New ESRI Working Paper No.30

Capacity Utilization and the Effect of Energy Price Shock in Japan

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September 2013

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Capacity Utilization and the Effects of Energy Price Increases in Japan *

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Abstract

It is well known that the standard real business cycle (RBC) model with energy cannot generate the large drops in value added following the energy price increases in the 1970s, although previous empirical studies have confirmed the important role of energy prices. In this paper, endogenous capacity utilization is incorporated into an otherwise standard RBC model as an amplification mechanism. The simulated results show that the endogenous capacity utilization successfully generates the large contraction in value added observed in the Japanese data. It is also shown that the introduction of capacity utilization produces more realistic dynamics of total factor productivity.

Keywords: relative price of energy; capacity utilization; neoclassical growth model.

*This is a chapter from my Ph.D. dissertation at Hitotsubashi University. I would like to thank my dissertation supervisor, Naohito Abe, for his support and discussions on this paper. I also benefited from the comments of Kenji Umetani, Ainosuke Kojima, Koji Hamada, Munechika Katayama, Katsuyuki Shibayama, Masaru Inaba, Michiru Sakane, Masanori Ono, Jun-Hyung Ko, Daisuke Miyakawa, Hiroshi Morita, and participants of the Economic and Social Research Institute Seminar, the Applied Economics Seminar at the Development Bank of Japan, the Japanese Economic Association Spring Meeting at Toyama University, and the Asian Meeting of the Econometric Society in Singapore. The views expressed in this paper are those of the author and do not necessarily reflect the official views of the Economic and Social Research Institute.

1 Introduction

The role of the relative price of energy in accounting for recessions has been investigated extensively in a large number of studies. The seminal work in this area is Hamilton (1983), which shows that all but one of the U.S. recessions over the period 1948–1972 were preceded by increases in oil prices.[1] Since then, two separate research topics in this area seem to have attracted the attention of many researchers. The first topic is the declining effect of oil price shocks in recent decades. As is well known, global oil prices rose as much in the 2000s as they did in the 1970s. However, it seems that output and inflation in most developed countries were not much affected by the continuous rise in oil prices observed in the 2000s.[2] The second topic is the failure of standard models to generate the large negative impact of oil price shocks on value added observed in the 1970s. For example, using structural vector autoregression and data for the United States over 1947:2–1980:3, Rotemberg and Woodford (1996) show that a 10% increase in the oil price results in a drop in output by 2.5% after five to seven quarters, whereas the standard one-sector stochastic growth model predicts only a 0.5% decline in output.

In this paper, the second topic is further investigated by analyzing the severe recession following the first oil crisis in Japan. In doing so, a simple neoclassical growth model with energy as an input for production is constructed, calibrated to the Japanese economy. As expected, the benchmark model with the actual time series of the relative price of energy shows an only modest effect on value added. Specifically, value added drops only by 0.7% in 1974 in the benchmark model compared to 4% in the data. This limited impact of the relative price of energy on value added is in line with the results of previous studies for other countries. For instance, using data for the United States, Kim and Loungani (1992) report that in the standard real business cycle (RBC) model with energy, only 16–35% of output volatility can be attributed to energy price shocks. Similarly, Aguiar–Conraria and Wen (2007), also focusing on the United States, show that in the standard RBC model, the first oil crisis leads only to a 2% drop in value added compared with an actual contraction of 8% in the data.

One interpretation of failure of the benchmark model to replicate the actual drop in value

[1] Also see Mork (1989), Hamilton (1996, 2003, 2009), Loungani (1986), Hooker (1996, 2002), Leduc and Sill (2004), and many others.

[2] See, for example, the discussions of Blanchard and Gali (2008), Blanchard and Riggi (2009), and Katayama (2013) on this topic.

added is that increases in the relative price of energy actually do not play a great role and other exogenous variables such as total factor productivity (TFP) play a more important role in explaining recessions. For example, Hayashi and Prescott (2002) show that the prolonged economic stagnation in Japan following the collapse of bubble economy at the beginning of the 1990s, the so-called “Lost Decade,” can be mainly accounted for by the slowdown in the TFP growth rate in the 1990s. However, our benchmark model taking actual TFP into account also fails to reproduce the sluggishness of the economy after the first oil crisis.[3] The limited role of the relative price of energy also contradicts the empirical findings of Hamilton (1983) and Rotemberg and Woodford (1996), which show that the oil price shocks had a large negative impact.

To generate the large drop in value added after the rise in the relative price of energy, a strong mechanism to amplify the effect of the sharp rise in the relative price of energy on value added is required. The most commonly used amplification mechanism in previous studies is the endogenous capacity utilization rate. Finn (2000) ties capacity utilization to energy consumption and successfully reproduces the sharp drop in value added caused by the oil price shock.Similary, Aguiar–Conraria and Wen (2007) introduce endogenous capacity utilization and the spillover effects across firms into an otherwise standard RBC model and show that energy price shocks alone are able to account for the stagnation in value added following the first oil shock in 1973.[4]

In this paper, the endogenous capacity utilization rate is incorporated in the benchmark model following Greenwood et al. (1988), and it is examined to what extent capacity utilization amplifies the effect of the sharp rise in the relative price of energy on value added and other aggregate variables. The analysis is closely related to the studies by Finn (2000) and Aguiar–Conraria and Wen (2007) but differs in two respects. First, energy-saving technological change is incorporated in order to reproduce the downward trend in real energy use. Neither Finn (2000) nor Aguiar–Conraria and Wen (2007) discuss how closely their simulated energy use follows the actual data. Second and more importantly, the role of purified TFP, in which the effects of variable capacity utilization are extracted from the original TFP, in the recession following the first oil shock is also

[3] This may seem a little surprising since feeding actual TFP series into a model often produces a good fit with the data. However, there also exist a number of economic episodes the actual series of TFP alone fail to replicate. See for example, Cole and Ohanian (1999), Beaudry and Portier (2002) and Conesa et al. (2007).

[4] Another amplification mechanism of the relative price of energy investigated in previous studies is imperfect competition. Rotemberg and Woodford (1996) show that a modest degree of imperfect competition leads to a larger effect of an energy price increase on both output and real wages. In this paper, this amplification mechanism is not used since endogenous capacity utilization is simpler to incorporate and is the mechanism most commonly used in previous studies.

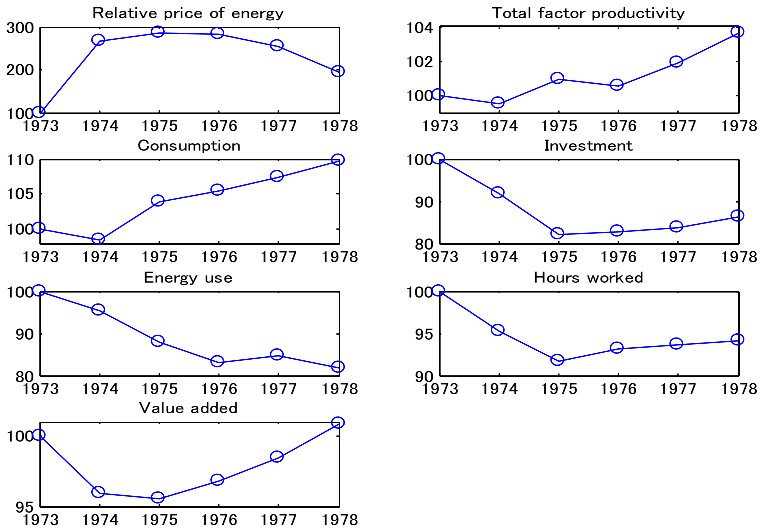

Figure 1: Paths of exogenous variables and aggregate variables per working-age population (15–64) over the period 1973—1978. All aggregate variables except hours worked are detrended by 2% and all variables are normalized to 100 in 1973.

investigated. Again, neither Finn (2000) nor Aguiar–Conraria and Wen (2007) examine the effects of time-varying (purified) TFP on aggregate variables.

Before going into the details of the model, it is useful to summarize the dynamics of exogenous variables and aggregate variables over the period 1973–1978 in Japan.[5] The first row of Figure 1 depicts two key exogenous variables: the relative price of energy and TFP. The relative price of energy is calculated by dividing the energy price deflator by the GNP deflator, while TFP is obtained as the Solow residuals in the production function in Equation (5) shown below. As can be seen, the upsurge in the relative price of energy in 1974 was substantial and by 1975, the relative price of energy had jumped almost threefold from its level in 1973, before showing a gradual downward trend thereafter. Another exogenous change in the Japanese economy in this period is the slowdown in TFP growth. The average annual growth rate of TFP over the period 1973–1978 was only 0.72% and the growth rate was in fact negative from 1973 to 1974 and from

[5]Since the main focus of this paper is the first oil crisis and its consequences for the Japanese economy, the analysis ends in 1978.

1975 to 1976.[6] This implies that the estimated TFP contains some noise not related to the true productivity measure, and this issue is attempted to be resolved later by endogenizing capacity utilization.

The rest of Figure 1 displays aggregate variables per working-age population. All variables except hours worked are detrended by 2%. Two notable features can be gleaned from Figure 1. First, value added declined by around 5% in 1975, and it took several years to return to the 2% linear trend. Second, all other aggregate variables also show substantial declines, especially energy use. Unlike the other variables, energy use continued to decline following the first oil shock in 1973 and did not recover, which likely is the result of energy-saving technological change, the role of which in reproducing the decline in energy use is discussed in Section 2.1.

The remainder of the paper is organized as follows. Section 2 describes the benchmark model, while Section 3 discusses the data construction and calibration. Section 4 then presents the simulation results of the benchmark model. Next, Section 5 describes the model with endogenous capacity utilization and presents the simulation results. Finally, Section 6 concludes the paper.

2 The neoclassical growth model with energy

To quantify the impact of the sharp rise in the relative price of energy on aggregate variables, a simple neoclassical growth model with energy is constructed, following Kim and Loungani (1992). The life-time utility of the infinitely lived representative household is

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

where N_t is the number of household members, β is the discount rate, c_t is consumption per household member, and h_t is the labor supply per household member. The representative household consists of N_t members at time t. The budget constraint of the household at time t is

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

[6] For the period before 1970, the growth rate of TFP using Equation (5) cannot be estimated due to the lack of energy-related data. However, using the standard Cobb–Douglas production function, Hayashi and Prescott (2002) show that the average annual growth rate of TFP in Japan for 1960–1973 was 6.5% compared with 0.8% for 1973–1983 and 3.7% for 1983–1991.

where X_t is aggregate investment, w_t is the wage rate, r_t is the rental rate of capital, and K_t is aggregate capital. The capital stock depreciates geometrically so that

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

The household chooses the infinite sequences of $\{c_t, k_{t+1}, h_t\}$ to maximize life-time utility (1) subject to the budget constraint (2) and the capital law of motion (3) given the initial level of capital stock.

The representative firm decides how much capital stock it rents, how much labor it employs, and how much energy it imports from abroad in each period to maximize profit π_t,

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

where Y_t is gross output, p_t is the relative price of energy, and E_t is aggregate energy imported from abroad. To make the analysis as simple as possible, it is assumed that the variation in p_t is exogenous to the firm so that it can import as much energy as it desires at the given price p_t. In this sense, the model is a small open economy.

Gross output is defined by a nested constant elasticity of substitution production function with constant returns to scale:

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

Γ_t is an index of labor-augmenting technological progress, z_t is the level of energy-saving technology, and ε is the elasticity of substitution between capital and energy use. The exogenous time-varying energy-saving technology is incorporated since it is shown in Niizeki (2012) that rapid growth of energy-saving technology is observed following the first oil crisis in Japan and that it is essential to reproduce the downward trend in energy use. The next subsection illustrates how the series of z_t are estimated. To close the model, the economy-wide resource constraint is

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

where V_t is aggregate value added.

On the balanced growth path, all aggregate variables (except labor input) grow at rate $\gamma_t + n_t$, where $\gamma_t \equiv \Gamma_{t+1}/\Gamma_t$ and $n_t \equiv N_{t+1}/N_t$, whereas aggregate hours worked grow at rate n_t. Compared to standard neoclassical growth models (see, e.g., Prescott 1986), this model has the following additional optimality condition regarding energy use:

$$p_t = \theta\mu\left(\frac{Y_t}{B_t}\right)\left(\frac{B_t}{z_t E_t}\right)^{\frac{1}{\varepsilon}} z_t, \tag{7}$$

where $B_t \equiv \left[(1-\mu)K_t^{\frac{\varepsilon-1}{\varepsilon}} + \mu(z_t E_t)^{\frac{\varepsilon-1}{\varepsilon}}\right]^{\frac{\varepsilon}{\varepsilon-1}}$.

The right hand side of Equation (7) is the marginal product of energy use. Thus, the firm decides how much energy it imports from abroad by equating the marginal cost and the marginal benefit of energy use, taking the relative price of energy as given.

2.1 Energy-saving technological change

In his seminal work, Hicks (1932) put forward the so-called "induced innovation hypothesis," which states that a change in relative factor prices will lead to innovation to enhance the efficient use of relatively expensive factors. In the context of energy use, the induced innovation hypothesis predicts improvements in energy-saving technology following an upsurge in the relative price of energy. There are several empirical studies that have sought to capture the causality from changes in the relative price of energy to 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 rises in energy prices have a statistically significant positive impact on energy-efficiency innovations. On the other hand, Newell et al. (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. Niizeki (2012) also estimates energy-saving technological change and shows that it is required to replicate the declining energy use observed following the first oil crisis in Japan.

In this paper, the level of energy-saving technology is estimated using the production function and the first order condition for energy use shown below:

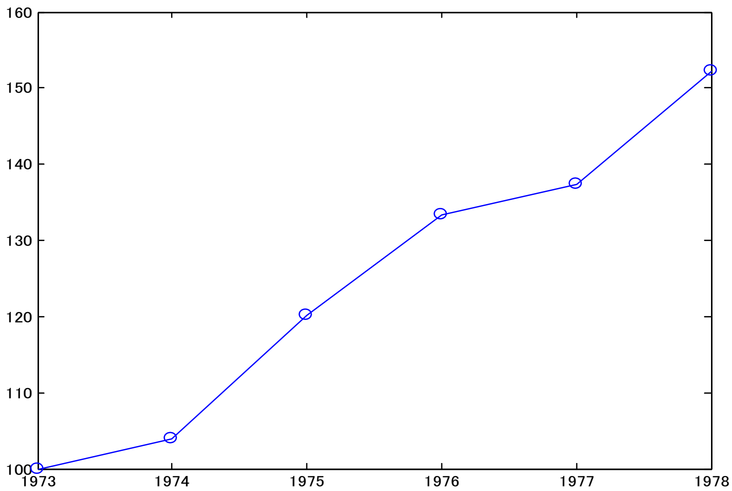

Figure 2: The level of energy-saving technology normalized to 100 in 1973.

$$Y_t = (\Gamma_t H_t)^{1-\theta} \left[(1-\mu) K_t^{\frac{\varepsilon-1}{\varepsilon}} + \mu (z_t E_t)^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}\theta} \tag{8}$$

$$p_t = \theta\mu \left(\frac{Y_t}{B_t} \right) \left(\frac{B_t}{z_t E_t} \right)^{\frac{1}{\varepsilon}} z_t. \tag{9}$$

Given the parameter values obtained in Section 3 and the actual time series for Y_t, H_t, K_t, E_t, and p_t, there are two unknown variables, Γ_t and z_t, and two equations, so that the series of $\{\Gamma_t, z_t\}_{1973}^{1978}$ can be obtained by solving the system of these equations for Γ_t and z_t each year.[7]

Figure 2 displays the estimated level of energy-saving technology normalized to 100 in 1973. As can be seen, rapid growth of energy-saving technology is observed following the first oil shock in 1973. In fact, the estimated average annual growth rate of energy-saving technology over the period 1973–1978 is 8.76%. These improvements in energy-saving technology are included in the original TFP growth rate estimated using a production function without energy-saving technological change. That is, the growth rate of TFP when assuming that z_t is unity throughout in Equation (5) is 1.67%. On the other hand, the modified TFP growth rate, which strips out

[7]See Niizeki (2012) for further discussion of energy-saving technology and its impact on aggregate variables in Japan, especially energy use, and Hassler et al. (2012) for the case of the United States.

improvements in energy-saving technology, that is, when z_t takes the estimated time-varying values, is 0.72%. Throughout this paper, the estimated time-varying levels of energy-saving technology are always fed into the model, so that the effect of energy-saving technological change is always excluded from the TFP series.

3 Data and calibration

3.1 Energy

In this paper, the energy-related variables are real 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). Real energy use E_t at time t is calculated as follows:

$$E_t \equiv \sum_i P_{i,0} Q_{i,t}, \tag{10}$$

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 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 in Japan 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:

$$DEF_t^P \equiv \frac{\sum_i P_{i,t} Q_{i,t}}{\sum_i P_{i,0} Q_{i,t}} \tag{11}$$

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

$$p_t \equiv \frac{DEF_t^P}{DEF_t^V}, \tag{12}$$

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

3.2 Other variables

Other variables are defined as follows. The working age population is defined as the number of people aged 15–64, which is obtained from the Population Census published by the Ministry of Internal Affairs and Communications. Average weekly hours worked per employed person (ℓ_t) are taken from the Monthly Labour Survey published by the Ministry of Health, Labour and Welfare, while the number of employed persons (M_t) is taken from the 1968 SNA (System of National Accounts) produced by the Economic and Social Research Institute, Cabinet Office. Using these data, the empirical counterpart of h_t is then calculated as follows:

$$h_t = \frac{\ell_t * M_t}{N_t * 16 * 7}. \tag{13}$$

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

The remaining variables are obtained from the 1968 SNA. The 1968 SNA is used for analysis since data based on the 1993 SNA are not available for the period before 1980. As the models described in this paper contain no government sector, it is necessary to adjust the data from the 1968 SNA to match up the series in the models.[8] In the 1968 SNA, real value added (real GNP in this paper) is decomposed into the following parts:

$$V_t = C_t + X_t + G_t + NX_t + NFP_t \tag{14}$$

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 payments." The nominal values are converted into real values by dividing them by the constant 1990 yen deflator.

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

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

$$V_t = C_t^{'} + X_t^{'} \tag{15}$$

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

Finally, the capital stock series are constructed using the perpetual inventory method. The initial capital stock, K_{1973} is set so that $K_{1973}/V_{1973} = 1.57$,[9] which is taken from the value in the dataset constructed by Hayashi and Prescott (2002). The series of subsequent values of capital stock is obtained by the law of motion for capital stock, Equation (3).

3.3 Calibration

In standard RBC models such as those by Prescott (1986) and King and Rebelo (2000), parameter values are set so that the steady state in the models is consistent with growth observations. This strategy is reasonable, since it is assumed in standard RBC models that per-capita variables are basically on a balanced growth path. They deviate from the balanced growth path only if the economy is hit by shocks. On the other hand, in the case of the Japanese economy in the 1970s, it seems more reasonable to assume that it was in a transition to a balanced growth path rather than on a balanced growth path.[10] Therefore, using growth observations to calibrate parameters would probably not be appropriate here. As an alternative strategy, therefore, some parameter values are calibrated using only data for the period 1973–1978, while the values of other parameters, which are usually regarded as constant over time, are either set at conventional values or taken from previous studies.

Combining the production function and the first order condition for energy use gives

[9] In fact, the value of K_{1973}/V_{1973} for 1973 in Hayashi and Prescott (2002) is 1.28. However, their calculation of capital stock does not include government capital, whereas the calculation here does. Therefore, the government capital-value added ratio (0.29) is added to 1.28, yielding 1.57 in total.

[10] For instance, the growth accounting exercise using Japanese data conducted by Hayashi and Prescott (2002) shows that the capital-output ratio was increasing and labor input per capita declining during the period 1973–1983, which is a typical transitional pattern observed in standard neoclassical growth models when the initial capital stock is less than the steady state level. On the other hand, the average growth rates of the capital-output ratio and labor input per capita during the period 1983–1991 were close to zero and the average growth rates of output per capita and TFP were almost identical, which implies that the Japanese economy was converging to a balanced growth path in this period.

$$\frac{1-\mu}{\mu} = \left(\frac{\theta Y_t - p_t E_t}{p_t E_t}\right)\left(\frac{E_t}{K_t}\right)^{\frac{\varepsilon-1}{\varepsilon}}, \quad \text{for} \quad t = 1973, 1974, ..., 1978. \tag{16}$$

Equation (16)[11] is solved for μ each year and μ is then averaged over 1973–1978, yielding $\mu = 0.005$.[12] The first order condition for h_t condition gives

$$\left(\frac{\alpha}{1-\alpha}\right)\left(\frac{h_t}{1-h_t}\right) = (1-\theta)\frac{y_t}{c_t}, \quad \text{for} \quad t = 1973, 1974, ..., 1978. \tag{17}$$

Equation (17) is solved for α and α is then averaged over 1973–1978, resulting in $\alpha = 0.709$. β and θ are set at 0.976 and 0.362, respectively, which are the values used in Hayashi and Prescott (2002). δ is set at the conventional value for annual data, 0.100.

The most important parameter to quantify the impact of the upsurge in the relative price of energy in this model is the elasticity of substitution between capital stock and energy use. It is well known that a high elasticity of substitution such as unity provides unrealistically volatile movements in energy use. For instance, Backus and Crucini (2000) claim that the elasticity of substitution between capital stock and oil should be around 0.09 to produce the realistic movements of oil prices and oil quantities in their model. On the empirical side, Hassler et al. (2012), using data for the United States and employing maximum likelihood estimation, arrive at an elasticity of substitution between energy and the capital/labor composite of 0.0044. Meanwhile, Miyazawa (2009), also using data for the United States and conducting a generalized method of moments estimation, arrives at values of $\varepsilon = 0.100$ and $\varepsilon = 0.086$. Given these results, ε in this paper is set to 0.1. Table 1 summarizes the calibration results.

4 Simulation results with benchmark model

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 four exogenous variables: the relative price of energy (p_t), the growth rate of TFP (γ_t), the level of energy-saving technology (z_t), and the growth rate of the working-age population (n_t). The model is then solved numerically by

[11] The calibrated value of μ is needed in order to obtain the time series for z_t, whereas the series of z_t is needed to calibrate μ. Thus, to calibrate μ, it is assumed that z_t takes unity over 1973–1978.

[12] The calibrated value of μ becomes almost zero when E_t and K_t are measured in billion yen. To avoid this problem, E_t is multiplied by 50 and p_t is divided by 50. Since $p_t E_t$ remains unchanged, the simulation results shown below are not affected by this manipulation.

Parameter	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	0.709
μ	Share of energy in capital-energy composite	0.005

Table 1: Parameter values

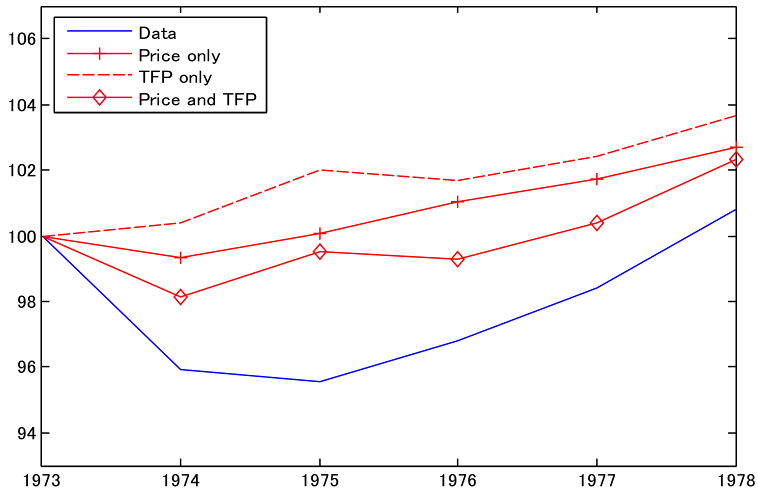

Figure 3: Detrended value added per working-age population (benchmark model vs. data) normalized to 100 in 1973.

applying a shooting algorithm given the initial capital stock level and the path of the exogenous variables. The levels of the exogenous variables after the period 1973–1978 are assumed to take the average value for the period 1973–1978 except in the case of energy-saving technology. The level of energy-saving technology is assumed to continue to take the 1978 value after the period 1973–1978.

Figure 3 shows three simulation results for value added. The first is the simulated path with the actual time series for the relative price of energy only, labeled "Price only." The second is the simulated path with the actual time series for the TFP growth rate only, labeled "TFP only." Finally, the third is the simulated path with the actual time series for the relative price of energy and the TFP growth rate, labeled "Price and TFP." To generate the path labeled "Price only," the TFP growth rate is set to its geometric mean over the period 1973–1978, while to obtain the path labeled "TFP only" the relative price of energy is set to its mean over the same period.[13] A notable feature in Figure 3 is that the upsurge in the relative price of energy alone fails to account for the drop in value added in 1974. In the "Price only" simulation, value added in 1974 declines by only 0.7%, while in the actual data it falls by about 4%. Finally, in the "Price and TFP" simulation, the sluggish growth rate of TFP adds to the negative effect on value added, but this is insufficient to account for the severe recession following the first oil shock in 1973. Next, Figure 4 displays the simulated paths for other aggregate variables. As can be seen, the simulated path for energy use reproduces the downward trend in energy use well because of the improvements in energy-saving technology.[14]

In sum, the simulation analysis using the benchmark model shows that the sharp rise in the relative price of energy plays a limited role in accounting for the decline in value added. In addition, the analysis suggests that sluggish TFP growth also does not appear to have played an important role in the recession following the first oil crisis, which contrasts with the findings by Hayashi and Prescott (2002) and Chen et al. (2006) that trends in TFP growth provide a good explanation of developments in macroeconomic variables in Japan. A likely reason why the relative price of energy in the benchmark model only plays a limited role in explaining the drop in value added is

[13] Since the main focus of this paper is the impact of the relative price of energy and the growth rate of TFP on value added, it is assumed that the other two exogenous variables always take the actual values.

[14] The simulation without energy-saving technological change (not shown in Figure 4) generates a path that substantially overpredicts energy use even with the upsurge in the relative price of energy. Thus, incorporating energy-saving technological change into the model is essential to reproducing the energy use actually observed in the data.

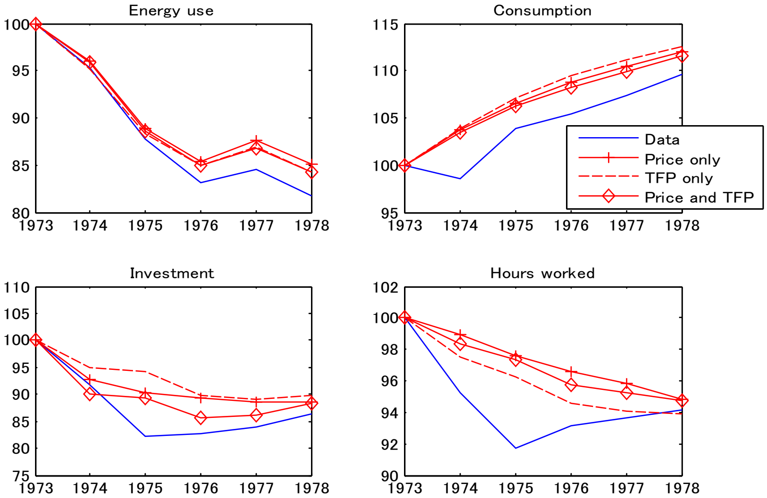

Figure 4: Other aggregate variables per working-age population (benchmark model vs. data) normalized to 100 in 1973.

the small ratio of real energy use to real value added ($p_t E_t / V_t$). In Japan, the average value of this ratio is only 3.7% during the period 1973–1978. That is, the relative price of energy does not play an important role in accounting for recessions simply because only a small amount of energy is needed for production.

In the next section, therefore, following Aguiar–Conraria and Wen (2007) and Finn (2000), endogenous capacity utilization is incorporated into the benchmark model as an amplification mechanism in order to examine whether this can help to explain the actually observed impact of the jump in the relative price of energy.

5 Endogenous capacity utilization

In the model with endogenous capacity utilization, the representative household faces the same problem as in the benchmark model, except that the depreciation cost of capital is now borne by the representative firm instead of the household. Thus, the budget constraint of the household at time t is

$$C_t + K_{t+1} - K_t = w_t H_t + r_t K_t. \tag{18}$$

The firm now is able to change its capacity utilization rate endogenously, so that the time t gross output is produced according to

$$Y_t = (\Gamma_t H_t)^{1-\theta} \left[(1-\mu)(u_t K_t)^{\frac{\varepsilon-1}{\varepsilon}} + \mu (z_t E_t)^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}\theta}, \tag{19}$$

where u_t is the capacity utilization rate. As in Greenwood at el. (1988), it is assumed that a more intensive use of the capital stock depreciates it more quickly:[15]

$$\delta_t = \frac{1}{\phi} u_t^{\phi}, \tag{20}$$

where $\phi > 1$. Capital stock is accumulated according to the following equation:

$$K_{t+1} = (1-\delta_t) K_t + X_t. \tag{21}$$

In sum, the representative firm maximizes the following profit function:

$$\pi_t \equiv Y_t - w_t H_t - (r_t + \delta_t) K_t - p_t E_t \tag{22}$$

subject to Equations (19), (20), and (21) given the initial capital stock and the actual time series of all exogenous variables. An additional optimality condition in this model is the first order condition for the capacity utilization rate. That is,

$$u_t^{\phi-1} K_t = \theta (1-\mu) \left(\frac{Y_t}{\tilde{B}_t} \right) \left(\frac{\tilde{B}_t}{u_t K_t} \right)^{\frac{1}{\varepsilon}} K_t, \tag{23}$$

where $\tilde{B}_t \equiv \left[(1-\mu)(u_t K_t)^{\frac{\varepsilon-1}{\varepsilon}} + \mu (z_t E_t)^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}}$. The left hand side of Equation (23) shows the additional depreciation of capital stock if the firm increases the capacity utilization rate by one unit. The right hand side represents the additional output the firm gains by raising the capacity utilization rate by one unit. Equation (23) requires that the marginal cost and benefit must be equal at optimum.

[15] Although Finn (2000) employs a slightly different specification in which the capacity utilization rate is an increasing function of energy use, the mechanisms are similar.

In order to obtain the TFP series taking the effect of capacity utilization into account, the actual time series for the capacity utilization rate is required. According to previous studies, there are at least three ways to obtain these series. The first is to use official statistics. The Ministry of Economy, Trade, and Industry (METI) provides the "Operating Ratio," which is calculated by dividing the actual production level by production capacity. Since the "Operating Ratio" published by METI is based on a survey of firms, the data are likely to be quite reliable. The shortcoming of these data, however, is that they only cover certain industries of the manufacturing sector, so that they do not provide an appropriate indicator of capacity utilization in the economy as a whole. The second way would be to use a proxy variable for the capacity utilization rate. Burnside et al. (1995), for example, use electricity consumption as a proxy. This seems like a reasonable assumption, since firms use more electricity when operating more machines. On the other hand, this indicator is likely to be downwardly biased when there are improvements in energy-saving technology. That is, electricity consumption can decline due not only to a drop in the capacity utilization rate, but also to improvements in energy-saving technology.

The third way to obtain the actual series for capacity utilization is to use the first order condition for the capacity utilization rate. In this paper, following Burnside and Eichenbaum (1996), this third methodology is employed. Specifically, the empirical counterpart of the capacity utilization rate is obtained by exploiting Equation (23). This means that it will also be necessary to recalculate the capital stock series, since the depreciation rate is no longer constant over time when applying the perpetual inventory method. In the analysis here, the time series of the capacity utilization rate and capital stock are obtained simultaneously as follows. First, the first order condition

$$u_{1973}^{\phi-1} = \theta(1-\mu)\left(\frac{Y_{1973}}{\tilde{B}_{1973}}\right)\left(\frac{\tilde{B}_{1973}}{u_{1973}K_{1973}}\right)^{\frac{1}{\varepsilon}} \tag{24}$$

is solved for the capacity utilization rate in 1973. Next, the depreciation rate for 1973 is calculated as follows:

$$\delta_{1973} = \frac{1}{\phi}u_{1973}^{\phi}. \tag{25}$$

Finally, plugging δ_{1973} into the law of motion for capital stock,

$$K_{1974} = (1-\delta_{1973})K_{1973} + X_{1973}, \tag{26}$$

Figure 5: Imputed capacity utilization rate and METI's "Operating Ratio." The values for both series in 1973 are normalized to 100.

yields the capital stock in 1974. This procedure is repeated for each year up to 1978. ϕ is calibrated so that the series of δ_t generated by the procedure above is equal to 0.100, which is the depreciation rate for capital stock in the benchmark model. This procedure leads to $\phi = 2.001$.

Figure 5 displays the imputed capacity utilization rate and METI's "Operating Ratio" for comparison. As can be seen, although both series show a decreasing trend after the first oil shock, the trend in the imputed capacity utilization rate is much smoother than that in the "Operating Ratio." The substantial drop in the capacity utilization rate implied by the "Operating Ratio" may look more realistic, but it needs to be remembered that the "Operating Ratio" is constructed using data only for certain industries in the manufacturing sector. The Appendix provides further justification for using the imputed capacity utilization rate instead of the "Operating Ratio" by constructing a crude measure of the capacity utilization rate in the non-manufacturing sector and showing that this series is much less volatile than the "Operating Ratio."[16]

The TFP series calculated by solving Equations (5) and (19) for Γ_t respectively are displayed in Figure 6. A notable feature in Figure 6 is that TFP in the benchmark model continues to be

[16]This result is also in line with findings by Miyazawa (2012) for Japan in the 1990s, which show that the capacity utilization rate imputed by using the first order condition for the capacity utilization rate is much less volatile than the "Operating Ratio."

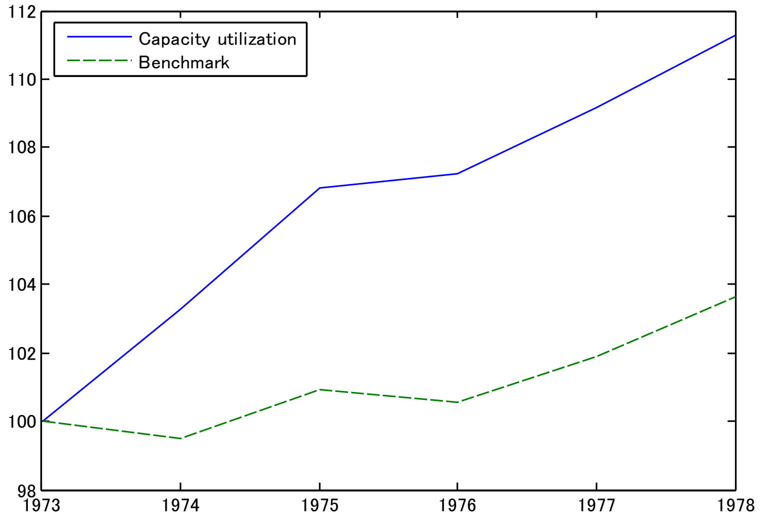

Figure 6: Comparison of the two TFP series. The line labeled "Benchmark" shows the TFP series obtained in the benchmark model, while that labeled "Capacity utilization" shows the series obtained in the capacity utilization model. The values of both series in 1973 are normalized to 100.

sluggish, whereas in the capacity utilization model TFP follows a steady growth path. The average growth rates of TFP over the period 1973–1978 are 0.72% in the benchmark model and 2.16% in the capacity utilization model. This discrepancy arises simply because the imputed capacity utilization rate follows a decreasing trend, as shown in Figure 5. In other words, the stagnation of the TFP growth rate in the benchmark model was spurious.

5.1 Simulation results with endogenous capacity utilization

Figure 7 shows the simulation result for value added with endogenous capacity utilization. First of all, the sharp rise in the relative price of energy now has a large depressing effect on value added. The driving force of this large depressing effect is the endogenous capacity utilization rate. When the relative price of energy rises, energy input decreases, leading to a reduction in value added. This is the direct effect and the simulation result from the benchmark model shows that this effect is very small due to the small ratio of real energy use to real value added. Once capacity utilization is endogenized, however, another effect emerges. That is, the declining capacity utilization rate

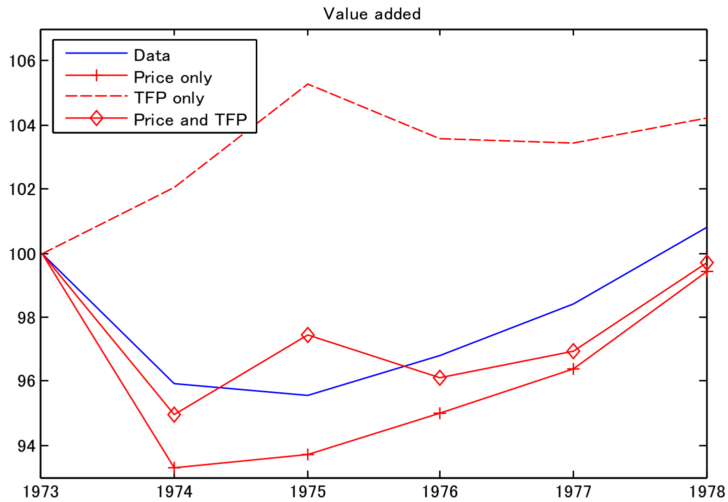

Figure 7: Detrended value added per working-age population (capacity utilization model vs. data) normalized to 100 in 1973.

generated in the capacity utilization model (observed in Figure 8) generates a further drop in value added. This decrease in the simulated path of capacity utilization is due to two different effects. The first effect is the surge in the relative price of energy. When the relative price of energy increases, energy use declines, leading to a decrease in the marginal product of capacity utilization, which, in turn, leads firms to decrease their capacity utilization. The second effect comes from the fact that the initial capital stock is below the steady state. Since the marginal product of capacity utilization is a decreasing function of capital stock and the marginal cost of capacity utilization is an increasing function of capital stock, the lower initial capital stock results in a higher marginal product and lower marginal cost of capacity utilization than in the steady state (see Equation (23)). Therefore, the initial capacity utilization rate is higher than its steady state. As capital stock is accumulated over time, the marginal product of capacity utilization decreases and the marginal cost of capacity utilization increases, leading to a reduction in capacity utilization over time.

The second salient feature in Figure 7 is that the simulated path generated by "TFP only" in the capacity utilization model shows steady economic growth even after the first oil shock. This indicates that the Japanese economy would have enjoyed stable growth if the first oil crisis had

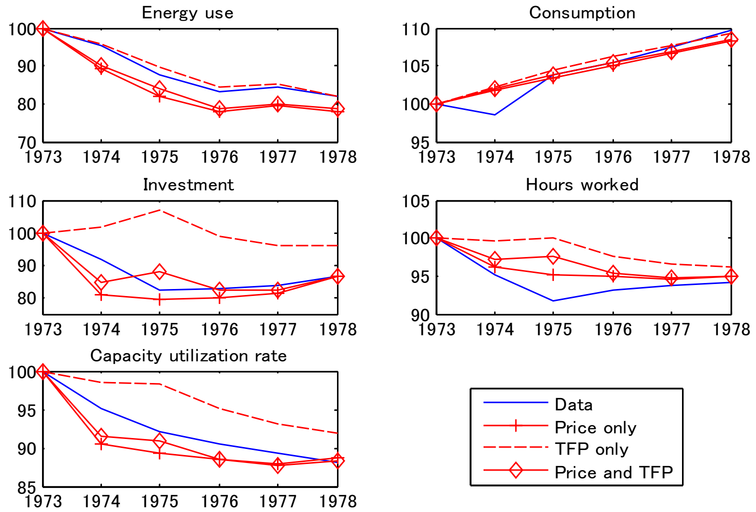

Figure 8: Other aggregate variables per working-age population (capacity utilization model vs. data) normalized to 100 in 1973.

not occurred. In other words, the capacity utilization model shows that the main cause of the economic recession in the wake of the first oil shock was the upsurge in the relative price of energy, which is consistent with conventional wisdom. Lastly, feeding the actual time series for the relative price of energy and the growth rate of TFP into the capacity utilization model now generates a good fit with the data.

Figure 8 displays the simulation results for other aggregate variables generated by the capacity utilization model. As in Figure 7, the simulation results labeled "Price only" actually underpredict the data for energy use, investment, and capacity utilization due to the large amplification mechanism driven by endogenous capacity utilization. However, the steady growth of purified TFP shifts up those simulated paths, leading to a reasonable fit with the data in the simulation labeled "Price and TFP." Figure 9 compares the simulation results in the benchmark model with the ones in the capacity utilization model. Both simulation results are derived by feeding the actual values of the relative price of energy and the growth rate of TFP into the model. As can be seen, although the simulated hours worked still substantially overpredict the data for 1975, the capacity utilization model performs better than the benchmark model overall except with regard to energy use.

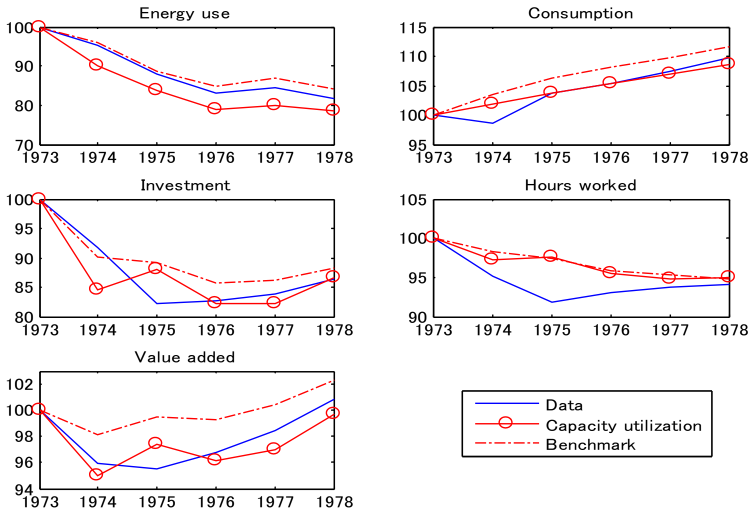

Figure 9: Comparison of the simulation results (benchmark vs. capacity utilization). Only the simulation results with "Price and TFP" in each model are shown for simplicity.

6 Conclusion

In this paper, a simple neoclassical growth model with energy as an input for production is constructed, calibrated to the Japanese economy, and used to examine the role of two key exogenous variables (the relative price of energy and the growth rate of TFP) to account for the severe recession following the first oil shock. In line with previous studies, the benchmark model shows that the relative price of energy has a limited role in accounting for the slump in value added due to the small ratio of real energy use to real value added. This means that to model the kind of drop in value added observed in the data it is necessary to incorporate a mechanism that amplifies the effect of the upsurge in the relative price of energy.

To this end, the present study proposed incorporating endogenous capacity utilization as such an amplification mechanism in the benchmark model. This capacity utilization model successfully generated a large negative effect of the sharp rise in the relative price of energy. In addition, the analysis also showed that the stagnation in TFP growth in the benchmark model was spurious due to the declining capacity utilization rate, and that the purified TFP series, in which the effect of time-varying capacity utilization is removed from the TFP in the benchmark model, shows steady growth steadily even after the first oil shock.

A Validity of the imputed capacity utilization rate

Figure 5 showed that the imputed capacity utilization rate for the entire economy is less volatile than the "Operating Ratio," which covers only selected industries in the manufacturing sector. In this Appendix, it is argued that this is probably due to the tendency that the capacity utilization rate in the manufacturing sector is more volatile than that in the non-manufacturing sector.

Note that in Japan there are no official statistics for the capacity utilization rate in the non-manufacturing sector. Therefore, in this Appendix, a proxy variable for the capacity utilization rate in the non-manufacturing sector following the methodology employed by the Cabinet Office, Government of Japan, is constructed. It is then shown that this is much less volatile than the "Operating Ratio."

To this end, first of all, the series of output divided by capital stock in the non-manufacturing sector is computed. The data for output and capital stock in the non-manufacturing sector are taken from the "Indices of Tertiary Industry Activity" published by the Ministry of Economy, Trade and Industry and the "Gross Capital Stock of Private Enterprises" published by the Cabinet Office, respectively. Then the cyclical component of this ratio extracted by applying the Hodrick–Prescott filter is used as a proxy for the capacity utilization rate in the non-manufacturing sector. Data for the period 1988–2005 are used, because the "Indices of Tertiary Industry Activity" are not available for years before 1988.

The imputed capacity utilization rate in the non-manufacturing sector is plotted with the "Operating Ratio" for comparison in Figure A.1. As can be seen, the "Operating Ratio" fell substantially during the 1990s, which is probably due to the severe economic conditions during the period, the so-called "Lost Decade." In contrast, the imputed capacity utilization rate in the non-manufacturing sector declined only somewhat, providing indirect evidence for the validity of the imputed capacity utilization rate in Figure 5. One might still argue that the " Operating Ratio " is the appropriate capacity utilization rate for the economy as a whole since the manufacturing sector is generally more capital-intensive than the non-manufacturing sector. That is, if most of the capital stock is used in the manufacturing sector, using the "Operating Ratio" as a proxy for the capacity utilization rate of the economy as a whole would be the correct choice. According to the "Gross Capital Stock of Private Enterprises" provided by the Cabinet Office, the gross capital stock share of the manufacturing sector in the economy ranges from 44.3% in 1980 to 37.0%

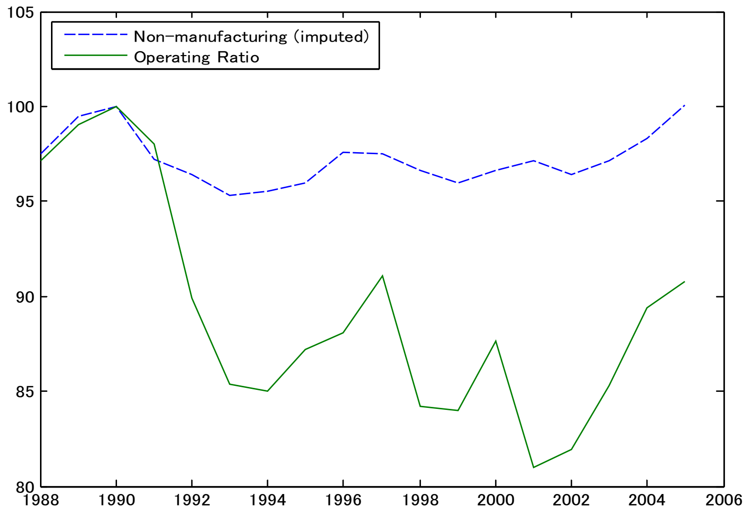

Figure A.1: The imputed capacity utilization rate in non-manufacturing and Operating Ratio. Both series are normalized to 100 in 1990.

in 2009. Although this share is not available for the 1970s due to a lack of data, simple linear extrapolation implies a share of around 50%. Since the real GDP share of the manufacturing sector in the Japanese economy has been about 25% since 1970, the manufacturing sector is indeed more capital-intensive than the non-manufacturing sector. Nevertheless, this does not mean that the capacity utilization rate in the non-manufacturing sector can be ignored in the process of imputing the capacity utilization rate for the economy as a whole. In sum, the imputed capacity utilization rate in Figure 5 likely is not far from the true capacity utilization rate in the economy as a whole.

References

[1] Aguiar–Conraria, L., and Wen, Y. (2007) "Understanding the Large Negative Impact of Oil Shocks," *Journal of Money, Credit and Banking*, Vol. 39, No. 4, pp. 925–944.

[2] Atkeson, A., and Kehoe, P. J. (1999) "Models of Energy Use: Putty-Putty versus Putty-Clay," *American Economic Review*, Vol. 89, No. 4, pp. 1028–1043.

[3] Backus, D. K., and Crucini, M. J. (2000) "Oil Prices and the Terms of Trade," *Journal of International Economics*, Vol. 50, pp. 185–213.

[4] Beaudry, P. and Portier, F. (2002) "The French Depression in the 1930s," *Review of Economic Dynamics*, Vol. 5, No. 1, pp. 73–99.

[5] Blanchard, O. J., and Gali, J. (2008) "The Macroeconomic Effects of Oil Price Shocks: Why Are the 2000s So Different from the 1970s," mimeo.

[6] Blanchard, O. J., and Riggi, M. (2009) "Why Are the 2000s So Different from the 1970s? A Structural Interpretation of Changes in the Macroeconomic Effects of Oil Prices," *NBER Working Paper Series*, No. 15467.

[7] Burnside, C., and Eichenbaum, M. (1996) "Factor-Hoarding and the Propagation of Business-Cycle Shocks," *American Economic Review*, Vol. 86, No. 5, pp. 1154–1174.

[8] Burnside, C., Eichenbaum, M., and Rebelo, S. (1995) "Capital Utilization and Returns to Scale," *NBER Macroeconomis Annual*, Vol. 10, pp. 67-124.

[9] Chen, K., İmrohoroğlu, A., and İmrohoroğlu, S. (2006) "The Japanese Saving Rate," *American Economic Review*, Vol. 96, No. 5, pp. 1850–1858.

[10] Cole, H. L., and Ohanian, L. E. (1999) "The Great Depression in the United States from a Neoclassical Perspective," *Federal Reserve Bank of Minneapolis Quarterly Review*, Vol. 23, pp. 2–24.

[11] Conesa, J. C., Kehoe, T. J., and Ruhl, K. J. (2007) "Modeling Great Depressions: The Depression in Finland in the 1990s," *Federal Reserve Bank of Minneapolis Quarterly Review*, Vol. 31, No. 1, pp. 16–44.

[12] Cooley, T. F. (1995) "Frontiers of Business Cycle Research," *Princeton University Press*, Princeton, New Jersey.

[13] Finn, M. G. (2000) "Perfect Competition and the Effects of Energy Price Increases on Economic Activity," *Journal of Money, Credit and Banking*, Vol. 32, No. 3, pp. 400–416.

[14] Fukunaga, I., and Osada, M. (2009) "Measuring Energy-Saving Technical Change in Japan," *Bank of Japan Working Paper Series*, No. 09–E–5.

[15] Greenwood, J., Hercowitz, Z., and Huffman, G. W. (1988) "Investment, Capacity Utilization, and the Real Business Cycle," *Americal Economic Review*, Vol. 78, Issue. 3, pp. 402–417.

[16] Hamilton, J. D. (1983) "Oil and the Macroeconomy since World War II," *Journal of Political Economy*, Vol. 91, No. 2, pp. 228–248.

[17] Hamilton, J. D. (1996) "This is what Happened to the Oil Price-Macroeconomy Relationship," *Journal of Monetary Economics*, Vol. 38, Issue. 2, pp. 215–220.

[18] Hamilton, J. D. (2003) "What is an Oil Shock?," *Journal of Econometrics*, Vol. 113, No. 2, pp. 363–398.

[19] Hamilton, J. D. (2009) "Causes and Consequences of the Oil Shock of 2007—08," *Brookings Papers on Economic Activity*, Vol. 2009, pp. 215–261.

[20] Hassler, J., Krusell, P., and Olovsson, C. (2012) "Energy-Saving Technical Change," *NBER Working Paper*, No. 18456.

[21] Hayashi, F., and Prescott, E. C. (2002) "Japan in the 1990s: A Lost Decade," *Review of Economic Dynamics*, Vol. 5, No. 1, pp. 206–235.

[22] Hayashi, F., and Prescott, E. C. (2008) "The Depressing Effect of Agricultural Institutions on the Prewar Japanese Economy," *Journal of Political Economy*, Vol. 116, No. 4, pp. 573–632.

[23] Hicks, J. R. (1932) *The Theory of Wages*, London: Macmillan.

[24] Hooker, M. A. (1996) "What Happened to the Oil Price-Macroeconomy Relationship," *Journal of Monetary Economics*, Vol. 38, No. 2, pp. 195–213.

[25] Hooker, M. A. (2002) “Are Oil Shocks Inflationary? Asymmetric and Nonlinear Specifications versus Changes in Regime,” *Journal of Money, Credit and Banking*, Vol. 34, No. 2, pp. 540–561.

[26] Katayama, M. (2013) “Declining Effects of Oil Price Shocks,” *Journal of Money, Credit and Banking*, forthcoming.

[27] Kim, I., and Loungani, P. (1992) “The Role of Energy in Real Business Cycle Models,” *Journal of Monetary Economics*, Vol. 29, pp. 173–189.

[28] King, R. G., and Rebelo, S. T. (2000) “Resuscitating Real Business Cycles,” *Handbook of Macroeconomics*, ch. 14.

[29] Leduc, S., and Sill, K. (2004) “A Quantitative Analysis of Oil-Price Shocks, Systematic Monetary Policy, and Economic Downturns,” *Journal of Monetary Economics*, Vol. 51, No. 4 pp. 781–808.

[30] Loungani, P. (1986) “Oil Price Shocks and the Dispersion Hypothesis,” *Review of Economics and Statistics*, Vol. 68, No. 3 pp. 536–539.

[31] Miyazawa, K. (2009) “Estimation of the Elasticity of Substitution Between Oil and Capital,” *Economics Bulletin*, Vol. 29, No. 2, pp. 655–660.

[32] Miyazawa, K. (2012) “Capacity Utilization in Japan’s Lost Decade: A Neoclassical Interpretation,” *Japan and the World Economy*, Vol. 24, No. 4, pp. 246–253.

[33] Mork, K. A. (1989) “Oil and the Macroeconomy When Prices Go Up and Down: An Extension of Hamilton’s Results,” *Journal of Political Economy*, Vol. 97, No. 3, pp. 740–744.

[34] Newell, R. G., Jaffe, A. B., and Stavins, R. N. (1999) “The Induced Innovation Hypothesis and Energy-Saving Technological Change,” *Quarterly Journal of Economics*, Vol. 114, No. 3, pp. 941–975.

[35] Niizeki, T. (2012) “Energy-Saving Technological Change in Japan,” *Global COE Hi-Stat Discussion Paper Series*, No. 218.

[36] Otsu, K. (2009) "A Neoclassical Analysis of the Postwar Japanese Economy," *The B.E. Journal of Macroeconomics*, Vol. 9, No. 1 (Contributions), Article 20.

[37] Popp, D. (2002) "Induced Innovation and Energy Prices," *American Economic Review*, Vol. 92, No. 1, pp. 160–180.

[38] Prescott, E. C. (1986) "Theory Ahead of Business Cycle Measurement," *Federal Reserve Bank of Minneapolis Quarterly Review*, No. 1042, pp. 9–22.

[39] Rotemberg, J. J., and Woodford, M. (1996) "Imperfect Competition and the Effects of Energy Price Increases on Economic Activity," *Journal of Money, Credit, and Banking*, Vol. 28, No. 4, pp. 549–577.