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Optimal Energy Policy for a Carbon Tax in Japan

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March 2017

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Climate change is a global challenge that must be addressed at the international level. In December 2015, the Paris Agreement was adopted at the 21st session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (COP21) held in Paris. The Paris agreement is aimed at keeping global temperature increases below 2 °C. Toward this goal, the Japanese government plans to reduce greenhouse gas emissions by 26% by fiscal year 2030 compared with fiscal year 2013. In this study, we evaluate the feasibility of Japan's energy policy for reducing CO2 emissions. We construct a macroeconometric model linked to an energy model to show the optimal future energy policy for Japan by applying optimal control to the social welfare function.

Keywords: Carbon tax, Energy model, Macroeconometric model, Optimal control
JEL classification: C30, P28, Q43, Q48

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Optimal Energy Policy for a Carbon Tax in Japan

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Climate change is a global challenge that must be addressed at the international level. In December 2015, the Paris Agreement was adopted at the 21st session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (COP21) held in Paris. This is the first universal treaty agreed by the 195 countries in place of the Kyoto Protocol. The Paris agreement is aimed at keeping global temperature increases below 2 °C or, if possible, below 1.5 °C above pre-industrial levels. Toward this goal, the Japanese government plans to reduce greenhouse gas emissions by 26% by fiscal year 2030 compared with fiscal year 2013. In this study, we evaluate the feasibility of Japan's energy policy for reducing CO_2 emissions. We construct a macroeconometric model linked to an energy model to show the optimal future energy policy for Japan by applying optimal control to the social welfare function.

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1. Introduction

Climate change is a global challenge that must be addressed at the international level. In December 2015, the Paris Agreement was adopted at the 21st session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (COP21) held in Paris. This is the first universal treaty agreed by the 195 countries in place of the Kyoto Protocol. The Paris agreement is aimed at keeping global temperature increases below 2 °C or, if possible, below 1.5 °C above pre-industrial levels. Additionally, the agreement includes reporting and revising emission goals in the regular meeting every five years. Before and during the Paris conference, countries were required to submit Intended Nationally Determined Contributions (INDCs) as the individual national climate action plan.

According to Japan's INDC, the plan for global warming countermeasures was a reduction of greenhouse gas (GHG) emissions of 26% by fiscal year 2030 compared with fiscal year 2013 (25.4% compared with fiscal year 2005). Moreover, the energy mix is set as a feasible reduction target. Assuming an annual economic growth rate of 1.7%, the share of nuclear energy will be 20–22%, renewable energy 22–24%, coal energy 26%, natural gas 27%, and oil 3% by fiscal year 2030. In this draft, this energy mix is well balanced for achieving the reduction in CO_2 emissions. However, it is doubtful whether this plan is feasible.

Since the Great East Japan Earthquake on March 11, 2011, the energy situation in Japan has changed dramatically. Following the Fukushima Daiichi nuclear disaster, the Japanese government reconsidered the Basic Energy Plan and shut down 55 domestic power plants on May 5, 2012. As a result, the dependency on oil and natural gas has risen to make up for the shortfall in nuclear power, and CO_2 emissions have increased rapidly. While nuclear energy is a core power for realizing a low-carbon society, given the current serious circumstances in Japan, it is difficult to overcome the strong public resistance to restarting the nuclear power plants. As Figure 1 illustrates, to achieve the INDC policy objectives, the oil energy share is required to decrease from 44% to 3%, and the nuclear energy share has to increase more than 20% within 13 years, which seems unrealistic.

The Japanese government has also implemented a carbon tax policy levied on the CO_2 released by burning fossil fuels from April in 2016. Taxation could be an effective way of incentivizing the industry to reduce CO_2 emissions. Specifically, the current levels of carbon tax are JPY 2040 per kL for crude oil and petroleum products, JPY 1080 per ton for LPG and LNG, and JPY 700 per ton for coal. No additional increase in the carbon tax has been planned yet, and it is currently unclear whether the current carbon tax is at an appropriate level or whether those policy objectives can be achieved. It is also questionable whether CO_2 emissions can be reduced by 26% by fiscal year 2030, compared with the CO_2 emission level in 2013.

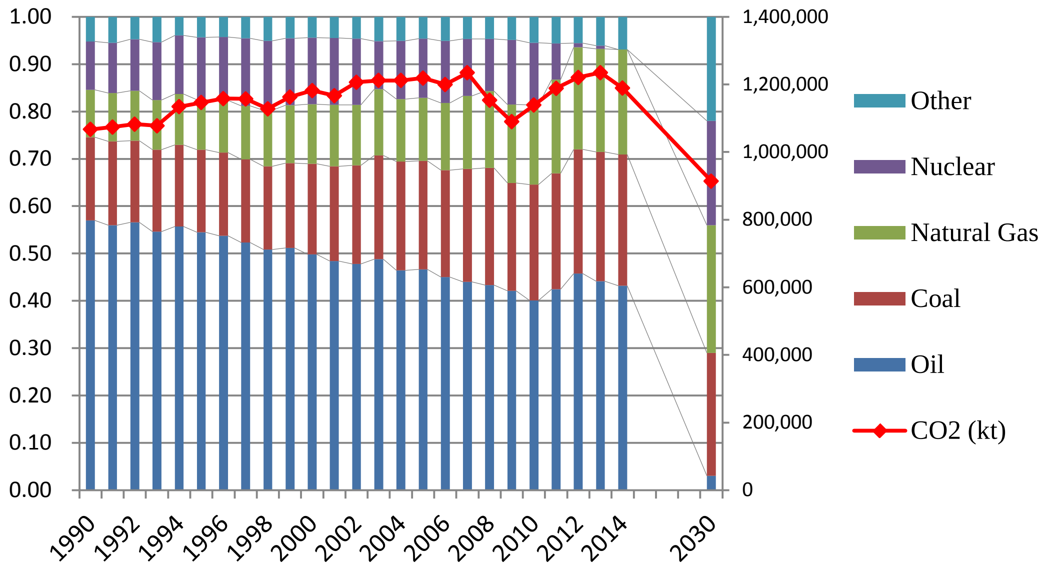

Figure 1. Historical energy share and CO_2 emissions, and the target for 2030.

In this study, we examine the feasibility of Japan's energy policy for reducing CO_2 emissions. We construct a macroeconometric model linked to an energy model and apply the approach of a social welfare function to evaluate the existing policy. The macroeconometric model largely follows traditional theory by using Klein's skeleton model (1983) and in the energy block, domestic primary energy prices for crude oil, natural gas, and coal are determined by energy prices in the international market and the exchange rate. Therefore, the domestic primary energy prices will change the demand for primary energies such as the composition of energy share. The linkage between the macroeconomic model and the energy model is made through the GDP deflator. The interaction of economic activity and energy demand enables CO2 emissions to be calculated. Our system can be used to make projections of economic variables in future periods. We then solve the optimization of the social welfare function in the period of the post sample, subject to the forecasted macroeconometric model, which links the macroeconometric model with the energy model , and we derive the future optimal carbon tax to achieve the policy target. The optimization is implemented using the optimal control approach for seeking solutions.

The rest of the paper is organized as follows. In Section 2, we explain the theoretical framework of the social welfare function and the policy reaction function. In Section 3, we present the whole model. Section 4 contains the data and the empirical analysis. Finally, concluding remarks are provided in Section 5.

2. Optimal Policy

In this section, we illustrate the theoretical framework of the optimal policy for Japan.

2.1. Social Welfare Function

Social Welfare Function and Policy Reaction Function

In analyzing optimal policy, we begin with the statement of policy objectives, namely, the social welfare function (Pissarides, 1972; Friedlaender, 1973; Chow, 1975). This approach assumes that the policy maker implicitly specifies the policy. In general, the social welfare function is expressed in a quadratic loss form as

$$F = w_1(U - U^*)^2 + w_2(V - V^*)^2 + w_3(Z - Z^*)^2, \quad (1)$$

where U is the actual value of the policy target variable, U^* is the desired value of the policy target variable, V and Z are the actual values of the policy instrument, $V^*$and Z^* are the desired values of the policy instrument, and w_1, w_2, and w_3 are weights. The social welfare function is composed of the actual and desired values of the target variables and policy instruments. Policy makers are assumed to be concerned with the difference between actual and desired values.

Minimization (1) by policy instrument V can derive the policy reaction function resulting from the decision maker's attempt to minimize the difference between actual and desired values as

$$\frac{\partial F}{\partial V} = 2w_1(U - U^*)\frac{\partial U}{\partial V} + 2w_2(V - V^*) + 2w_3(Z - Z^*)\frac{\partial Z}{\partial V} = 0, \quad (2)$$

where we suppose that the conjunctional variation between policy instruments as $\partial Z/\partial V$ equals zero. Rearranging (2), the optimal policy on V is obtained as

$$V = V^* - \frac{w_1}{w_2}(U - U^*)\frac{\partial U}{\partial V}. \quad (3)$$

Similarly, we obtain the optimal policy on Z as

$$Z = Z^* - \frac{w_1}{w_3}(U - U^*)\frac{\partial U}{\partial Z}. \quad (4)$$

In this study, we attempt to evaluate the optimal energy policy for the Japanese carbon tax. Thus, Japan's carbon tax is the policy instrument. The policy targeted values we use are based on

Japan's INDC. Namely, we assume the following social welfare function as

$$F = w_1(x - x^*)^2 + w_2(CO2 - CO2^*)^2$$
$$+w_3(s_{oil} - s_{oil}^*)^2 + w_4\left(s_{gas} - s_{gas}^*\right)^2 + w_5(s_{col} - s_{col}^*)^2 \quad (5)$$
$$+w_6(\tau_{oil} - \tau_{oil}^*)^2 + w_7\left(\tau_{gas} - \tau_{gas}^*\right)^2 + w_8(\tau_{col} - \tau_{col}^*)^2,$$

where x is the actual rate of economic growth, $CO2$ denotes the actual level of CO_2 emissions, and s_{oil} , s_{gas}, and s_{col} are the actual shares of energy for oil, natural gas, and coal, respectively. These are policy target variables. τ_{oil}, τ_{gas}, and τ_{col} are the rates of carbon tax for oil, natural gas, and coal, respectively, which are policy instruments. Asterisks represent the desired/target values of the variables.

In addition, policy makers would not concentrate only on a fixed plan, irrespective of future change. They would determine on the basis of future prospects of the macro economy. Hence, it would be more realistic and relevant to evaluate the policy determination according to future economic observation as:

$$F_{t+2} = F_t + F_{t+1}$$
$$F_{t+3} = F_t + F_{t+1} + F_{t+2} \quad (6)$$
$$\vdots$$

Therefore, we modify equation (5) and redefine the social welfare function as:

$$F = w_1 \sum_{r=t}^{2030} (x_r - x_r^*)^2 + w_2 \sum_{r=t}^{2030} (CO2_r - CO2_r^*)^2$$
$$+w_3 \sum_{r=t}^{2030} \left(s_{oil,r} - s_{oil,r}^*\right)^2 + w_4 \sum_{r=t}^{2030} \left(s_{gas,r} - s_{gas,r}^*\right)^2 + w_5 \sum_{r=t}^{2030} \left(s_{col,r} - s_{col,r}^*\right)^2 \quad (7)$$
$$+w_6 \sum_{r=t}^{2030} \left(\tau_{oil,r} - \tau_{oil,r}^*\right)^2 + w_7 \sum_{r=t}^{2030} \left(\tau_{gas,r} - \tau_{gas,r}^*\right)^2 + w_8 \sum_{r=t}^{2030} \left(\tau_{col,r} - \tau_{col,r}^*\right)^2$$

In this study, the social welfare function of (7) is applied for simulating the optimal carbon tax. Specifically, we set target values of x^* = 1.7%, $CO2^*$ = 26% (compared with 2013), s_{oil}^* = 3%, s_{gas}^* = 27%, and s_{col}^* = 26% for 2030, based on the target values in Japan's INDC for the Paris Agreement. We use τ_{oil}^* = 2040 yen per kL, τ_{gas}^* = 1080 per ton, and τ_{col}^* = 700 per ton, which are constant from 2016 to 2030 based on the current Japanese carbon tax plan.

2.2. Policy Reaction Function

Policy Reaction Function to Oil Carbon Tax

The policy reaction function of the oil carbon tax can be obtained by differentiating (7) with respect to a policy instrument τ_{oil} as

$$\begin{aligned}\frac{\partial F}{\partial \tau_{oil,t}} = w_1 \sum_{r=t}^{2030} (x_r - x_r^*) \frac{\partial x_r}{\partial \tau_{oil,t}} + w_2 \sum_{r=t}^{2030} (CO2_r - CO2_r^*) \frac{\partial CO2_r}{\partial \tau_{oil,t}} \\ + w_3 \sum_{r=t}^{2030} \left(s_{oil,r} - s_{oil,r}^*\right) \frac{\partial s_{oil,r}}{\partial \tau_{oil,t}} + w_4 \sum_{r=t}^{2030} \left(s_{gas,r} - s_{gas,r}^*\right) \frac{\partial s_{gas,r}}{\partial \tau_{oil,t}} \\ + w_5 \sum_{r=t}^{2030} \left(s_{col,r} - s_{col,r}^*\right) \frac{\partial s_{col,r}}{\partial \tau_{oil,t}} + w_6 \left(\tau_{oil,t} - \tau_{oil,t}^*\right) = 0.\end{aligned} \quad (8)$$

Rearranging (8), the optimal oil carbon tax is derived as

$$\begin{aligned}\tau_{oil,t} = \tau_{oil,t}^* - \frac{w_1}{w_6} \sum_{r=t}^{2030} (x_r - x_r^*) \frac{\partial x_r}{\partial \tau_{oil,t}} - \frac{w_2}{w_6} \sum_{r=t}^{2030} (CO2_r - CO2_r^*) \frac{\partial CO2_r}{\partial \tau_{oil,t}} \\ - \frac{w_3}{w_6} \sum_{r=t}^{2030} \left(s_{oil,r} - s_{oil,r}^*\right) \frac{\partial s_{oil,r}}{\partial \tau_{oil,t}} - \frac{w_4}{w_6} \sum_{r=t}^{2030} \left(s_{gas,r} - s_{gas,r}^*\right) \frac{\partial s_{gas,r}}{\partial \tau_{oil,t}} \\ - \frac{w_5}{w_6} \sum_{r=t}^{2030} \left(s_{col,r} - s_{col,r}^*\right) \frac{\partial s_{col,r}}{\partial \tau_{oil,t}}.\end{aligned} \quad (9)$$

Policy Reaction Function to Natural Gas Carbon Tax

The policy reaction function of the natural gas carbon tax is derived by differentiating (7) with respect to a policy instrument τ_{gas}.

$$\begin{aligned}\frac{\partial F}{\partial \tau_{gas,t}} = w_1 \sum_{r=t}^{2030} (x_r - x_r^*) \frac{\partial x_r}{\partial \tau_{gas,t}} + w_2 \sum_{r=t}^{2030} (CO2_r - CO2_r^*) \frac{\partial CO2_r}{\partial \tau_{gas,t}} \\ + w_3 \sum_{r=t}^{2030} \left(s_{oil,r} - s_{oil,r}^*\right) \frac{\partial s_{oil,r}}{\partial \tau_{gas,t}} + w_4 \sum_{r=t}^{2030} \left(s_{gas,r} - s_{gas,r}^*\right) \frac{\partial s_{gas,r}}{\partial \tau_{gas,t}} \\ + w_5 \sum_{r=t}^{2030} \left(s_{col,r} - s_{col,r}^*\right) \frac{\partial s_{col,r}}{\partial \tau_{gas,t}} + w_7 \left(\tau_{gas,t} - \tau_{gas,t}^*\right) = 0\end{aligned} \quad (10)$$

The optimal natural gas carbon tax is derived as

$$\tau_{gas,t} = \tau^*_{gas,t} - \frac{w_1}{w_7}\sum_{r=t}^{2030}(x_r - x^*_r)\frac{\partial x_r}{\partial \tau_{gas,t}} - \frac{w_2}{w_7}\sum_{r=t}^{2030}(CO2_r - CO2^*_r)\frac{\partial CO2_r}{\partial \tau_{gas,t}}$$

$$-\frac{w_3}{w_7}\sum_{r=t}^{2030}\left(s_{oil,r} - s^*_{oil,r}\right)\frac{\partial s_{oil,r}}{\partial \tau_{gas,t}} - \frac{w_4}{w_7}\sum_{r=t}^{2030}\left(s_{gas,r} - s^*_{gas,r}\right)\frac{\partial s_{gas,r}}{\partial \tau_{gas,t}} \quad (11)$$

$$-\frac{w_5}{w_7}\sum_{r=t}^{2030}\left(s_{col,r} - s^*_{col,r}\right)\frac{\partial s_{col,r}}{\partial \tau_{gas,t}}.$$

Policy Reaction Function to Natural Gas Carbon Tax

Similarly, we differentiate (7) with respect to a policy instrument τ_{col} as

$$\frac{\partial F}{\partial \tau_{col,t}} = w_1\sum_{r=t}^{2030}(x_r - x^*_r)\frac{\partial x_r}{\partial \tau_{col,t}} + w_2\sum_{r=t}^{2030}(CO2_r - CO2^*_r)\frac{\partial CO2_r}{\partial \tau_{col,t}}$$

$$+w_3\sum_{r=t}^{2030}\left(s_{oil,r} - s^*_{oil,r}\right)\frac{\partial s_{oil,r}}{\partial \tau_{col,t}} + w_4\sum_{r=t}^{2030}\left(s_{gas,r} - s^*_{gas,r}\right)\frac{\partial s_{gas,r}}{\partial \tau_{col,t}} \quad (12)$$

$$+w_5\sum_{r=t}^{2030}\left(s_{col,r} - s^*_{col,r}\right)\frac{\partial s_{col,r}}{\partial \tau_{col,t}} + w_8\left(\tau_{col,t} - \tau^*_{col,t}\right) = 0.$$

Rearranging (12), we derive the policy reaction function of carbon tax of coal as

$$\tau_{col,t} = \tau^*_{col,t} - \frac{w_1}{w_8}\sum_{r=t}^{2030}(x_r - x^*_r)\frac{\partial x_r}{\partial \tau_{col,t}} - \frac{w_2}{w_8}\sum_{r=t}^{2030}(CO2_r - CO2^*_r)\frac{\partial CO2_r}{\partial \tau_{col,t}}$$

$$-\frac{w_3}{w_8}\sum_{r=t}^{2030}\left(s_{oil,r} - s^*_{oil,r}\right)\frac{\partial s_{oil,r}}{\partial \tau_{col,t}} - \frac{w_4}{w_8}\sum_{r=t}^{2030}\left(s_{gas,r} - s^*_{gas,r}\right)\frac{\partial s_{gas,r}}{\partial \tau_{col,t}} \quad (13)$$

$$-\frac{w_5}{w_8}\sum_{r=t}^{2030}\left(s_{col,r} - s^*_{col,r}\right)\frac{\partial s_{col,r}}{\partial \tau_{col,t}}.$$

Thus, three optimal equations of carbon tax (9) (11) and (13) are estimated. We apply the optimal control techniques in order to solve the framework of social welfare function/policy reaction function. The optimal carbon tax is derived subject to the macroeconometric model linked to an energy model. While theses policy reaction function intends time lags from initial year to 2030, we focus on two time lags in empirical analysis.

3. Model Structure

Our model mainly follows Yano and Kosaka (2001) and Kosaka (2015). The structure of our model consists of a macroeconometric block and an energy block. The macroeconometric main block is based on the Klein's skeleton model (1983), which is presented in Appendix. A.

The energy block is explained in this section. The energy block illustrates the mechanism of determining the final energy consumption and generating CO_2 emissions.

Determination of Final/Primary Energy Demand

The primary energy consumption of fossil fuel (crude oil, natural gas, and coal) increases CO_2 emissions. The regulation of the reduction of CO_2 emissions constrains economic development.

We assume a two-level constant elasticity of substitution (CES) production function with capital, labor, and final energy as inputs. Two-level CES production is specified as

$$X_t = A\left[\alpha_1 {L_t}^{\beta_1} + (1-\alpha_1){H_t}^{\beta_1}\right]^{\frac{1}{\beta_1}} \tag{14}$$

$$H_t = \left[\alpha_2 {K_t}^{\beta_2} + (1-\alpha_2){E_{F,t}}^{\beta_2}\right]^{\frac{1}{\beta_2}}, \tag{15}$$

where A is the total efficiency parameter of production, L_t, K_t, and $E_{F,t}$ are the labor, capital stock, and final consumption of energy, respectively, α_1, and α_2 are the distribution parameters, and β_1 and β_2 denote the elasticity of substitution. $0 < \alpha_1, \alpha_2 < 1$ and $\beta_1, \beta_2 < 1$. By solving the cost minimization, we obtain

$$\frac{E_{F,t}}{K_t} = \left[\frac{P_{K,t}}{P_{F,t}}\left(\frac{1-\alpha_2}{\alpha_2}\right)\right]^{\frac{1}{1-\beta_2}}, \tag{16}$$

where $P_{K,t}$ is the capital price and $P_{F,t}$ is the final energy price. This equation determines the final energy consumption.

There is a large loss in converting from primary energy to final energy. To consider this, we specify the primary energy supply, $E_{1,t}$, as

$$E_{1,t} = f_E\left(E_{F,t}\right). \tag{17}$$

Determination of Composition of Primary Energy

The primary energy supply can be defined by the summation of each primary energy demand as

$$E_{1,t} = D_{oil,t} + D_{gas,t} + D_{col,t} + D_{nuc,t} + D_{oth,t}, \tag{18}$$

where $D_{oil,t}$, $D_{gas,t}$, $D_{col,t}$, $D_{nuc,t}$, and $D_{oth,t}$ are the final energy consumptions of crude oil, natural gas, coal, nuclear, and other energy sources like geothermal heat and renewable energy, respectively.

The distributions of primary energy are determined by the share of the four types of energy sources.

$$D_{oil,t} = s_{oil,t} E_{1,t} \tag{19}$$

$$D_{gas,t_t} = s_{gas,t} E_{1,t} \tag{20}$$

$$D_{col,t} = s_{col,t} E_{1,t} \tag{21}$$

$$D_{nuc,t} = s_{nuc,t} E_{1,t} \tag{22}$$

Here, $s_{oil,t}$, $s_{gas,t}$, $s_{col,t}$, and $s_{nuc,t}$ are the share of crude oil, natural gas, coal, and nuclear, respectively. The other energy is expressed as the remaining amount

$$D_{oth,t} = \left(1 - s_{oil,t} - s_{gas,t} - s_{col,t} - s_{nuc,t}\right) E_{1,t}, \tag{23}$$

where $s_{oth,t}$ is the share of other energy sources including geothermal heat and renewal energy.

Because the energy demand varies substitutionally as relative energy prices change, the share of energy is determined by the mechanism

$$\ln s_{i,t} = f\left\{\ln s_{i,t-1}, \ln\left(\frac{PE_{j,t} PE_{k,t} PE_{l,t}}{P_{i,t}}\right)\right\}, \quad i = oil, gas, col \ : \ j,k,l \neq i \tag{24}$$

where $PE_{oil,t}$ is the domestic end-use oil price, $PE_{gas,t}$ is the domestic end-use natural gas price, and $PE_{col,t}$ is the domestic end-use price.

Determination of CO_2 Emissions

The CO_2 emissions can be calculated by the carbon emission factor for fossil fuel energy sources as

$$CO2_t = R_{oil,t} D_{oil,t} + R_{gas,t} D_{gas,t} + R_{col,t} D_{col,t}, \tag{25}$$

where $CO2_t$ is CO_2 emissions, and $R_{oil,t}$, $R_{gas,t}$, and $R_{col,t}$ are the CO_2 emission factors of oil, natural gas, and coal, respectively. In this study, we assume $R_{oil,t}$ = 2.8641, $R_{gas,t}$ = 2.0675, and $R_{col,t}$ = 3.7620.[2]

Determination of Domestic Primal Energy Price

The domestic primary energy prices are assumed to respond to international energy prices and the exchange rate. The determination of domestic primary energy prices can be defined as

$$PE_{oil,t} = f_o(P_{oil,t}e_t) \tag{26}$$

$$PE_{gas,t} = f_g(P_{gas,t}e_t) \tag{27}$$

$$PE_{col,t} = f_c(P_{col,t}e_t), \tag{28}$$

where e_t is the exchange rate and $P_{oil,t}$, $P_{gas,t}$, and $P_{col,t}$ are the international prices in US dollars of crude oil, natural gas, and coal, respectively. In particular, we assume that $P_{oil,t}$ is the West Texas Intermediate (WTI) world crude oil spot price. Then, as for natural gas price, we use the Henry Hub natural gas spot price. Thus, $P_{oil,t}$, $P_{gas,t}$, and $P_{col,t}$ are determined by the international market.

The primary energy price can be defined by the average of the individual primary energy prices with share weights of

$$P_{1,t} = s_{oil,t}PE_{oil,t} + s_{gas,t}PE_{gas,t} + s_{col,t}PE_{col,t}. \tag{29}$$

The primary energy price is related to the final energy price as

$$P_{f,t} = f(P_{1,t}). \tag{30}$$

Carbon Tax

Carbon taxes incentivize reducing CO_2 emissions. In Japan, carbon taxes are added to fossil fuels according to the level of CO_2 emissions. Thus, the domestic primary energy price is written as

$$PE_{oil,t} = f_o(P_{oil,t}e_t) + \tau_{oil,t} \tag{31}$$

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2 We refer to the *Energy and Economic Statistics Survey 2013* (in Japanese) published by the Energy Data and Modeling Center in Japan.

$$PE_{gas,t} = f_g(P_{gas,t}e_t) + \tau_{gas,t} \quad (32)$$

$$PE_{col,t} = f_c(P_{col,t}e_t) + \tau_{col,t}. \quad (33)$$

The Japanese government introduced a carbon tax for reducing CO_2 emissions of JPY 2040 per kL for crude oil and petroleum products; 1080 per ton for LPG and LNG JPY; and JPY 700 per ton for coal.

Decomposition of CO_2 Emissions

The CO_2 emissions are decomposed as

$$\begin{aligned} CO2_t &= \left(\frac{CO2_t}{co2_t}\right)\left(\frac{E_{1,t}}{E_{F,t}}\right)\left(\frac{E_{F,t}}{X_t}\right)\left(\frac{X_t}{N_t}\right)N_t \\ &= k_t\left(\frac{1}{e_{1,t}}\right)(e_{F,t})\bar{X}_t N_t, \end{aligned} \quad (34)$$

where $\kappa_t = CO2_t/E_{1,t}$ is CO_2 emissions per unit total primary energy supply, $CO2_t = CO2_t/N_t$ is the rate of CO_2 emissions per capita, $e_{1,t} = E_{F,t}/E_{1,t}$ is the energy conversion efficiency, $e_{F,t} = E_{F,t}/XR_t$ is the energy intensity, and $\bar{X}_t = XR_t/N_t$ is the total output per capita.

4. Simulation Analysis

4.1. Data

We employ several data sources to investigate how the level of Japanese carbon tax might be set in order to reach the targeted CO_2 emission. We mainly use the annual National Accounts Statistics published by the OECD National Accounts Statistics Database from 1990 to 2013 for constructing a Japanese macroeconometric model. The capital stock data are based on the System of National Accounts (SNA) by Cabinet Office, Government of Japan. The related primary energy data rely on the Commodity Trade Statistics Database (UN Comtrade). The data for demand of primary energy as crude oil, natural gas, and coal are based on the volume of import data published by UN Comtrade. Prices of primary energy are calculated by dividing trade values in current dollar values by volume of trade. Final energy consumption data of each energy source is from Energy Balances of OECD Countries published by the International Energy Agency (IEA). Final energy prices of oil, natural gas, and coal are incorporated from the IEA's oil information, natural gas information, and coal information, respectively.

4.2. Estimation Results and Final Test

Estimated Results

We estimate the stochastic equations of the macroeconometric model and the energy model in a sample period from 1990 to 2013, applying ordinary least squares. The several estimation results are shown in Appendix B.

Final Test

In total, our system consists of 37 simultaneous equations, comprising 19 estimated equations and 18 definitional identities. We conducted the final test from 1990 to 2013 (annual). Table 1 shows the root mean square error (RMSE). Some endogenous variables might not be satisfactory. In particular, prices appear slightly unstable. However, the overall performance of this system is acceptable.

== Table 1 ==

4.3. Baseline Simulation

We run the system in the post-sample period from 2014 to 2030 (annual). We are required to make the data for the exogenous variables in the post-sample in advance. Some variables are created along with their trends, whereas the others are set at a constant value at the end of sample 2013.

The policy instruments in this study correspond to carbon taxes for oil, natural gas, and coal. According to climate change policies by the Japanese government, there are no plans to increase the tax rate. Thus, we use a constant value from 2016 to 2030. This baseline is used for calculating the optimal carbon tax from 2014 to 2020 of JPY 2,040 per kL for crude oil and petroleum products, 1080 per ton for LPG and LNG JPY, and JPY 700 per ton coal.

4.4. Scenario Simulation of Optimal Carbon Tax

In general, the policy reaction function coefficients of equations (9), (11), and (13) are estimated by regression based on the econometrics. However, this study takes the reverse approach. By assigning values to those weights in post-sample (from 2014 to 2030), we identify the policy reaction function and yield the optimal level of carbon tax ($\tau_{oil,t}$, $\tau_{gas,t}$, and $\tau_{col,t}$).

Each explanatory variable has different units and scales. Thus, all weights are standardized so that the targeted carbon tax values ($\tau^*_{oil,t}$, $\tau^*_{gas,t}$, and $\tau^*_{col,t}$) are equal to 1. An optimal carbon tax ($\tau_{oil,t}$, $\tau_{gas,t}$, and $\tau_{col,t}$) above 1 implies that the carbon tax should be increased to achieve the policy goals. However, an optimal carbon tax under 1 means that it is possible to decrease the carbon tax. We attempt to examine how the optimal carbon tax rate changes depending on policy weights based on the following four scenarios.

Scenario 1: All weights are equivalently significant.

As a basic case, this scenario supposes that individual policy objectives of economic growth, CO2 emissions, and the energy mix are equally important to implement. All weights of the policy reaction function are set in 1. Specifically, equation (9) contains $w_1/w_6 = 1$, $w_2/w_6 = 1$, $w_3/w_6 = 1$, $w_4/w_6 = 1$, and $w_5/w_6 = 1$, and similar methods are applied to equations (11) and (13).

Table 2 shows the optimal carbon tax levels for Scenario 1. All values are above 1, which suggests that the current level of carbon tax is too low to complete the target value. When converted into a price, the results show that the optimal oil carbon tax should be raised from the current level of 2,040 JP yen to 3,495 JP Yen, the natural gas carbon tax should be raised from 1,080 to 1,963 JP Yen, and the coal carbon tax should be raised from 700 to 1,633 JP Yen in 2030.

== Table 2 ==

Scenario 2: The weight attached to economic growth is most significant.

Assuming that the annual economic growth of 1.17 is the first priority among the targets, we give $w_1/w_6 = 10$ in equation (9), $w_1/w_7 = 10$ in equation (11), and $w_1/w_8 = 10$ in equation (13). All other weights, namely CO2 emissions, and the energy mix of oil, natural gas, and coal, remain equal to 1. Table 3 presents the results for Scenario 2. The values in parentheses denote the rate of divergence from the values of Scenario 1. Overall, when the priority is economic growth, the simulated values show that the carbon tax levels could be decreased slightly.

== Table 3 ==

Scenario 3: The weight attached to the rate of CO2 emissions is most significant.

Scenario 3 implies that the priority of the policy is to realize the desired rate of CO2 emissions reduction. Specifically, we give w_2/w_6= 2 in equation (9), w_2/w_7= 2 in equation (11), and w_2/w_8= 2 in equation (13). All other weights , namely economic growth, and the energy mix of oil, natural gas, and coal, are equal to 1. As Table 4 shows, the current tax rate is too low to achieve the policy objective of the CO2 emissions reduction. The optimal carbon tax levels should be increased as follows: oil carbon tax raised 2.43 times, natural gas raised 2.64 times, and coal raised 3.67 times. In terms of price, the oil carbon tax should be raised from the current tax of 2,040 JP Yen to 4,951 JP Yen, natural gas from 1,080 JP Yen to 2,846 JP Yen, and coal from 700 JP Yen to 2,566 JP Yen.

== Table 4 ==

Scenario 4: The share of the energy mix is emphasized.

We examine three scenarios that alter the weights of oil, natural gas, and coal. Table 5 shows the results of this scenario in which the weight of the oil share of energy is changed. The results show that the optimal oil carbon tax should be increased, whereas natural gas and coal as alternative energy sources can be decreased slightly. Tables 6 and 7 show the results of optimal oil carbon taxes with changes made to the weights of the natural gas and coal, respectively. These results suggest that the carbon tax of the corresponding energy tends to increase; whereas, the carbon tax of alternative energy sources can decrease slightly.

== Table 5 ==

== Table 6 ==

== Table 7 ==

Scenario 5: This scenario assigns different levels of importance to the policy objects.

We consider that the policy objects have different priorities and thus assign different weights as follows: CO2 emission weight = 2.5, oil share = 30, and natural gas = 10. Table 8 presents the results. To realize the targets, oil carbon tax should be raised 2.78 times, natural gas 3.04 times, and coal 4.31 times. In monetary terms, oil tax should be raised to 5,681 JP Yen (from 2,040 JP Yen), natural gas to 3,287 JP Yen (from 1,080 JP Yen), and coal to 3,020 JP Yen (from 700 JP Yen).

== Table 8 ==

5. Conclusions

This study constructed a macroeconometric model linked to an energy model for Japan. By implementing optimal control in our system, we forecasted the future optimal carbon tax rate from 2016 to 2030. The findings are summarized as follows.

1. It will be difficult to achieve the target reduction of CO_2 emissions, energy mix share, and economic growth at the current carbon tax level. The simulation results show that the carbon tax needs to be at least doubled.
2. In particular, the reduction of CO_2 emissions compared with 2013 among policy targets would be hardest to achieve. Occasionally, the government will be asked to review this policy

objective.

3. It will be difficult to realize an annual economic growth rate of 1.7%. Furthermore, if it assumes that the rate of economic growth is more than 1.7%, due to tight tradeoff between economic growth and reduction of CO_2 emissions, the carbon tax would be required to decrease.

The simulated results show that the INDC's policy objectives are not feasible at the current carbon tax levels. To achieve these goals, carbon taxes should be increased significantly as soon as possible. However, carbon taxes are just one climate policy instrument available to governments to reduce CO2 emissions; other policies to establish a low cost society include adopting electric vehicles or promoting renewable energies.

While our system analyzed the optimal energy policy for Japan and examined the feasibility of the policy targets, the system requires some improvements. First, the international energy price (WTI oil price and Henry Hub natural gas price) should be endogenized in this model. The variation of world energy prices affects the domestic energy price, which affects the demand/supply of energy and consequently the macro economy. Our system should be extended to link to the world energy model, which describes the international market of crude oil and natural gas. Second, the domestic macroeconometric model should be expanded to an international macroeconometric model to include other countries. The reduction of CO_2 emissions is a global problem that requires international cooperation, and this interdependence should be described. These improvements will be implemented in future studies.

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Table 1. Evaluation of Model Performance by RMSE (Selected Variables)

Variables	RMSE
Consumption (real)	0.00
GDP (real)	0.00
Capital (real)	0.00
Capital Price	0.00
Energy Intensity	0.00
Share of demand for Coal	0.01
Share of demand for Natural Gas	0.01
Share of demand for Crude Oil	0.02
GDP deflator	0.02
Consumption of Primary Energy	0.02
CO2 emission per unit total primary energy supply	0.05
Consumption of Primary Energy: Natural Gas	4.23
Consumption of Primary Energy: Coal	4.83
Consumption of Primary Energy: Crude Oil	11.08
Supply/Demand of Final Energy	14.74
Demand of Primary Energy	21.79

Table 2. Optimal Carbon Tax Levels for Scenario 1

Year	Oil	Natural Gas	Coal
2016	1.182	1.098	1.196
2017	1.255	1.144	1.281
2018	1.316	1.192	1.373
2019	1.371	1.242	1.464
2020	1.422	1.296	1.553
2021	1.467	1.351	1.640
2022	1.509	1.407	1.726
2023	1.548	1.465	1.811
2024	1.584	1.523	1.896
2025	1.618	1.583	1.980
2026	1.649	1.643	2.063
2027	1.680	1.703	2.146
2028	1.709	1.765	2.229
2029	1.742	1.804	2.300
2030	1.713	1.818	2.333

Table 3. Optimal Carbon Tax Levels for Scenario 2

Year	Oil		Natural Gas		Coal	
2016	1.180	(-0.01%)	1.10	(-0.03%)	1.200	(-0.01%)
2017	1.250	(-0.01%)	1.14	(-0.03%)	1.280	(-0.01%)
2018	1.320	(-0.01%)	1.19	(-0.03%)	1.370	(-0.01%)
2019	1.370	(-0.01%)	1.24	(-0.03%)	1.460	(-0.01%)
2020	1.420	(-0.01%)	1.30	(-0.02%)	1.550	(-0.01%)
2021	1.470	(-0.01%)	1.35	(-0.02%)	1.640	(-0.01%)
2022	1.510	(-0.01%)	1.41	(-0.02%)	1.730	(-0.01%)
2023	1.550	(-0.01%)	1.46	(-0.02%)	1.810	(0.00%)
2024	1.580	(-0.01%)	1.52	(-0.02%)	1.900	(0.00%)
2025	1.620	(-0.01%)	1.58	(-0.02%)	1.980	(0.00%)
2026	1.650	(0.00%)	1.64	(-0.02%)	2.060	(0.00%)
2027	1.680	(0.00%)	1.70	(-0.02%)	2.150	(0.00%)
2028	1.710	(0.00%)	1.76	(-0.02%)	2.230	(0.00%)
2029	1.740	(0.00%)	1.80	(-0.02%)	2.300	(0.00%)
2030	1.710	(0.00%)	1.82	(-0.02%)	2.330	(0.00%)

Table 4. Optimal Carbon Tax Levels for Scenario 3

Year	Oil		Natural Gas		Coal	
2016	1.36	(15.42%)	1.20	(8.97%)	1.39	(16.36%)
2017	1.51	(20.33%)	1.29	(12.60%)	1.56	(21.96%)
2018	1.63	(24.04%)	1.38	(16.09%)	1.75	(27.19%)
2019	1.74	(27.10%)	1.48	(19.51%)	1.93	(31.69%)
2020	1.84	(29.68%)	1.59	(22.82%)	2.11	(35.60%)
2021	1.94	(31.87%)	1.70	(25.96%)	2.28	(39.03%)
2022	2.02	(33.77%)	1.81	(28.94%)	2.45	(42.08%)
2023	2.10	(35.42%)	1.93	(31.73%)	2.62	(44.81%)
2024	2.17	(36.89%)	2.05	(34.36%)	2.79	(47.26%)
2025	2.24	(38.21%)	2.17	(36.82%)	2.96	(49.50%)
2026	2.30	(39.40%)	2.29	(39.13%)	3.13	(51.54%)
2027	2.36	(40.49%)	2.41	(41.30%)	3.29	(53.41%)
2028	2.42	(41.49%)	2.53	(43.34%)	3.46	(55.15%)
2029	2.48	(42.62%)	2.61	(44.58%)	3.60	(56.53%)
2030	2.43	(41.65%)	2.64	(44.99%)	3.67	(57.15%)

Table 5. Optimal Carbon Tax Levels: Case of Oil Share in Scenario 4

Year	Oil		Natural Gas		Coal	
2016	1.18	(0.02%)	1.10	(-0.03%)	1.19	(-0.06%)
2017	1.26	(0.03%)	1.14	(-0.03%)	1.28	(-0.07%)
2018	1.32	(0.03%)	1.19	(-0.04%)	1.37	(-0.08%)
2019	1.37	(0.04%)	1.24	(-0.04%)	1.46	(-0.09%)
2020	1.42	(0.04%)	1.29	(-0.04%)	1.55	(-0.10%)
2021	1.47	(0.04%)	1.35	(-0.04%)	1.64	(-0.10%)
2022	1.51	(0.05%)	1.41	(-0.04%)	1.72	(-0.11%)
2023	1.55	(0.05%)	1.46	(-0.04%)	1.81	(-0.11%)
2024	1.58	(0.06%)	1.52	(-0.05%)	1.89	(-0.12%)
2025	1.62	(0.06%)	1.58	(-0.05%)	1.98	(-0.12%)
2026	1.65	(0.06%)	1.64	(-0.05%)	2.06	(-0.13%)
2027	1.68	(0.07%)	1.70	(-0.05%)	2.14	(-0.13%)
2028	1.71	(0.07%)	1.76	(-0.05%)	2.23	(-0.14%)
2029	1.74	(0.07%)	1.80	(-0.05%)	2.30	(-0.14%)
2030	1.71	(0.07%)	1.82	(-0.05%)	2.33	(-0.14%)

Table 6. Optimal Carbon Tax Levels: Case of Natural Gas Share in Scenario 4

Year	Oil		Natural Gas		Coal	
2016	1.18	(-0.01%)	1.10	(0.01%)	1.20	(-0.01%)
2017	1.25	(-0.01%)	1.14	(0.01%)	1.28	(-0.02%)
2018	1.32	(-0.01%)	1.19	(0.01%)	1.37	(-0.02%)
2019	1.37	(-0.01%)	1.24	(0.01%)	1.46	(-0.02%)
2020	1.42	(-0.01%)	1.30	(0.01%)	1.55	(-0.02%)
2021	1.47	(-0.01%)	1.35	(0.01%)	1.64	(-0.02%)
2022	1.51	(-0.01%)	1.41	(0.01%)	1.73	(-0.02%)
2023	1.55	(-0.01%)	1.46	(0.01%)	1.81	(-0.03%)
2024	1.58	(-0.01%)	1.52	(0.01%)	1.90	(-0.03%)
2025	1.62	(-0.01%)	1.58	(0.01%)	1.98	(-0.03%)
2026	1.65	(-0.01%)	1.64	(0.01%)	2.06	(-0.03%)
2027	1.68	(-0.01%)	1.70	(0.01%)	2.15	(-0.03%)
2028	1.71	(-0.02%)	1.76	(0.01%)	2.23	(-0.03%)
2029	1.74	(-0.02%)	1.80	(0.01%)	2.30	(-0.03%)
2030	1.71	(-0.02%)	1.82	(0.01%)	2.33	(-0.03%)

Table 7. Optimal Carbon Tax Levels: Case of Coal Share in Scenario 4

Year	Oil		Natural Gas		Coal	
2016	1.18	(-0.01%)	1.10	(-0.01%)	1.20	(0.02%)
2017	1.25	(-0.01%)	1.14	(-0.01%)	1.28	(0.02%)
2018	1.32	(-0.01%)	1.19	(-0.01%)	1.37	(0.02%)
2019	1.37	(-0.01%)	1.24	(-0.01%)	1.46	(0.02%)
2020	1.42	(-0.01%)	1.30	(-0.01%)	1.55	(0.03%)
2021	1.47	(-0.01%)	1.35	(-0.01%)	1.64	(0.03%)
2022	1.51	(-0.01%)	1.41	(-0.01%)	1.73	(0.03%)
2023	1.55	(-0.01%)	1.46	(-0.01%)	1.81	(0.03%)
2024	1.58	(-0.01%)	1.52	(-0.01%)	1.90	(0.03%)
2025	1.62	(-0.01%)	1.58	(-0.01%)	1.98	(0.03%)
2026	1.65	(-0.02%)	1.64	(-0.01%)	2.06	(0.03%)
2027	1.68	(-0.02%)	1.70	(-0.01%)	2.15	(0.03%)
2028	1.71	(-0.02%)	1.76	(-0.01%)	2.23	(0.03%)
2029	1.74	(-0.02%)	1.80	(-0.01%)	2.30	(0.03%)
2030	1.71	(-0.02%)	1.82	(-0.01%)	2.33	(0.03%)

Table 8. Optimal Carbon Tax Levels: Scenario 5

Year	Oil		Natural Gas		Coal	
2016	1.46	(23.16%)	1.25	(13.42%)	1.49	(24.23%)
2017	1.64	(30.53%)	1.36	(18.86%)	1.70	(32.57%)
2018	1.79	(36.09%)	1.48	(24.09%)	1.93	(40.37%)
2019	1.93	(40.69%)	1.61	(29.22%)	2.15	(47.07%)
2020	2.06	(44.56%)	1.74	(34.18%)	2.37	(52.89%)
2021	2.17	(47.86%)	1.88	(38.89%)	2.59	(58.01%)
2022	2.27	(50.70%)	2.02	(43.35%)	2.81	(62.55%)
2023	2.37	(53.20%)	2.16	(47.55%)	3.02	(66.61%)
2024	2.46	(55.40%)	2.31	(51.48%)	3.23	(70.27%)
2025	2.55	(57.38%)	2.46	(55.18%)	3.44	(73.59%)
2026	2.63	(59.17%)	2.61	(58.64%)	3.64	(76.63%)
2027	2.70	(60.81%)	2.76	(61.89%)	3.85	(79.42%)
2028	2.77	(62.33%)	2.91	(64.95%)	4.06	(82.00%)
2029	2.86	(64.01%)	3.01	(66.81%)	4.23	(84.07%)
2030	2.78	(62.56%)	3.04	(67.44%)	4.31	(84.97%)

Appendix A. Framework of Macroeconometric Model

This section illustrates the macroeconometric model. We follow Klein's skeleton model (1983). Since this is a conventional model, we do not provide a detailed explanation (Klein, 1983).

Endogenous Variables

XR_t	: Gross domestic product (real)	L_t	: Employment
CR_t	: Private final consumption (real)	LF_t	: Labor force
IR_t	: Gross fixed capital formation (real)	w_t	: Wage rate
EXR_t	: Exports (real)	r_t	: Interest rate (real)
IMR_t	: Imports (real)	$T_{1,t}$	: Indirect tax (nominal)
KR_t	: Capital stock (real)	$T_{2,t}$	: Direct tax (nominal)
DR_t	: Depreciation (real)	$T_{3,t}$	: Corporation profit tax (nominal)
Y_t	: National income (nominal)	$T_{r,t}$	: Transfer payments (nominal)
π_t	: Corporation profit (nominal)	e_t	: Exchange rate
p_t	: GDP deflator		

Exogenous Variables

GR_t	: Government final consumption (real)	N_t	: Population
WT_t	: World trade transactions (real)	$p_{w,t}$	: World trade price
M_t	: Money supply (nominal)	$p_{m,t}$	: Import price

Identities

Real GDP

$$XR_t = CR_t + GR_t + IR_t + EXR_t - IMR_t \tag{A.1}$$

Nominal GDP

$$p_t XR_t = Y_t + \left(T_{1,t} + T_{2,t} + T_{3,t} - T_{r,t}\right) - p_t DR_t \tag{A.2}$$

National income

$$w_t L_t + \pi_t = Y_t + \left(T_{2,t} + T_{3,t} - T_{r,t}\right) \tag{A.3}$$

Capital stock

$$KR_t = KR_{t-1} + IR_t - DR_t \tag{A.4}$$

Behavior and Technological Relations

Consumption

$$\frac{CR_t}{N_t} = a_0 + a_1\left(\frac{Y_t}{N_t p_t}\right) + a_2\left(\frac{CR_{t-1}}{N_{t-1}}\right) + u_{1,t} \tag{A.5}$$

Investment

$$IR_t = b_0 + b_1 XR_t + b_2 r_t + b_3 K_{t-1} + u_{2,t} \tag{A.6}$$

Export

$$EXR_t = c_0 + c_1 WT_t + c_2\left(\frac{p_{w,t}}{p_t}\right) + c_3 EXR_{t-1} + u_{3,t} \tag{A.7}$$

Import

$$IMR_t = d_0 + d_1 XR_t + d_2\left(\frac{p_t}{p_{m,t}}\right) + d_3 IMR_{t-1} + u_{4,t} \tag{A.8}$$

Employment

$$\log L_t = f_0 + f_1 \log XR_t + f_2 \log K_{t-1} + f_3 L_{t-1} + u_{5,t} \tag{A.9}$$

Price formation

$$p_t = g_0 + g_1\left(\frac{w_t L_t}{XR_t}\right) + g_2 p_{m,t} + u_{6,t} \tag{A.10}$$

Wage fate

$$w_t = h_0 + h_1\left(\frac{XR_t}{L_t}\right) + h_2 p_t + u_{7,t} \tag{A.11}$$

Labor force

$$\frac{LF_t}{N_t} = i_0 + i_1\left(\frac{LF_t - L_t}{LF_t}\right) + i_2\left(\frac{w_t}{p_t}\right) + u_{8,t} \tag{A.12}$$

Velocity of circulation of money

$$\log\left(\frac{p_t XR_t}{M_t}\right) = j_0 + j_1 r_t + j_2 \Delta \log p_t + u_{9,t}$$

$$j_1 < 0,\ j_2 > 0 \tag{A.13}$$

Depreciation

$$DR_t = k_0 + k_1 KR_{t-1} + u_{10,t} \tag{A.14}$$

Indirect tax

$$T_{1,t} = l_0 + l_1(p_t XR_t) + u_{11,t} \tag{A.15}$$

Indirect tax

$$T_{2,t} = m_0 + m_1 Y_t + u_{12,t} \tag{A.16}$$

Corporation tax

$$T_{3,t} = n_0 + n_1\pi_t + u_{13,t} \tag{A.17}$$

Transfer payments

$$T_{r,t} = o_0 + o_1(LF_t - L_t) + o_2 w_t + u_{14,t} \tag{A.18}$$

Exchange Rate

$$\log e_t = q_0 + q_1 \log\left(\frac{p_t}{p_t^{USA}}\right) + q_2(r_t^{USA} - r_t) - q_3\left(\frac{EXR_t - IMR_t}{p_t XR_t}\right) + u_{15,t} \tag{A.19}$$
$$q_1 > 0,\ \ q_2 > 0,\ \ q_3 > 0$$

Appendix B. Estimated Results

Macroeconomic Model

(B.1) Consumption (Real)

CPR_JPN/POP_JPN=0.7979 * CPR_JPN(-1)/POP_JPN

(0.1076)

[0.9154]

+0.1654 * YD_JPN/(POP_JPN*PGDP10_JPN)

(2.6043)

[0.017]

+8.1234

(11.2643)

[0.000]

Adj.R^2=0.977 S.E.=18.589 D.W.=1.728

(B.2) Investment (Real)

LOG(IR_JPN)= 0.0047*LOG(RGB_JPN)-1.1145*LOG(GDPR_JPN(-2))+40.736

(8.2064) (-4.4825) (0.1628)

[0.000] [0.0002] [0.8723]

Adj.R^2=0.715 S.E.=0.044 D.W.=0.765

(B.3) Export (Real)

EXR_JPN=11032730*PWT_ALL/PGDP10_JPN+0.4657*WT_ALL+-11059715

(-6.3796) (21.4246) (2.7604)

[0.000] [0.000] [0.0114]

Adj.R^2=0.989 S.E.=1792848 D.W.=0.987

(B.4) Import (Real)

IMR_JPN=0.2141*IMR_JPN(-1) +3666615*PGDP10_JPN/PIM10_JPN

(-6.5178) (7.5696)

[0.000] [0.000]

+0.4004*GDPR_JPN-140000000

(0.8869) (1.9036)

[0.3857] [0.0715]

Adj.R^2=0.976 S.E.=2040428 D.W.=1.063

(B.5) Disposable Income

YD_JPN=0.918*(GDPR_JPN*PGDP10_JPN-(TAX1_JPN+TAX2_PR_JPN-TR_RP_JPN)-DR_JPN *PGDP10_JPN)

(2.6101)

[0.0177]

+28048974

(31.426)

[0.000]

Adj.R^2=0.981 S.E.=1566733 D.W.=0.881

(B.6) Depreciation (Real)

DR_JPN=0.0562*K2R_JPN(-1)+32790732

(8.2935) (16.1472)

[0.000] [0.000]

Adj.R^2=0.932 S.E.=1974607 D.W.=0.558

(B.7) Labor Force

LOG(L_JPN)=0.8459*LOG(L_JPN(-1))-0.1359*LOG(K2R_JPN)

(-1.0053) (6.1276)

[0.3297] [0.000]

+0.3045*LOG(GDPR_JPN)-1.5377

(-6.679) (8.5147)

[0.000] [0.000]

Adj.R^2=0.925 S.E.=0.004 D.W.=2.05

(B.8) Wage Rate

WAGE_RATE_JPN=4752.457*LOG(PGDP10_JPN)+0.5453*GDPR_JPN/L_JPN-278.0113

(-0.4089) (6.1719) (7.4909)

[0.6868] [0.000] [0.000]

Adj.R^2=0.717 S.E.=76.956 D.W.=0.533

(B.9) Capital

K2R_JPN-K2R_JPN(-1)= 0.6654*IR_JPN-DR_JPN+11463523

(3.0955) (3.7634)

[0.0062] [0.0014]

Adj.R^2=0.409 S.E.=12081209 D.W.=2.417

Energy Model

(B.10) Demand of Final Energy

LOG(FE_D_ALL_JPN/K2R_JPN)=-0.5998*LOG(PF_JPN(-1)/PK10_JPN(-1))-11.0018

(-29.7322) (-10.8877)

[0.000] [0.000]

Adj.R^2=0.861 S.E.=0.052 D.W.=0.872

(B.11) Demand of Primary Energy

D1_ALL_JPN=1.4242*FE_D_ALL_JPN+26.4908

(0.535) (9.4696)

[0.598] [0.000]

Adj.R^2=0.794 S.E.=12.801 D.W.=0.917

(B.12) Price of Final Energy

PF_JPN=0.012*P1_JPN+639.6767

(25.7121) (13.2719)

[0.000] [0.000]

Adj.R^2=0.884 S.E.=62.797 D.W.=0.36

(B.13) Price of Primary Energy : Crude Oil

PE1_OIL_JPN=8.2959*_P_OIL_WTI*E_JPN-3832.652

(-2.6186) (31.7694)

[0.0154] [0.000]

Adj.R^2=0.977 S.E.=3650.467 D.W.=0.492

(B.14) Price of Primary Energy: Natural Gas

LOG(PE1_GAS_JPN)=0.1526*LOG(_P_GAS_HENRY_HUB*E_JPN)

(-0.2177)

[0.8296]

+0.9353*LOG(P1_GAS_JPN(-1))-0.1743

(11.4711) (2.0765)

[0.000] [0.0497]

Adj.R^2=0.879 S.E.=0.174 D.W.=1.886

(B.15) Price of Primary Energy : Coal

LOG(PE1_COL_JPN)=0.9374*LOG(_P_COL_NWE*E_JPN)+0.7977

(0.8658) (8.8387)

[0.3955] [0.000]

Adj.R^2=0.763 S.E.=0.199 D.W.=1.076

(B.16) Share of Primary Energy Consumption : Crude Oil

LOG(S1_OIL_JPN)=0.0056*LOG(P1_GAS_JPN*P1_COL_JPN/P1_OIL_JPN)

(-0.503)

[0.6202]

+0.9428*LOG(S1_OIL_JPN(-1))-0.1036

(12.8311) (0.2219)

[0.000] [0.8265]

Adj.R^2=0.908 S.E.=0.031 D.W.=2.117

(B.17) Share of Primary Energy Consumption : Natural Gas

LOG(S1_GAS_JPN)=00.0329*LOG(P1_OIL_JPN*P1_COL_JPN/P1_GAS_JPN)

(-0.9671)

[0.3445]

+0.9798*LOG(S1_GAS_JPN(-1))-0.2963

(16.9031) (1.3832)

[0.000] [0.1811]

Adj.R^2=0.97 S.E.=0.043 D.W.=2.262

(B.18) Share of Primary Energy Consumption: Coal

LOG(S1_COL_JPN)=0.0754*LOG(P1_GAS_JPN*P1_OIL_JPN/P1_COL_JPN)

(-4.222)

[0.0004]

+0.6553*LOG(S1_COL_JPN(-1))-1.4194

(7.2987) (4.4528)

[0.000] [0.0002]

Adj.R^2=0.975 S.E.=0.026 D.W.=2.118