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A Quantitative Analysis of Oil-Price Shocks, Systematic Monetary Policy, and Economic Downturns[1]

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ABSTRACT

Are the recessionary consequences of oil-price shocks due to oil-price shocks themselves or to contractionary monetary policies that arise in response to inflation concerns engendered by rising oil prices? Can systematic monetary policy be used to alleviate the consequences of oil shocks on the economy? This paper builds a dynamic general equilibrium model of monopolistic competition in which oil and money matter to study these questions. The economy's response to oil-price shocks is examined under a variety of monetary policy rules in environments with flexible and sticky prices. We find that easy-inflation policies amplify the negative output response to positive oil shocks and that systematic monetary policy accounts for up to two thirds of the fall in output. On the other hand, we show that a monetary policy that targets the (overall) price level substantially alleviates the impact of oil-price shocks.

1. Introduction

Are the recessionary consequences of oil-price shocks due to oil-price shocks themselves or to contractionary monetary policies that arise in response to inflation concerns engendered by rising oil prices? Recent work by Bernanke, Gertler, and Watson (1997) argues the latter: an alternative monetary policy to the one in place during the 1970s could have largely eliminated the negative output consequences of the oil-price shocks experienced by the U.S. in the 1970s and 1980s. This view has recently been challenged in a paper by Hamilton and Herrera (2000), which maintains that Bernanke, Gertler, and Watson's (BGW) empirical model is misspecified. Hamilton and Herrara argue a model that is more consistent with the time series properties of the data upholds the conventional view that it is the increases in the price of oil that lead directly to contractions in real output and that contractionary monetary policy plays a secondary role in amplifying or mitigating the resulting economic fluctuations. Thus, while there is widespread agreement that oil-price shocks have been an important factor for the volatility of real output in the postwar period, there is less agreement on the channel of transmission.

Analyses of the role of the interaction between oil-price shocks and monetary policy in generating recessions have largely been based on empirical vector autoregression (VARs) models that generate impulse responses of economic variables to oil-price shocks under alternative monetary policy reaction functions. These reduced-form models are largely silent on the channels through which oil-price changes affect real output. Further, any VAR-based analysis of the reaction of the economy to oil-price shocks under alternative monetary policy specifications runs squarely into the Lucas critique: It is problematic to assume that reduced-form coefficients are stable across different policy regimes. Sims (1997), in his discussion of the BGW paper, points out some of the difficulties of basing alternative policy simulations on reduced form estimates, especially when the alternative policies considered are far from historical experience. Indeed, as Sims points out, the fixed-interest-rate rule estimates in BGW imply explosive behavior in prices.

The contribution of this paper is to examine the economy's response to oil-price shocks under alternative monetary policy rules using a stochastic, dynamic general equilibrium model and to quantify the relative importance of both oil-price shocks and monetary policy as contributing factors to recessionary episodes. Since the model is based on the primitives of preferences, technology, policy rules, and the stochastic processes governing shocks, it provides a structural alternative for examining how the economy responds to shocks under different monetary policy specifications.

The literature has emphasized several different channels through which oil-price shocks might affect real output apart from any monetary-policy-induced effects. First, oil enters the production function of firms just like any other input. If oil and capital are complements, then an increase in the price of oil leads firms to demand less oil and capital and brings about a fall in production. An increase in the price of oil also acts like a tax that transfers income from oil-importing to oil-exporting nations. To the extent that oil exporters do not spend all their oil revenues on goods from oil-importing nations, demand and production will fall in the latter. Oil-price movements may also increase the uncertainty that investors face. Increased risk may lead investors to delay new investment projects with a subsequent lowering of future output. Finally, as emphasized by Hamilton (2000), oil-price movements may not affect all firms equally. In response to oil-price shocks, production and employment may respond more in some industries than in others. If it is costly to shift labor and capital across sectors of the economy, then employment and output will fall following a rise in oil prices.

The extent to which each of these factors is a contributor to the transmission of oil-price shocks to the real economy remains an open question. We build a model that focuses on the first two channels described above. Oil usage is tied to how intensively monopolistically competitive firms use capital. Greater capital utilization requires more oil input, which is assumed to be supplied only from abroad. The supply of oil is taken to be exogenous in the model, and foreign oil producers do not spend any of the proceeds on the oil-importing country's domestic output. The production side of our model follows Finn (1995) and thus differs from Kim and Loungani (1992) and Rotemberg and Woodford (1996), who have oil entering directly in firms' production functions.

We model firms as monopolistic competitors in order to examine how oil-price shocks and monetary policy interact to produce volatility in models with both flexible and sticky prices. We begin by modeling an economy with flexible prices and in which households face a cash-in-advance constraint on consumption purchases in a limited participation environment. As shown by Christiano (1991), the portfolio rigidity in the limited participation setup allows monetary shocks to have liquidity effects in addition to the usual anticipated inflation effects. Which effect dominates depends on how the models are parameterized. We then introduce sticky prices to examine the sensitivity of our results to an alternative environment. In the sticky price version of the model, monetary policy affects the economy through an additional channel: by stimulating aggregate demand that firms then meet by raising output and increasing employment.

Within this basic framework we embed a monetary authority that follows either a money growth rate rule or one of a variety of simple Taylor rules that set the short-term nominal interest rate as a function of inflation and output. We then examine the response of the economy to oil-price shocks under these alternative policy rules. Calibrating the model to match certain features of the U.S. economy, we find that an easy-inflation policy amplifies the negative impact of positive oil shocks on output. The driving force behind these results is the following. A dovish central bank attempts to respond to the shock by aggressively lowering the nominal interest rate, which tends to lower the financing cost for the firm and thus increase employment and output. To do so, the central bank increases the growth rate of money. However, an aggressive lowering of the nominal interest rate requires a substantial monetary injection that raises current and future inflation. Inflation jumps up enough that, since the central bank cares about inflation as well, the nominal interest rate actually ends up rising. This in turn leads to an even more substantial drop in output.

We also study the economy's response to a rise in the price of oil under other monetary policy rules that have been proposed as potentially good guides to the conduct of monetary policy. In particular, we compare the response of the economy to an oil-price shock when the central bank follows a rule that pegs either the inflation rate, or the price level, or the nominal short-term interest rate. Contrary to BGW, we find that pegging the interest rate slightly amplifies the drop in output and the rise in inflation following an exogenous oil-price increase. On the other hand, the central bank could substantially alleviate the impacts of oil-price shocks by adopting a policy that targets the (overall) price level. The intuition behind this result is that to keep the price level constant as oil prices are rising, the central bank needs to deflate domestic non-oil prices. This calls for a restrictive monetary policy that leads to less expected inflationary pressures and a resulting fall in the nominal interest rate. Lower interest rates then stimulate employment and output. In this sense the best policy is tough medicine.

Negative oil-price shocks are often cited as examples of negative total factor productivity (TFP) shocks. We show that attempting to capture the effects of oil-price shocks on the economy indirectly by studying negative shocks to TFP can be misleading. Oil-price shocks imply a different response of relative prices than do TFP shocks. Because monetary policy reacts, in part, to movements in inflation this different response of prices leads to different policy responses that substantially affect the impact on output.

Finally, our model structure is one in which oil-price movements have symmetric effects on output. That is, oil-price increases lower output and oil-price decreases raise output. In the data, however, oil-price shocks appear to have an asymmetric effect on output–oil-price increases are followed by lower output, but oil-price decreases have little, if any, effect on output. Our focus is on the recessionary consequences of positive oil-price shocks and on how monetary policy interacts with oil-price shocks to amplify or mitigate the output response to such oil-price increases. We use the model to study the impact of oil-price increases under alternative policy rules. While we are unable to capture the asymmetric response of output to oil-price shocks, the model does generate what look like recessions following an oil-price increase.

The rest of the paper is organized as follows. Section 2 presents the model, and Section 3 describes its calibration. The results, for both the closed and the small-open economies, are described in Section 4. Section 5 concludes.

2. Model

In this section we present a dynamic monetary model with monopolistic competition in which oil use is tied to the capital utilization rate. The model structure has elements from Hairault and Portier (1993), Finn (1995), and Christiano (1991). Our simulations will examine the behavior of both flexible and sticky price versions of the model under a variety of monetary policy rules.

2.1. Preferences and technology

The economy comprises h households, indexed by i, which are identical, and n firms indexed by j. Firm j produces Y_j units of good j and all firms share a common production technology

$$Y_{j,t} \leq A_t (u_{j,t} K_{j,t})^{\alpha} H_{j,t}^{1-\alpha}$$

with $K_{j,t}$ the capital stock used by firm j with variable utilization rate $u_{j,t}$, and $H_{j,t}$ the quantity of labor used in production. The production technology is subject to random shocks A_t which are common across all firms.

Households i has preferences given by:

$$E_0 \sum_{t=0}^{\infty} \beta^t U(C_{i,t}, L_{i,t})$$

with $L_{i,t}$ leisure supplied by household i and $C_{i,t}$ a CES aggregate of the n consumption goods produced in the economy:

$$C_{i,t} = (\sum_{j=1}^{n} C_{j,t}^{\frac{\theta-1}{\theta}})^{\frac{\theta}{\theta-1}},$$

with θ a parameter governing the elasticity of substitution across goods. The price index P_t is given by:

$$P_t = (\sum_{j=1}^{n} P_{j,t}^{1-\theta})^{\frac{1}{1-\theta}}$$

which satisfies $P_t C_{i,t} = \sum_{j=1}^{n} P_{j,t} C_{i,j,t}$.

Household i begins a period with $M_{i,t}$ dollars that are carried over from the previous period's economic activity. Prior to the realization of any current-period stochastic shocks, the household deposits $N_{i,t}$ dollars with the financial intermediary. The remaining money balances are used to finance consumption purchases. The household faces a cash-in-advance constraint on its consumption purchases:

$$P_t C_{i,t} \leq M_{i,t} - N_{i,t}.$$

Households rent accumulated capital to firms and sell labor services $H_{i,t}$ subject to the constraint $L_{i,t} + H_{i,t} \leq 1$. Capital is a composite of the n goods, given as a CES aggregate. Following Hairault and Portier (1993), we assume that the investment index has the same structure as the consumption index. Thus:

$$K_{i,t+1} = (1 - \delta(u_{i,t}))K_{i,t} + I_{i,t}$$

where:

$$I_t = \left(\sum_{j=1}^{n} I_{j,t}^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}}$$

Note that the depreciation rate on capital depends on how intensively it is used in production $(u_{i,t})$. We specify:

$$\delta'(u_t) > 0, \ \delta''(u_t) > 0.$$

To induce an aggregate liquidity effect in response to unanticipated monetary shocks, households are assumed to face a portfolio rigidity. Households deposit funds at a financial intermediary before any monetary shock is observed. After making a deposit, households are unable to rebalance portfolios for the remainder of the period: they must wait until the following period. After the deposit decision is made, period uncertainty is resolved. In particular, the household makes its consumption, investment, and labor supply decisions after observing all of the current period's shocks. At the end of the period, the household receives labor income, principal, and interest from the intermediary deposit, cash dividend payments from the intermediary and firm, and earns the rental rate z_t on its capital stock. Thus, money balances evolve according to

$$M_{i,t+1} = M_{i,t} - N_{i,t} - P_t C_{i,t} - P_t I_{i,t} + R_t N_{i,t} + W_t H_{i,t} + z_t K_{i,t} + \Pi_{i,t}^f + \Pi_{i,t}^b$$

where W_t is the nominal wage, R_t is the gross nominal interest rate, Π_t^f is the cash dividend paid by the firm, and Π_t^b is the cash dividend paid by the financial intermediary. The financial intermediary accepts deposits from households and receives the monetary injection (X_t) from the central bank. These funds $\sum_i N_{i,t} + X_t$ are then loaned out to firms at the gross interest rate R_t. Consequently, the aggregate cash dividend received by households from the bank satisfies $\sum_i \Pi_{i,t}^b = R_t X_t$.

Firms are required to borrow funds from financial intermediaries at the gross nominal rate R_t to finance their current-period wage bill. These loans must then be repaid at the end of the period. In addition, firm j must purchase energy ($e_{j,t}$) for use in production at the price P_t^e. To capture the impact of OPEC on the supply of oil, we assume that the price of energy (oil) is exogenous.[1] Following Finn (1995), energy utilization is tied to capital utilization: the more intensively capital is used, the greater the energy requirement:

$$\frac{e_{j,t}}{K_{j,t}} = a(u_{j,t})$$

with

$$a'(u_t) > 0, \; a''(u_t) > 0.$$

[1]Backus and Crucini (2000) looked at a three-country model in which the supply of oil was, in part, exogenous.

Firms choose labor, capital, utilization, and energy to maximize the discounted value of dividend payments:

$$E_0 \sum_{t=0}^{\infty} \beta^{t+1} \vartheta_{t+1} \Pi^f_{j,t}$$

where

$$\Pi^f_{j,t} \equiv P_{j,t} Y_{j,t} - W_t H_{j,t} R_t - z_t K_{j,t} - P^e_t e_{j,t} - P_t \frac{\phi}{2} \left(\frac{P_{j,t}}{P_{j,t-1}} - \overline{g} \right)^2 .$$

The last term in the expression represents a cost of price adjustment, with $\overline{g}$ the mean money growth rate. Firms do not face price-adjustment costs in steady state (there is no growth in the model). Note that the time t dividend is discounted with a time $t+1$ discount factor (stochastic pricing kernel ϑ_{t+1}) because households cannot use current-period dividends to finance current-period consumption.

The firm maximizes discounted cash flow subject to the constraint:

$$Y_{j,t} \leq Y^d_{j,t}$$

where $Y^d_{j,t}$ is the total demand for firm j's output. Maximizing the CES consumption index subject to the expenditure constraint gives the demand for firm j's output as:

$$Y^d_{j,t} = \left(\frac{P_{j,t}}{P_t} \right)^{-\theta} Y^d_t$$

with:

$$Y^d_t = \sum_{i=1}^{h} (C_{i,t} + I_{i,t}) + \sum_{j=1}^{n} \frac{\phi}{2} \left(\frac{P_{j,t}}{P_{j,t-1}} - \overline{g} \right)^2 .$$

2.2. Equilibrium

We assume a symmetric monopolistic competition equilibrium in which behavior is identical across households and across firms. This allows us to treat the economy as comprising a representative household and a representative firm.

Let $s_{i,t} = \{K_{i,t}, M_{i,t}, \Omega_t\}$ be the state vector for household i, where $\Omega_t = \{A_t, P^e_t\}$ is the exogenous part of the state vector. A symmetric monopolistic competition equilibrium for the economy is a set of household decision rules for $C_{i,t}(s_{i,t})$, $K_{i,t}(s_{i,t})$, $H_{i,t}(s_{i,t})$, $M_{i,t+1}(s_{i,t})$, $N_{i,t}(s_{i,t})$, a set of capital, price, and labor decision rules for firms $K_{j,t}(s_{j,t}), P_{j,t}(s_{j,t})$, and $H_{j,t}(s_{j,t})$, and a price vector$\{P_{j,t}, z_t, W_t, R_t\}_{j=1}^{n}$ such that households maximize utility subject to their constraints, firms maximize profits subject to their constraints, and the capital, goods, labor, and money markets clear. Finally, for symmetry, $s_{i,t} = s_{h,t}$ for all i and $s_{j,t} = s_{f,t}$ for all j. Thus, in a symmetric equilibrium all households face the same state vector and all firms face the same state vector.

3. Calibration

3.1. Preferences and technology

We specify household preferences by:

$$U(C_t, 1 - L_t) = \frac{(C^{\eta}(1 - L)^{1-\eta})^{1-\sigma}}{1 - \sigma}$$

with γ set so that the agent works a third of his time in steady state. The discount factor β is 0.99 so we think of a period in the model as a quarter.

We set θ (the parameter governing the elasticity of substitution across goods) to 6.17, which yields a steady-state markup of 1.19, a value similar to that estimated by Morrison (1990); this value is standard in the literature. When we examine the sticky price version of the model we specify the parameter of the price-adjustment cost function $\phi = 0.10$ which implies that firms contemporaneously erase about 50 percent of the discounted gap between the sequence of expected future prices and the sequence of prices that would be optimal, if there were no adjustment costs. The value we use for ϕ in the stick price version of the model is consistent with the value estimated by Kim (2000).

We follow Finn's (1995) specifications for the utilization and depreciation functions $a(u_t)$ and $\delta(u_t)$:

$$a(u_t) = \frac{1}{\gamma_1} u_t^{\gamma_1}$$

$$\delta(u_t) = \frac{1}{\gamma_2} u_t^{\gamma_2}.$$

The parameters γ_1 and γ_2 are calibrated so that both the depreciation rate on capital $\delta(u)$ and the ratio of oil usage to the capital stock ($e_t/K_t = a(u_t)$) equal the averages found in the data over the sample 1973 to 1999. Since our focus is on the impact of oil-price shocks, we measure energy usage e_t as average oil usage for the private and government sectors and K_t as the average capital stock measured as private nonfarm, nonresidential capital.

The production function is Cobb-Douglas:

$$F(K_t u_t, H_t, z_t) = A_0 \exp(\mu_t)(u_t K_t)^\alpha H_t^{1-\alpha}$$

with share parameter $\alpha = 0.34$. The technology shock process is given by $\mu_t = \varphi\mu_{t-1} + \varepsilon_t$ with $\varphi = 0.95$.

3.2. Monetary policy

We analyze the economy's response to oil-price shocks under a variety of monetary policy rules.[2] We first study the model under interest-rate rules, which, following Clarida, Gali, and Gertler (2000) (CGG) are of the form:

$$i_t = \rho i_{t-1} + (1-\rho)\Theta(\pi_t - \pi^*) + (1-\rho)\Psi(Y_t - Y^*) + \xi_t, \tag{3.1}$$

where π^* and Y^* are steady-state levels of inflation and output. CGG examine the empirical performance of this rule over the post-1979 period and estimate the parameters $\widehat{\rho} = 0.79$, $\widehat{\Theta} = 2.15$, and $\widehat{\Psi} = 0.93$. Our baseline parameterization of the monetary policy rule uses the following estimates: $\rho = 0.9$, $\Theta = 2.15$, and $\Psi = 0.93$. We concentrate on the post-1979 estimates because we are interested in finding the impact of oil-price shocks on the economy using a rule that gives unique equilibria. CGG's pre-1979 estimates imply multiplicity of equilibria in our model (see Christiano and Gust (1999) and CGG).[3] The slightly higher value of ρ under our baseline parameterization is chosen so as to give unique rational expectations equilibria under a wide range of values for $\widehat{\Theta}$ and $\widehat{\Psi}$.

Since one objective of the paper is to study the extent to which central banks can alleviate the effects of oil-price shocks through the use of different policy

[2] When there is no price-adjustment cost, the optimal monetary policy in this model is a Friedman rule that sets the nominal interest rate to zero each period. Positive nominal interest rates distort economic activity via the cash-in-advance constraints faced by the firm and household. Since we do not generally observe economies operating under the Friedman rule and since we are interested in computing the respective contributions of oil shocks and systematic monetary policy to economic downturns, we assume a second-best world in which the central bank follows an empirically relevant rule.

[3] Our value of ρ is slightly higher than CGG's in order to guarantee a unique equilibrium under a variety of weights on the inflation and output gaps.

functions, we also simulate the model assuming that the central bank lets the money supply adjust endogenously to target either the inflation rate, the price level, or the interest rate:

$$\lambda_{k,t} = \lambda_k^*, \qquad\qquad \lambda_k = \{\pi,\ p,\ i\}. \tag{3.2}$$

We use the model's first order conditions to solve for steady state and then linearize the system of equilibrium conditions around it. Before discussing the findings, we first present the empirical response of the U.S. economy to an increase in the price of oil.

3.3. Calibrating the output response to an oil-price shock

We calibrate the model so that the output response following an oil-price shock approximates that found in the U.S. data. There is a large literature documenting how U.S. real output responds to oil-price shocks over the post-WWII era. The data suggest that the output response is asymmetric: output responds much more to a rise in oil prices than to a fall. Note that this feature of the data is not captured by our model, which has a symmetric response of output to positive and negative oil-price shocks. Since our primarily focus is on the consequences of alternative monetary policy responses to oil-price increases, we calibrate the model to match that feature of the data.

Hamilton (2000) provides a nice discussion of the empirical literature on oil-price shocks and macroeconomic activity. The empirical literature suggests that oil-price increases have a much greater effect on output than do oil-price decreases. This asymmetry has been modeled in many ways. For the purposes of this paper we choose a simple VAR specification that gives results that are in line with those found in the literature. To get an empirical estimate of the output response to positive oil-price shocks, we run a VAR using the following variables: log level real GDP less domestic oil production, log level CPI less energy, federal funds rate, and oil-price increases. The data are quarterly, with the estimation period running from 1973Q1 to 2000Q4. Oil-price increases are constructed by taking the first difference of the log of oil prices, then setting negative values to zero. Thus, only oil-price increases affect the other variables in the system. The oil-price series is the spot price of West Texas Intermediate Crude.

The responses of real GDP (LRY), prices (LPRICE), and interest rates (FEDFUNDS) to a one-standard-deviation increase in the oil-price series (POSOIL) are plotted in Figure 1. We used a Cholesky decomposition to compute the responses with the ordering oil-price increases, output, prices, interest rates. However, the impulse responses are not sensitive to alternative orderings. We find that in response to an increase in the price of oil (a one-standard-deviation increase in the figure), real output falls, the price level rises, and interest rates initially rise, then fall. The magnitude of the impulse responses implies that, at its maximum, real output falls 4.5 percent in response to a doubling of the price of oil. We calibrate our model using the steady state relative price of oil so that the model matches this output response to an oil-price increase.[4]

4. Results

4.1. Impulse responses

To get some intuition for the basic operation of the model, we first look at the response of the economy to a doubling of oil prices when monetary policy follows our benchmark Taylor rule ($\rho = 0.9$, $\Theta = 2.15$, $\Psi = 0.93$) and prices are perfectly flexible. The solid lines in Figure 2 show the responses of capacity utilization, investment, inflation, hours worked, output, and nominal interest to a doubling of the price of oil. An increase in the price of oil causes a direct income effect, via the resource constraint, that reduces consumption and increases work effort. With a higher price of oil, the cost of capital utilization rises, so firms use capital less intensively. This leads to a direct effect on production that reduces output and reinforces the negative income effect of the rise in oil prices. Lower capital utilization also reduces the marginal productivity of labor and, thus, the real wage. This induces households to substitute out of work effort and into leisure, with substitution effects dominating income effects. Capital accumulation is discouraged as agents smooth consumption and expect a lower return to investment. The persistence in the process for oil prices generates the persistence in these impulse responses.

The nominal interest rate rises following the oil-price increase. This happens because the fall in output leads to an increase in the price level and the inflation rate. Since the central bank places relatively more weight on deviations of the

[4]Since to solve the model we linearize the system of equlibrium conditons around the deterministic steady state, the value of the relative price of oil in steady state affects the response of output to an oil-price shock.

inflation rate from its target than to the output gap, it raises the nominal interest rate. Therefore, the increase in the interest rate contracts the demand for financing, even more and adds to the negative impact on output. Note that the interest rate rises even though the drop in output leads firms to demand less labor and financing which, other things equal, puts downward pressure on the interest rate. Given a different monetary policy, the interest rate can potentially fall following an increase in the price of oil.

To put the contribution of systematic monetary policy in perspective we also trace out the effects of an oil-price shock assuming monetary policy follows a k percent rule in which the growth rate of money is determined exogenously. The economy's response to this rule is shown by the dotted lines in Figure 2. Except for the nominal interest rate, the economy's response to a doubling of oil prices is qualitatively the same as that of the benchmark-Taylor-rule economy. Under the k percent rule, though, the interest rate falls because firms need less financing because of the drop in production. Note, though, that a doubling of oil prices has a much smaller impact on the economy when the central bank follows a k percent rule. For instance, the drop in output following a doubling of oil prices is only about 25 percent of that under the benchmark Taylor rule. In the next section we present estimates of the contributions of oil shocks and systematic monetary policies to the fall in output.

4.2. Systematic monetary policy and oil-price shocks

We now consider how the economy responds to oil-price shocks under a variety of interest rate rules. Figures 3 and 4 display the responses of output, inflation, and the nominal interest rate for Taylor-type interest rate rules that differ in the weights placed on the inflation and output gaps. The figures plot the responses for ranges of $(1-\rho)\Theta$ and $(1-\rho)\Psi$ (see equation (3.1)) as we vary Θ and Ψ. We again let the price of oil double. The ranges over which we let Θ and Ψ vary give unique equilibria. Generally, we find that for values of Θ much lower than those shown in the figure (and conditional on $\rho = 0.9$) we get indeterminacy.

Figure 3 shows the results when the central bank puts increasing weight on deviations of inflation from steady state for a given weight on the output gap. A hawkish policy (one that puts a higher weight on inflation) is beneficial in the sense that it leads to a smaller loss in output and a lower inflation rate, as well as low nominal interest rates. This is especially so when the weight on output is relatively high. For instance, the third row of Figure 3 shows that when the central bank places a low weight on inflation and a high weight on the output gap ($\Psi = 1.8$), the fall in output is most severe, as is the rise in inflation. Recall that under our benchmark calibration that matched the postwar estimates from Clarida, Gali, and Gertler (2000), the parameters governing the weight on the inflation and the output gaps are set to 2.15 and 0.93, respectively. This parameterization corresponds to point A in Figure 2. Needless to say, for this parameterization the central bank's reaction function adds to both the drop in output and the rise in inflation following an increase in oil prices compared to a more hawkish policy.

Figure 4 shows the same variables' responses when the central bank puts increasing weight on the output gap, for a given weight on inflation. We see that an increasing weight on the output gap amplifies all of the variables' responses. Again, under the benchmark calibration, the economy's responses would be at point A.

The driving force behind these results is the following. A dovish policy (one that puts a high weight on the output gap and a low weight on inflation) attempts to respond to the rise in oil prices by aggressively lowering the nominal interest rate, which tends to lower the financing cost for firms and stimulate employment and output. To do so the growth rate of money must be increased. However, an aggressive lowering of the nominal interest rate requires a substantial monetary injection that raises current and future inflation. Inflation jumps up enough that, since the central bank cares about inflation as well, the nominal interest rate actually ends up rising. This in turn leads to an even more substantial drop in output. In our framework, even though the central bank puts a lot of weight on trying to stabilize output, it can end up leading to an even greater drop in output as well as higher inflation.[5] Note that if the weight on inflation in the policy rule were to be lowered further in order to try to minimize the anticipated inflation effect, the model solution becomes indeterminate.

The literature on monetary policy rules has also argued that an inflation target or a price-level target could be a useful guide for policymakers. To gauge the potential impact of different systematic monetary policies, we simulated the model when the central bank pegs either the inflation rate, the (overall) price level, or

[5] Christiano and Gust (1999) find similar results in response to a shock to total factor productivity in a slightly different monetary framework without oil prices.

the interest rate according to (3.2).[6] Figures 5 presents the results of this exercise. We find that the interest rate rule estimated by Clarida, Gali, and Gertler (2000), which we use in our benchmark calibration, amplifies both the drop in output and the increase in the inflation rate, relative to the proposed alternative rules. The economy responds about identically to a rise in the price of oil, under either inflation targeting or an interest rate peg. Under these two rules, the drop in production is more than halved compared to the interest rate rule. Note that, contrary to BGW, we do not find that pegging the interest rate in the face of rising oil prices would erase the negative output response. As Sims (1997) pointed out, the fixed-interest-rate rule estimates in BGW imply explosive behavior in prices. When this explosive behavior is ruled out and the behavior of the economy is stationary, an interest rate peg does not lead to a positive movement in output. In our framework, to get a positive output response following an oil shock, the central bank would need to target the price level. Indeed, output increases by approximately 1.5 percent following a doubling of oil prices. This may initially appear puzzling, since, *ceteris paribus*, a rise in the cost of production should lead to a drop in output. However, under price-level targeting, the central bank needs to deflate prices in the nonoil sector of the economy to keep the (overall) price level from rising. This implies a restrictive monetary policy that in turn leads to less expected inflationary pressures and ultimately a fall in the nominal interest rate. The anticipated inflation effect outweighs the liquidity effect primarily because the drop in the money growth rate necessary to stabilize prices is persistent. Since firms must borrow funds to finance labor input, the lower nominal interest rate leads to increased employment and output.

Finally, we present model-based estimates of the contributions of oil-price shocks and systematic monetary policy to economic downturns. To isolate the contribution of a rise in the price of oil to the drop in output, we assume that monetary policy follows a k percent rule as described in the previous section. This implies that, following the oil-price shock, monetary policy stays constant

[6] Pegging the nominal interest rate in our environment leads to the well-known problem of price-level indeterminacy. To get around that problem we mimic a pure interest-rate *peg* by simulating the model using an interest-rate *rule* with very small weights on inflation and output deviations and $\rho = 1.0001$. This leads to a unique rational-expectations equilibrium in which the movements in the nominal interest rate are extremely small. (For a discussion of similar results and a more exhaustive study of the regions of indeterminacy in models with sticky prices or limited participation see Rotemberg and Woodford (1999) and Christiano and Gust (1999)) An alternative strategy would be to use the fiscal theory of the price level.

and the impact on output can be solely attributed to the oil-price shock itself. By simulating the model under alternative monetary policy rules and comparing the results to those of the k percent rule we can get an estimate of the importance of the systematic part of monetary policy in contributing to the movements in real output. We consider the following exercise. We take our benchmark model and calibrate it so that the fall in output after a doubling of oil prices matches that implied by our VAR estimates. We then replace the Taylor rule monetary policy with a k percent rule policy and calculate the cumulative drop in output after a doubling of oil prices. We treat the resulting cumulative drop as being entirely due to oil-price shocks with no contribution from systematic monetary policy. The model is then simulated under alternative policy rules and impulse responses are calculated for a doubling of oil prices. From the cumulative drops in output under these various rules, we subtract the cumulative drop in output under the k percent rule to assess the contribution of systematic monetary policy to recessions following oil-price shocks. Table 1 presents the results of this exercise. We find that systematic monetary policy can be a nonnegligible factor that amplifies the initial negative impact of rising oil prices on output. In fact, under the interest rate rule (and holding TFP constant), about two thirds of the fall in production can be attributed to systematic monetary policy. Since, according to Clarida, Gali, and Gertler (2000), this rule appears to an accurate description of the behavior followed by the Federal Reserve's Federal Open Market Committee, the results give some weight to the arguments that oil shocks by themselves do not cause recessions. Rather, the way the central bank systematically responds to movements in output and inflation following a rise in the price of oil is the main reason output drops so much. The negative output consequences of oil-price shocks would also be less severe if the central bank kept the nominal interest rate constant. In this case, monetary policy would contribute only about 6 percent to the fall in output. In this sense, our results are similar to those of BGW, although, as we argued previously, the central bank, in our model, cannot eradicate the negative impact of oil-price shocks on output by targeting the interest rate. The table finally shows that the recessionary effects of oil-price shocks can, to a certain extent, be alleviated if the central bank targets either the inflation rate or the overall price level. The fall in output is only 0.3 percent under the latter policy compared to 6.4 percent under the k percent rule.

4.3. Systematic monetary policy and TFP shocks

Oil-price shocks are often cited as examples of bad TFP shocks. An obvious question is whether explicitly modeling energy useage is important or whether the same results are obtained by studying the impact of TFP shocks. To demonstrate the importance of introducing oil we reproduced Figure 5 assuming that TFP initially falls instead of assuming that the price of oil rises. The shock to TFP is such that the response of output, under the interest-rate rule, is the same as that following a doubling of oil prices. Figure 6 reports the results. It shows that analyzing the impacts of oil-price shocks indirectly through TFP shocks may be misleading. Contrary to our results in Figure 5, Figure 6 shows that none of the systematic monetary policies we examine lead to a positive output response following a negative TFP shock. TFP and oil-price shocks lead to different responses of output under the price-level target because they imply different movements in core prices. To keep the price level constant following a rise in the price of oil the central bank must deflate prices in the nonoil sector, which ultimately leads to a lower nominal interest rate. Since, following a negative TFP shock, the price of oil stays constant, the central bank does not need to deflate the nonoil sectors of the economy as much to keep the price level constant. As a result, the nominal interest rate falls less following a TFP shock. Explicitly introducing an oil sector matters because it affects monetary policy through the relative price channel.

4.4. Sticky prices

Up to this point, we have assumed that prices were perfectly flexible. It is natural to consider whether adding price stickiness has a significant impact on our findings. Price stickiness is easily parameterized in the model by setting the adjustment cost parameter ϕ to a positive nonzero value. As discussed above, our parameterization sets $\phi = 0.10$. All other parameter values are kept the same as in the flexible price version of the model. Figures 7 and 8, which replicate the experiments plotted in Figures 2 and 5, show how the sticky price economy responds to a doubling of oil prices under a range of monetary policy rules. A comparison of these figures to those for the flexible price economy shows that there is no qualitative difference and little quantitative difference in the response of the two economies to an oil-price shock. Table 2 shows how oil-price increases and systematic policy account for output downturns following oil-price increases in the sticky price economy. Comparing these results to those in Table 1 (the flexible price economy) shows little difference in the performance of the two models. In both cases a systematic interest rate rule that adjusts the nominal interest rate in response to inflation and output gaps can have a significant impact on the response of the economy to exogenous oil-price shocks. Further, the accounting exercise gives virtually the same answers for the flexible price and sticky price versions of the model. We conclude that adding sluggish price adjustment, in this particular model framework, does little to change the quantitative conclusions reached from examining the flexible price environment.

5. Conclusion

Our model suggests that alternative monetary policy rules lead to a wide variety of economic responses to oil-price shocks. Easy inflation policies are seen to amplify the impacts of oil-price shocks on output and inflation while a policy that targets the overall price level is much better able to smooth out the impacts of oil-price shocks. Generally, systematic monetary policy is seen to play a substantial role in how the economy responds to oil-price shocks. A version of the model that uses an interest rate rule calibrated to match that followed by U.S. monetary authorities in the post-Volcker era implies that up to two thirds of the economy's response to oil-price shocks is due the way monetary policy responds to those shocks. While our results suggest that central banks cannot fully insulate their economies from the consequences of oil-price shocks, the way in which monetary policy is conducted plays a substantial role in how the consequence of oil-price shocks play out in the economy.

6. Appendix: Solving for Equilibrium

The representative household's problem is:

$$\max E_0 \sum_{t=0}^{\infty} \beta^t U(C_t, 1 - H_t)$$

subject to the cash-in-advance constraint:

$$P_t C_t \leq M_t - N_t$$

and the budget constraint:

$$M_{t+1} = M_t - N_t - P_t C_t - P_t I_t + R_t N_t + W_t H_t + r_t K_t + \Pi_t^f + \Pi_t^b$$

by choice of $\{C_t, H_t, K_{t+1}, N_t, M_{t+1}\}$.

Define $M_t^c = M_t - N_t$ as the cash set aside by the household for consumption purchases. Let the economywide state vector be denoted by S_t and the state vector for the individual household be (K_t, M_t^c, N_t, S_t). If $V(K, M^c, N, S)$ is the maximized utility of the household in state (K, M^c, N, S), then V satisfies

$$\begin{aligned} V(K, M^c, N, S) &= \max\{U(C, 1-H) + \beta E_t V(K', M^{c\prime}, N', S') + \\ &\quad \lambda_1[RN + WH + rK + \Pi^f + \Pi^b - M^{c\prime} - N' - PI] + \\ &\quad \lambda_2[M^c - PC] \end{aligned}$$

The first order conditions for the household problem are then given by:

$$\begin{aligned} U_c &= P\lambda_2 \\ -U_L &= W\lambda_1 \\ \beta E_t V_{K'} &= \lambda_1 P \\ \beta E_t V_{M^{c\prime}} &= \lambda_1 \\ \beta E_t V_{N'} &= \lambda_1 \end{aligned}$$

and the envelope theorem gives:

$$\begin{aligned} V_M &= \lambda_2 \\ V_N &= R\lambda_1 \\ V_K &= \lambda_1(P(1-\delta(u)) + r) \end{aligned}$$

Eliminating the multipliers then gives the Euler equations:

$$\begin{aligned} \frac{-U_L}{W} &= \beta E_t\{\frac{U_{c'}}{P'}\} \\ \frac{U_L}{W} &= \beta E_t\{R'\frac{U_{L'}}{W'}\} \\ U_L\frac{P}{W} &= \beta E_t\{\frac{U_{L'}}{W'}(P'(1-\delta(u) + r')\} \end{aligned}$$

The firm's problem is to maximize the discounted value of its dividend payments: $E_0 \sum_{t=0}^{\infty}[\beta^{t+1}U_c(t+1)/P_{t+1}]\Pi_t^f$ where profits Π_t^f are as defined in the text and subject to the constraint $Y_j = (P_j/P)^{-\theta}Y^d$.

The first order conditions for the firm's problem are:

$$
\begin{aligned}
\frac{U_c'}{P'} &= \lambda F_H \\
\frac{U_c'}{P'}R &= \lambda F_K \\
0 &= \beta^{t+1}\frac{U_c'}{P'}\left(P_j\theta\left(\frac{P_j}{P}\right)^{\theta-1}\frac{Y^d}{P} + \left(\frac{P_j}{P}\right)^{-\theta}Y^d - P\phi\left(\frac{P_j}{P_{j-1}} - g\right)\frac{1}{P_{j-1}}\right) + \\
&\quad \beta^{t+2}E_{t+1}\frac{U_c''}{P''}P'\phi\left(\frac{P_j'}{P_j} - g\right)\frac{P_j'}{P_j^2} + \beta^{t+1}\lambda\theta\left(\frac{P_j}{P}\right)^{-\theta-1}\frac{Y^d}{P} \\
\beta^{t+1}\frac{U_c'}{P'}P &= \beta^{t+2}E_{t+1}\frac{U_c''}{P''}P'\left(r' + (1-\delta(u)) - \frac{P_e'}{P'}a(u')\right)
\end{aligned}
$$

The market-clearing conditions for the economy are then:

$$
\begin{aligned}
PC + P(K' - (1-\delta(u))K) + P^e e + P_t\frac{\phi}{2}\left(\frac{P}{P_{-1}} - \overline{g}\right)^2 &= PF(Ku, H, z) \\
H &= L \\
N + X &= WH \\
M &= M^s
\end{aligned}
$$

where M^s is the money supply.

Since we allow the money stock to grow over time, nominal variables must be deflated by the money stock to render them stationary. We linearize the stationary equilibrium conditions around steady state values and solve the system using the algorithm in King-Watson (1998).

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Response to Cholesky One S.D. Innovations ± 2 S.E.

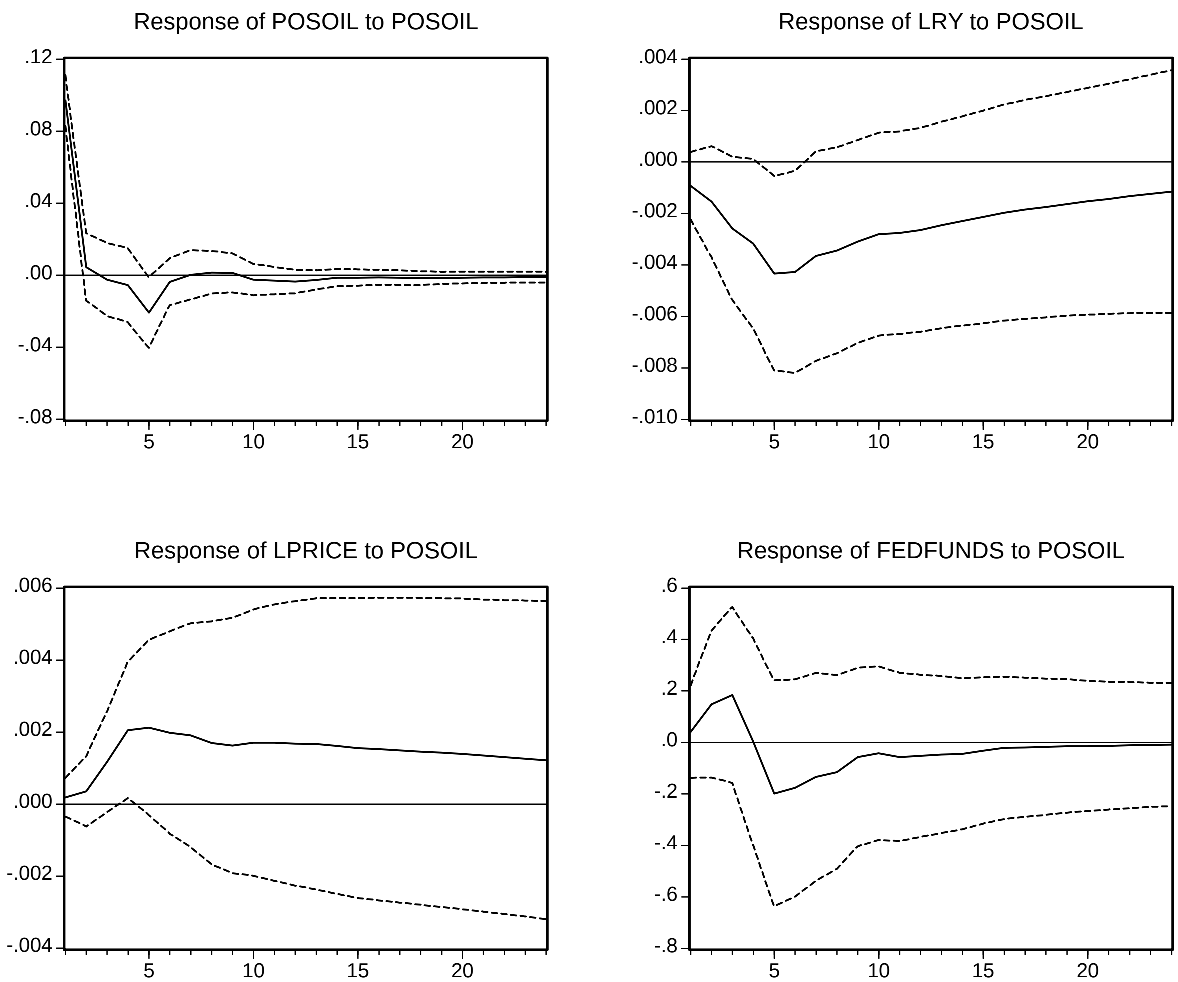
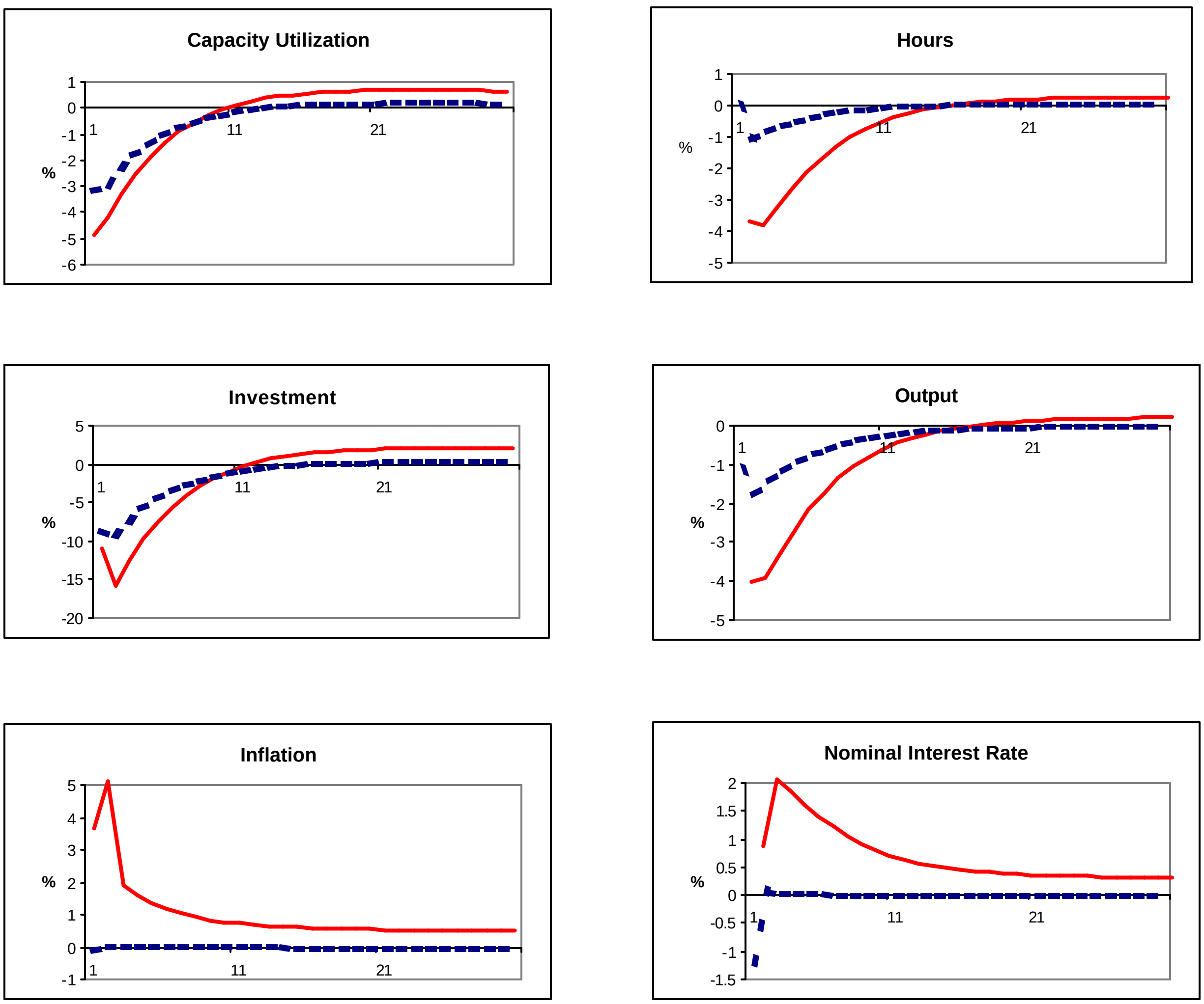


Figure 2. Impulse-Responses To a Doubling of Oil Prices



Interest-Rate Rule___
K-Percent Rule ----

Figure 3. Varying the Weight on Inflation

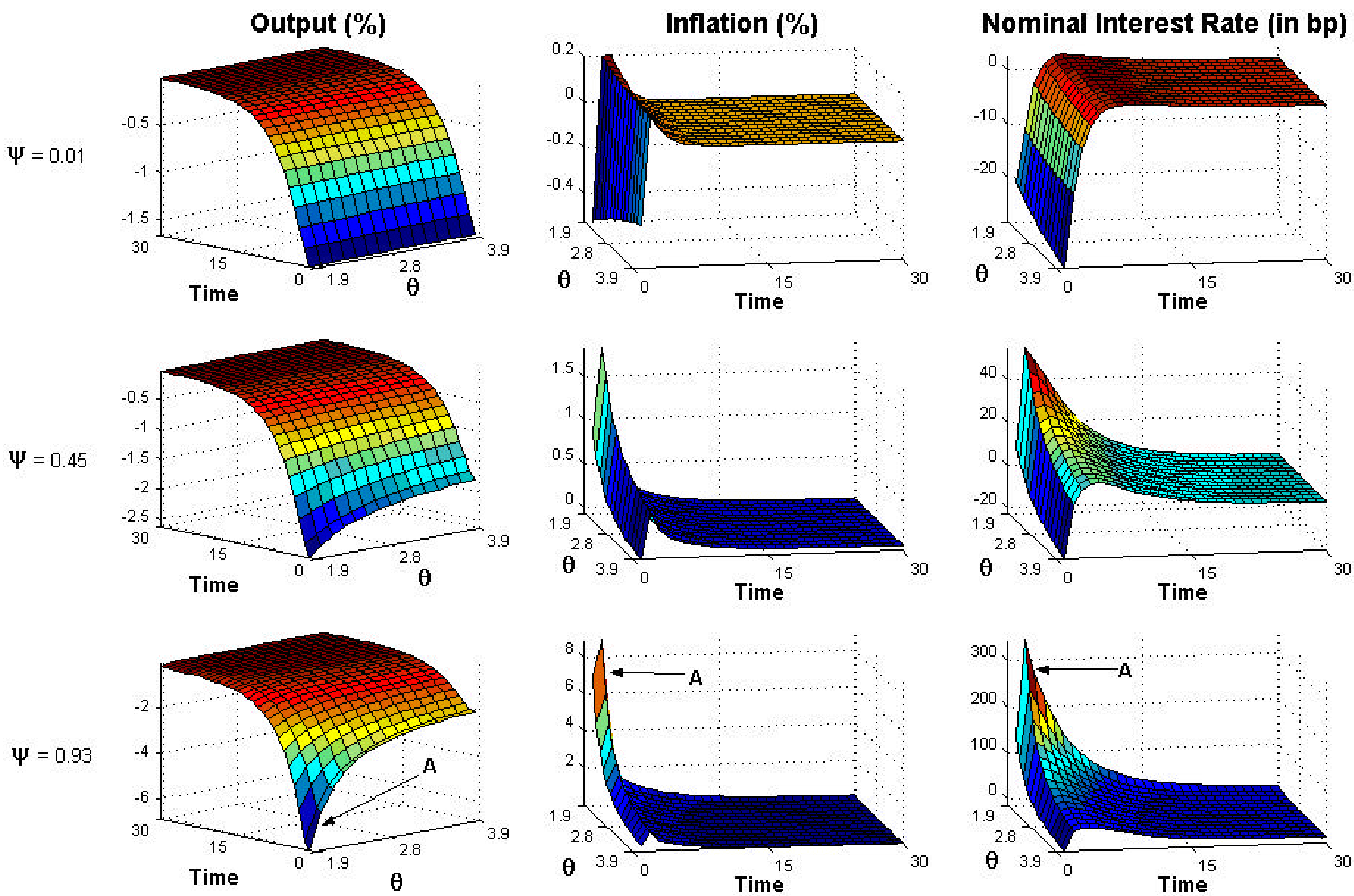


Figure 4. Varying the Weight on Output

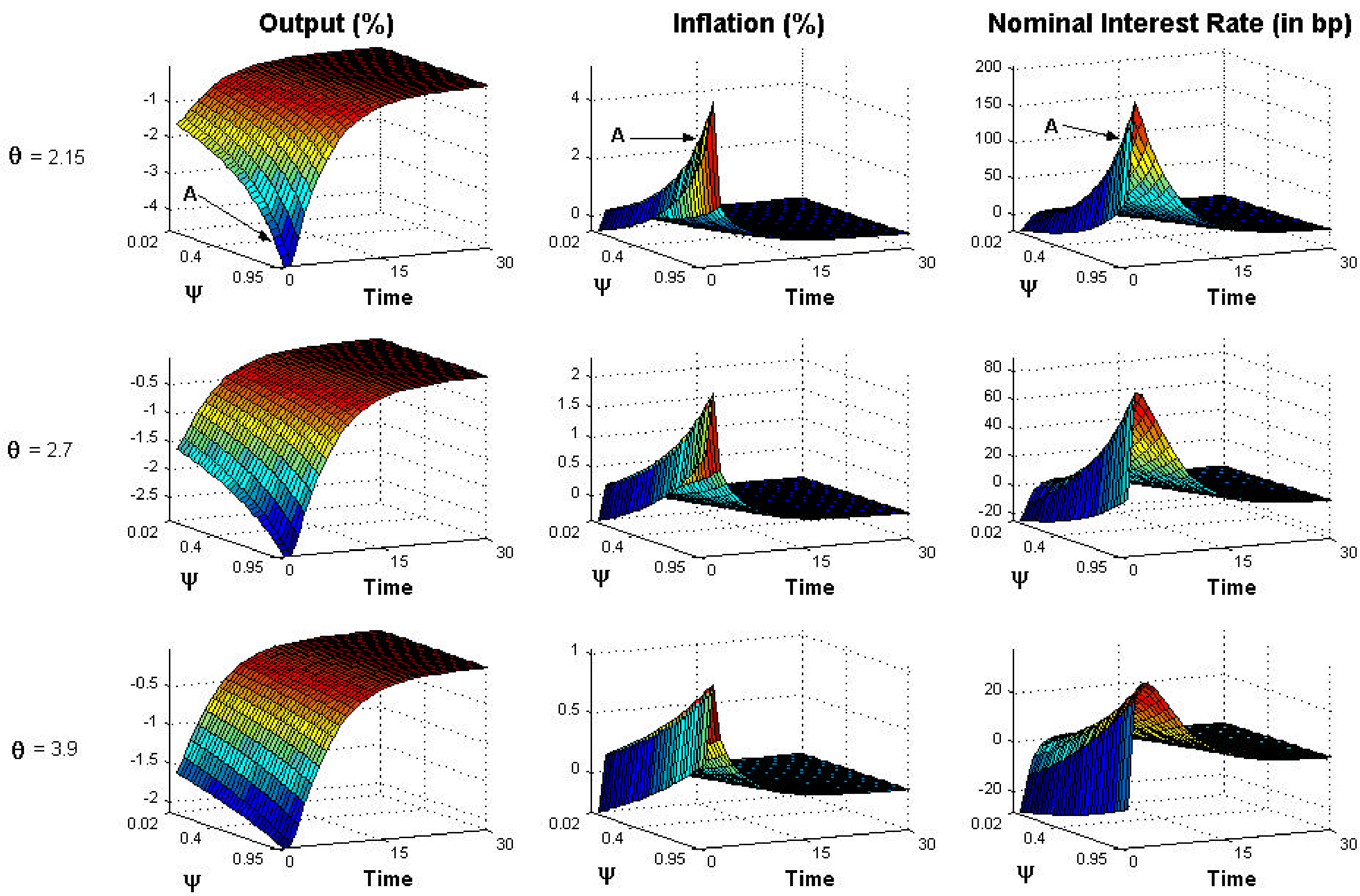


Figure 5. Economy's Responses Under Different Monetary Policies

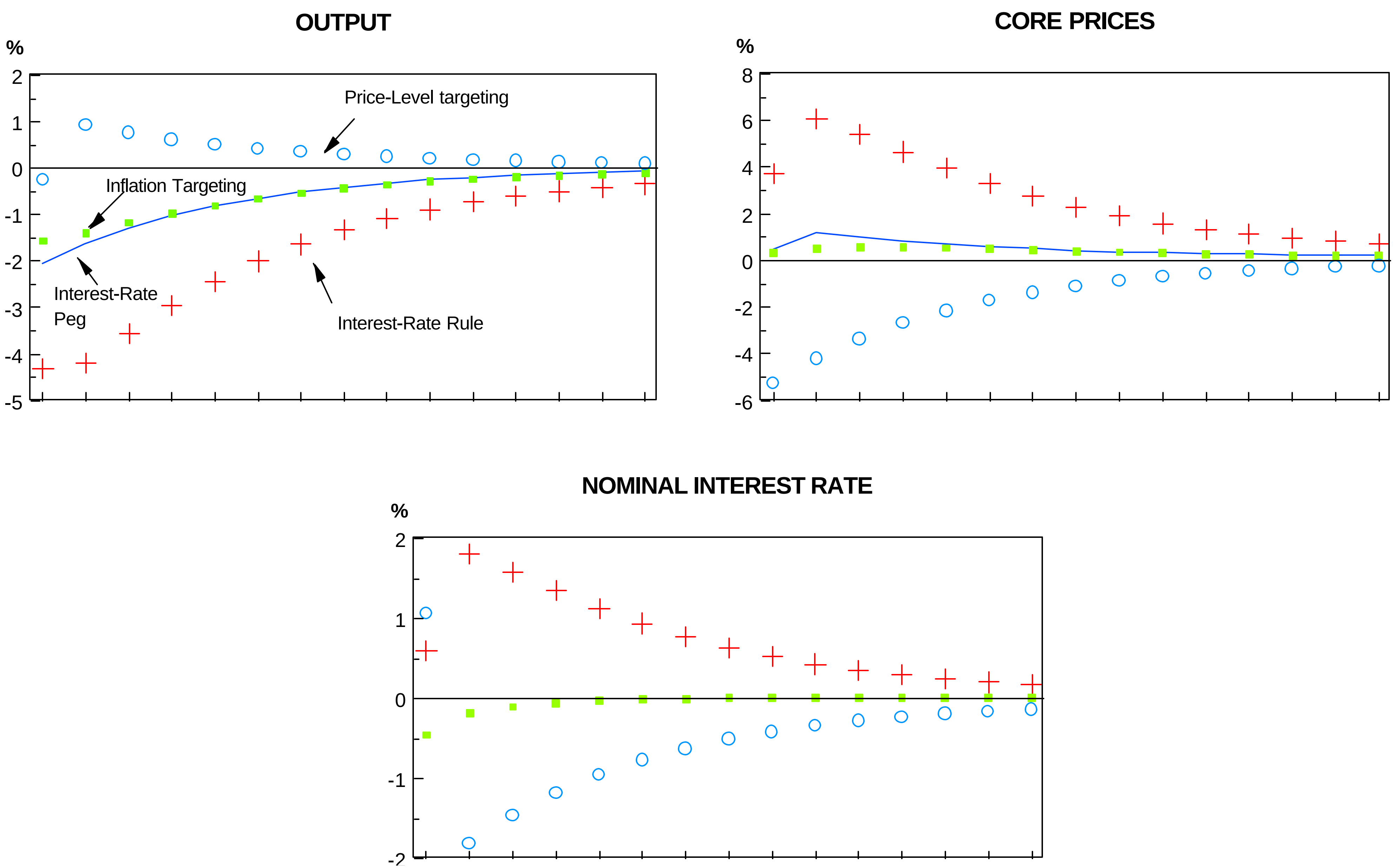


Figure 6. Economy's Responses Following a Negative TFP Shock

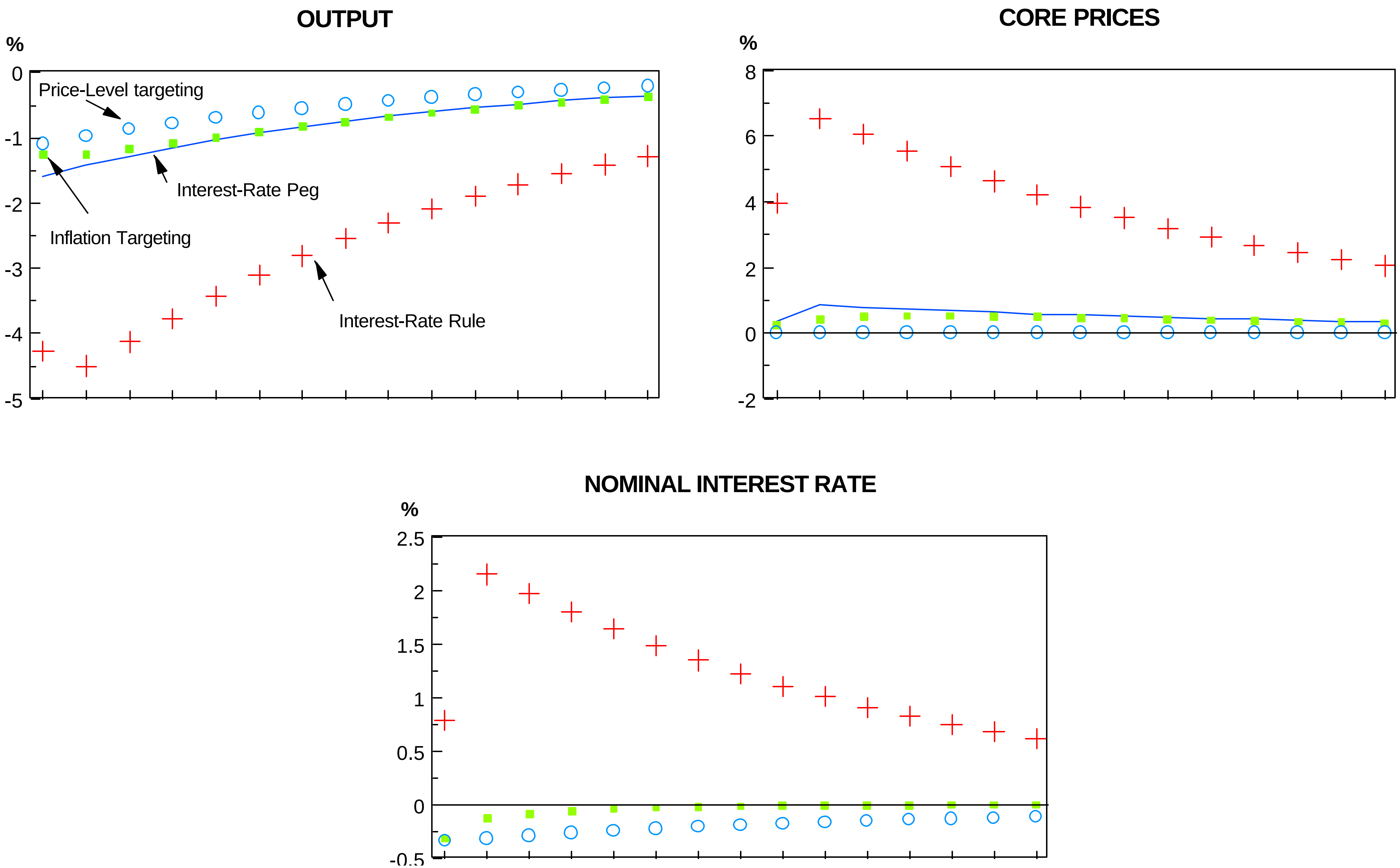
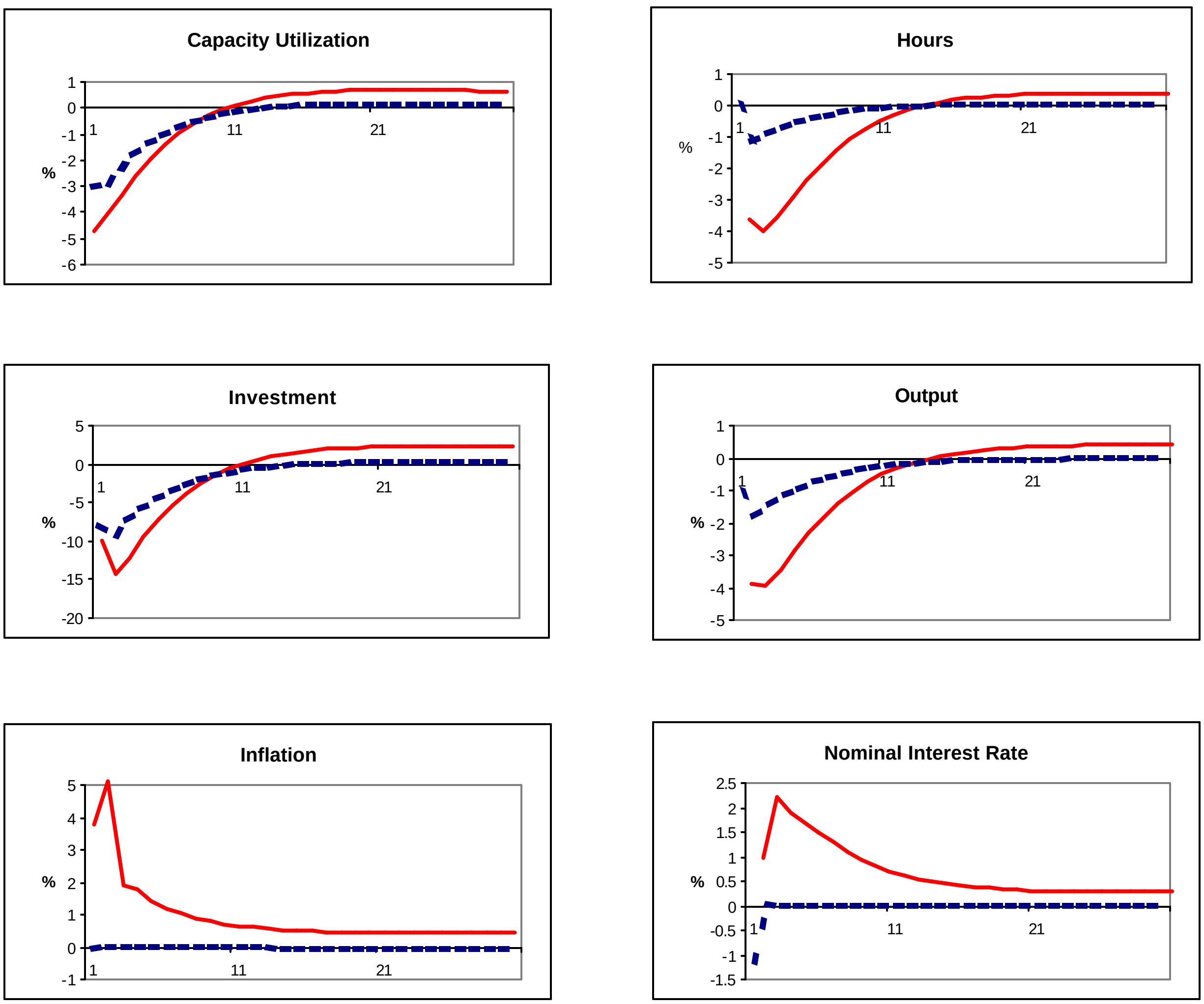


Figure 7. Impulse-Responses To a Doubling of Oil Prices (With Sticky Prices)



Interest-Rate Rule___
K-Percent Rule ----

Figure 8. Economy's Responses Under Different Monetary Policies (Sticky Prices)

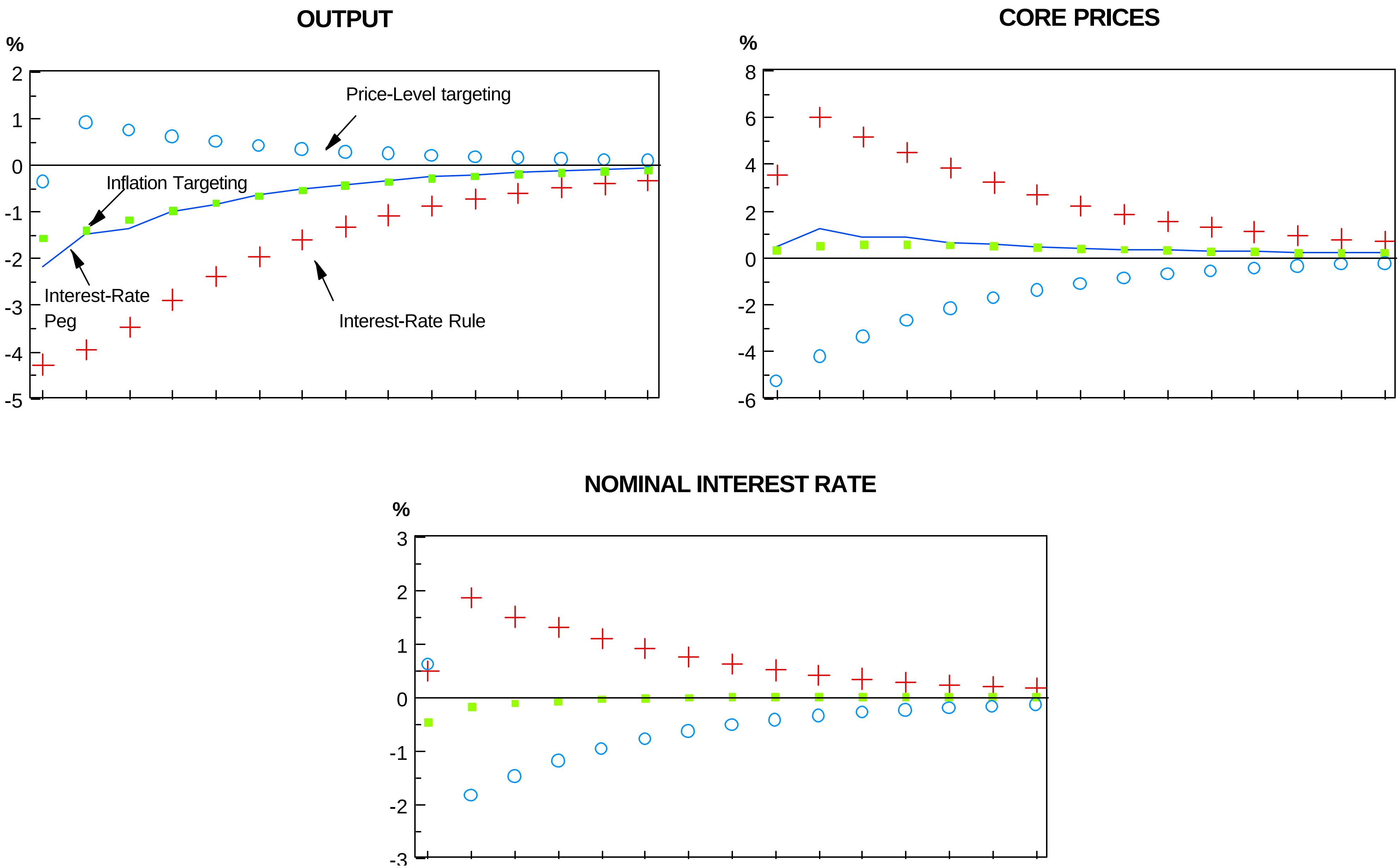


Table 1. Contributions of Oil-Price Increases and Systematic Monetary Policy to Recessions Following an Oil Shock

	Cumulative Negative Impact on Output (%)	*% Due to Oil-Price Increase*	*% Due to Systematic Monetary Policy*
Interest-Rate Peg	-10.3	90.6	9.4
Interest-Rate Rule	-29	32.1	67.9
Inflation Targeting	-9.54	97.5	2.5
Price-Level Targeting	-0.25	100	0

* Based on a doubling of the price of oil and flexible prices. The percentage due to the oil-price increase is based on the cumulative drop in output following the oil shock, under a k% rule, which equals –9.3%.

Table 2. Contributions of Oil-Price Increases and Systematic Monetary Policy to Recessions Following an Oil Shock (With Sticky Prices)

	Cumulative Negative Impact on Output (%)	*% Due to Oil-Price Increase*	*% Due to Systematic Monetary Policy*
Interest-Rate Peg	-10.29	90.4	9.6
Interest-Rate Rule	-28.23	32.9	67.1
Inflation Targeting	-9.54	97.5	2.5
Price-Level Targeting	-0.36	100	0

* Based on a doubling of the price of oil and a price-adjustment cost equal to 10%. The percentage due to the oil-price increase is based on the cumulative drop in output following the oil shock, under a k% rule, which equals –9.3%.