DALLASFED

Working Paper

Monetary Policy, the Tax Code and the Real Effects of Energy Shocks

William T. Gavin, Benjamin D. Keen and Finn E. Kydland

Federal Reserve Bank of Dallas
Research Department
Working Paper 1304
May 2013

Monetary Policy, the Tax Code, and the Real Effects of Energy Shocks*

William T. Gavin Benjamin D. Keen Finn E. Kydland

May 29, 2013

Abstract

This paper develops a monetary model with taxes to account for the apparently asymmetric and time-varying effects of energy shocks on output and hours worked in post-World War II U.S. data. In our model, the real effects of an energy shock are amplified when the monetary authority responds to that shock by changing its inflation objective. Specifically, higher inflation raises households' nominal capital gains taxes since those taxes are not indexed to inflation. The increase in taxes behaves as a negative wealth effect and generates an immediate decline in output, investment, and hours worked. The large drop in investment then causes a gradual but very persistent decline in the capital stock. That protracted decline in the capital stock is associated with an extended period of low productivity growth and high inflation. Those real effects from the increase in nominal capital gains taxes are magnified by the tax on nominal interest income, which is also not indexed to inflation. A prolonged period of higher inflation and lower productivity growth following a negative energy shock is consistent with the stagflation of the 1970s. The negative effects, however, subsided greatly after 1980 because the Volcker disinflation policy prevented the Fed from accommodating negative energy shocks with higher inflation.

Key words: Inflation, Realized Capital Gains, Tax Code, Energy Shocks

JEL Classification: E32; E52; E62

*Gavin, Research Division, Federal Reserve Bank of St. Louis, St. Louis, MO (gavin@stls.frb.org); Keen, Department of Economics, University of Oklahoma, Norman, OK (ben.keen@ou.edu); Kydland, Department of Economics, University of California, Santa Barbara, CA (kydland@econ.ucsb.edu). Benjamin D. Keen and Finn E. Kydland thank the Federal Reserve Banks of Dallas and St. Louis for research support on this project. The research benefited from helpful comments of participants at the AMES 2011 in Seoul, the Tsinghua Macroeconomic Workshop 2011 in Beijing, the SED 2011 meetings in Ghent, and the CEF 2012 meetings in Prague. We also thank Fei Mao for research assistance on an earlier version of the paper. The views expressed are those of the authors and are not necessarily those of the Federal Reserve Banks of Dallas and St. Louis, or the Federal Reserve System. Any errors are our own.

1 Introduction

Understanding the effects of energy shocks on aggregate fluctuations has occupied research economists for the past 35 years. The first problem is to justify theoretically how an energy shock could have such a large impact on output and hours worked when energy is such a small factor in production. A second problem is that energy shocks which drive up prices are estimated to have a large negative impact on the economy, whereas energy shocks which push down prices are estimated to have small positive effects. A third problem is to explain why the negative impact of higher energy prices moderated so much after 1983.

In this paper, we develop a monetary model with taxes to account for the apparent asymmetric and time-varying effects of energy shocks on output and hours worked. The model includes energy as a consumption good and as a third factor in a CES production function with capital and labor. The model includes taxes on income from labor, capital, bonds, and realized nominal capital gains. Shifts in the monetary policy regime change the way in which inflation expectations respond to energy shocks. Energy shocks directly affect output and hours worked by altering the relative price of energy. Indirect effects, which operate through the interaction between monetary policy and the tax code, amplify the direct effects and can be larger in size than the direct effects, especially at longer-term horizons. Monetary policy has real effects because shifts in the inflation objective change the expected tax on bond interest income and capital gains.

The model is used to compute the effects of energy shocks under alternative policy regimes which are calibrated to post-World War II data. We find that energy shocks had a large impact on the real economy before 1980 because the Fed allowed the inflation rate target to change in response to those shocks. Medium- to long-run inflation expectations rose with adverse shocks to the energy supply. Higher expected inflation increased the expected taxes on capital gains, which caused an immediate decline in output and hours worked. That effect was amplified by the tax on bond interest income. Beginning in October 1979, Fed Chairman Paul Volcker announced a shift towards an aggressive anti-inflation policy. Under that regime, the inflation rate target and inflation expectations no longer responded to energy shocks, which may explain the greatly diminished effect of energy shocks on the real economy as documented in Hooker (1996).

The next section briefly reviews the literature on the macroeconomic consequences of energy shocks. Following that we describe the model used in this study with an emphasis on the tax code and the role of energy. We calibrate the model based on long-run relationships and microeconomic studies. Our results show that a monetary policy which accommodates energy price hikes can have large effects on the real economy, both in the short run on output and hours worked and in the long run on capital and productivity.

2 Energy Shocks in the U.S. Postwar Economy

In this paper, energy shocks represent supply shocks to all forms of energy with the understanding that, historically, the largest shocks to the U.S. energy supply have been to the supply of crude oil. Because of the quality and availability of data, our model is calibrated to data on energy consumed by U.S. households despite the fact that the model has energy in consumption and production. We model the energy shock as an exogenous innovation to supply. Overall, our paper contributes to a large literature on the empirical regularities of oil prices, output, and inflation by examining the interaction between taxation and monetary policy.

Hamilton (1983, 2009) documents that all but one of the post-World War II recessions was preceded by a significant increase in the price of crude oil. The tripling of oil prices prior to the deep recession of 1974 had a profound impact on conventional wisdom about the effects of energy shocks. Following a sharp rise in oil prices, initial estimates from January 1976 indicated that GDP declined 7.7 percent from the business cycle peak in 1973:Q4 to the trough in 1975:Q1. In comparison, initial estimates in January 2010 of the "Great Recession" indicated that GDP only fell 3.7 percent from its 2007:Q4 peak to the 2009:Q2 trough.[1] That large GDP decline in 1974 motivated economists to examine the effects of energy shocks on the real economy.

Baily (1981) argues that the capital stock in place prior to 1973 was dependent on low-price energy and that the sharp rise in the relative price of oil caused a substantial share of the capital stock to become obsolete. Wei (2003) develops a general equilibrium model with putty-clay investment and shows that this feature cannot account for either the magnitude of the declines in output and hours worked or the large drop in equity prices that occurred in 1973-1974. Alpanda and Peralta-Alva (2010) show that Wei's results for equity prices depend on the particular way in which she defines investment. Using a standard definition of investment and the putty-clay model of capital, Alpanda and Peralta-Alva (2010) find that the oil shock could explain about half of the decline in equity prices, but like Wei (2003), could not explain the large drop in output and hours worked.

The failure of the U.S. economy to respond positively to the oil price declines of 1986 and the mild recession following the oil price hikes of 1990 led researchers to ask whether changes in the oil market could explain the moderation in aggregate volatility that occurred around 1983 (the "Great Moderation"). Part of the decrease in volatility is attributable to a decline in the size of shocks and part is due to an increase in the efficiency of energy use, as the ratio of energy consumption to GDP fell by about half from 1974 to 2008. Although most studies assume a break in the early 1980s, with distinct high and low efficiency periods, the actual change in the ratio of energy use to GDP occurs around 1973-1974. Energy use prior to 1973 grew at about the same rate as real GDP. After 1973, per capita energy use remained relatively constant, while per capita real GDP continued to grow.

Rotemberg and Woodford (1996) argue that monopolistic competition is needed to capture the large effects of oil prices on the economy. Finn (2000) shows that making capacity utilization and the depreciation rate dependent on energy use has the same relative effect as introducing monopolistic competition. Leduc and Sill (2004) determine that the monetary policy rule matters in a general equilibrium model with oil prices. Specifically, they find that the Fed negatively affected output following the 1970's oil price shocks because they over tightened the money supply after each shock. Aguiar-Conraria and Wen (2007) develop a model with increasing returns to scale and a multiplier-accelerator mechanism which tracks the real economy very well following the 1973 oil price shocks, but cannot explain why the economy does not respond to later oil price shocks in a similar manner.

Dhawan, Jeske, and Silos (2010) offer an empirical explanation for the large effects of energy shocks during the 1970s. Using a Markov-switching model with shocks to energy prices and total factor productivity, they find that energy shocks have a large and significant impact on output prior

[1]The vintage data sets can be found at the Federal Reserve Bank of Philadelphia's website: http://www.philadelphiafed.org/research-and-data/real-time-center/real-time-data/data-files/ROUTPUT/.

to 1983. The model then switches in 1983 and the post-1983 estimates show that the spillover effect disappears. They do not, however, offer an economic explanation for the spillover that amplifies the effect of energy shocks on output or a reason why it disappears. Our model provides a theory which could account for their finding in the data and explain why it went away in the 1980s.

Although all of those papers make important contributions to the literature, none of them examine the effects of energy shocks in a model with taxes. This paper investigates the impact that taxes and monetary policy have on the response of key economic variables to an energy shock. Our results provide a potential theoretical explanation for the large real effects generated after an energy shock prior to the early 1980s and the small real effects observed afterwards.

3 The Model

This paper develops a real business cycle (RBC) model with taxation to examine the impact of an energy shock when the central bank endogenously adjusts its inflation target to that shock. Our model incorporates an energy sector into Gavin, Kydland, and Pakko's (2007) monetary policy model with taxation. Energy in our specification is both a consumption good and a factor of production. The government taxes four sources of household income: labor, bond interest, capital, and realized capital gains. Labor and capital income taxes affect the steady state, but they do not have a measurable effect on business cycle dynamics. Capital gains are modeled such that households can manage when their capital gains are realized (and taxable) subject to some adjustment costs. Our results indicate that capital gains and bond interest income taxes can have important effects when monetary policy responds to energy shocks.

3.1 Energy

Each period, the economy is endowed with a stochastic level of energy, e_t, which follows an AR(1) process:

$$\ln(e_t/e) = \rho_e \ln(e_{t-1}/e) + \sigma_e \varepsilon_{e,t}, \tag{1}$$

where e is the steady-state level of e_t, $0 \leq \rho_e < 1$, $\sigma_e > 0$, and $\varepsilon_{e,t} \sim N(0,1)$. Energy is purchased in a perfectly competitive market for a price of $P_{e,t}$ by households for consumption, $e_{c,t}$, and by firms for use in the production process, $e_{y,t}$, such that

$$e_t = e_{c,t} + e_{y,t}. \tag{2}$$

Finally, the profits from the energy sector, $T_t^e = P_{e,t} e_t$, are remitted to the households via a lump-sum payment.

3.2 Firms

Since energy, $e_{y,t}$, is an input into the production of non-energy output, $y_{n,t}$, we use a CES production function for non-energy output.[2] Specifically, non-energy output is produced by combining

[2]A similar production function has been used in other macroeconomic studies of energy effects. See, for example, Kim and Loungani (1992), Alpanda and Peralta-Alva (2010), and Dhawan, Jeske, and Silos (2010).

labor, n_t, capital, k_t, and energy inputs with a stochastic level of technology, z_t, and a nonstochastic level of labor-augmenting technological progress, x_t, such that

$$y_{n,t} = z_t(\psi k_t^{\upsilon_f} + (1-\psi)e_{y,t}^{\upsilon_f})^{\alpha/\upsilon_f}(x_t n_t)^{1-\alpha}, \tag{3}$$

where $\psi > 0$ represents the steady-state ratio of energy used in production to capital, υ_f is the elasticity of substitution between energy and capital, and $0 < \alpha < 1$. The stochastic technology factor, z_t, follows an AR(1) process:

$$\ln(z_t/z) = \rho_z \ln(z_{t-1}/z) + \sigma_z \varepsilon_{z,t}, \tag{4}$$

where z is the steady-state level of z_t, $0 \leq \rho_z < 1$, $\sigma_z > 0$, and $\varepsilon_{z,t} \sim N(0,1)$. Labor-augmenting technological progress, x_t, on the other hand, increases at a deterministic gross growth rate of $\gamma^{1/(1-\alpha)}$.

Each period, firms sell non-energy output in a perfectly competitive market at a price of $P_{n,t}$ and purchase labor, capital services, and energy in competitive markets for a nominal wage of W_t, a nominal capital rental rate of $P_{n,t}q_t$, and an energy price of $P_{e,t}$, respectively, where q_t is the real rental rate of capital. Firms' profit maximization under the assumption of perfect competition implies that the nominal wage, the nominal capital rental rate, and the price of energy equal the price of non-energy output multiplied by the marginal products of labor, capital, and energy, respectively. Aggregate output, y_t, then is calculated as follows:

$$P_t y_t = P_{n,t} y_{n,t} + P_{e,t} e_t,$$

where P_t is the aggregate price level:

$$P_t = P_{n,t}^{(1-\omega_y)} P_{e,t}^{\omega_y}, \tag{5}$$

and $\omega_y = P_e e/(P_n y + P_e e)$ is energy's share of aggregate output in the steady state.

3.3 Households

Households gain a discounted stream of expected utility from consumption, c_t, and leisure, l_t,

$$E_0 \left[\sum_{t=0}^{\infty} \beta^t \frac{\left(c_t^{\theta} l_t^{1-\theta}\right)^{1-\zeta}}{1-\zeta} \right], \tag{6}$$

where E_0 is the expectational operator at time 0, the discount factor is $0 < \beta < 1$, the intertemporal elasticity of consumption is $1/\zeta > 0$, and the preference parameter θ is between 0 and 1. The households' consumption good is a CES composite of non-energy consumption, $c_{n,t}$, and energy consumption,

$$c_t = (b_1 c_{n,t}^{\upsilon_h} + b_2 e_{c,t}^{\upsilon_h})^{1/\upsilon_h}, \tag{7}$$

where υ_h is the elasticity of substitution between non-energy and energy consumption, and b_1 and b_2 are constants that are calibrated such that $b_1(c_{n,t}/c_t)^{\upsilon_h}$ and $b_2(e_{n,t}/c_t)^{\upsilon_h}$ are set equal to non-energy's and energy's shares of consumption, respectively.

The endowment of time available to households is normalized to one in order to identify the fraction of time households spend on leisure, l_t, work, n_t, and adjusting their financial portfolio, s_t:

$$l_t + n_t + s_t = 1. \tag{8}$$

The time households spend adjusting their portfolio, s_t, is the shopping-time costs associated with holding money balances. Specifically, the shopping-time costs increase as the ratio of nominal consumption spending to the amount of money carried over from the previous period, M_{t-1}, rises:

$$s_t = \chi \left(\frac{P_t c_t}{M_{t-1}} \right)^{\eta}, \tag{9}$$

where $\chi > 0$ is a scale parameter and $\eta > 0$ is the curvature parameter in the money-time trade-off.

Each period, households, who own the capital, rent it to the firms and select their level of investment, i_t, such that

$$k_{t+1} = i_t + (1-\delta)k_t, \tag{10}$$

where δ is the depreciation rate. As the value of their capital stock changes, households accrue capital gains (or losses), but can manage the time in which those capital gains are realized. The timing is important because realized capital gains, G_t, are taxed by the government. Specifically, households manage their level of unrealized capital gains, U_t, subject to a capital gains adjustment costs function, $\Phi(G_t/U_t)$,

$$U_{t+1} = U_t + (P_{n,t} - P_{n,t-1})\, k_t - \Phi(G_t/U_t)U_t, \tag{11}$$

where $(P_{n,t} - P_{n,t-1})\, k_t$ are the capital gains accrued in period t. The steady-state capital gains adjustment costs, $G_t - \Phi(G_t/U_t)U_t$, are assumed to be zero (i.e., $\Phi(G/U) = G/U$) and are decreasing and convex in G/U (i.e., $\Phi'(\cdot) > 0$ and $\Phi''(\cdot) < 0$).

Households begin each period with their initial nominal money balances, M_{t-1}, and receive the principal plus after-tax interest from their nominal bond holdings, $(1 + (1-\tau^B)(R_{t-1} - 1))B_{t-1}$, where R_t is the gross nominal interest rate on bond holdings, B_t, from period t to $t+1$. During the period, households receive after-tax earnings from labor, $(1-\tau^n)W_t n_t$, after-tax earnings from their capital holdings, $((1-\tau^k)q_t + \tau^k\delta)P_{n,t}k_t$, government transfer payments, T_t^G, and profits from the energy sector, T_t^E, but must pay taxes on realized capital gains, $\tau^G G_t$, where τ^B, τ^n, τ^k, and $\tau^G$are the tax rates on bond interest income, labor income, capital income, and realized capital gains, respectively. Those funds are utilized by households to finance their purchases of non-energy consumption goods, $P_{n,t}c_{n,t}$, investment goods, $P_{n,t}i_t$, and energy consumption, $P_{e,t}e_{c,t}$. The remaining funds are used by households to purchase bonds, B_t, and acquire end-of-period money balances, M_t. Thus, households' nominal budget constraint is

$$\begin{aligned} P_{n,t}(c_{n,t} + i_t) + P_{e,t}e_{c,t} + B_t + M_t \;\; = \;\; & (1 + (1-\tau^B)(R_{t-1} - 1))B_{t-1} + M_{t-1} \\ & +((1-\tau^k)q_t + \tau^k\delta)P_{n,t}k_t \\ & +(1-\tau^n)W_t n_t + T_t^G + T_t^E - \tau^G G_t. \end{aligned} \tag{12}$$

3.4 Government

The government collects revenue by printing money, $T_t^M = M_t - M_{t-1}$, and taxing labor income, bond interest income, capital income, and nominal capital gains. It then redistributes all tax revenue back to households in the form of a lump-sum payment, T_t^G. Therefore, the government's budget constraint is

$$T_t^G = \tau^n W_t n_t + \tau^k (q_t - \delta) P_{n,t} k_t + \tau^B \left(R_{t-1} - 1\right) B_t + \tau^G G_t + T_t^M. \tag{13}$$

The government, via its central bank, sets monetary policy using a nominal interest rate rule:

$$\ln\left(\frac{R_t}{R}\right) = (1 + \phi_\pi) \ln\left(\frac{\pi_t}{\pi_t^*}\right), \tag{14}$$

where $\pi_t = P_t/P_{t-1}$ is the aggregate inflation rate, π_t^* is the time-varying inflation rate target, and $\phi_\pi > 0$. Prior to January 2012, the Fed did not have an explicit inflation rate target, but instead, shifted their implied target over time. We incorporate that concept into our model by assuming that the central bank's inflation target adjusts in response to energy supply shocks:

$$\ln(\pi_t^*/\pi^*) = \rho_\pi \ln(\pi_{t-1}^*/\pi^*) - \xi \sigma_e \varepsilon_t^e, \tag{15}$$

where $\xi \geq 0$ is the central bank's endogenous response of monetary policy to energy shocks, π^* is the steady-state inflation rate target, and $0 \leq \rho_\pi < 1$.[3] Finally, the money stock under any nominal interest rate rule is determined endogenously from the households' money demand.

4 Equilibrium and Calibration

The equations representing our model's first-order conditions, identity equations, and exogenous shocks comprise the set of difference equations that generate the model's systematic equilibrium. To obtain a stationary equilibrium, the nominal and real trends in the model data are eliminated by dividing the nominal variables by $\gamma^t P_t$ and the real variables with a deterministic trend by γ^t.[4] Since all of the transformed variables are stationary, the model's nonstochastic steady-state equilibrium can be determined. We then linearize the system of equations around its nonstochastic steady state and apply standard techniques to find the linearized model's solution.

We consider and label two monetary policy regimes (early and late) which are calibrated to periods with different energy shares and distinctly different monetary policies. The early regime is calibrated to a period, 1973:Q1-1979:Q3, roughly spanning the time between the end of the Bretton Woods fixed exchange rate system and the beginning of the Volcker monetary policy reform in October 1979. We ignore the short period, October 1979 through October 1982, during which the Fed targeted a reserve quantity rather than the federal funds rate. The late regime is calibrated to a time, 1983:Q1-2007:Q4. Therefore, we exclude the beginning of the financial crisis and a period

[3] There is a substantial amount of literature on how monetary policy has responded or should respond to energy or oil price shocks. See, for example, Leduc and Sill (2004), Bodenstein, Erceg, and Guerrieri (2011), and Kormilitsina (2011).

[4] Since the variables in the time constraint, n_t, l_t, and s_t, do not have a deterministic trend, they are not divided by γ^t.

in which monetary policy has been constrained by the zero lower bound on nominal interest rates. Parameter assignments for the two monetary policy regimes are discussed below and summarized in Table 1. With the exception of the energy shares and the monetary policy parameters, all the structural parameters are the same across both regimes.

We calibrate the quarterly discount factor, β, to be equal to 0.99. The quarterly gross steady-state inflation rate is 1.01, which assumes a trend annual inflation rate of 4 percent in both the early and late periods. The gross quarterly real growth rate, γ, is set to 1.004 in order to match the U.S. post-World War II average annual per capita real GDP growth rate of 1.6 percent.

Capital's share of output, α, is fixed to 0.33. The persistence of the technology shock, ρ_z, is assumed to be equal to 0.95 in both periods, while the standard deviation of the technology shock is set to 0.59 percent per quarter in the early period and 0.47 percent in the late period. Those values are estimated residuals from the output equation in a bivariate VAR including energy and output that are discussed in detail below. The elasticity of substitution between energy and capital, υ_f, is set to -0.9, which is larger in absolute value than the -0.7 used by Kim and Loungani (1992) and Dhawan, Jeske, and Silos (2010). When $\upsilon_f = -0.7$, the price elasticity of demand for energy is about unity. Empirical estimates, however, suggest that the price elasticity of energy is greater than 2. Therefore, we assume $\upsilon_f = -0.9$ because that calibration generates the most price-inelastic short-run factor demand for our model (around 1.5). A parameterization of $\upsilon_f < 0$ also signifies that energy and capital are complements in the production process. Parameter ψ is set so that energy's share in the production of output is 5.3 percent in the early period and 3.7 percent in the late period. The steady-state relative prices of energy and non-energy are assumed to be equal $(P_n = P_e)$. Persistence in the energy series, ρ_e, is equal to 0.92, which is obtained from the estimates in Dhawan, Jeske, and Silos (2011). The standard deviation of the energy shock, σ_e, is calibrated using estimates from our bivariate VAR with energy and output. That is, σ_e is set to 2.81 percent in the early period and 1.26 percent in the late period.

The tax rates are calibrated based on the average marginal tax rates for 1960 to 2002 from the NBER TAXSIM model.[5] Specifically, the tax rate is set to 24.4 percent for labor income, 25.8 percent for bond interest income, 34.1 percent for capital income, and 20.2 percent for realized capital gains.

Turning to the household sector, the preference parameter, θ, is specified to be consistent with Ghez and Becker's (1975) panel-data estimates in which households spend approximately 30 percent of their available time working. The risk-aversion parameter, σ, is set equal to 2, while the quarterly depreciation rate, δ, is assumed to be 2.5 percent. Our parameterization of b_1 and b_2 from the CES component of the utility function is consistent with the average ratio of energy used in consumption to aggregate consumption, 0.072 in the early period (1969:Q1-1979:Q3), and 0.046 in the late period (1983:Q1-2007:Q4). The elasticity of substitution between energy and non-energy consumption, υ_h, is set to -0.9 in order to generate a high degree of short-run inelasticity in energy demand.

The shopping-time parameter η is set to -1. That calibration implies that the interest rate elasticity of money demand is -0.5, which is consistent with empirical evidence summarized by Mulligan and Sala-i-Martin (1997) and Lucas (2000). The scale parameter χ is specified such that, in the steady state, households spend an additional 1 percent of their working time adjusting their portfolio, s, or 0.3 percent of their total available time.

[5]See Table 9 in Feenberg and Poterba (2003).

Our assumption is that capital gains adjustment costs are present when the economy deviates from its steady state but are zero at the steady state (i.e., $\Phi(G/U) = G/U$). Since the model is solved using linearizing approximation methods, we only need to identify the parameter values for Φ, $\Phi'(\cdot)$, and $\Phi''(\cdot)$ and do not have to specify a functional form for $\Phi(G_t/U_t)$. The value for $\Phi'(\cdot)$ is calibrated, so that the steady-state ratio of realized capital gains to accrued capital gains, $G/((1-1/\pi)k)$, is 0.4.[6] As for $\Phi''(\cdot)$, that value is determined by setting the elasticity of the marginal capital gains adjustment costs with respect to G/U, $(G/U)\Phi''(\cdot)/\Phi'(\cdot)$, equal to -1.1.[7]

During the early period, the Fed responds passively to inflation, so we utilize a relatively low value of 0.375 for ϕ_π in the policy rule. When a nominal bond income tax is present in a model with a Taylor-type monetary policy rule, Edge and Rudd (2007) show that the inflation coefficient in the policy rule, $1+\phi_\pi$, must be noticeably larger than one to ensure the model has a unique equilibrium. The condition for determinacy in our model is given by[8]

$$\left(1 - \frac{\beta\tau^B}{\pi\gamma}\right)(1+\phi_\pi) > 1. \tag{16}$$

The condition necessary for model determinacy when $\tau^B = 0$ is just the Taylor principle, $1+\phi_\pi > 1$. When $\tau^B > 0$, the value of ϕ_π necessary for the model to have a unique equilibrium rises as τ^B gets bigger. For our baseline model, the threshold for determinacy is a value of ϕ_π that is approximately equal to 0.339. In the late period, the Fed is more aggressive in responding to inflation, so we set ϕ_π equal to 0.5, as suggested by Taylor (1993), for that regime.

For the process driving the inflation target, we set ρ_π equal to 0.97 in the early period and 0.84 in the late period based on estimates obtained using the augmented Dickey-Fuller method in Gavin, Kydland, and Pakko (2007). Empirical evidence from the pre-1979 period finds that the inflation rate follows a stochastic trend and that the inflation premium in long-term interest rates displays a unit root.[9] The problem for our model is that when the inflation target is a random walk, the tax effects from an energy shock are incredibly large in the early regime. Those shocks raise long-run inflation expectations and the expected tax on bond interest income and capital gains. Stock (1991) derives confidence intervals for the largest roots in the macro data set used by Nelson and Plosser (1982). For CPI inflation, the 80 percent confidence interval ranges from 0.922 to 1.031. Our early regime value for ρ_π lies in the middle of that range. Our prior is that the weight on energy shock,

[6] Over the sample period, realized capital gains are equal to about 40 percent of accrued capital gains–changes in the nominal capital stock measured as the net stock of private nonresidential assets. Some capital gains are never realized. For example, capital gains taxes are not paid by tax-exempt institutions such as pension funds. When assets with unrealized capital gains are bequeathed to heirs, the basis for the capital gains is reset to current market value and no capital gains tax is due on the increased asset value earned during the lifetime of the deceased. (Note: Those assets are still subject to estate taxes for higher-valued estates.)

[7] This calibration is consistent with Auerbach's (1988) regression results showing that a 1 percent increase in the capital gains tax rate is associated with a 0.56 percent decline in realized capital gains. A simulation experiment using the time-series property of Auerbach's data on capital gains realizations generates a similar result with an elasticity measure equal to -1.1.

[8] The derivation of this result is in an appendix available upon request.

[9] Ireland (2007) estimates a DSGE model of the U.S. economy. He finds that in the pre-1980 period the inflation target can be modeled as a random walk with exogenous shocks or as a stochastic trend that reacts to other economic shocks. Kozicki and Tinsley (2005) estimate a unit root in trend inflation for this early period. Ellingsen and Soderstrom (2004) and Dewachter and Lyrio (2006) find that the inflation premium in long-term interest rates also has a unit root.

ξ, in the inflation rate target equation should be about equal to the weight of energy prices, ω_y, in the aggregate price index. Thus, ξ is set to 0.072 for the early regime. In the late regime, however, we set ξ equal to 0 under the assumption that the Volcker monetary policy reform prevented the Fed from adjusting policy in response to an energy shock. When conducting sensitivity tests of the early-regime policy parameters with the late-regime energy shares, we set ξ equal to 0.046.

4.1 The Data: Energy Shocks and Aggregate Fluctuations

What percentage of non-energy output fluctuations can be attributed to energy shocks in U.S. data? To answer that question, we estimate a bivariate VAR with energy and output.[10] Energy is measured as the log of per capita energy from the Personal Consumption Expenditures (PCE) component of GDP, while output is calculated as the log of per capita value of the real PCE minus the energy component of the PCE plus real investment. Figure 1 shows the energy shock (i.e., the energy residual identified in a Cholesky decomposition) for the periods 1973:Q1-1979:Q3 and 1983:Q1-2007:Q4. One key result from our estimated VAR model is that the standard deviation of the energy shock in the early period is twice as large as in the late period. Figure 2 shows the dynamic responses of energy and output to a one-standard-deviation shock to the energy supply in that VAR. The left column displays the impulse responses for the early period, while the right column presents the responses for the late period. In both samples, the energy shocks are persistent and the effects on output are positive and significant. One difference between the sample periods is that the energy shock's contribution to the variance of output is much smaller in the late period. Specifically, the first row of Table 2 shows that energy shocks account for 47.6 percent and 66.4 percent of output's variability at the 4- and 8-quarter forecast horizons, respectively, in the early period, but only account for 13.4 percent and 19.7 percent, respectively, in the late period.

To check the sensitivity of our results, we also construct the energy variable using the Energy Information Agency (EIA) monthly data on total primary energy used in the United States. The energy component of PCE and the EIA measure of energy as a share of GDP follow very similar trends, both declining on average from 1973 to 2012. The variance decomposition for output using the EIA energy variable is reported in the second row of Table 2. In the early period, the energy shock's contribution to output is statistically significant and accounts for between 6.0 percent and 6.8 percent of output variation over the first 8 quarters. In the late period, however, energy shocks are responsible for only 0.9 to 1.7 percent of output movements and are not statistically significant.

Although we assume that the energy supply is exogenous, many other studies assume that the energy price is exogenous. Therefore, the third row of Table 2 reports energy's impact on the variance of output when the VAR contains the relative price of energy instead of the supply of energy. The relative price of energy is the chain price index for the energy component of PCE deflated by the chain price index for GDP. In the early period, the relative price of energy accounts for over 66.6 percent and 81.4 percent of output fluctuations at the 4- and 8-quarter forecast horizons, respectively. The effect on output fluctuations falls to 6.7 percent and 6.3 percent, respectively, and is not statistically significant after 1982.

Finally, we use the HP filter to detrend our data on output, the PCE measure of energy, and the PCE price deflator index. Table 3 presents the business cycle correlations for those data series. We find the energy supply to be procyclical in both periods, while the energy price is strongly

[10] The VAR also includes two lags and a time trend.

countercyclical in the early period and modestly procyclical in the late period. In the early period, the contemporaneous correlation between output and energy is 0.71 with the peak cross-correlation occurring with energy leading output by 2 quarters. The strongest cross-correlations in the late period happen with energy leading output by 3 to 4 quarters but that number is below 0.5. As for the relative energy price, its contemporaneous correlation with output is -0.60 in the early period, and its strongest cross-correlation occurs when the trough in energy prices leads output by 2 or 3 quarters. In the late period, the energy price is weakly procyclical with a contemporaneous correlation of 0.25, and it lags output by 1 or 2 quarters. That procyclical result is consistent with Kilian's (2009) finding that in recent years shifts in oil demand, as opposed to oil supply, are primarily responsible for changes in crude oil prices.

5 Computational Experiments

This section examines the effects of energy supply shocks on the economy under alternative assumptions about monetary policy, taxes, and the structure of the energy sector. The key issue we address is why energy appears to matter so much more before 1980 and so much less afterwards. In our analysis, the two periods are treated as separate monetary policy regimes and each period has its own level of efficiency in energy use. We proceed to explain how monetary policy interacts with the tax code and show how different taxes influence the effects of energy shocks on the economy.

5.1 Model Results

In the early regime, the Fed accommodates temporary increases in energy prices caused by negative energy supply shocks by raising its inflation rate target. The Fed reacts more aggressively to inflation in the late regime and no longer adjusts their inflation target to energy shocks. Table 4 shows the model's cyclical properties for both regimes. As in the case of the VARs described above, our model includes an energy shock and a technology shock. In both regimes, the correlation between energy supply and output is positive but is much higher in the early regime. The correlation between energy prices and output, however, is strongly negative in the early regime but weakly positive in the late regime.

We now describe the responses of key economic variables to a persistent 1 percent negative energy supply shock that takes about 10 years to decay back to its steady state. Figure 3 displays the impulse responses for the following three specifications: Early regime is indicated by a solid blue line, early regime with late regime energy shares is indicated by a dashed-dot green line, and late regime is indicated by a dashed red line. The area between the solid blue line and the dashed-dot green line represents the effect due to the smaller energy shares in consumption and production. The area between the dashed-dot green line and the dashed red line shows the effect due to different monetary policy parameters. In Figure 3, the vertical axis of each chart reports the percent deviation from the steady state. The horizontal axis displays the number of quarters, from 0 to 100.

Higher energy prices following a negative energy supply shock push up production costs, which in turn encourages firms to raise prices. In the early regime, the central bank has a low value for ϕ_π, 0.375, and allows the inflation target to rise to accommodate higher energy prices. Inflation rises more in that regime because the public knows that the central bank is soft on inflation. The inflation increase in the late regime is much smaller because the central bank is more hawkish in fighting inflation. As Equation (16) demonstrates, the presence of the bond interest income tax introduces another term into the condition for determinacy in the nominal interest rate rule. That tax effectively lowers the central bank's response to inflation for any given value of ϕ_π. Intuitively, the inflation rate, the nominal interest rate, and the pre-tax real interest rate have to rise enough to pay the fluctuating tax on bond interest income. The after-tax real interest rate, on the other hand, remains relatively constant, as in a standard RBC model. That tax mechanism is present in both regimes, but a more aggressive monetary policy against inflation in the late regime prevents energy shocks from having as large of an effect on the economy.

The nominal interest rate responses look similar to those for inflation. In the policy rule, a value of $\phi_\pi > 0.339$ means that the nominal interest rate jumps more than inflation. Inflation and the nominal interest rate move less in the early regime with the late regime energy shares mainly because the value of ξ is lower, 0.046, reflecting the smaller share of energy in the consumer basket. As we demonstrate below, the important effect of the late-regime energy shares on inflation and interest rates comes from the fact that the coefficient on the energy shock in the inflation target equation, $\xi,$ is equal to the smaller share of energy in consumption. The more aggressive response to inflation in the late regime keeps inflation and interest rates even closer to the steady state.

The 1 percent energy shock causes an immediate decline in output of about 0.2 percent in the early regime, which is slightly more than double the effect in the late regime. The large jump in inflation expectations in the early regime raises the expected capital gains tax, which acts as a negative wealth shock and amplifies the drop in output after a negative energy shock. Initially, the higher energy share and the less aggressive monetary policy are responsible for about an equal amount of the additional output decline. In subsequent periods, the impact from the higher energy share dissipates more quickly, so that by year 10 most of the additional fall in output is due to the soft monetary policy of the early regime. The response of consumption to an energy shock is influenced by the household's ability to smooth consumption by selecting the timing of when to realize accrued capital gains. Immediately following a negative energy shock, the household delays the realization of capital gains and reduces investment to mitigate a drop in consumption. That decline in consumption continues for the next 20 or so quarters in the early regime but quickly reverses course in the late regime.

The energy shock reduces the combined energy/capital input, which pushes down the marginal product of labor. A lower marginal product of labor reduces both labor demand and the real wage causing the household to substitute away from work towards leisure. When the effects of the energy shock are amplified and propagated by monetary policy, the household expects the capital stock to decline for a longer period of time and anticipates that the real wage will remain persistently low in the near term. As time progresses, labor hours recover faster than the real wage or the capital stock. The reason why labor returns more quickly is that the wealth effect from a lower capital stock mitigates the substitution effect caused by a lower real wage.

Capital stock falls in response to a lower supply of energy. The direct effect of less energy is a reduction in the marginal product of capital. That effect is amplified by the temporary increase in the expected tax on capital gains. When the inflation target is very persistent (i.e., ρ_π is large), the expected tax on capital gains rises substantially which further pushes down the capital stock. Although accrued capital gains initially increase, realized capital gains (which household pays taxes on) drop. They decline because the household sets the marginal benefit of higher consumption equal to the marginal cost of having their portfolio of unrealized capital gains rise further. After 10 quarters, the household starts realizing some of those additional unrealized capital gains in order to balance the costs of a larger portfolio of unrealized capital gains against the benefits of further smoothing consumption.

5.2 Inspecting the Mechanism: Monetary Policy and the Tax Code

Both monetary and fiscal policy influence the effects of energy shocks on the economy. Although monetary policy determines how inflation responds to energy shocks, fiscal policy, via a tax code which is imperfectly indexed to inflation, controls how the real economy reacts. Our model ignores the lack of inflation indexing in labor and capital income taxes present in the economy prior to the Tax Reform Act of 1981. Findings by Altig and Carlstrom (1991) suggest that the direction and magnitude of our results would be stronger if we incorporate the pre-1981 tax code in the model. Our focus, however, is on modeling the economic effects of an energy shock in a specification which includes the tax structure currently in place. That is, we specify a tax code in which only bond interest income and capital gains taxes are not indexed to inflation. Such analysis would be particularly useful to policymakers if the Fed were deciding whether or not to implement a monetary policy in which they adjust their inflation target in response to energy shocks.

To examine the sensitivity of our results, we analyze the effects of key monetary and fiscal policy parameters on a range of economic variables to an energy shock. Table 5 displays the expected present value of each variable's deviation from its steady state over a period of 25 years after an initial 1 percent negative energy supply shock.[11] In other words, the values in Table 5 represent a discounted value of the area under the impulse responses over the first 100 quarters following an energy shock. The first three columns of Table 5 show the computed values for the three regimes presented in Figure 3. A comparison of those three columns indicates that the change in monetary policy is more influential in reducing the effects of an energy shock than the reduction in energy's share of output. Specifically, the present value of output deviations is -7.5 percent after a negative energy shock in the early regime. When we assume the lower energy shares from the late regime, that output number falls to -5.3 percent. It declines further to -1.7 percent once we incorporate the monetary policy from the late regime. Therefore, 3.6 percentage points of the 5.8 point decline in output variability is attributable to monetary policy, while only 2.2 percentage points is related to the reduced share of energy in the economy. Most other variables exhibit a similar reduction in volatility following an energy shock.

Columns 4-6 of Table 5 display the sensitivity of our results to key monetary policy parameters in the early regime. Column 4 shows that reducing the value of ρ_π has a larger effect on moderating the economy's response to an energy shock than lowering energy's share of output. When ρ_π drops from 0.97 to 0.84, the effects of an energy shock on output, inflation, and other key variables fall dramatically. For example, output declines from -7.5 percent with $\rho_\pi = 0.97$ to -3.2 percent with $\rho_\pi = 0.84$, while inflation decreases from 10.0 percent to 2.6 percent. A lower value for

[11] These are approximations to the steady state using computed values for the first 100 quarters,

$$PV = \sum_{i=0}^{i=99} \beta^i x_{t+i},$$

where $\beta = 0.99$ and the elements of x_t are deviations of model variables from their steady states.

ρ_π, in theory, limits the increase in expected inflation and expected capital gains taxes following a negative energy shock. Lower taxes on capital gains dampen the fall in investment which, in turn curbs the declines in output and capital stock. The relatively higher capital stock restrains the drop in the marginal product of labor, so that real wages and labor do not decrease as much. The lower value for ρ_π also means that the inflation target returns to its steady state more quickly. Column 5 reports the effects of raising the reaction to the inflation gap, ϕ_π, from 0.375 to 0.5 in the monetary policy rule. Increasing the value of ϕ_π works just like lowering ρ_π, except that its impact on moderating the economy's response to an energy shock is smaller. Another important policy parameter which influences the effect of energy shocks is the coefficient on the energy shock, ξ, in the inflation target process. If the central bank does not respond to energy shocks by adjusting the inflation target ($\xi = 0$), column 6 reveals that the present value of inflation deviations is less volatile at 2.0 percent than at 10.0 percent when $\xi = 0.072$. Similarly, output deviations decline from -7.5 percent when $\xi = 0.072$ to -3.0 percent when $\xi = 0$. Monetary policy has three parameters which affect the inflationary response to energy supply shocks. Making monetary policy less accommodative in any of those three dimensions reduces the real effects of energy shocks.

Columns 7-9 show the sensitivity of our early regime results to the tax rates on bond interest income and capital gains. Since inflation target movements are caused strictly by the monetary policy changes, shifts in tax rates have no effect on the inflation target. Column 7 illustrates that setting the bond tax, τ^B, to zero limits the response of output, inflation, and both nominal and real pre-tax interest rates to energy shocks. Those results highlight the role that the bond interest income tax plays in amplifying the nominal and real effects of an energy shock. Column 8 then reports our results when the capital gains tax, τ^G, is set to zero. Without a capital gains tax, energy shocks have smaller effects on output, consumption, investment, capital, and labor, but have larger impacts on inflation and the nominal interest rate. In column 9, tax rates on bond interest income and capital gains are equal to zero. Since those two taxes are the only type of nominal frictions in our model, the model's response to an energy shock mimics the response one would expect to observe in a standard RBC model.

6 Conclusion

This paper investigates how the oil price shocks of the 1970s could have led to both a large decline in output and hours worked and a sharp rise in the inflation rate. Prior to 1980, the Fed responded to oil price shocks by allowing the inflation rate to rise. Although the Fed raised interest rates following the 1970's oil shocks, that particular increase was insufficient to prevent inflation and long-run inflation expectations from rising. As a result, higher inflation increased the effective taxes on both bond interest income and capital gains. Capital gains taxes are paid on realized capital gains, so that the accrual equivalent tax rate is much lower than the statutory tax rate. Households select when to pay the capital gains taxes, and can avoid those taxes altogether on about 60 percent of the gains (in reality they do that by placing funds in tax-exempt retirement accounts or by bequeathing the capital to heirs). Nevertheless, that mechanism is still powerful enough to generate sizeable real effects from oil price shocks. Once Fed Chairman Paul Volcker adopted a disinflationary policy and stopped accommodating energy price shocks, the impact of oil price shocks on the economy was greatly reduced.

Our model generates solutions for several apparent puzzles from the 1970s macroeconomic experience. First, it explains why the real economy reacted so sharply to the first oil shocks. Second, it rationalizes why the real effects from an oil price shock dissipated after 1980. Third, it explains how both a stagnant economy and high inflation could exist simultaneously. Those results contribute to our understanding of the past, but also carry an important warning for policymakers today. Since bond interest income and capital gains taxes are still not indexed to inflation, reversion to a monetary policy regime which accommodates energy price shocks risks returning us to the high inflation and slow growth economy of the 1970s.

Some economists argue that the Fed should raise the inflation target but for very different reasons, including the zero lower bound on interest rates, the large stock of outstanding government debt, the loss of home equity during the financial crisis, the high unemployment rate, and the rising cost of crude oil. Each of those recommendations must be evaluated on its merits in a model that includes the relevant features. A critical feature which should be included in any business cycle model is the tax code and how it interacts with inflation under the proposed monetary policy regime.

References

[1] Aguiar-Conraria, Luis, and Yi Wen. “Understanding the Large Negative Impact of Oil Shocks.” *Journal of Money, Credit and Banking*, June 2007, 39(4), 925-944.

[2] Alpanda, Sami, and Adrian Peralta-Alva. “Oil Crisis, Energy-Saving Technological Change and the Stock Market Crash of 1973-1974.” *Review of Economic Dynamics*, October 2010, 13(4), 824-842.

[3] Altig, David, and Charles Carlstrom. “Inflation, Personal Taxes, and Real Output: A Dynamic Analysis.” *Journal of Money, Credit and Banking*, August 1991, 23(3), 547-571.

[4] Auerbach, Alan J. “Capital Gains Taxation in the United States: Realizations, Revenue, and Rhetoric,” *Brookings Papers on Economic Activity*, 1988, 2, 595-631.

[5] Baily, Martin N. “Productivity and the Service.” *Brookings Papers on Economic Activity*, 1981, 1, 1-50.

[6] Bodenstein, Martin, Christopher J. Erceg, and Luca Guerrieri. “Oil Shocks and External Adjustment.” *Journal of International Economics*, March 2011, 83(2), 168-184.

[7] Dewachter, Hans, and Marco Lyrio. “Macro Factors and the Term-Structure of Interest Rates.” *Journal of Money, Credit and Banking*, February 2006, 38(1), 119–140.

[8] Dhawan, Rajeev, Karsten Jeske, and Pedro Silos. “Productivity, Energy Prices, and the Great Moderation: A New Link.” *Review of Economic Dynamics*, July 2010, 13(3), 715-724.

[9] Edge, Rochelle M., and Jeremy B. Rudd. “Taxation and the Taylor Principle.” *Journal of Monetary Economics*, November 2007, 54(8), 2554-2567.

[10] Ellingsen, Tore, and Ulf Soderstrom. “Why are Long Rates Sensitive to Monetary Policy?” IGIER Working Paper no. 256, March 2004.

[11] Feenberg, Daniel R., and James M. Poterba. “The Alternative Minimum Tax and Effective Marginal Tax Rates.” NBER Working Paper 10072, November 2003.

[12] Finn, Mary G. “Perfect Competition and the Effects of Energy Price Increases on Economic Activity.” *Journal of Money, Credit and Banking*, August 2000, 32(3), 400-416.

[13] Gavin, William T., Finn E. Kydland, and Michael R. Pakko. “Monetary Policy, Taxes, and the Business Cycle.” *Journal of Monetary Economics*, September 2007, 54(6), 1587-1611.

[14] Ghez, Gilbert R., and Gary S. Becker. “The Allocation of Time and Goods over the Life Cycle.” Columbia University Press, New York, 1975.

[15] Hamilton, James D. “Oil and the Macroeconomy Since World War II.” *Journal of Political Economy*, April 1983, 91(2), 228-248.

[16] Hamilton, James D. “Causes and Consequences of the Oil Shock of 2007-2008.” Working Paper University of California, San Diego, April 27, 2009.

[17] Hooker, Mark A. "What Happened to the Oil-Price Macroeconomy Relationship?" *Journal of Monetary Economics*, October 1996, 38(2), 195-213.

[18] Ireland, Peter N. "Changes in the Federal Reserve's Inflation Target: Causes and Consequences." *Journal of Money, Credit and Banking*, December 2007, 39(8), 1851-1882.

[19] Kilian, Lutz. "Not All Oil Price Shocks Are Alike: Disentangling Demand and Supply Shocks in the Crude Oil Market." *American Economic Review*, June 2009, 99(3), 1053-1069.

[20] Kim, In-Moo, and Prakash Loungani. "The Role of Energy in Real Business Cycle Models." *Journal of Monetary Economics*, April 1992, 29(2), 173-189.

[21] Kormilitsina, Anna. "Oil Price Shocks and the Optimality of Monetary Policy." *Review of Economic Dynamics*, January 2011, 14(1), 199-223.

[22] Kozicki, Sharon, and P.A. Tinsley. "Permanent and Transitory Policy Shocks in an Empirical Macro Model with Asymmetric Information." *Journal of Economic Dynamics and Control*, November 2005, 29(11), 1985–2015.

[23] Leduc, Sylvan, and Keith Sill. "A Quantitative Analysis of Oil Price Shocks, Systemic Monetary Policy, and Economic Downturns." *Journal of Monetary Economics*, May 2004, 51(4), 781-808.

[24] Lucas, Robert. E., Jr. "Inflation and Welfare." *Econometrica*, March 2000, 68(2), 247-274.

[25] Mulligan, Casey B., and Xavier X. Sala-i-Martin. "The Optimum Quantity of Money: Theory and Evidence." *Journal of Money, Credit and Banking*, November 1997, 29(4), 687-715.

[26] Nelson, Charles R., and Charles I. Plosser. "Trends and Random Walks in Macroeconomic Time Series with a Unit Root," *Journal of Monetary Economics*, 1982, 10(2), 129-162.

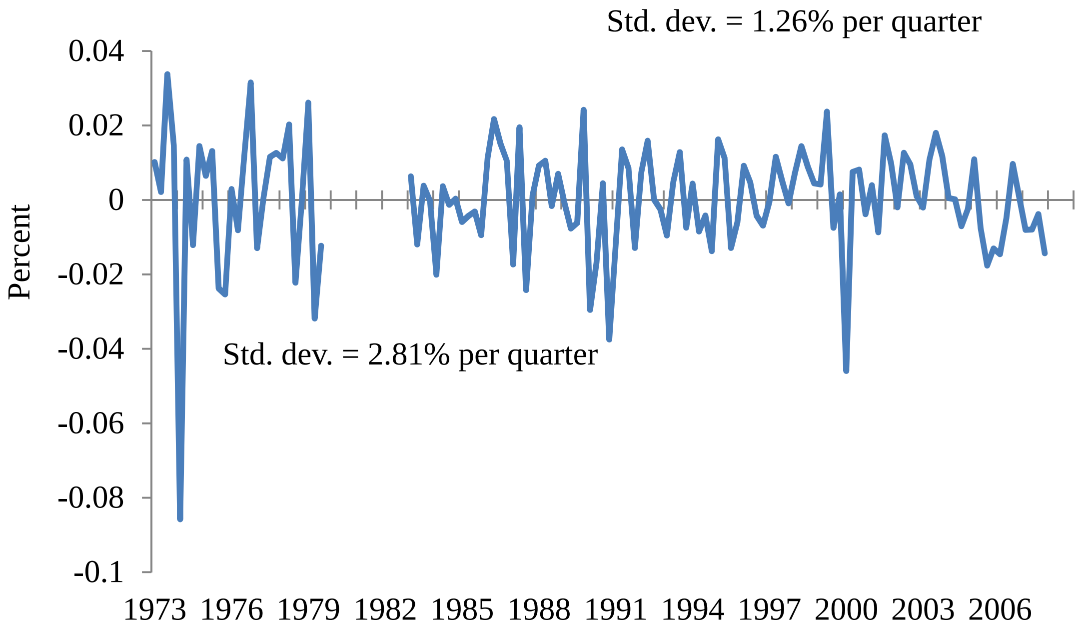
[27] Rotemberg, Julio, and Michael Woodford. "Imperfect Competition and the Effects of Energy Price Increases on Economic Activity," *Journal of Money, Credit and Banking*, November 1996, 28(4), 549-577.

[28] Stock, James H. "Confidence Intervals for the Largest Autoregressive Root in U.S. Macroeconomic Time Series," *Journal of Monetary Economics*, December 1991, 28(3), 435-459.

[29] Taylor, John B. "Discretion versus Policy Rules in Practice," *Carnegie-Rochester Conference Series on Public Policy*, 1993, 39, 195-214.

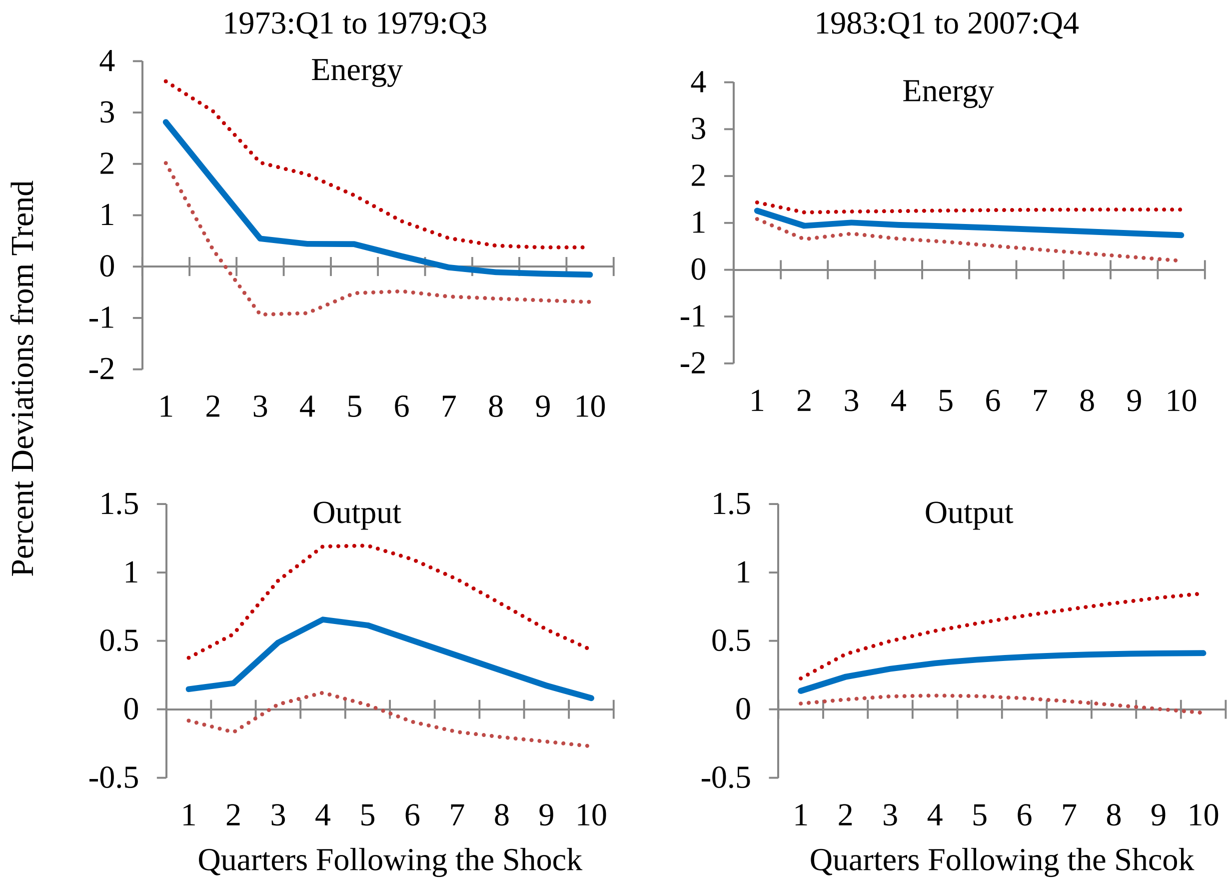
[30] Wei, Chao. "Energy, the Stock Market, and the Putty-Clay Investment Model." *American Economic Review*, March 2003, 93(1), 311-324.

Figure 1. Energy Shock*



* Energy is measured as the energy component of PCE. The energy shock is the residual in a bivariate VAR with private output excluding energy. Energy shocks are identified with a Cholesky decomposition in which energy is the first variable. The periods 1979:Q4 to 1982:Q4 and post-2007 are excluded because the monetary policy rules were very different and inconsistent with our model assumptions during these periods. The VARs include two lags and a time trend as well as the log of per capita time series for real energy and real output.

Figure 2. VAR Responses to a Positive 1 Std. Dev. Energy Supply Shock*



* The impulse responses are identified in a Cholesky decomposition with energy as the lead variable. The dotted red lines are equal to the impulse response plus or minus two standard deviations.

Figure 3. Model Responses to a 1 Percent Adverse Energy Shock

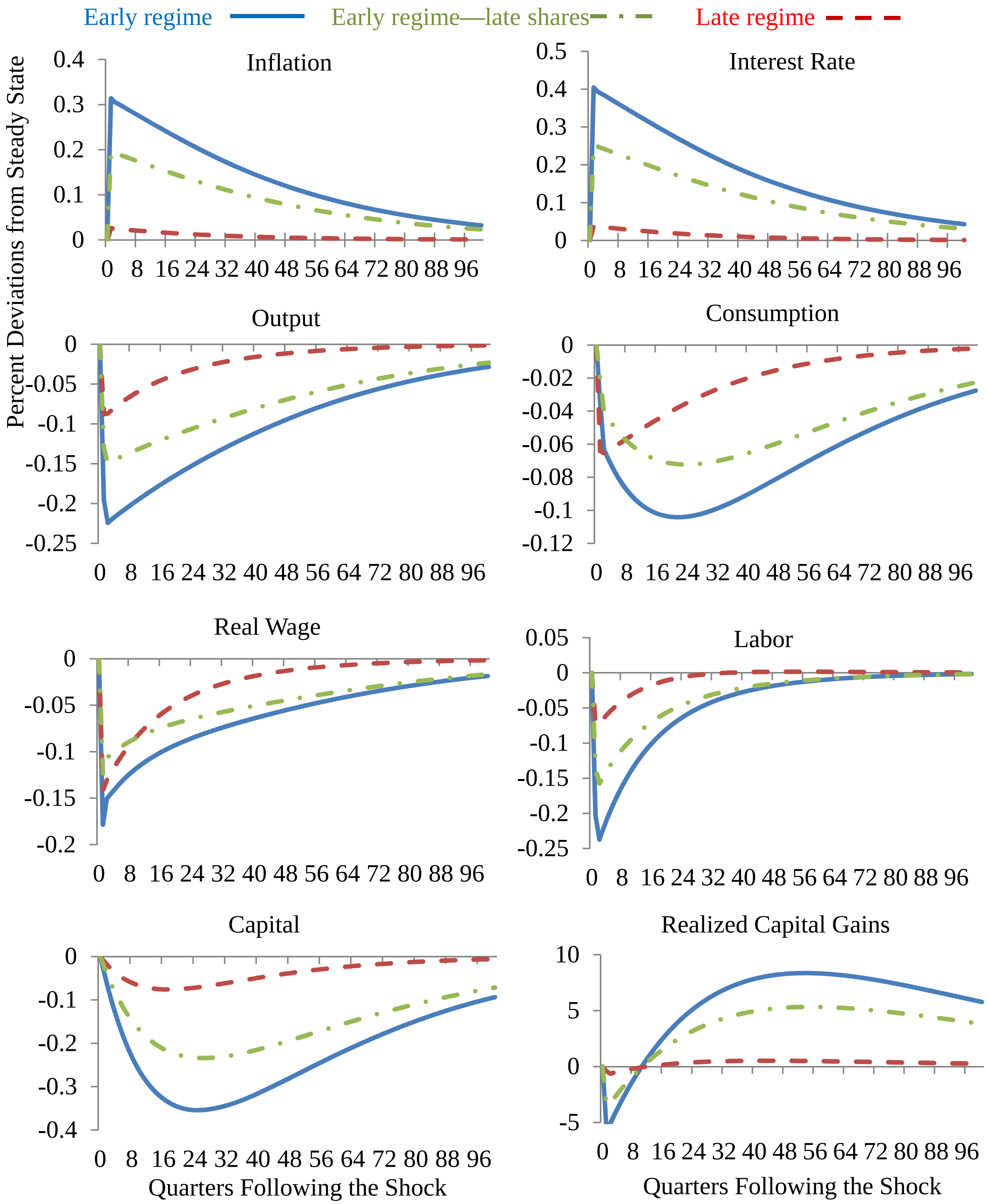


Table 1. Parameter Calibrations

Parameter	Symbol	Value*
Depreciation rate	δ	0.025
Discount factor	β	0.99
Relative risk aversion	σ	2
Capital share in production	α	0.33
Shopping-time parameter	η	1
Steady-state share of labor time	N	0.3
Steady-state share of shopping time	S	0.003
Labor tax rate	τ^n	0.24
Capital tax rate	τ^k	0.34
Bond tax rate	τ^B	0.26
Capital gains tax rate	τ^G	0.20
Steady-state ratio of realized to accumulated capital gains	G/U	0.0094
Elasticity of marginal adjustment costs w.r.t. G/U	ζ	-1.1
Steady-state output growth	γ_x	1.004
Steady-state inflation	γ_p	1.01
CES capital/energy substitution parameter	v^f	-0.9
CES consumption/energy substitution parameter	v^h	-0.9
Energy share in production	ψ	0.053/0.037
S.D. of the technology shock	σ_z	0.0059/0.0047
Persistence in technology	ρ_z	0.95
Energy share used in consumption	e_c/c	0.072/0.046
Fed's reaction to inflation	ϕ_π	0.375/0.5
Inflation target response to energy shock	ξ	0.072/0
S.D. of the energy shock	σ_e	0.0281/0.0126
Persistence in energy	ρ_e	0.92
Persistence in the inflation target	ρ_π	0.97/0.84

*If two values are shown, they represent the early/late regimes.

Table 2. Contribution of Energy Shocks to the Forecast Error Variance of Output

	1973:Q1 to 1979:Q3		1983:Q1 to 2007:Q4	
U.S. Data[1]	4-quarter	8-quarter	4-quarter	8-quarter
Energy component in PCE	47.6%	66.4%	13.4%	19.7%
EIA measure of energy used in the United States	6.0%	6.8%	0.9%	1.7%
Relative price of energy	66.6%	81.4%	6.7%	9.4%
Model results[2]	Early regime		Late regime	
Baseline	38.3%	39.6%	3.1%	2.9%

[1] These values are calculated using a bivariate VAR with U.S. data.

[2] These values are calculated using the two shocks, technology and energy, in the model.

Table 3. Cyclical Behavior of Energy: U.S. Data

1973–1979	Std. Dev.	t-5	t-4	t-3	t-2	t-1	t	t+1	t+2	t+3	t+4	t+5
y	2.4%	0.13	0.33	0.54	0.73	0.89	1	0.89	0.73	0.54	0.33	0.13
e	4.1%	0.42	0.60	0.73	0.77	0.75	0.71	0.54	0.35	0.14	-0.11	-0.17
pe	9.6%	-0.55	-0.72	-0.83	-0.83	-0.74	-0.60	-0.43	-0.23	0.00	0.21	0.30
1983–2007		t-5	t-4	t-3	t-2	t-1	t	t+1	t+2	t+3	t+4	t+5
y	1.4%	0.26	0.44	0.60	0.75	0.89	1	0.89	0.75	0.60	0.44	0.26
e	1.5%	0.45	0.49	0.49	0.45	0.42	0.35	0.19	0.01	-0.09	-0.17	-0.28
pe	8.1%	-0.08	-0.05	0.01	0.10	0.15	0.25	0.30	0.30	0.24	0.19	0.13

Corr(y_t , x_{t+i}) for x = {y, e, pe} for i = -5 to +5.

Note: y is private output less energy, e is the energy component of PCE and pe is the chain price index for the energy component of PCE.

Table 4. Cyclical Behavior of Energy: The Model

Early regime	Std. Dev.	*t*-5	*t*-4	*t*-3	*t*-2	*t*-1	*t*	*t*+1	*t*+2	*t*+3	*t*+4	*t*+5
y	1.3%	0.00	0.13	0.29	0.50	0.74	1.00	0.74	0.50	0.29	0.13	0.00
e	3.6%	0.07	0.15	0.24	0.36	0.49	0.59	0.38	0.21	0.07	-0.03	-0.10
pe	5.8%	-0.10	-0.16	-0.23	-0.31	-0.41	-0.45	-0.26	-0.10	0.01	0.09	0.15
Late regime		*t*-5	*t*-4	*t*-3	*t*-2	*t*-1	*t*	*t*+1	*t*+2	*t*+3	*t*+4	*t*+5
y	0.8%	0.00	0.12	0.28	0.48	0.72	1.00	0.72	0.48	0.28	0.12	0.00
e	1.6%	0.01	0.03	0.06	0.09	0.14	0.18	0.12	0.07	0.04	0.01	-0.02
pe	2.8%	-0.04	-0.03	-0.01	0.01	0.04	0.08	0.08	0.08	0.08	0.07	0.06

Corr(y_t , x_{t+i}) for x = {*y*, *e*, *pe*} for i = -5 to +5.

Note: *y* is private output less energy, *e* is the energy component of PCE and *pe* is the chain price index for the energy component of PCE.

Table 5. Sensitivity of Results to Policy Parameters

	Baseline early regime	Early regime, late shares	Late regime	Baseline with ρ_π=0.84	Baseline with ϕ_π=0.5	Baseline with ξ=0	Baseline with τ^B=0	Baseline with τ^G=0	Baseline with τ^B and $\tau^G = 0$
	1	2	3	4	5	6	7	8	9
y	-7.5	-5.3	-1.7	-3.2	-4.6	-3.0	-2.9	-3.1	-2.1
c	-4.8	-3.4	-1.7	-2.8	-3.5	-2.7	-2.6	-3.3	-2.3
i	-21.9	-15.0	-3.7	-7.8	-12.4	-7.2	-7.1	-5.0	-3.8
k	-15.5	-10.5	-2.7	-5.7	-8.9	-5.2	-5.2	-3.7	-2.8
n	-3.7	-2.6	-0.7	-1.4	-2.1	-1.3	-1.3	-2.2	-1.0
w	-4.5	-3.5	-2.3	-3.3	-3.7	-3.3	-3.3	-2.5	-2.9
R	13.0	8.4	0.9	3.5	6.5	2.8	2.0	14.1	2.1
r	3.3	2.1	0.3	1.0	1.7	0.8	0.1	3.7	0.2
rat	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.2
π	10.0	6.4	0.6	2.6	4.9	2.0	1.9	10.7	2.0
π*	1.8	1.1	0.0	0.4	1.8	0.0	1.8	1.8	1.8

Monetary policy parameters in the baseline early regime are ρ_π=0.97, φ_π=0.375, and ξ=0.072.
Monetary policy parameters in the late regime are ρ_π=0.84, φ_π=0.5, and ξ=0.
The energy share in consumption is 0.072 in the early regime and 0.046 in the late regime.
Tax rates in both baseline regimes are τ^n=0.244, τ^B=0.258, τ^k=0.341, and τ^G=0.202.
The present value of energy deviations is -11.2 percent following the 1 percent shock.