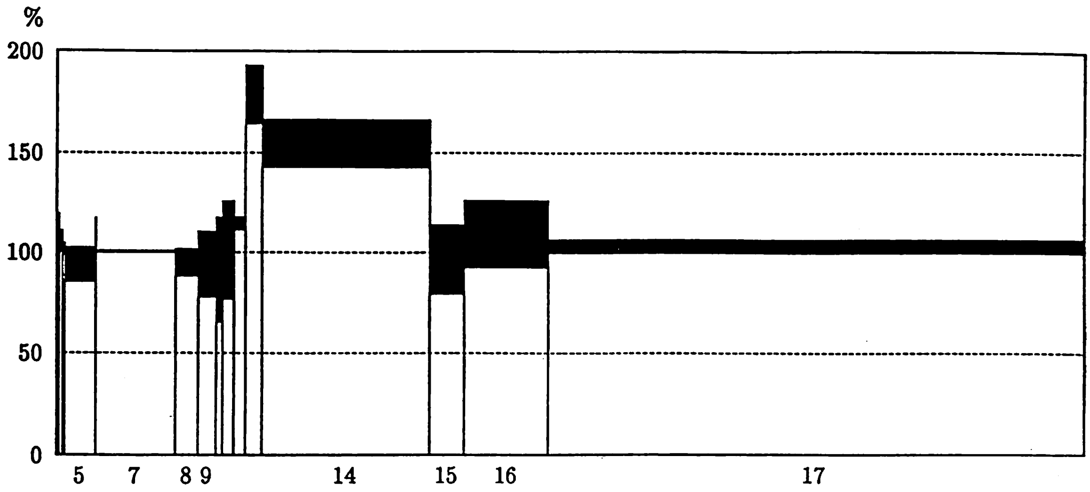


Figure 7: Sky Line Map in Labor Contents in 1990 and 2030:Base Case

Skyline Map in 1990 (Case I)



Skyline Map in 2030 (Case I)

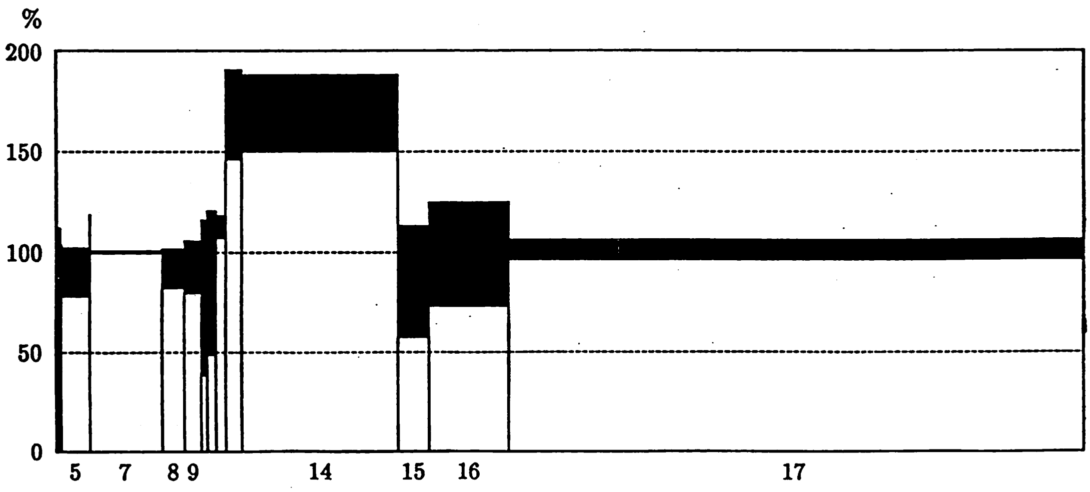


Figure 8: Sky Line Map in Labor Contents in 1990 and 2030:Case I

revenue are assumed to transfer to the rest of the world, decrease in real GNP would be larger than that in Case II which a part of the carbon tax revenue assumes to restore to the deduction of capital income tax. It has to be noted, however, that although the GNP growth might be maintained in Case II rather than in Case I, the rate of carbon tax in order to stabilize the CO_2 emissions would be higher in Case II rather than in Case I, because CO_2 emission increases gradually due to the recovery of the economic activity.

5. The introduction of carbon tax has sizable impacts not only on the economic growth in the aggregate level, but also on the prices and quantities by industries. Prices of energies and capital service increase relatively rather than those of labor service and materials. Consequently, there occurs input substitutions from energy and capital uses to labor and material uses and simultaneously changes of resource allocation in the economy, in which resource will be reallocated from energy and capital using industries to labor and material using industries.

6. According to our results shown in Table 4 and 5, we have to impose the carbon tax at the level of 600 - 700 dollars per 1 ton carbon in order to stabilize per capita CO_2 emission in the year 2000 at the level of 1990. On the other hand, Jorgenson - Wilcoxon (1993) showed that in the United States 17 dollars carbon tax levy per 1 ton carbon is enough to stabilize the emissions at the per capita level of 1990. Comparing two results carefully, we can conclude that the main sources of difference between the two came from the differences of the reducing level of CO_2 emission in the year 2000. The Japanese economy will be expected to continue fairly higher economic growth and to expand the emissions rapidly rather than that in the United States. In our results we have to reduce CO_2 emission in 2000 by almost 40%, while in the U.S. 14.4% reduction is enough to stabilize. We try to estimate carbon tax levy per 1 ton carbon at the same level of the reduction of CO_2 in our model. The results are as follows:

	Jorgenson-Wilcoxen	Kuroda-Shimpo	
Period	Steady State (2050)	1993	1994
CO_2 reduction(%)	14.4%	13.4%	18.6%
Carbon Tax/tC	\$ 16.96/tC	\$ 37.09/tC	\$ 52.59/tC

There are still some differences at the level of carbon tax even if we would try to adjust the reducing level. It might come from the possibility of energy saving in technology in terms of the substitutability among factors and the feasibility of technical progress, which mostly depend upon the level of the energy efficiency at the present stage in each country. Therefore, we can conclude that it is highly important to choose and adjust the policy target of reducing CO_2 emissions carefully at the stage of development of the economy internationally in order to avert inequality of the burden of the economy stemmed from the differences of the targets.

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