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Energy-Saving Technological Change in Japan *

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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 alone 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 progress

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1 Introduction

In the 1970s and 1980s, Japan experienced a dramatic change in the relationship between real energy use and real gross national product (GNP). One way to gauge this is to look at real energy use relative to real GNP, or what will be referred to as the energy-GNP ratio hereafter, where real energy use is calculated as the total quantity of fossil fuels[1] (petroleum, coal, and liquid natural gas) consumed measured in constant prices.[2] Figure 1 depicts the trend in Japan's energy-GNP ratio over the past four decades. As can be seen, the energy-GNP ratio stood at close to 2.4% in 1973 but subsequently declined sharply. By 1988, it had fallen to about 1.3%, i.e., almost half of the 1973 value and since then has remained at this level.

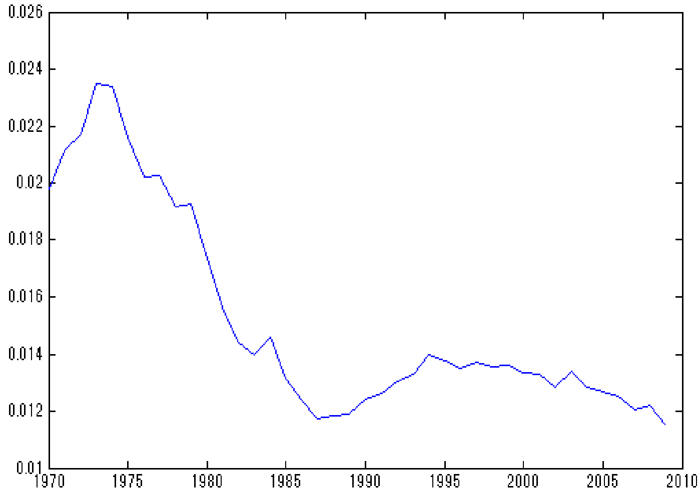

Figure 1: Real energy use-real GNP ratio. Real energy use is the total quantity of fossil fuels consumed measured in constant prices.

Discussion to explain the drop in the energy-GNP ratio 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 output increases, we would expect the input of energy per unit of output, 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.[3] 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

[1] Energy use here excludes nuclear power due to the lack of price data.

[2] Real energy use here is measured in yen terms rather than in terms of quantity such as joule or British thermal units (Btus) to make it easier to compare energy use with GNP. See the Appendix for details of the data construction.

[3] The calculation of the energy price deflator is described in the Appendix.

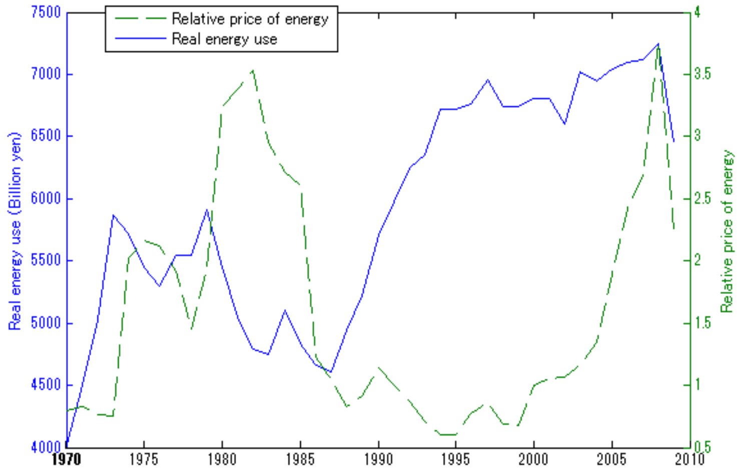

Figure 2: Real energy use and relative energy price

beginning of the 1970s. On the other hand, real energy use measured in yen, dipped following the first oil shock and declined substantially following the second. Therefore, the substitution effect is a good potential candidate for explaining the drop in the energy-GNP ratio.

Against this background, the purpose of this paper is to examine the reasons for the drop in the energy-GNP ratio during the 1970s and 1980s by quantitatively examining the two possible explanations. To do so, a simple neoclassical growth model with energy as a third input for production is constructed and two simulations are conducted. 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 energy-GNP ratio. In the second simulation, an estimated path of energy-saving technology is additionally fed into the model to examine the role of energy-saving technological change.

From an economic perspective, there are at least two reasons why it is important to understand why the energy-GNP ratio has fallen. The first is related to the carbon dioxide emissions associated with fossil fuel consumption, which represent a negative externality. Since the energy considered in this paper consists of fossil fuel, a reduction in the energy-GNP ratio implies a reduction in this negative externality per unit of GNP. The second reason why it is important to understand why the energy-GNP ratio has fallen is in the context of business cycles. Taking their cue from the "Great Moderation" debate going back to Stock and Watson (2002), which suggests that the United States and other major economies, including Japan, Germany and France, have experienced a decline in the volatility of business cycle fluctuations in recent decades, Ko and Murase (2010) examined the case of Japan. They find that the volatility of output in Japan declined in the mid-1970s, although it did increase again in the late 1980/early 1990s and again in the late 2000s.[4] The decline in the

[4]The increase in volatility of output in the late 1980s/early 1990s coincides with the collapse of the bubble economy that Japan experienced in the second half of the 1980s, while that in the late 2000s coincides with the

energy-GNP ratio may be one possible explanation for the decrease in the volatility of output in the mid-1970s, since it may have made the economy less sensitive to energy price shocks.

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.

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 and conducts sensitivity analyses. 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 model.[5] The model 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

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

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

$$Y_t = \tau_t H_t^{\theta}[(1-\alpha)K_t^{-\iota} + \alpha E_t^{-\iota}]^{-\frac{(1-\theta)}{\iota}}, \tag{5}$$

where Y_t is aggregate output, τ_t is total factor productivity (TFP), p_t is the energy price in terms of final goods, and E_t is aggregate energy use. As will be discussed below, several studies, such as Hassler, Krusell, and Olovsson (2011), suggest that the elasticity of substitution between energy and other inputs is considerably less than unity. Therefore, a nested constant elasticity of

recent financial crisis. The general trend of the volatility of output, however, is downward-sloping.

[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 uncertainty in the model here.

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

substitution production function with constant returns to scale is used.[7] The firm imports energy from abroad at exogenously given price p_t per unit.[8] TFP is also exogenous to the firm and is assumed to grow over time at the average TFP growth rate for the period 1970-2009. A number of studies have highlighted the important role of the time-varying growth rate of TFP (e.g., Cole and Ohanian 1999, Hayashi and Prescott 2002, Otsu 2008) in macroeconomic analyses. However, since improvements in TFP simply result in a simultaneous increase in GNP and energy use, they do not play a crucial role in changes in the energy-GNP ratio.[9] Therefore, a constant rate of TFP growth is assumed in this paper.

The resource constraint is as follows:

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

where VA_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), Chen, İmrohoroğlu, and İmrohoroğlu (2006), and Hassler, Krusell, and Olovsson (2011), it is assumed that agents have perfect foresight about the sequence of exogenous variables. This assumption is relaxed in Section 4.3. 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.[10]

3 Calibration

There are six parameters $\{\beta, \delta, \theta, A, \alpha, s\}$ to calibrate. s is the elasticity of substitution between capital stock and energy, and $s \equiv 1/(1+\iota)$.

The value for β is borrowed from Otsu (2008) and set at 0.98. δ is obtained from Hayashi and Prescott (2002) and set at 0.089. The capital stock series are constructed using the perpetual inventory method. For θ, the average labor income share in GNP for the period 1970-2009 is used. The leisure weight in preferences, A, is obtained by solving the intra-temporal optimal condition for A,

$$A = \theta \frac{Y_t}{C_t} \frac{1-h_t}{h_t}, \tag{7}$$

and averaging equation (7) over the 1970-2009 period.[11] To calibrate α, the production function and the first-order condition for energy use are combined as follows:

[7] Hassler, Krusell, and Olovsson (2011) employ an alternative specification of the utility function, namely:

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

The simulation results are robust to this alternative utility function.

[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] Note that to replicate the trend shown in Figure 1 a shock that diminishes energy use for a given level of GNP is needed.

[10] It is assumed that the capital stock reaches its balanced growth level in 1989. Thus, the initial capital stock is obtained as $(k_{1970}/k_{1989}) * kss \simeq 0.36 * kss$, where kss denotes the steady state level of capital stock.

[11] Weekly hours worked per working-age person is defined as

$$\frac{1-\alpha}{\alpha} = \left(\frac{(1-\theta)Y_t - p_t E_t}{p_t E_t}\right)\left(\frac{E_t}{K_t}\right)^{-\iota} \tag{8}$$

Equation (8) is then solved for α and α is then averaged over 1970-2009.

Previous studies provide numerous estimates of s, the elasticity of substitution between capital stock and energy. For instance, Kim and Loungani (1992) use two values, $s = 0.588$ taken from Morrison and Berndt (1981) and $s = 1.000$ taken from Griffin and Gregory (1976), and conduct separate simulations to compare the results. Backus and Crucini (2000) report a value of $s = 0.09$, while Miyazawa (2010) conducts a generalized method of moments estimation and reports values of $s = 0.100$ and $s = 0.086$. Finally, Hassler, Krusell, and Olovsson (2011)[12] use maximum likehood estimation and arrive at an elasticity of substitution between energy and the capital/labor composite of 0.053. In this paper, $s = 0.15$ is employed. Note that as long as s is around 0.1, the main results shown in Section4 are not substantially affected.

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 2009 are the same as the averages over the period 1970-2009. The calibration results are shown in Table 1.

Parameters	Description	Value
s	Elasticity of subst. btw. capital and energy	0.1500
θ	Labor share	0.6157
δ	Depreciation rate of capital	0.0890
β	Discount factor	0.9800
A	Leisure weight in preferences	2.3047
α	Share of energy in capital-energy composite	0.0358

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.

As can be seen in Figure 3, 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

$$h_t \equiv \frac{\ell_t * M_t}{N_t * 16 * 7},$$

where ℓ_t is average weekly hours worked per worker and M_t is employment. Following Otsu (2008), it is also assumed that the maximum number of hours worked per day is 16.

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

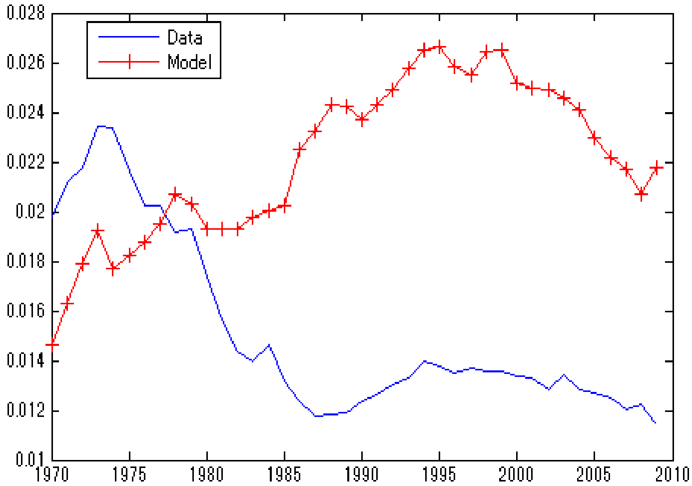

Figure 3: Energy-GNP ratio taking only the change in the relative energy price into consideration

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. To examine the large discrepancy between the data and the model after the 1970s, the actual data and the simulation results for GNP and energy use are shown separately in Figure 4. Both variables are detrended at 2% per year and normalized to 100 for 1970.[13] As can be seen, the discrepancy in the energy-GNP ratio between the data and the model is mainly due to the use of energy, not GNP.

The next task therefore is to examine what leads the model to overpredict energy use. The answer lies in the first order condition for energy use:

$$p_t = (1-\theta)\tau_t H_t^{\theta}[(1-\alpha)K_t^{-\iota} + \alpha E_t^{-\iota}]^{-\frac{(1-\theta)}{\iota}-1}\alpha E_t^{-\iota-1}, \tag{9}$$

where the left hand side is the marginal cost, while the right hand side is the marginal product, and hence the marginal benefit, of energy use. Although these are equal in equilibrium, it is not guaranteed that they are equal in practice. Figure 5 shows the marginal benefit relative to the marginal cost of energy use calculated from the actual data. As can be seen, from the 1980s onward, the marginal benefit considerably outweighs the marginal cost of energy use. This implies that it would be optimal for firms to increase energy input so that the marginal benefit equals the marginal cost of energy use. Since this was not the case, the question arises why firms did not purchase more energy after the 1970s. A possible answer to this question is energy-saving technological progress.

[13]Following Hayashi and Prescott (2002), a trend growth rate of 2% is used here because it is the average growth rate of the U.S. economy in the 20th century. In other words, the model here assumes that all variables except labor input grow at 2% once the model economy reaches its balanced growth path.

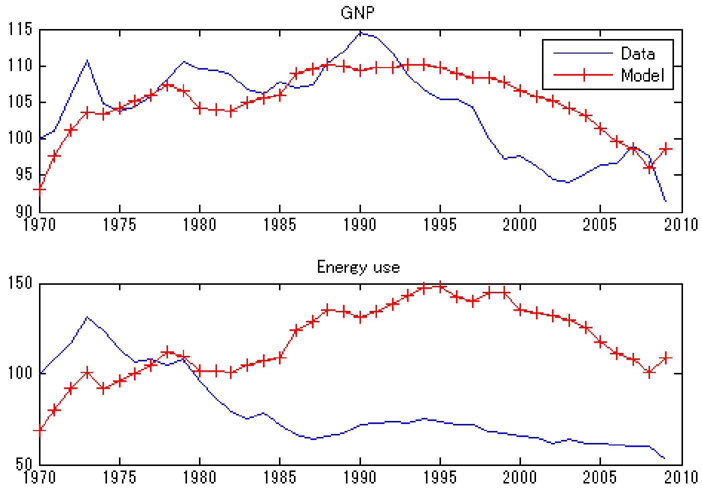

Figure 4: GNP and energy use: Data vs. model

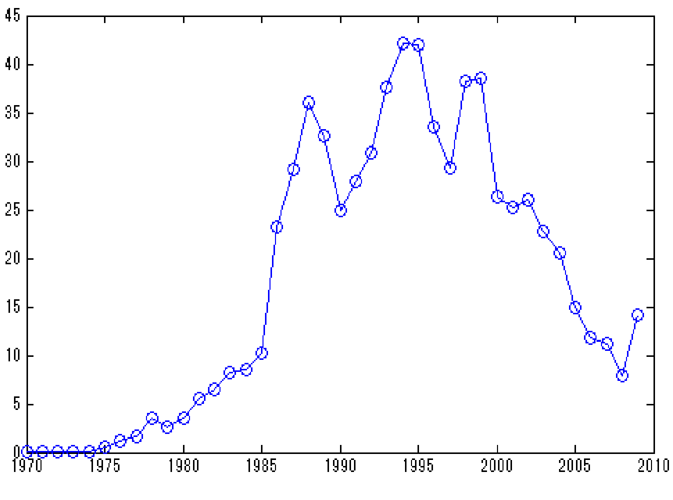

Figure 5: Marginal benefit relative to marginal cost of energy use calculated from the actual data

4.2 The role of energy-saving technological progress

The previous subsection suggested that, from the 1980s, firms did not increase their energy input even though, according to the model, this should have afforded them with greater profits. 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-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 (2011) 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:

$$Y_t = \tau_t H_t^{\theta}[(1-\alpha)K_t^{-\iota} + \alpha(z_t E_t)^{-\iota}]^{-\frac{(1-\theta)}{\iota}}, \tag{10}$$

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 in this case, since there are two unknowns $\{\tau_t, z_t\}$ but only one equation (equation (10)). To estimate z_t, the first-order condition for energy use shown below is used, and equations (10) and (11) are solved simultaneously for τ_t and z_t:

$$p_t = (1-\theta)\tau_t H_t^{\theta}[(1-\alpha)K_t^{-\iota} + \alpha(z_t E_t)^{-\iota}]^{-\frac{(1-\theta)}{\iota}-1}\alpha(z_t E_t)^{-\iota-1} z_t \tag{11}$$

Since the effect of energy-saving technological progress is removed from TFP growth, τ_t is now renamed "modified TFP." The measured level of energy-saving technology, TFP and modified TFP are displayed in Figure 6. TFP is measured as a residual using equation (5), so that it includes the effect of energy-saving technological progress.

The figure shows that the energy-saving technology level starts to rise in the early 1970s and exceeds a value of 3 by the mid-1980s. After that, it continues to fluctuate around a value of 3.5.[14]

Table 2 shows the average annual growth rates of TFP, modified TFP, and the energy-saving technology level in each period. As can be seen, the rate of growth in the energy-saving technology level in the 1970s and 1980s was substantial and remained non-negligible thereafter. In addition, the average annual growth rate of TFP over the 1970-2009 period was 2.18%, whereas the modified

[14]Note that in Section 4.1 it was assumed that z_t is always equal to 1.

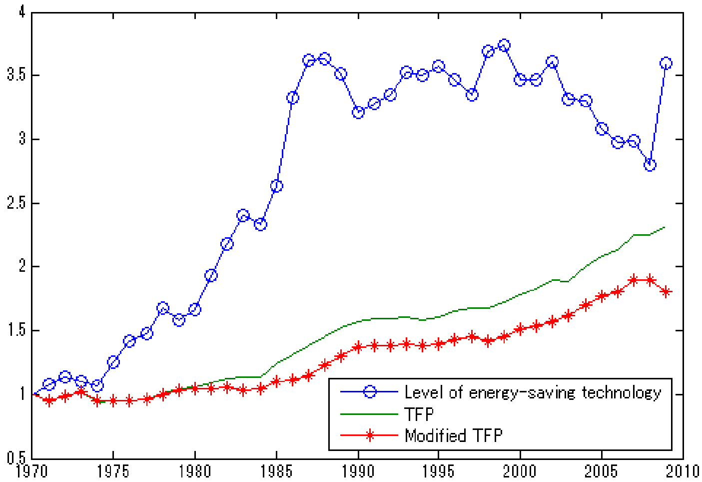

Figure 6: Measured level of energy-saving technology, TFP and modified TFP. The initial levels are normalized to unity.

Variables	1970-79	1980-89	1990-99	2000-09	1970-2009
TFP	0.46%	4.11%	0.49%	2.94%	2.18%
Modified TFP	0.40%	2.46%	0.29%	2.04%	1.53%
Energy-saving technology	5.21%	8.61%	0.82%	0.40%	3.34%

Table 2: Average annual growth rates of exogenous variables

TFP growth rate was only 1.53%. This suggests that about 30% $\simeq 100 * (1 - (1.53/2.18))$ of the TFP improvements in this period is attributable to energy-saving technological progress. This number may be too large. There are at least two possible reasons to think why this might be the case. First, the definition of energy here excludes nuclear energy, resulting in overestimation of energy-saving technological progress. Nuclear power plants started to be built in Japan in the late 1960s, and in fiscal 2009, nuclear energy accounted for approximately 12% of Japan's total energy supply. 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.

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. Similarly, the jump seen for 2009 unlikely reflects a sharp rise in the level of energy-saving technology and instead simply is due to the fact that in this year energy use decreased despite the drop in the relative energy price shown in Figure 2. Thus, short-term fluctuations in z_t need to be regarded with a degree of caution; however, from a longer-term perspective, Figure 6 is likely to present a relatively accurate picture of improvements in the level of energy-saving technology.

Next, 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 7 presents the simulation result. 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.

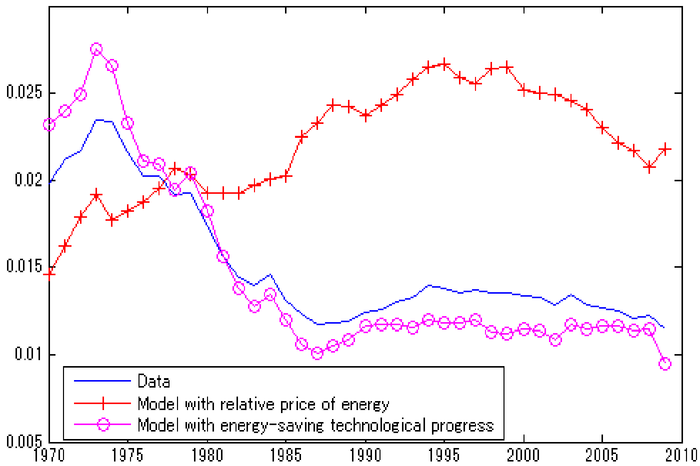

Figure 7: Energy-GNP ratio with energy-saving technological progress

4.3 Sensitivity analysis

So far it has been assumed that economic agents have perfect foresight about the future path of the relative price of energy. In other words, deterministic simulations were conducted. However, it would be more plausible to treat energy price shocks as surprising events. Therefore, in this subsection a stochastic simulation is conducted à la Chen, İmrohoroğlu, and İmrohoroğlu (2006) to examine how much the results obtained in Section 4 depend on the perfect foresight assumption.

In the stochastic simulation, it is assumed that economic agents believe that the relative price of energy indefinitely remains constant at its average price. However, at the beginning of each period, they learn the actual energy price level. Thus, the energy price can be seen as the forecast error and represents a "surprise" or "energy price shock." Note that even though they face a "surprise" or "energy price shock" every period, they still assume that the energy price will remain constant at its average in the future.

Figure 8 compares the simulation results of the deterministic and the stochastic model. The two simulated paths are quite similar, yielding the conclusion that surprise shocks to the relative energy price play a limited role in explaining the changing dynamics in the energy-GNP ratio.

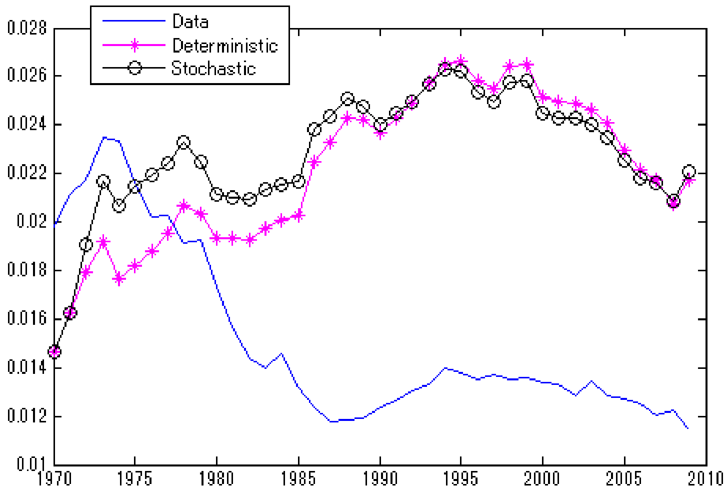

Figure 8: The role of expectations

5 Conclusion

In this paper, a simple neoclassical growth model with energy as a third factor of production 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 the relative price of energy alone cannot explain the movement in the energy-GNP ratio when an elasticity of substitution between capital and energy use in a reasonable range is assumed. Second, the estimated level of energy-saving technology more than tripled 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. These issues are left for future research.

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6 Appendix

This Appendix briefly describes the construction of the data series for the current study. The data are obtained from two distinct sources: the "Trade Statistics of Japan" published by the Ministry of Finance, which are used for the energy data, and the study by Kobayashi and Inaba (2006), from which data for other aggregate variables are obtained.

6.1 Energy

In the analysis here, the energy-related variables are aggregate energy use, E_t, and the relative price of energy, p_t. These variables are constructed based on the methodology developed by Atkeson and Kehoe (1999). Aggregate energy use E_t at time t is calculated as follows:

$$E_t \equiv \sum_i P_{i,0} Q_{i,t}, \tag{12}$$

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 2000. Note that $P_{i,0}$ is the CIF price converted into Japanese yen, so that exchange rate changes are already taken into account. $Q_{i,t}$ is the amount of imported type i energy in year t. Note that $Q_{i,t}$ is the amount of imports, not the amount of consumption of type i energy. However, since most of the energy imported in any given year is consumed within the year, $Q_{i,t}$ is treated as the amount of consumption of 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:

$$DEF_t^P \equiv \frac{\sum_i P_{i,t} Q_{i,t}}{\sum_i P_{i,0} Q_{i,t}} \tag{13}$$

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 2000:

$$p_t \equiv \frac{DEF_t^P}{DEF_t^Y}, \tag{14}$$

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

6.2 Other aggregate variables

Other aggregate variables are constructed based on the study by Kobayashi and Inaba (2006), which extended Hayashi and Prescott's (2002) data set with some adjustments. There are four differences between Kobayashi and Inaba's (2006) data and my data set. First, my data set is updated to the latest year, 2009. Second, since the government sector is not included in the analysis here, government consumption is incorporated in aggregate consumption C_t, while government fixed capital formation is included in aggregate investment X_t. Third, the capital stock series are constructed using the perpetual inventory method. Fourth, because energy is an input, it is subtracted from gross output to obtain value added.