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Energy-Saving Technological Change in Japan

Takeshi Niizeki

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Economic and Social Research Institute
Cabinet Office
Tokyo, Japan

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Takeshi Niizeki

Economic and Social Research Institute, Cabinet Office

Abstract

The energy-dependence of Japan's economy declined considerably following the first oil crisis in 1973. This paper examines what caused the sharp drop in the use of energy per unit of gross national product (GNP) observed in the 1970s and 1980s, using a simple neoclassical growth model with energy as a third production input. Two possible candidates are investigated: (i) the substitution effect due to changes in the relative price of energy, and (ii) energy-saving technological progress. The findings are as follows. First, the substitution effect alone is weak and cannot account for the decline in the energy-GNP ratio. Second, the estimated level of energy-saving technology more than tripled between 1970 and the late 1980s, and the model with energy-saving technological progress is able to explain the drop in the energy-GNP ratio well.

Keywords: relative energy price; energy-saving technological change; neoclassical growth model.

JEL codes: E20, F20, O30, Q43

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1 Introduction

The energy-dependence of Japan's economy declined considerably following the first oil crisis in 1973. Figure 1 depicts the relationship between the natural logarithm of energy use[1] and real Gross National Product (GNP)[2] over FY 1955-1998. As you can see in Figure 1, the energy use proportionally increased as the economy grew over 1955-1972. This relationship dramatically changed following the first oil crisis. During the period 1973-1988, the real GNP grew by 73.6% whereas the energy use actually declined by 7.4%. That is, the energy use relative to real GNP, or what will be referred to as the energy-GNP ratio hereafter, dropped substantially over the period 1973-1988.

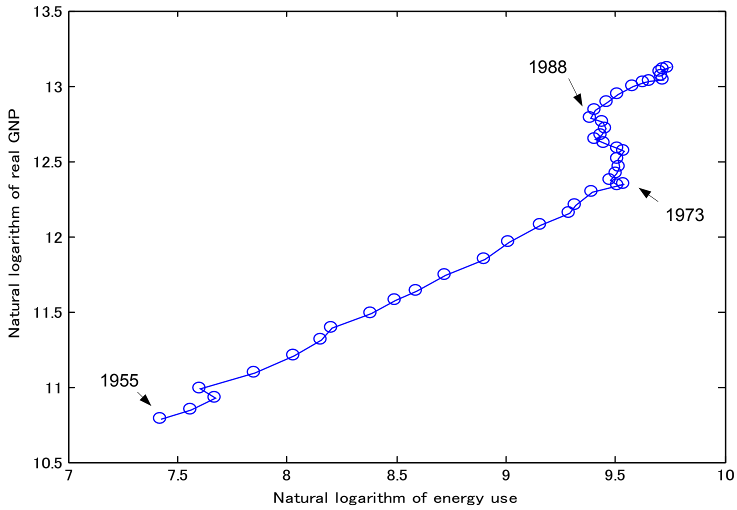

Figure 1: The relationship between energy use and real GNP

Against this background, the purpose of this paper is to examine quantitatively the reasons for the drop in the energy-GNP ratio observed in the 1970s and 1980s using a simple neoclassical growth model with energy as an input. Discussion to explain the drop in the energy-GNP ratio

[1]The data for energy use is taken from the "General energy supply and demand balance" published by the Agency for Natural Resources and Energy and it is calculated as the domestic supply of fossil fuels (petroleum, coal, and liquid natural gas) measured in petajoules. The domestic supply of fossil fuels is treated as the energy use here since most of the total domestic supply of energy are consumed domestically within a year. For instance, only 5.7% and 1.5% of total domestic supply of energy were exported and accumulated as an inventory respectively in FY 1970.

[2]Real GNP is obtained using the GNP deflator with 1990 as the base year.

has generally focused on two possible candidates: (i) the substitution effect, and (ii) energy-saving technological progress. The substitution effect works as follows. When the relative price of energy rises, energy is substituted with other inputs such as labor and capital. Thus, as value added increases, we would expect the input of energy per unit of value added, or the energy-GNP ratio, to decrease. The trends in the actual relative price of energy and in real energy use are depicted in Figure 2, where the relative price of energy is calculated by dividing the energy price deflator by the GNP deflator. Since the price data for energy use is not available in the "General energy supply and demand balance", the remaining part of this paper uses alternatively the "Trade Statistics of Japan" published by the Ministry of Finance as a data source for real energy use under the assumption that all energy required for production is imported in Japan.[3] Real energy use is calculated as the total quantity of imported fossil fuels (petroleum, coal, and liquid natural gas) evaluated at the base year price.[4] As can be seen, the relative price of energy shot up in 1973, the year of the first oil shock, and again in 1979, the year of the second oil shock, so that by the mid-1980s it had more than tripled when compared with the beginning of the 1970s. On the other hand, real energy use measured in billion yen, dipped following the first oil shock and declined substantially following the second. Therefore, the substitution effect would be one potential candidate for explaining the drop in the energy-GNP ratio.

The second candidate to account for the drop in the energy-GNP ratio is the improvements in energy-saving technology. The story would be that the sharp rises in relative price of energy in the 1970s increased the demand for more energy-efficient products, leading to aggressive research and development expenditures. Since the energy-GNP ratio only shows the modest increase after 1985 when the relative price of energy dropped sharply, it is plausible to consider that the Japanese economy became less energy-dependent due to energy-saving technological change.

To examine the role of two possible candidates described above in accounting for the drop in the energy-GNP ratio, two simulations are conducted using a simple neoclassical growth model with energy. In the first simulation, the actual path of the relative price of energy is fed into the model as an exogenous variable to examine the quantitative impact of the substitution effect on the

[3]According to Agency for Natural Resources and Energy (2012), the share of domestically supplied energy (excluding nuclear power generation) in total energy supply was 14.9%, 6.7%, and 5.8% in the 1970s, 80s, and 90s, respectively. Therefore, it would be not much unrealistic to assume that Japan imports all energy needed for production.

[4]See Appendix 1 for details of data construction.

energy-GNP ratio. In the second simulation, at first, the actual series of energy-saving technology are estimated as residuals. Then an estimated path of energy-saving technology is additionally fed into the model to examine the role of energy-saving technological change.

The findings of this paper are as follows. The substitution effect due to changes in the relative price of energy is weak and, taken alone, cannot account for the drop in the energy-GNP ratio. On the other hand, once the estimated path of energy-saving technology is incorporated into the model, the energy-GNP ratio generated by the model fits well with the actual data.

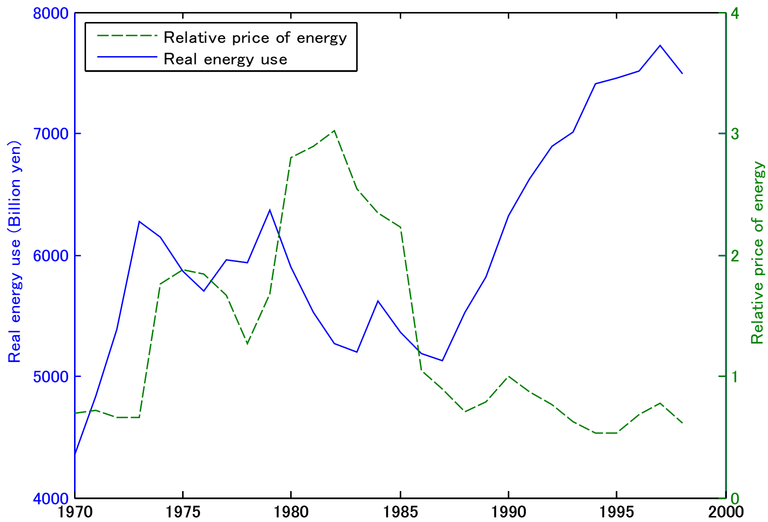

Figure 2: Real energy use and relative energy price

This remainder of the paper is organized as follows. Section 2 describes the model, while Section 3 discusses the calibration. Next, Section 4 presents the simulation results. Section 5 concludes the paper.

2 The Model

The model employed here is based on that developed by Kim and Loungani (1992), who incorporate energy as a third input into an otherwise standard real business cycle (RBC) model.[5] The model

[5]Kim and Loungani (1992) assume that fluctuations in the relative price of energy are stochastic, while the model employed here incorporates the actual path of the relative energy price into the model. In other words, there is no

assumes that there is a representative household with N_t members at time t. In addition, for simplicity it is assumed that the size of household does not grow over time.[6] The household chooses the path of consumption, leisure, and investment so as to maximize the life-time utility function

$$\max_{\{c_t,h_t,k_{t+1}\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \beta^t N_t \Big[(1-\alpha)\ln c_t + \alpha \ln(1-h_t)\Big], \tag{1}$$

subject to

$$C_t + X_t = w_t H_t + r_t K_t \tag{2}$$

$$X_t = K_{t+1} - (1-\delta)K_t, \tag{3}$$

where C_t is aggregate consumption, X_t is aggregate investment, w_t is the wage rate, H_t is aggregate hours worked, r_t is the rental rate of capital, δ is the depreciation rate, and β is the discount factor. The time endowment is normalized to unity and is divided into labor and leisure.

The representative firm faces the following profit maximization problem:

$$\max_{\{K_t,H_t,E_t\}} Y_t - r_t K_t - w_t H_t - p_t E_t \tag{4}$$

subject to

$$Y_t = (\Gamma_t H_t)^{1-\theta}\Big[(1-\mu)K_t^{\frac{\varepsilon-1}{\varepsilon}} + \mu E_t^{\frac{\varepsilon-1}{\varepsilon}}\Big]^{\frac{\varepsilon}{\varepsilon-1}\theta}. \tag{5}$$

where Y_t is gross output, Γ_t is total factor productivity (TFP), p_t is the relative price of energy, and E_t is aggregate energy use. As will be discussed below, several studies, such as Hassler, Krusell, and Olovsson (2012), suggest that the elasticity of substitution between energy and other inputs is considerably less than unity. Therefore, a nested constant elasticity of substitution production function with constant returns to scale is used.[7] The firm imports energy from abroad

uncertainty in the model here as in Hayashi and Prescott (2002) and Chen et al. (2006).

[6]The simulation results remain largely unaffected when this assumption is changed and the population is allowed to grow.

[7]Hassler, Krusell, and Olovsson (2012) employ an alternative specification of the production function, namely:

$$Y_t = \Big[(1-\gamma)[A_t K_t^{\alpha} L_t^{1-\alpha}]^{\frac{\varepsilon-1}{\varepsilon}} + \gamma[A_t^E E_t]^{\frac{\varepsilon-1}{\varepsilon}}\Big]^{\frac{\varepsilon}{\varepsilon-1}},$$

at exogenously given price p_t per unit.[8] TFP is also exogenous to the firm.

The resource constraint is as follows:

$$C_t + X_t = Y_t - p_t E_t \equiv V_t, \tag{6}$$

where V_t denotes value-added at time t. That is, output produced domestically is either consumed, invested, or exported as payment for imported energy. Note that exports are equal to imports in each period, so that the trade balance is always zero. Finally, as in the studies by Hayashi and Prescott (2002, 2008) and Chen et al. (2006), it is assumed that agents have perfect foresight about the sequence of exogenous variables. The model is then solved numerically by applying a shooting algorithm given the initial capital stock level and the path of exogenous variables. The initial capital stock is taken from the actual data.

3 Calibration

The model is calibrated to the Japanese economy for the period 1970-1998.[9] The values for β and θ are set at 0.976 and 0.362, taken from Hayashi and Prescott (2002). δ takes 0.100, a conventional value for annual data. The leisure weight in preferences, α, is obtained by solving the intra-temporal optimal condition for α,

$$\left(\frac{\alpha}{1-\alpha}\right)\left(\frac{h_t}{1-h_t}\right) = (1-\theta)\frac{y_t}{c_t}, \quad \text{for} \quad t = 1970, ..., 1998. \tag{7}$$

and averaging them over the 1970-1998 period. To calibrate μ, the production function and the first-order condition for energy use are combined as follows:

$$\frac{1-\mu}{\mu} = \left(\frac{\theta Y_t - p_t E_t}{p_t E_t}\right)\left(\frac{E_t}{K_t}\right)^{\frac{\varepsilon-1}{\varepsilon}}, \quad \text{for} \quad t = 1970, ..., 1998. \tag{8}$$

where A_t is capital/labor-augmenting technology and A_t^E is fossil energy-augmenting technology. The simulation results shown below are robust to this alternative production function as well.

[8] In the case that fossil fuels are extracted domestically, an alternative interpretation of the energy price would be that p_t represents the unit cost of fossil energy extraction. However, since Japan imports almost all its fossil energy from abroad, this interpretation is not employed here.

[9] The analysis ends in 1998 since the 1968 SNA (System of National Accounts) data, the data source for many aggregate variables in this paper, is not available after 1998. As our focus is the economic reasons behind the changing dynamics of energy-GNP ratio observed in the 1970s and 80s, this coverage of years is enough.

Equation (8) is then solved for μ and μ is then averaged over 1970-1998.

Previous studies provide numerous estimates of ε, the elasticity of substitution between capital stock and energy. For instance, Backus and Crucini (2000) report a value of $\varepsilon = 0.09$, while Miyazawa (2010) conducts a generalized method of moments estimation and reports values of $\varepsilon = 0.100$ and $\varepsilon = 0.086$. Finally, Hassler, Krusell, and Olovsson (2012)[10] use maximum likelihood estimation and arrive at an elasticity of substitution between energy and the capital/labor composite of 0.0044 (and not statistically significant). In this paper, $\varepsilon = 0.100$ is employed.

The path of exogenous variables after the observation period also needs to be specified in order to conduct the simulation below. Here, it is simply assumed that the relative price of energy, p_t, and the TFP growth rate after 1998 are the same as the averages over the period 1970-1998. The calibration results are shown in Table 1.

Parameters	Description	Value
ε	Elasticity of subst. btw. capital and energy	0.100
θ	Capital/Energy composite share	0.362
δ	Depreciation rate of capital	0.100
β	Discount factor	0.976
α	Leisure weight in preferences	0.712
μ	Share of energy in capital-energy composite	0.162

Table 1: Parameter values

4 Results

4.1 The role of the relative price of energy

As can be seen in Figure 2, there were two major spikes in the relative price of energy in the 1970s — one in 1973 and one in 1979. Using the simple growth model introduced here, let us now examine whether the substitution effect alone, triggered by the surge in the relative energy price, can explain the observed decline in the energy-GNP ratio. The simulation result is shown in Figure 3.

The vertical axis represents the energy-GNP ratio (real energy use divided by real GNP). In the data, this ratio stood at 2.7% in 1973 but subsequently declined sharply. By 1988, it had fallen

[10] Note that their production function, shown in footnote 7, is slightly different from the one employed here.

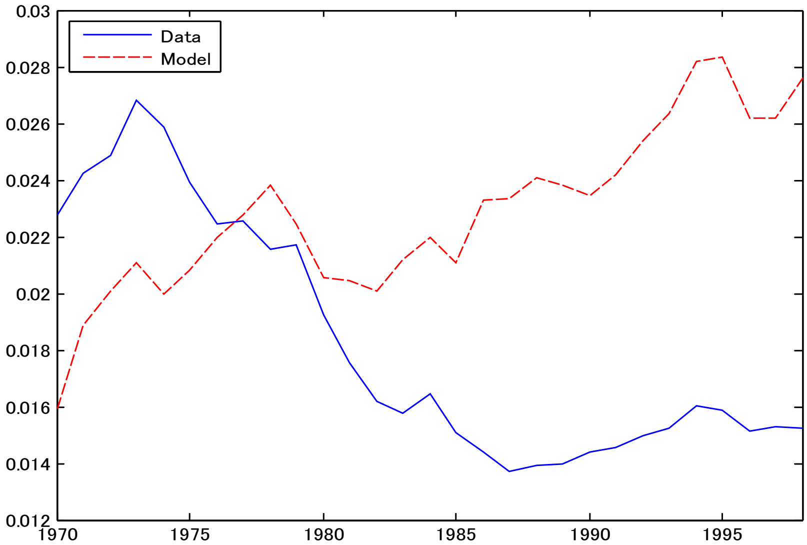

Figure 3: Energy-GNP ratio (benchmark model)

to about 1.4%, i.e., almost half of the 1973 value and since then has shown only an slight upward trend. The simulation result[11] shows that energy price fluctuations influence the energy-GNP ratio, but not substantially. The energy-GNP ratio does decrease after 1973 and 1979, but the extent is very limited. In addition, in the model, the energy-GNP ratio continues to rise in the mid-1980s reflecting the downturn in the relative price of energy, while in the actual data the ratio declines. In sum, it is concluded that the substitution effect alone fails to account for the drop in the energy-GNP ratio.

4.2 The role of energy-saving technological progress

The previous subsection suggested that the energy-GNP ratio generated by the model overpredicted the actual data. This suggests the possible presence of energy-saving technological progress.

There are a number of empirical studies that have sought to examine the role of energy-

[11] In the simulation, the actual series of TFP growth rate are also fed into the model. The TFP growth rate, however, does not play a crucial role in changes in the energy-GNP ratio since improvements in TFP simply result in a simultaneous increase in energy use and GNP. In other words, exogenous changes that diminish energy use for a given level of GNP is needed to reproduce the trend shown in Figure 3.

saving technological change. For instance, Popp (2002), using U.S. patent data from 1970 to 1994, looks at the impact of increases in energy prices on energy-efficiency innovations. He finds that the rise in energy prices has a statistically significant positive impact on energy-efficiency innovations. On the other hand, Newell, Jaffe, and Stavins (1999) investigate whether energy prices affect the energy efficiency of new models of energy-using consumer durables, such as room air conditioners and gas water heaters, and conclude that for some products the direction of innovation is influenced by changes in energy prices. For Japan, Fukunaga and Osada (2009) measure energy-saving technological change by estimating time-varying biases of technical change. They report that the bias of technical change for energy input in the 1980s was energy-saving.

Another strand of studies deals with energy-saving technological change from a theoretical perspective. Alpanda and Peralta-Alva (2010) introduce technology-specific capital and irreversible investment in a two-sector model and succeed in generating the drop in the energy-output ratio observed in the United States after the first oil crisis. Meanwhile, Hassler, Krusell, and Olovsson (2012) developed a neoclassical growth model with non-renewable resources and measured the level of energy-saving technology in the United States, assuming perfect competition in input markets. They find that energy-saving technological progress started in 1973 and, using their model, moreover show that it is essential for generating the actual time path of real energy.

In this paper, the level of energy-saving technology is measured as follows. First, z_t is added into the production function:

$$Y_t = (\Gamma_t H_t)^{1-\theta}\left[(1-\mu)K_t^{\frac{\varepsilon-1}{\varepsilon}} + \mu(z_t E_t)^{\frac{\varepsilon-1}{\varepsilon}}\right]^{\frac{\varepsilon}{\varepsilon-1}\theta}. \tag{9}$$

where z_t is the level of energy-saving technology. In macroeconomic analyses, the level of technology, such as z_t here, is generally estimated as a residual. However, that strategy does not work in this case, since there are two unknowns $\{\Gamma_t, z_t\}$ but only one equation (Equation 9), given the parameter values and the actual time series for Y_t, H_t, K_t and E_t. To estimate z_t, the first-order condition for energy use shown below is used, and Equations (9) and (10) are solved simultaneously for Γ_t and z_t:

$$p_t = \theta\mu\left(\frac{Y_t}{B_t}\right)\left(\frac{B_t}{z_t E_t}\right)^{\frac{1}{\varepsilon}} z_t, \tag{10}$$

Variables	1970-79	1980-89	1990-98	1970-1998
TFP	2.46%	3.52%	1.58%	2.58%
Modified TFP	2.19%	1.96%	1.01%	1.77%
Energy-saving technology	5.47%	6.60%	1.65%	4.37%

Table 2: Average annual growth rates of exogenous variables

where $B_t \equiv \left[(1-\mu)K_t^{\frac{\varepsilon-1}{\varepsilon}} + \mu(z_t E_t)^{\frac{\varepsilon-1}{\varepsilon}}\right]^{\frac{\varepsilon}{\varepsilon-1}}$.Since the effect of energy-saving technological progress is removed from TFP growth, Γ_t is now renamed "modified TFP." The measured level of energy-saving technology, TFP and modified TFP are displayed in Figure 4 and the average annual growth rates of these series in each period are summarized in Table 2.

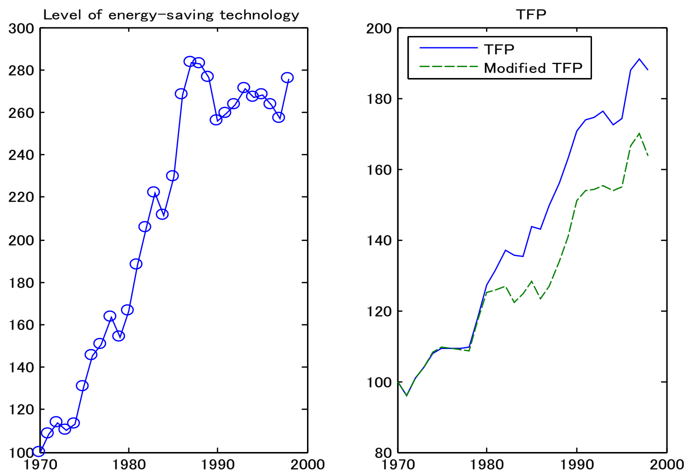

Figure 4: Measured level of energy-saving technology, TFP and modified TFP. The initial levels are normalized to 100.

As can be seen, the growth in the energy-saving technology in the 1970s and 1980s was substantial. Indeed, the average annual growth rates of energy-saving technology were 5.47% and 6.60% in the 1970s and 80s, respectively. These improvements in energy-saving technology partially account for the growth of TFP, resulting in the lower rate of growth in modified TFP. For example, the growth rate of TFP in the 1980s was 3.52% whereas the growth rate of modified TFP was only 1.96%.

As a whole, the average annual growth rate of TFP over 1970-1998 was 2.58%, whereas the modified TFP growth rate was only 1.77%. This suggests that about $31.4\% \simeq 100*(1-(1.77/2.58))$ of the TFP improvements in this period is attributable to energy-saving technological progress. This number may be too large and there are at least two possible reasons to think why this might be the case. First, the definition of energy here excludes nuclear power due to the lack of price data. This implies that substituting nuclear power for fossil fuels results in the improvements in energy-saving technology. In Appendix 2, it is briefly examined to what extent the growth of energy-saving technology is mitigated by the inclusion of nuclear power. Second, during the period, Japan's industrial structure changed from one dominated by heavy industries (such as steel and shipbuilding) to one dominated by knowledge-intensive industries (such as electronics), which decreased energy use. This change is not directly related to energy-saving technological progress but is included in the measured z_t.

Another problem with the series of z_t is that it suggests that the level of energy-saving technology occasionally declines — something that runs counter to our perceptions of technology. The likely reason is that z_t is estimated as a residual so that it contains other elements which are not related to energy-saving technological progress. Thus, short-term fluctuations in z_t need to regarded with a degree of caution; however, from a longer-term perspective, Figure 4 is likely to present a relatively accurate picture of improvements in the level of energy-saving technology.

The stop of the improvements in energy-saving technology in the 1990s is also eye-catching and this may be triggered by the following two possible reasons. First, the chronic slump of Japanese economy in the 1990s, well known as the "Lost Decade" may have weakened the firms' incentive to increase the R&D expenditure related to energy-saving technology. According to the "Survey of Research and Development" provided by Ministry of Internal Affairs and Communications, the average annual growth rates of R&D expenditure (natural sciences and engineering only) were 14.6% and 9.9% in the 1970s and 80s whereas only 2.2% in the 1990s. Second, Japan's energy efficiency may have reached some kind of upper-bound in the late 1980s. In fact, Agency for Natural Resources and Energy (2012) shows that the primary energy supply relative to real GDP is 2.6 in the U.S. and 2.3 in the European Union (27 countries) in comparison with 1.0 in Japan in 1990. In sum, while the estimated levels of energy-saving technology probably have some factors not related to the true technological progress in energy efficiency, it captures, at least, the trend of the improvements in energy-saving technology.

Before examining the impact of the energy-saving technology in the energy-GNP ratio, it would

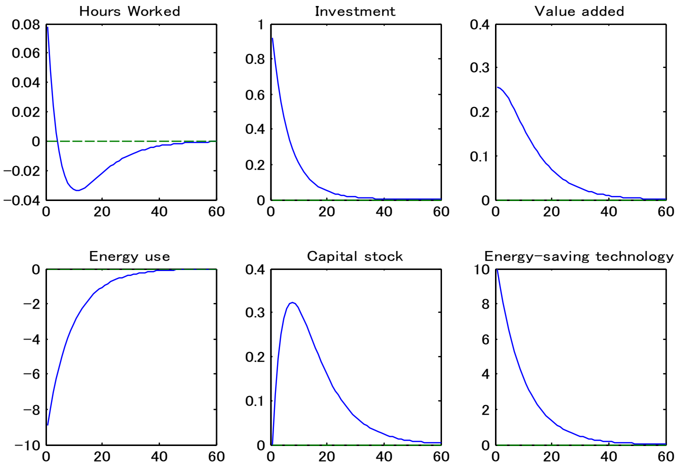

Figure 5: Impulse responses to a 10% energy-saving technology shock

be useful to look at the impulse responses of aggregate variables to a stochastic energy-saving technology shock as in the standard real business cycle models in order to understand the role of energy-saving technology in the model. Thus, it is temporally assumed that the energy-saving technology follows a first-order autoregressive process and that the persistent parameter is 0.9 for simplicity. Figure 5 displays the impulse responses to a 10% positive energy-saving technology shock. The improvements in energy-saving technology require less energy to produce the same amount of output, leading to the decrease in energy use (in this case -9%). This increase in energy-saving technology, however, raises the marginal products of capital and labor, resulting in the rise in investment and hours worked. In total, value added increases by 0.25% due to the 10% positive energy-saving technology shock. Since the improvements in energy-saving technology decreases the energy use and increases the value added, this impulse response analysis implies that the energy-saving technology could be a good candidate for explaining the drop of the energy-GNP ratio.

Finally, the impact of energy-saving technological progress on the dynamics of the energy-GNP ratio is examined. In addition to the relative energy price, the time path of the level of energy-saving technology obtained in Section 4.2 is fed into the model. Figure 9 presents the simulation results generated by the model taking the only substitution effect into account, labeled

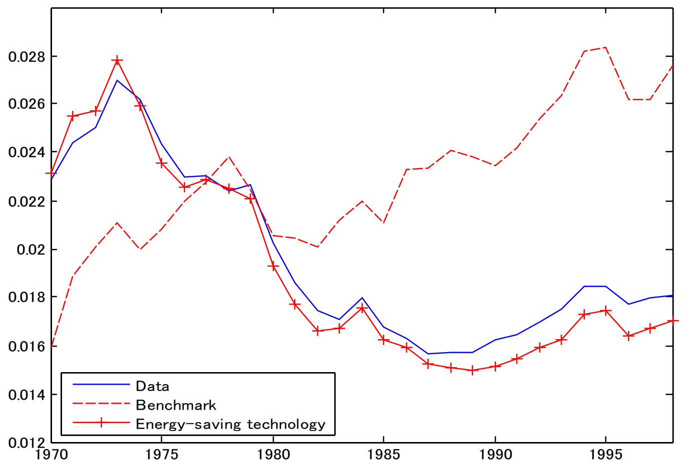

Figure 6: Energy-GNP ratio with energy-saving technology

as "Benchmark" and the model taking the substitution and the energy-saving technology effects into account, labeled as 'Energy-saving technology." This time, the model with energy-saving technological progress closely fits the data. The reason is as follows. After 1973, the level of energy-saving technology starts to increase considerably, and by the end of the 1980s, it has more than tripled. Due to energy-saving technological progress, the energy required to produce the same amount of output for a given level of capital stock and hours worked declined. As a result, the energy-GNP ratio decreased over this period.

Figure 7 displays the comparison of the simulation results for other aggregate variables. As can be seen, the model with energy-saving technology also does a better job in accounting for the dynamics of other aggregate variables. This is due to the fact that the better model prediction of the energy use driven by the improvements in energy-saving technology also improves the model explanation power for other aggregate variables.

5 Conclusion

In this paper, a simple neoclassical growth model with energy as an input is constructed, and it is examined to what extent the model can account for the observed decline in the energy-GNP ratio. The findings can be summarized as follows. First, the substitution effect resulting from a rise in

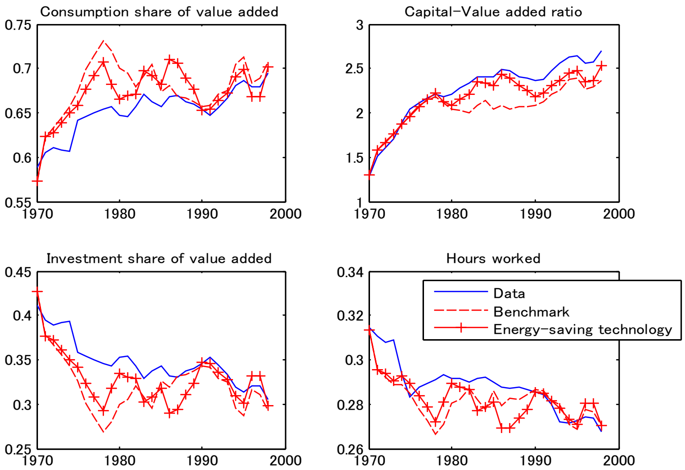

Figure 7: Comparison of the simulation results

the relative price of energy alone cannot explain the movement in the energy-GNP ratio. Second, the estimated level of energy-saving technology improved substantially during the 20 year period from 1970 to the late 1980s. And third, when energy-saving progress is incorporated, the model can account for the decrease in the energy-GNP ratio.

There are some possible extensions to improve the analysis presented here. First, as discussed in Section 4.2, because the energy-saving technology level is estimated as a residual, it probably contains other factors which are not related to energy-saving technological change. This means that it is necessary to estimate "pure" energy-saving technological change. Second, since energy-saving technological change is treated as exogenous, endogenizing technological progress represents another potentially interesting extension (See some discussions in Popp et al., 2010). These issues are left for future research.

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Appendix 1

This Appendix describes the construction of the data series for the current study.

Energy

In this paper, the energy-related variables are real energy use, E_t, and the relative price of energy, p_t. The data source for the energy-related variables is the "Trade Statistics of Japan" published by the Ministry of Finance. As briefly explained in Section 1, although the "General energy supply and demand balance" published by the Agency for Natural Resources and Energy has greater detailed information such as what percentage of the total domestic supply of primary energy comes from the nuclear power generation, the "Trade Statistics of Japan" is used in this paper since the latter contains the energy price data which is essential to examine the impact of the substitution effect and to estimate the series of energy-saving technology.

The energy-related variables are constructed based on the methodology developed by Atkeson and Kehoe (1999). real energy use E_t at time t is calculated as follows:

$$E_t \equiv \sum_i P_{i,0} Q_{i,t}, \tag{11}$$

where i denotes the type of energy. In the analysis here, there are three types of energy: petroleum, coal, and liquid natural gas. $P_{i,0}$ is the price of type i energy in the base year, which is 1990. Note that $P_{i,0}$ is the CIF (cost,insurance and freight) price converted into Japanese yen, so that exchange rate changes are already taken into account. $Q_{i,t}$ is the quantity of imported type i energy in year t.

To construct the relative price of energy, the energy price deflator at time t, denoted as DEF_t^P, is derived as follows:

$$DEF_t^P \equiv \frac{\sum_i P_{i,t} Q_{i,t}}{\sum_i P_{i,0} Q_{i,t}} \tag{12}$$

Then the relative price of energy, p_t, is constructed by dividing the energy price deflator by the GNP deflator, whose base year is also 1990:

$$p_t \equiv \frac{DEF_t^P}{DEF_t^V}, \tag{13}$$

where DEF_t^V is the GNP deflator at time t.

Other variables

The working age population is defined as the number of people between ages 15-64 and is obtained from the "Census population" published by the Ministry of Internal Affairs and Communications. The average weekly hours worked per employed person (ℓ_t) is from the "Monthly Labor Survey" published from the Ministry of Health, Labor and Welfare and the number of employed persons (M_t) is available from the 1968 SNA (System of National Account) produced by the Economic and Social Research Institute, Cabinet Office. Then, the empirical counterpart of h_t is calculated as follows,

$$h_t = \frac{\ell_t * M_t}{N_t * 16 * 7}. \tag{14}$$

Following Otsu(2009), it is assumed that the maximum number of hours worked per day is 16.

The rest of the variables are obtained from the 1968 SNA. The 1968 SNA is used for analysis since 1993 SNA is not available before 1980. As the models described in this paper contain no government sector, it is required to adjust the data from 1968 SNA for matching up series in the models.[12] In the 1968 SNA, real value added (real GNP in this paper) is decomposed into the following parts:

$$V_t = C_t + X_t + G_t + NX_t + NFP_t \tag{15}$$

where V_t is real value added, C_t is real "Private final consumption expenditure", X_t is the sum of real "Gross fixed capital formation" and real "Change in inventories", G_t is real "Final consumption expenditure of government", NX_t is real "Net exports (excluding real energy imports)", and NFP_t is real "Net factor payment." The nominal variables are converted into the real ones by dividing them by a constant 1990 yen deflator.

[12]See Cooley (1995), Hayashi and Prescott (2002), and Conesa et al. (2007) for data construction strategies to be consistent with neoclassical growth models.

Following Hayashi and Prescott (2002), the real "Final consumption expenditure of government " is included in C_t and both the real "Net exports (excluding real energy imports)" and the real "Net factor payment" are incorporated in X_t. That is,

$$V_t = C_t^{'} + X_t^{'} \tag{16}$$

where $C_t^{'}$ is the sum of C_t and G_t, $X_t^{'}$ is the sum of X_t, NX_t, and NFP_t. V_t, $C_t^{'}$, and $X_t^{'}$ are the empirical counterparts of valu added, aggregate consumption and aggregate investment in this paper, respectively.

Finally, the capital stock series are constructed using a perpetual inventory method. The initial capital stock, K_{1970} is set so that $K_{1970}/V_{1970} = 1.29$,[13] which is the value taken from the dataset constructed by Hayashi and Prescott (2002). The subsequent series of capital stock are obtained by the law of motion for capital stock, Equation (3).

Appendix 2

As discussed in Section 4.2, one of the shortcomings that the estimated level of energy-saving technology has is that substituting nuclear power generation for fossil fuel energy is interpreted as improvements in energy-saving technology. In this Appendix, the crude estimation of the energy supply by nuclear power generation is attempted and it is examined to what extent the inclusion of nuclear power generation influences the level of energy-saving technology and other simulation results.

Since the imports data are used to construct the real energy use, one way to include the nuclear power generation into the definition of energy use is to use the imported quantity of uranium ore, a raw material of nuclear power generation. The drawback of this approach, however, is that the spent nuclear fuel is reused repeatedly so that it is difficult to obtain the price information.

In this Appendix, it is simply assumed that the inclusion of nuclear power generation into the definition of energy does not affect the relative price of energy. Then, the real energy use E_t is inflated based on the ratio of the energy supply by the nuclear power generation to the energy

[13]In fact, the value of K_{1970}/V_{1970} in 1970 is 1.04 in Hayashi and Prescott (2002). Their calculation of capital stock does not include the government capital whereas ours does. Therefore, the government capital-value added ratio (0.25) is added up to 1.04, leading to 1.29 in total.

supply by the fossil fuels.[14]

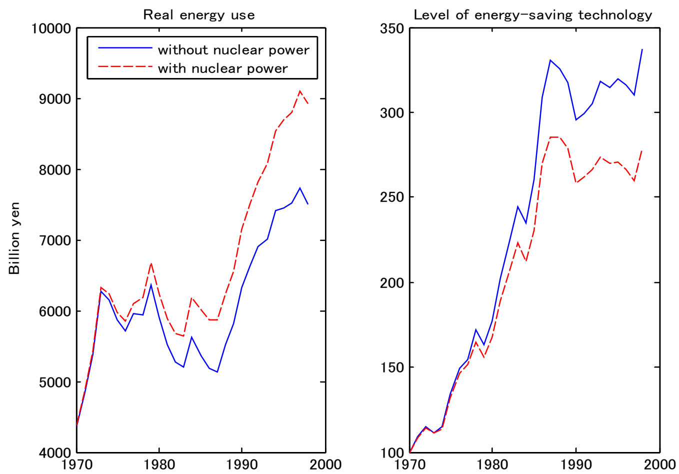

Figure 8: Real energy uses and the series of energy-saving technology with and without nuclear power generation

Figure 8 displays the real energy uses and the estimated levels of energy-saving technology with and without nuclear power generation. As can be seen, the discrepancy between the energy uses with and without nuclear power generation expands in the later periods, reflecting the fact that the share of energy supply by nuclear power generation in total supply has had an upward trend since the beginning of the 1970s. The right side of Figure 8 shows that the path of energy-saving technology taking the nuclear power generation into account is located below the original path, indicating that the improvements in energy-saving technology were partially spurious caused by substituting nuclear power for fossil fuel.

Figure 9 shows the effect of the inclusion of nuclear power generation on the energy-GNP ratio. Once the nuclear power generation is considered, the actual energy-GNP ratio in the data shows the higher ratio than in the original data in the 1980s and 1990s due to the prevalence of nuclear power generation. The simulation result, however, also tracks the actual energy-GNP ratio well. This is simply reflecting the fact that the improvements in energy-saving technology dampened in the late 1980s and 1990s, as shown in the right panel of Figure 8.[15] In sum, although the inclusion

[14]The data source is the "General supply and demand balance" provided by the Agency for Natural Resources and Energy.

[15]The simulation result for other variables with the inclusion of nuclear power generation produces almost identical

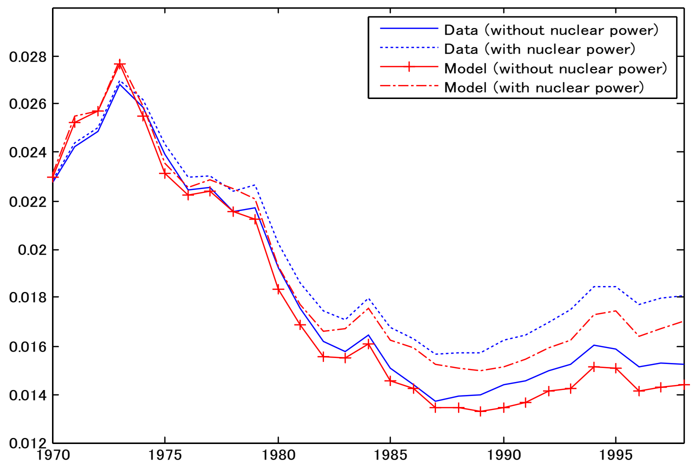

Figure 9: Energy-GNP ratio with the inclusion of nuclear power generation into the definition of energy

of nuclear power generation into the definition of energy provides us more purified energy-saving technology, it does not affect the main results in this paper that the drop in energy-GNP ratio was triggered mainly by the improvements in energy-saving technology.

resutls to the one without it.