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Energy-Saving Technological Change and the Great Moderation

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Abstract

The "Great Moderation" referring to the mitigated volatility of output and other aggregate variables, began in the mid-1980s in the United States. In this paper, we discuss the contribution of energy-saving technological progress toward the Great Moderation. The time path of energy-saving technology is estimated following the approach by Hassler, Krusell, and Olovsson (2011) and fed into a standard real business cycle model with energy as a production input. The simulation results show that the impulse response of value added to a 10% energy price shock is mitigated from −0.54% to −0.34% due to energy-saving technological progress. This implies that such progress is partially accountable for the Great Moderation.

Keywords: energy-saving technological change, energy price shocks, Great Moderation

1. Introduction

The "Great Moderation," referring to the mitigated volatility of output and other aggregate variables such as consumption, investment and hours worked, began in the mid-1980s in the United States. Table 1 displays the cyclical behavior of the U.S. economy from 1949 to 1983, 1984 to 2009, and 1949 to 2009. The break point between periods corresponds to previous studies such as Kim and Nelson (1999) and McConnell and Perez-Quiros (2000). All data are logged and detrended using the Hodrick–Prescott filter. (Note 1) Energy use is defined as the unweighted sum of primary energy consumption (petroleum, natural gas, coal, and nuclear electric power). Energy price is calculated by dividing the energy price deflator by the GNP deflator. (Note 2) As shown in Table 1, the volatility of all variables except energy price declines from the first (early) to the second (late) sample periods. In particular, the volatility of output reduces by 37% even though the late period includes a sharp drop in output triggered by the financial crisis in 2008.

Several reasons for the Great Moderation are discussed in previous studies, and these can be broadly divided into two groups. The first focuses on the importance of the reduced volatility of exogenous shocks. For instance, Arias, Hansen, and Ohanian (2007) show that the volatility of output declines simply because the volatility of total factor productivity (TFP) is approximately halved. Another group focuses on structural changes. Jaimovich and Siu (2009) claim that demographical changes can significantly contribute to the Great Moderation. McConnell and Perez-Quiros (2000) emphasize the role of better inventory management, whereas Clarida, Gali, and Gertler (2000) underscore the improvement in monetary policy.

In this paper, the role of energy-saving technological progress in the Great Moderation is examined. Blanchard and Gali (2008) show that the negative impulse response of output to an oil price shock is muted since the mid-1980s. We conjecture that the output response to an oil price shock has been weakened because of improvements in energy-saving technology. To examine this hypothesis, the time series of energy-saving technology is estimated following the approach by Hassler et al. (2011) and fed into a standard real business cycle model with energy as a production input. We then compare the impulse responses of the aggregate variables driven by an energy price shock between the two sample periods. The simulation results indicate that energy-saving technological progress has partially contributed to the Great Moderation.

The remainder of the paper is organized as follows: Section 2 describes the model, Section 3 discusses the data and calibrations, Section 4 presents the simulation results, and Section 5 concludes.

Table 1. Cyclical behavior of the U.S. economy

Variable	1949-2009 (Total) SD(%)	1949-83 (Early) SD(%)	1984-2009 (Late) SD(%)	ratio (Late/early)
Output($\hat{y}_t$)	2.28	2.68	1.68	0.63
Consumption($\hat{c}_t$)	1.79	2.01	1.51	0.75
Investment($\hat{x}_t$)	6.98	7.82	5.88	0.75
Capital stock($\hat{k}_t$)	1.50	1.81	1.00	0.55
Hours worked($\hat{h}_t * \hat{em}_t$)	1.95	2.07	1.83	0.88
Hours($\hat{h}_t$)	0.64	0.67	0.61	0.92
Employment($\hat{em}_t$)	1.41	1.51	1.29	0.85
TFP($\hat{A}_t$)	1.36	1.71	0.74	0.44
Energy use($\hat{e}_t$)	2.66	2.94	2.29	0.78
Energy price($\hat{p}_t$)	13.54	12.72	14.64	1.15

Notes: The data frequency is annual and spans from 1949 to 2009. All data are logged and detrended using the Hodrick–Prescott filter. The smoothing parameter in the Hodrick–Prescott filter is set to 100. The data on energy use and energy price are taken from the U.S. Energy Information Administration (2009), the data on hours worked and employment come from Cociuba, Prescott, and Ueberfeldt (2009), and all other data are taken from the Bureau of Economic Analysis.

2. The Model

The model employed here is based on the standard real business cycle model developed by Hansen (1985). There is a representative household who has preferences defined over consumption and leisure as follows:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[(1-\alpha)\ln C_t + \alpha \frac{\ln(1-\bar{H})}{\bar{H}} H_t\right] \tag{1}$$

where E_0 is the expectation operator conditioned on information known at time 0, C_t is aggregate consumption, H_t is aggregate hours worked, β is the discount factor, and α is the leisure weight in preferences. In this economy, labor is indivisible so that workers either work $\bar{H}$ hours or not at all. The indivisibility of labor is incorporated in the model because it is consistent with the fact that most fluctuations in aggregate hours worked in the United States come from variations in employment, not in hours worked, as shown in Table 1. (Note 3) The household supplies labor and rents its own capital stock to a representative firm, so its budget constraint for each period is:

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

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

$$\mathrm{K}_{t+1} = X_t + (1-\delta)K_t \tag{3}$$

There is one firm that demands labor and capital stock from the household. One feature of this model is that the firm also purchases energy as a third input for production from outside the economy, so a profit maximization problem is

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

subject to

$$Y_t = \left[(1-\emptyset)[A_t K_t^{\theta} H_t^{1-\theta}]^{\frac{\sigma-1}{\sigma}} + \emptyset[z_t E_t]^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}} \tag{5}$$

where Y_t is gross output, A_t is capital/labor-augmenting technology, z_t is the level of energy-saving technology, σ is the elasticity of substitution between capital/labor composites and energy, and p_t is the relative price of energy. This production-function specification is taken from Hassler et al. (2011). It is assumed that p_t is exogenous to the firm and follows a first-order autoregressive process:

$$\ln p_{t+1} = \varphi \ln p_t + \varepsilon_{t+1} \tag{6}$$

where ε_{t+1} is an independent and identically distributed normal random variable, with mean zero and variance σ_p^2. The economy-wide resource constraint is

$$\mathrm{C}_t + X_t = Y_t - p_t E_t \equiv V_t \tag{7}$$

where V_t is value added. That is, output produced domestically is either consumed, invested, or exported as payment for imported energy. (Note 4)

3. Data and Calibration

The data on energy price and energy use are taken from the U.S. Energy Information Administration (2009). The nominal energy price is calculated as the weighted average of each nominal price of energy. The real energy price is calculated by dividing the nominal energy price by the GNP deflator. Energy use is defined as the unweighted sum of the primary energy consumption (petroleum, natural gas, coal, and nuclear electric power), measured in billion British thermal units (Btu). Although most previous studies define energy use as the consumption of fossil fuels, we also include the consumption of nuclear electric power, because its consumption share has increased since the first oil crisis. (Note 5) Figure 1 depicts the primary energy consumption by type from 1949 to 2009. As shown, the consumption of nuclear electric power begins rising in the early 1970s and accounts for almost 10% of total primary energy consumption in 2009.

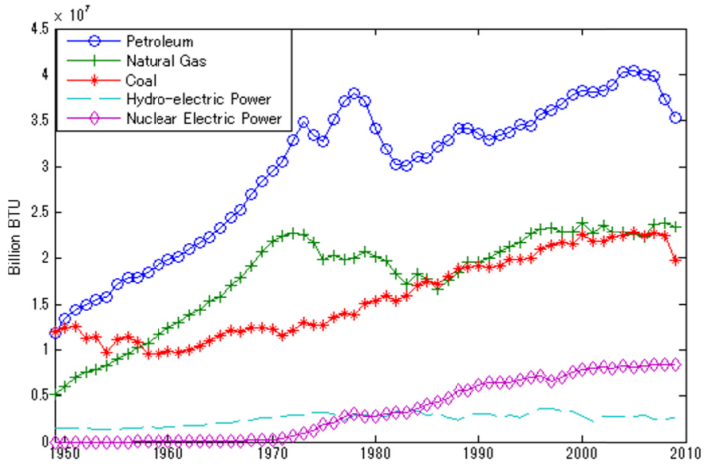

Figure 1. Composition of primary energy consumption

The data on hours worked and employment are taken from Cociuba et al. (2009). The capital stock series are constructed by a perpetual inventory method. The data for the other variables are taken from the Bureau of Economic Analysis (BEA).

The parameter values are set in a standard fashion and summarized in Table 2. The most important parameter in this analysis is σ (the elasticity of substitution between capital/labor composites and energy). Hassler et al. (2011) estimate σ by the maximum likelihood method, using the production function shown in Equation (5), and they determine that $\sigma = 0.0053$. We therefore use this value for σ in our analysis. The persistent parameter for energy price and the standard deviation of energy price shocks in a stochastic process are obtained by conducting ordinary least square (OLS) estimations of Equation (6).

Table 2. Parameter values

Parameters	Description	Value
σ	Elasticity of subst. btw. capital/labor and energy	0.005
θ	Capital share in income	0.333
δ	Depreciation rate of capital	0.088
β	Discount factor	0.960
α	Leisure weight in preferences	0.666
$\bar{H}$	Fixed hours worked	0.580
ϕ	Share of energy in production	0.050
φ	Persistence parameter for energy price	0.422
σ_p	Standard deviation of energy price shocks	0.137

4. Results

4.1 Measuring Energy-Saving Technology

Following Hassler et al. (2011), the level of energy-saving technology is calculated as follows. By assuming perfect competition in the input markets, labor share (H_t^{Share}) and energy share (E_t^{Share}) are respectively given by

$$\mathrm{H}^{Share} = \frac{\partial Y_t}{\partial H_t}\frac{H_t}{Y_t} = (1-\theta)(1-\emptyset)\left[\frac{A_t K_t^{\theta} H_t^{1-\theta}}{Y_t}\right]^{\frac{\sigma-1}{\sigma}} \tag{8}$$

and

$$\mathrm{E}^{Share} = \frac{\partial Y_t}{\partial E_t}\frac{E_t}{Y_t} = \emptyset\left[\frac{z_t E_t}{Y_t}\right]^{\frac{\sigma-1}{\sigma}} \tag{9}$$

Equations (8) and (9) are solved for A_t and z_t respectively. That is,

$$A_t = \frac{Y_t}{K_t^{\theta} H_t^{1-\theta}}\left[\frac{H_t^{Share}}{(1-\theta)(1-\emptyset)}\right]^{\frac{\sigma}{\sigma-1}} \tag{10}$$

and

$$z_t = \frac{Y_t}{E_t}\left[\frac{E_t^{Share}}{\emptyset}\right]^{\frac{\sigma}{\sigma-1}} \tag{11}$$

Once the data for $Y_t, K_t, H_t, E_t^{Share}, H_t^{Share}$ over the 1949–2009 period and the parameter values for $\theta, \emptyset, \sigma$ are given, Equations (10) and (11) provide the levels of capital/labor-augmenting technology and energy-saving technology.

Figure 2 illustrates the evolution of these types of technology. The initial levels of each technology are normalized to unity. The annual mean growth rate of the level of energy-saving technology is 0.43% from 1949 to 1973, compared with 2.15% from 1974 to 2009. These growth rates are slightly lower than those calculated by Hassler et al. (2011) because we also include nuclear electric power in addition to fossil fuels in the definition of energy use. In Hassler et al. (2011), the substitution of nuclear electric power for fossil fuels is interpreted as energy-saving technological progress.

The question is, to what extent has energy-saving technological progress, as shown in Figure 2, contributed toward the Great Moderation? Before addressing this question, we discuss the role of energy-saving technological progress on the aggregate variables in our model.

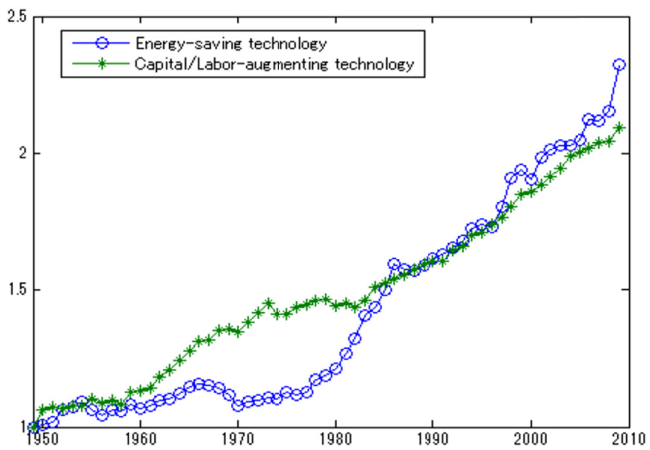

Figure 2. Levels of energy-saving technology and capital/labor-augmenting technology

Note: The initial levels of each technology are normalized to unity, where 1949 = 1.

4.2 Role of Energy-Saving Technological Change

In this subsection, we examine how energy-saving technological progress affects the aggregate variables in our model. We assume that energy-saving technology follows a first-order autoregressive process, as shown below:

$$\ln z_{t+1} = \rho \ln z_t + \epsilon_{t+1} \tag{12}$$

where ϵ_{t+1} is an independent and identically distributed normal random variable, with mean zero and variance σ_z^2.

Figure 3 displays the impact of a 10% positive energy-saving technological shock on the aggregate variables. (Note 6) The shock decreases the marginal product of energy, resulting in a decline in energy use. The shock, however, raises the marginal products of capital and labor and therefore stimulates investment and labor.

Considering these effects, a 10% energy-saving technological shock increases the value added by 0.6%.

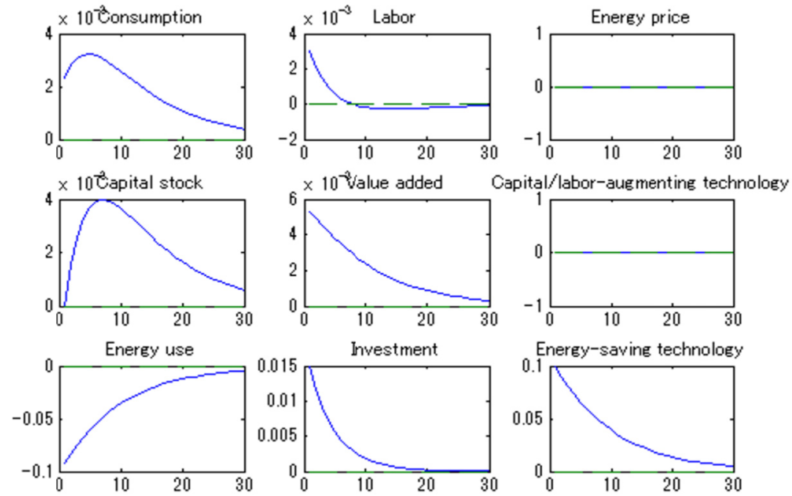

Figure 3. Impulse responses of the aggregate variables to a 10% positive energy-saving technology shock

Note: The vertical axis shows the percentage deviation from the steady state.

We then examine the extent to which energy-saving technological change contributes to the Great Moderation by investigating the impulse responses of the aggregate variables to a positive energy-price shock. This time, the level of energy-saving technology (z_t) takes the sample means for each sample. That is, z_t is 1.11 for the period from 1949 to 1983 and 1.81 for the period from 1984 to 2009. We then generate and compare two impulse responses to a 10% energy price shock under the different levels of energy-saving technology. The stochastic process for energy price is outlined in Equation (6).

Note that the only difference between the impulse responses in the different samples is the level of energy-saving technology. Figure 4 presents the simulation results. As discussed in Kim and Loungani (1992), an energy price shock affects both labor demand and labor supply. The labor demand curve shifts to the left because of the dampened marginal product of labor. The labor supply curve shifts to the right because of the negative income effect from the increased cost of energy imports. Under reasonable parameter settings, the labor demand effect dominates the labor supply effect, resulting in a decline in labor at equilibrium. (Note 7) An energy price shock also diminishes the marginal product of capital, leading to a reduction in investment. In total, value added declines.

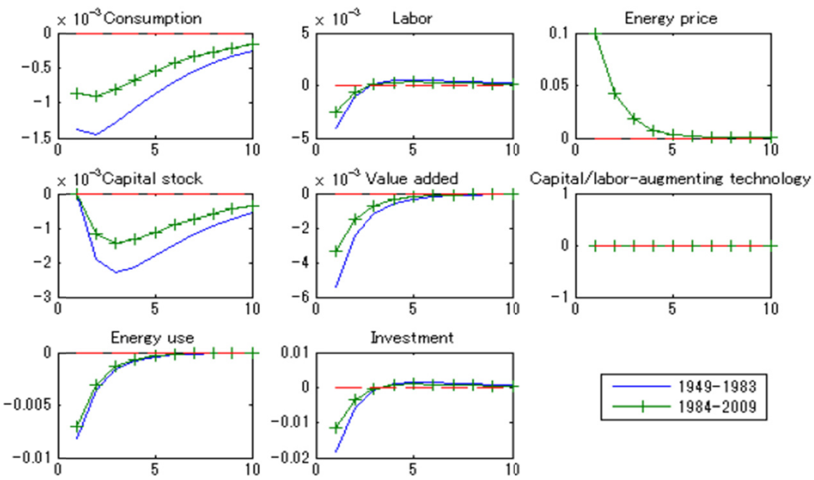

Figure 4. Impulse responses of the aggregate variables to a 10% positive energy price shock

Note: The vertical axis shows the percentage deviation from the steady state. The 1949–1983 period represents the impulse responses with a low level of energy-saving technology (z = 1.11), whereas the 1984–2009 period represents the impulse responses with a high level of energy-saving technology (z = 1.81).

All impulse responses, as shown in Figure 4, are mitigated due to energy-saving technological progress. In particular, while the value added declines 0.54% because of a relatively low level of energy-saving technology, it decreases only 0.34% with a high level of energy-saving technology. That is, the impact of an energy price shock on value added is mitigated by 37%. Thus, we conclude that the improvements in energy-saving technology are partially responsible for the Great Moderation.

5. Conclusion

In this paper, we investigate the impact of energy-saving technological progress on the Great Moderation using a standard real business cycle model with energy use as an input. As in Hassler et al. (2011), we observe improvements in energy-saving technology following the first oil crisis. We subsequently incorporate into our model the actual sample averages of energy-saving technology from 1949 to 1983 and 1984 to 2009 and quantify the influence of this technological improvement on the Great Moderation. Our impulse response analysis of a 10% energy price shock shows that the value added declines 0.54% in the 1949–1983 period but only 0.34% in the 1984–2009 period. This suggests that the Great Moderation is partially a result of energy-saving technological change.

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Notes

Note 1. The time interval is annual because only annual energy-related data are available annually.

Note 2. See Section 3 for details of the data construction.

Note 3. This indivisibility enlarges the impact of a technology shock on the labor supply. See Hansen (1985) for details.

Note 4. Exports are equal to imports in each period so that the trade balance is always zero.

Note 5. Another reason why the nuclear electric power is included into the definition of energy use is that if the energy use only refers to the consumption of fossil fuels, substituting fossil fuels for nuclear electric power can be interpreted as energy-saving technological progress, which is not necessarily correct.

Note 6. For simplicity, it is assumed that the persistence parameter is 0.9.

Note 7. Another aspect of an energy price shock is that it plays an important role in reducing the high correlation between wages and hours worked in standard real business cycle models. See Kim and Loungani (1992) for details.