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**From the Great Inflation to the Great Moderation: Assessing the
Roles of Firm-Specific Labor, Sticky Prices and Labor Supply
Shocks**

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Abstract:

We develop and estimate a dynamic stochastic general equilibrium model that features sticky prices, a variable elasticity of demand facing firms and firm-specific labor. While reconciling to a good extent the micro and macro evidence on the behavior of prices, the model offers an accurate account of the dramatic increase in macroeconomic stability from the Great Inflation (1948:I-1979:II) to the Great Moderation (1984:I-2006:II). Reminiscent of the evidence in Shapiro and Watson (1988), the paper shows that labor-supply shocks are the key source of the reduction in the volatility of output growth, followed by investment-specific shocks. However, changes in the behavior of the private sector, a less accommodative monetary policy and smaller shocks explain almost evenly the large decline of the variability in inflation.

Keywords: Great moderation, firm-specific labor, variable demand elasticity, nominal price rigidity

JEL Classification: E31, E32

1 Introduction

This paper explores the reasons for the spectacular increase in macroeconomic stability from the Great Inflation (1948:I-1979:II) to the Great Moderation (1984:I-2006:II). However, unlike previous studies on the sources of the large declines in the volatilities of output growth and inflation, our paper proposes a fully-articulated dynamic stochastic general equilibrium (DSGE) model of the postwar U.S. economy that also tries to reconcile for the first time in this strand of literature the evidence from microeconomic data suggesting that firms reoptimize prices relatively frequently with that from aggregate time series about the inertial nature of the inflationary process. To this end, we estimate a DSGE model of the U.S. economy that rests on two main pillars. First, following Kimball (1995), price-setting monopolistic competitors face a variable elasticity of demand. Second, building on Woodford (2003, chapter 3), labor is specific to the firm or industry. While implying a plausible behavior of prices for the postwar period, our model captures close to 80 percent of the sharp decline in the volatility of output growth and 86 percent of the fall in the variability of inflation.

The volatilities of output growth and inflation have both decreased dramatically since the mid-1980's, with the former falling by 55 percent and the later by 65 percent (see the evidence presented in Section 2).¹ Three broad categories of explanations have been proposed so far. A first category suggests that significant changes in economic institutions, technology, business practices, or other structural features have increased the capacity of the economy to absorb shocks. For example, McConnell and Perez-Quiros (2000) and Kahn et al. (2002) argue that improved management of business inventories, resulting from advances in computation and communication have reduced fluctuations in inventory stocks, thereby dampening the cyclical movements of output.² A second category, exemplified by the work of Clarida et al. (2000) and Boivin and Giannoni (2006), among others, contends that the Federal Reserve has fought inflation more aggressively after 1980, increasing the stabilizing powers of monetary policy.³ A third category, known as the “good luck hypothesis”, claims that the economy has been prone to much smaller disturbances after 1984.

¹Further evidence on the Great Moderation can be found in Kim and Nelson (1999), McConnell and Perez-Quiros (2000), Blanchard and Simon (2001) and Stock and Watson (2003).

²Using a DSGE model, Iacoviello et al. (2007) provide evidence that changes in the volatility of inventory shocks, or in structural parameters associated with inventories, have played a minor role in dampening the volatility of output growth and inflation during the Great Moderation.

³Stock and Watson (2003), Sims and Zha (2006) and Smets and Wouters (2007) argue that monetary policy had a small impact on the decrease of the volatility of output growth during the Great Moderation.

The benchmark model used for the purpose of our investigation embeds the following main structural components: i) monopolistically competitive firms produce differentiated intermediate goods, ii) nominal prices are set on the basis of Calvo-style contracts, iii) firms face a variable elasticity of demand, iv) labor is specific to the firm, v) workers can vary their effort, vi) preferences are characterized by habit formation for consumption, vii) investment is costly to vary, and viii) the Federal Reserve follows a Taylor-type of rule.

The economy is subjected to five structural shocks. Our choice of shocks is dictated by empirical evidence reported in the literature on the identification of the underlying sources of business-cycle fluctuations. Two are sources of technical change, two are random variations in preferences and one is a shock to monetary policy. Inspired by a long line of research into the effects of permanent technology shocks, the first one is a random-walk total factor productivity shock (e.g., Blanchard and Quah, 1989; King et al., 1991; Galí, 1999). The second is an investment-specific shock (e.g., Greenwood et al., 1988; Fisher, 2006). The third and the fourth shocks are to the marginal rate of substitution between goods and work, one affecting consumption directly in the utility function (labeled consumption shock) (e.g., Baxter and King, 1991; Hall, 1997; Galí and Rabanal, 2004) and the other, hours worked (labeled labor supply shock) (Shapiro and Watson, 1988; Smets and Wouters, 2003).⁴ The fifth shock is to the Taylor rule.

As some other researchers do (e.g., Stock and Watson, 2003; Sims and Zha, 2006; Smets and Wouters, 2007; Arias et al., 2007; Leduc and Sill, 2007; Justiniano and Primiceri, 2007), we find that smaller shocks are the key source of the declining volatility of output growth. However, unlike other authors before us, we find that labor supply shocks are the most significant source of the increased stability in output fluctuations. Reminiscent of the evidence in Shapiro and Watson (1988) showing that shifts in labor supply have been a key driving force of postwar U.S. business cycles, our model assigns close to 50 percent of the fall in the volatility of output growth to smaller labor supply shocks. We also find that smaller investment-specific shocks account for nearly 22 percent of the decline in output fluctuations. In contrast, the sources of the decline in the volatility of inflation are spread almost evenly between changes in the behavior of the private sector, a less accommodative monetary policy and smaller structural shocks.

While helping to understand the causes of the Great Moderation, our model also tries to reconcile the micro and macro evidence on the behavior of prices. Using summary statistics from the

⁴Erceg et al. (2000) also build on the distinction between consumption shocks and leisure shocks in the utility function.

Consumer Price Index micro data compiled by the U.S. Bureau of Labor Statistics, Bils and Klenow (2004) argue that firms change prices quite frequently, once every 4.3-5.5 months, whether they look at posted prices or regular prices. Focusing on regular prices, Nakumara and Steinsson (2007) find that new prices are posted less frequently, once every 8-11 months. Still, the evidence in Klenow and Kryvtsov (2008) points to a frequency of price changes which is somewhere in between—once every 4 to 7 months on average—depending on the treatment of sale prices. On the other hand, a look at the behavior of prices using time-series data suggests that inflation is quite persistent, with positive autocorrelations out to lags of about three years (e.g., Fuhrer and Moore, 1995; Galí and Gertler, 1999).

Calvo-style models of price reoptimization account for the statistical behavior of postwar U.S. inflation, but only with estimates of the frequency of price reoptimization that are implausibly low. To resolve the conflicting pictures between micro and macro evidence on prices, Altig et al. (2005) and Eichenbaum and Fisher (2007) estimate a DSGE model in which firm-specific physical capital is costly to adjust. Furthermore, the later authors also assume that monopolistically competitive firms face a variable elasticity of demand. Here, we focus on a variable demand elasticity and firm-specific labor.⁵ These ingredients imply that a firm's marginal cost depends positively on its own level of output. Thus, when a firm contemplates raising its price, it knows that a higher price lowers demand and output. In turn, a lower output reduces marginal cost, other things equal, giving the firm the incentive to post a lower price. As a result, aggregate inflation is less responsive to a given aggregate marginal cost shock.

The estimation strategy is the following. First, the benchmark model is estimated with data covering the postwar period from 1948:I to 2006:II. Our econometric procedure is similar to that used by Ireland (2001, 2003). We find that the frequency of price reoptimization predicted by our model is once every two quarters on average. In contrast, with a constant demand elasticity and integrated labor markets, we find that firms reoptimize prices once every 5.4 quarters on average (see also Galí and Gertler, 1999). While predicting a relatively modest average amount of time between price reoptimization, the model generates a substantial amount of persistence in inflation. Furthermore, it yields a positive, serial correlation of output growth at short horizons, and hence meets the challenge of generating plausible output dynamics (e.g., Cogley and Nason, 1995). The model also closely matches the volatilities of output growth and inflation, and the correlation

⁵See also Edge (2002) who looks at the impact of staggered nominal contracts and firm-specific labor on the transmission of monetary shocks from the perspective of a DSGE model calibrated to the U.S. postwar economy, and Matheron (2006) who estimates a New Keynesian Phillips Curve with firm-specific labor using Euro data.

between output growth and inflation over the postwar period.

We then reestimate the model with a sample of data for the Great Inflation and the Great Moderation. The benchmark model closely matches the volatilities of output growth and inflation in each subperiod. The model accounts for most of the sharp declines in the volatilities of output growth and inflation, predicting a fall of 43 percent of the volatility of output growth and a decrease of 56 percent of the variability in inflation after the mid-1980's, not far from the actual percentages.

We detect some statistically significant changes in structural parameter values from the first to the second subperiod. Habit persistence decreases. The degree of investment adjustment costs increases. The Federal Reserve's tendency to smooth interest rates is weaker, and the Fed's response to deviations of inflation from target is stronger (see also Clarida et al. 2000). The response of inflation to marginal cost decreases slightly, so the frequency of price reoptimization is marginally higher during the second subperiod. Still, the average length of time between price reoptimization always remains below three quarters in each subperiod. Lastly, we find that there are significant differences in the estimated variances of the shocks, but no strong evidence of a statistically significant change in the persistence of the stochastic processes generating the shocks.

The paper is organized as follows. Section 2 briefly describes the changes in the volatility of output growth and inflation from the Great Inflation to Great Moderation. Section 3 develops our DSGE model with a variable elasticity of demand and firm-specific labor. Section 4 discusses some econometric issues. Section 5 reports our empirical findings for the entire postwar period and analyzes the results. Section 6 presents our results for the two subperiods and identifies the sources of the Great Moderation. Section 7 offers concluding remarks.

2 Output Growth Volatility and Inflation Variability from the Great Inflation to the Great Moderation

The volatilities of output growth and inflation have both considerably declined from the Great Inflation to the Great Moderation.⁶ Figure 1 displays the evolution of the growth rate of output and the rate of inflation from 1948:I to 2006:II.⁷ It also presents 20-quarter rolling standard deviations

⁶Following McConnell and Perez-Quiros (2000) and others, we adopt 1984:I as the starting date of the Great Moderation.

⁷Output is converted into per capita terms after being divided by the civilian noninstitutional population 16 years and above.

for these variables. The volatility of output growth has recorded two major declines, the first occurring between 1961 and 1965, and the second between 1984 and 1990. However, the recent decline is more dramatic, with the volatility of output growth falling from a high 1.8 percent in 1984 to a low 0.45 percent in 1990. It has remained below 1 percent ever since.

The U.S. economy has also experienced a lengthy period of high inflation from the mid-1960s to the early 1980s. However, there have been large declines both in the level and in the volatility of inflation after 1984. The variability of inflation has decreased from a high 0.81 percent in 1984 to a low 0.25 percent in 2006.⁸

Table 1 reports the standard deviations of output growth and inflation, and the correlations between output growth and inflation during the postwar period, the Great Inflation and the Great Moderation. In all periods, output growth was considerably more volatile than inflation. Furthermore, the correlation between output growth and inflation was mildly negative. The volatility of output growth declined by 55 percent and the variability of inflation by 65 percent from the Great Inflation to the Great Moderation. Meanwhile, the correlation between the growth rate of output and the inflation rate became increasingly negative, falling from -0.17 in the first subperiod to -0.31 in the second subperiod.

3 A DSGE Model with a Variable Elasticity of Demand, Firm-Specific Labor and Nominal Price Rigidity

The economy is populated by a large number of members of a representative household, each endowed with a differentiated labor skill indexed by $i \in [0, 1]$. There is also a large number of firms, each producing a differentiated intermediate good indexed by $j \in [0, 1]$. Following Woodford (2003, chapter 3), a key feature of the model rests on the specificity of the labor relationship between a particular firm or industry, and a particular type of skill. That is, the i^{th} member of the household supplies labor only to the j^{th} firm, while the j^{th} firm hires only the i^{th} type of skill. For the sake of simplicity, we assume that $i = j$.

While labor is firm-specific, no single household's member has monopoly power and no single firm has monopsony power. Hence, a way to understand the specificity of the labor relationship between the i^{th} member of the household and the j^{th} firm is to think of each point i on the unit interval continuum as representing a large number of individuals supplying a specific type of labor

⁸We have also looked at Hodrick-Prescott filtered data and found similar results.

and of each point j on the unit interval continuum as representing a large number of firms employing this particular type of skill. For example, we may think of factor specificity at the level of a region or an industry.

3.1 The Household

The household's preferences are described by the following expected utility function:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\epsilon_{c,t} U(C_t, C_{t-1}) - \epsilon_{h,t} \int_0^1 V(H_{i,t}) di - \int_0^1 \varkappa(e_{i,t}) di \right], \quad (1)$$

where

$$U(C_t, C_{t-1}) = \ln(C_t - bC_{t-1}),$$

$$V(H_{i,t}) = \frac{\chi_h}{1 + \eta_h} H_{i,t}^{1+\eta_h},$$

$$\varkappa(e_i) = \frac{\chi_e}{1 + \eta_e} e_{i,t}^{1+\eta_e}.$$

$\beta \in (0, 1)$ is the subjective discount factor, C_t is the aggregate consumption good in period t , and C_{t-1} is the habit reference level for consumption. The variables $H_{i,t}$ and $e_{i,t}$ denote the hours worked and the level of effort of the i^{th} member of the household, respectively. The parameter $b \in [0, 1]$ measures the degree of habit formation for consumption; η_h and η_e are two positive parameters. The household's preferences are affected by shocks to consumption $\epsilon_{c,t}$ and hours worked $\epsilon_{h,t}$. Both are described by first-order autoregressive processes:

$$\ln(\epsilon_{c,t}) = \rho_c \ln(\epsilon_{c,t-1}) + \varepsilon_{c,t}, \quad (2)$$

$$\ln(\epsilon_{h,t}) = \rho_h \ln(\epsilon_{h,t-1}) + \varepsilon_{h,t}, \quad (3)$$

where $0 \leq \rho_c < 1$, $0 \leq \rho_h < 1$, and $\varepsilon_{c,t}$ and $\varepsilon_{h,t}$ are zero-mean, serially uncorrelated, and normally distributed innovations with standard deviations σ_c and σ_h , respectively.

The household enters period t with bond holdings B_{t-1} , and a predetermined stock of physical capital K_t which is rented to the intermediate-good firms at the real rental rate R_t^k . The household's member i supplies effective hours worked $e_{i,t}H_{i,t}$ to firm j at the nominal wage rate $W_{i,t}$. At the end of period t , the household receives total nominal dividends D_t from the firms. The household purchases B_t units of bonds, C_t units of an aggregate consumption good at the nominal price P_t , and I_t units of an aggregate investment good from the finished-good firm.⁹ The household's flow

⁹We follow the standard practice of assuming complete financial markets. This implies that the household's members are identical with respect to consumption and bond holdings. The source of heterogeneity between the household's members is produced only by the existence of segmented labor markets.

budget constraint is:

$$C_t + I_t + \frac{B_t}{R_t P_t} \leq \frac{B_{t-1}}{P_t} + \int_0^1 W_{i,t}^r e_{i,t} H_{i,t} di + R_t^k K_t + \frac{D_t}{P_t}. \quad (4)$$

where $W_{i,t}^r = \frac{W_{i,t}}{P_t}$ is the real wage of the i^{th} member of the household, and R_t is the gross nominal interest rate between periods t and $t+1$. We impose the explicit borrowing constraint $B_t \geq -B$, $B \geq 0$ to prevent the household from running Ponzi schemes.

The stock of physical capital obeys the following law of motion:

$$K_{t+1} = (1 - \delta)K_t + \epsilon_{i,t}(1 - S(I_t/I_{t-1}))I_t, \quad (5)$$

where δ is the rate of depreciation of physical capital. The second term on the right-hand side of (5) embodies the investment adjustment costs. The function $S(\cdot)$ is positive, convex and satisfies $S(\epsilon_a) = S'(\epsilon_a) = 0$, where ϵ_a determines the steady-state growth rate of output (see below). Following Greenwood et al. (1988) and Fisher (2006), $\epsilon_{i,t}$ is an investment-specific shock which follows the first-order autoregressive process:

$$\ln(\epsilon_{i,t}) = \rho_i \ln(\epsilon_{i,t-1}) + \varepsilon_{i,t}, \quad (6)$$

where $0 \leq \rho_i < 1$, and $\varepsilon_{i,t}$ is a zero-mean, serially uncorrelated, and normally distributed innovation with standard deviation σ_i . The household maximizes the utility function (1) subject to the budget constraint (4), and the capital accumulation equation (5). The first-order conditions corresponding to this problem are:

$$\left(\frac{\epsilon_{c,t}}{C_t - bC_{t-1}} \right) - \beta b E_t \left(\frac{\epsilon_{c,t+1}}{C_{t+1} - bC_t} \right) = \Lambda_t, \quad (7a)$$

$$\epsilon_{h,t} \chi_h H_{i,t}^{\eta_h} = W_{i,t}^r e_{i,t} \Lambda_t, \quad (7b)$$

$$\chi_e e_{i,t}^{\eta_e} = W_{i,t}^r H_{i,t} \Lambda_t, \quad (7c)$$

$$Q_t = \beta E_t \left[\frac{\Lambda_{t+1}}{\Lambda_t} \left(R_{t+1}^k + (1 - \delta)Q_{t+1} \right) \right], \quad (7d)$$

$$Q_t = \frac{1 - \beta E_t \left[\frac{\Lambda_{t+1}}{\Lambda_t} Q_{t+1} S' \left(\frac{I_{t+1}}{I_t} \right) \left(\frac{I_{t+1}}{I_t} \right)^2 \epsilon_{i,t+1} \right]}{\left[1 - S \left(\frac{I_t}{I_{t-1}} \right) - S' \left(\frac{I_t}{I_{t-1}} \right) \left(\frac{I_t}{I_{t-1}} \right) \right] \epsilon_{i,t}}, \quad (7e)$$

where Λ_t is the Lagrange multiplier associated with the budget constraint (4). Equation (7a) equals the marginal utility of date- t consumption to its opportunity cost. Equations (7b) and (7c) equal the marginal disutility of hours and effort to their respective earnings. The Euler condition for capital (7d) says that the shadow price of installed capital, measured by marginal Tobin's Q,

equals the expected future value of Q net of depreciation plus the expected future return on capital. Equation (7e) determines the optimal level of investment.

3.2 The Firms

The representative finished-good firm is perfectly competitive and produces Y_t units of the finished good, using the following general variety aggregator proposed by Kimball (1995):

$$\int_0^1 G\left(\frac{Y_{i,t}}{Y_t}\right) di = 1, \quad (8)$$

where $Y_{i,t}$ denotes the quantity of the intermediate good i used in the production of the composite finished-good Y_t . The function $G(\cdot)$ is increasing, strictly concave, and satisfies $G(1) = 1$. The finished-good firm purchases $Y_{i,t}$ at the nominal price $P_{i,t}$. The first-order condition corresponding to the finished-good firm's profit maximization problem is,

$$\zeta_{i,t} = G'^{-1}\left(\frac{P_{i,t}}{P_t} \int_0^1 G'(\zeta_{i,t}) \cdot \zeta_{i,t} di\right), \quad (9)$$

where $\zeta_{i,t} = Y_{i,t}/Y_t$, and $G'(\cdot)$ denotes the partial derivative of $G(\cdot)$. In the absence of profits, the nominal price P_t is given by,

$$P_t = \int_0^1 P_{i,t} G'^{-1}\left(\frac{P_{i,t}}{P_t} \int_0^1 G'(\zeta_{i,t}) \cdot \zeta_{i,t} dj\right) di. \quad (10)$$

The intermediate-good firm i produces $Y_{i,t}$ units of a differentiated intermediate good i using firm-specific effective labor hours $e_{i,t}H_{i,t}$, and $K_{i,t}$ units of the homogeneous stock of physical capital. Hence, output $Y_{i,t}$ is produced through the following production function:

$$Y_{i,t} = \begin{cases} K_{i,t}^\alpha (\epsilon_{a,t} e_{i,t} H_{i,t})^{1-\alpha} - \epsilon_{a,t} \Phi & \text{if } K_{i,t}^\alpha (\epsilon_{a,t} e_{i,t} H_{i,t})^{1-\alpha} \geq \epsilon_{a,t} \Phi \\ 0 & \text{otherwise,} \end{cases} \quad (11)$$

where $\alpha \in (0, 1)$ is the share of physical capital in the production of intermediate good i , $\Phi > 0$ is a common fixed-cost term,¹⁰ and $\epsilon_{a,t}$ is the labor-augmenting level of technology. The technology shock is generated by the logarithmic random-walk process with drift:

$$\ln(\epsilon_{a,t}) = \ln(\epsilon_a) + \ln(\epsilon_{a,t-1}) + \varepsilon_{a,t}, \quad (12)$$

where $\varepsilon_{a,t}$ is a zero-mean, serially uncorrelated, and normally distributed innovation with standard deviation σ_a .

¹⁰The inclusion of increasing returns to scale through the fixed term cost allows the firms to earn zero profits in the steady state. Rotemberg and Woodford (1995) argue that during the postwar period, average pure profits have been close to zero in the U.S. economy. The price markup can thus be calibrated at a conventional value.

Each period, cost minimization implies the following first-order conditions for the representative firm :

$$(1 - \alpha) \left(\frac{Y_{i,t} + \epsilon_{a,t}\Phi}{e_{i,t}H_{i,t}} \right) MC_{i,t} = W_{i,t}^r, \quad (13a)$$

$$\alpha \left(\frac{Y_{i,t} + \epsilon_{a,t}\Phi}{K_{i,t}} \right) MC_{i,t} = R_t^k, \quad (13b)$$

where $MC_{i,t}$ denotes firm's i real marginal cost. Hence, firm i equates the marginal product of each input to its shadow price. Nominal prices are set by contracts in a staggered fashion. In each period, firm i faces probability $1 - \xi$ of reoptimizing its price $P_{i,t}$. In a symmetric equilibrium, the firms which are allowed to reoptimize prices in period t choose the same optimal price P_t^* . Profit maximization yields the following first-order condition:

$$\frac{P_t^*}{P_t} = \frac{E_t \sum_{\tau=0}^{\infty} (\beta\xi)^\tau \frac{\Lambda_{t+\tau}}{\Lambda_t} (-\varepsilon(\zeta_{i,t+\tau}) MC_{i,t+\tau})}{E_t \sum_{\tau=0}^{\infty} (\beta\xi)^\tau \frac{\Lambda_{t+\tau}}{\Lambda_t} \left(\frac{P_t}{P_{t+\tau}} (1 - \varepsilon(\zeta_{i,t+\tau})) \right)}. \quad (14)$$

This equation determines the firm's optimal relative price, $\varepsilon(\zeta_{i,t})$ denoting the demand elasticity of a differentiated good i defined as $\varepsilon(\zeta_{i,t}) = - \left(\frac{G'(\zeta_{i,t})}{G''(\zeta_{i,t})\zeta_{i,t}} \right)$. With perfectly flexible prices, (14) simplifies to:

$$\frac{P_t^*}{P_t} = \frac{\varepsilon(\zeta_{i,t})}{\varepsilon(\zeta_{i,t}) - 1} MC_{i,t},$$

which says that a firm's optimal relative price is equal to the product of the markup and marginal cost. The markup implied by Kimball's (1995) specification is time-varying.¹¹ The aggregate price level in (10) is determined by,

$$P_t = (1 - \xi) P_t^* G'^{-1} \left(\frac{P_t^*}{P_t} \int_0^1 G'(\zeta_{i,t}) \cdot \zeta_{i,t} di \right) + \xi P_{t-1} G'^{-1} \left(\frac{P_{t-1}}{P_t} \int_0^1 G'(\zeta_{i,t}) \cdot \zeta_{i,t} di \right). \quad (15)$$

Inflation dynamics is described by the Phillips Curve equation (see the appendix):

$$\pi_t = \beta E_t \pi_{t+1} + \Gamma m c_t, \quad (16)$$

where

$$\Gamma = \frac{(1 - \beta\xi)(1 - \xi)}{\xi} \varphi^{-1}.$$

From now on, a lower case variable denotes the log-deviation from its steady-state value of the corresponding upper case variable; π_t is the rate of inflation, i.e., $\pi_t = p_t - p_{t-1}$, and $m c_t$ is the aggregate real marginal cost.

¹¹It is constant under the familiar Dixit-Stiglitz aggregator.

The response of inflation to marginal cost is measured by Γ , which is given by (see the appendix):

$$\varphi = 1 + \varphi_1 + \varphi_2, \quad \varphi_1, \varphi_2 > 0. \quad (17)$$

Here, φ_1 follows from the assumption that firms face a variable demand elasticity, and φ_2 from assuming that labor is firm-specific. Both parameters reduce the impact of marginal cost on inflation.

The first parameter is $\varphi_1 = \mu\epsilon$, where $\mu = \frac{1}{\varepsilon(1)-1}$ stands for the net price markup, $\varepsilon(1)$ is the demand elasticity of intermediate good i evaluated at the steady state, and ϵ is the percent change in the elasticity of demand following a one percent change in the relative price of the good evaluated at the steady state. A Dixit-Stiglitz form of demand, i.e. $\epsilon = 0$ implies $\varphi_1 = 0$, leading inflation to be more responsive to marginal cost and less persistent.

The parameter φ_2 is

$$\varphi_2 = (\varepsilon(1) - 1) \left[\frac{A - B}{(1 + \alpha(A - B))^{I^F}} - 1 \right],$$

where $A = \frac{1+\eta_h}{1-\alpha}$ and $B = \frac{(1+\eta_h)^2}{(2+\eta_h+\eta_e)(1-\alpha)}$. The indicator function I^F equals one if capital is homogeneous and mobile across firms as in the benchmark model, or 0 if capital is fixed as in Sbordone (2002) for example.¹²

To illustrate why firm-specific labor lowers the impact of marginal cost on inflation and increases its persistence, we make the simplifying assumptions that capital is fixed ($I^F = 0$), effort is constant ($\eta_e \rightarrow \infty$ and $B = 0$), and that demand is of the Dixit-Stiglitz form ($\epsilon = 0$). The Phillips Curve equation becomes:

$$\pi_t = \beta E_t \pi_{t+1} + \frac{(1 - \beta\xi)(1 - \xi)}{\xi} (1 + \varphi'_2)^{-1} mc_t, \quad (18)$$

where

$$\varphi'_2 = \varepsilon(1) \left(\frac{Y}{Y + \Phi} \right) (1 - \alpha)^{-1} (\alpha + \eta_h).$$

Consider, for example, the case of an expansionary policy shock. With sticky prices, the policy shock exerts an upward pressure on real wages, so a firm contemplates raising its price with or without firm's specific labor. With firm-specific labor, a firm's labor demand depends positively on its own level of output. In turn, a firm's output depends negatively on its relative price. The expansionary policy shock generates a rise in the firm's relative price, putting a downward pressure on the firm's output, labor demand and real wages. The downward pressure on real wages thus acts as a countervailing influence on the firm's incentive to raise its price.

¹²Notice that $\frac{Y}{Y+\Phi} = \frac{\varepsilon(1)-1}{\varepsilon(1)}$, where Y denotes the steady-state level of output.

The term φ'_2 can be explained as follows. With the firm's relative price rising, the firm's level of output falls by a factor of $\varepsilon(1)$. The firm's labor demand then decreases by $\left(\frac{Y}{Y+\Phi}\right)$, so the real wages decline by a factor of η_h . In turn, this lowers a firm's real marginal cost by a factor of $(1-\alpha)^{-1}$. Also, the higher the elasticity of labor demand (i.e. the higher α is), the smaller is the adjustment of real wages and prices following the policy shock.¹³

3.3 The Monetary Policy Rule

The Federal Reserve sets the short-term nominal interest rate using a Taylor-type of rule:

$$r_t = \rho_r r_{t-1} + (1 - \rho_r) [\rho_\pi \pi_t + \rho_y g_{yt}] + \varepsilon_{m,t}. \quad (19)$$

The variables π_t and g_{yt} stand for the deviations of inflation and output growth from their steady-state values, whereas $\varepsilon_{m,t}$ is a zero-mean, serially uncorrelated, and normally distributed innovation with standard deviation σ_m . The interest rate reaction function involves the output growth rate. This specification is consistent with the empirical analysis of interest rate determination in Erceg and Levin (2003). Furthermore, as stressed by Orphanides and Williams (2002), it also ensures that the mismeasurement of the potential level of output does not affect the conduct of monetary policy. Other examples of DSGE models in which Taylor rules feature the output growth rate include Galí and Rabanal (2004), Liu and Phaneuf (2007) and Smets and Wouters (2007).

4 Econometric Procedures

We take a log-linear approximation of the model's equilibrium conditions around the deterministic steady state. The resulting system of linear difference equations is solved using the methods outlined in Klein (2000). The system can be written in its state-space form as

$$\begin{aligned} x_{t+1} &= \Upsilon_1 x_t + \Upsilon_2 \varepsilon_{t+1}, \\ z_t &= \Upsilon_3 x_t, \end{aligned}$$

where x_t is a vector of unobservable state variables, ε_{t+1} is a vector that includes the five structural shocks $\varepsilon_{a,t}$, $\varepsilon_{m,t}$, $\varepsilon_{c,t}$, $\varepsilon_{h,t}$, $\varepsilon_{i,t}$, and z_t is a vector of observable variables. The elements of matrices Υ_1 , Υ_2 , and Υ_3 are functions of the deep parameters of the model. We estimate the system using maximum likelihood methods and quarterly U.S. data on the following variables: the growth rate

¹³This can be seen more clearly from the log-linearized labor demand equation, $\left(\frac{Y}{Y+\Phi}\right) y_{i,t} + mc_{i,t} = w_{i,t} + h_{i,t}$ and the log-linearized marginal cost equation, $mc_{i,t} = (1-\alpha)w_{i,t} + \alpha r_t^k$.

of per capita consumption, the growth rate of per capita investment, the rate of inflation, and the nominal interest rate. Let Θ be the vector of parameters that we intend to estimate and T the number of observations on each variable. The Gaussian log likelihood function $L(\Theta)$ for the sample $\{z_t\}_{t=1}^T$ can be constructed recursively using the Kalman filter described by Hamilton (1994, chapter 13). The likelihood function (ignoring the constant term) is :

$$L(\Theta) = -\frac{1}{2} \sum_{t=1}^T \ln|\Omega_t| - \frac{1}{2} \sum_{t=1}^T u_t' \Omega_t^{-1} u_t,$$

where $u_t = z_t - \hat{E}(z_t | z_{t-1}, z_{t-2}, \dots, z_1)$, $E(u_t u_t') = \Omega_t$ and $\hat{E}(\cdot)$ denotes the linear projection operator.

The benchmark model includes 26 parameters related to preferences, technology, the shock processes, and monetary policy. They are summarized by $\{\beta, \delta, \eta_h, \chi_h, \eta_e, \chi_e, b, S''(\epsilon_a), \alpha, \Phi, \epsilon_a, \rho_r, \rho_\pi, \rho_g, \rho_c, \rho_h, \rho_i, \Gamma, \varepsilon(1), \epsilon, \xi, \sigma_c, \sigma_h, \sigma_i, \sigma_a, \sigma_m\}$. Some parameters are calibrated prior to estimation. The parameter δ takes a value of 0.025, implying an annualized rate of capital depreciation of 10 percent. The share of physical capital into the production of intermediate goods α is 0.36. The steady-state values of the nominal interest rate and ϵ_a which determines the steady-state growth rate of output are chosen to match the U.S. data over our sample. These values imply $\beta = 0.9935$. The value assigned to χ_h in the utility function is such that the fraction of time devoted to work is 0.30 in the steady state, while the value of χ_e implies that effort equals one in the steady state. We cannot simultaneously estimate ξ , $\varepsilon(1)$, ϵ , and Γ . We set $\varepsilon(1) = 10$ in the benchmark model, implying a gross price markup of 11 percent. The parameter ϵ takes a value of 10, consistent with the symmetric translog specification of Bergin and Feenstra (2000).

4.1 Data

Our sample of data runs from 1948:I to 2006:II.¹⁴ Real consumption is measured by the sum of real personal consumption expenditures on nondurable goods and services. Investment is the sum of real personal consumption expenditures on durable goods and fixed private investment. The nominal interest rate is the Three-Month Treasury Bill rate. The price index is the price deflator of output in the nonfarm business sector. The consumption and investment series are divided by the civilian noninstitutional population 16 years and over.

¹⁴The data have been obtained from the Haver Analytics Economics Database.

5 Empirical Results

5.1 Maximum Likelihood Estimates

We first estimate the benchmark model using data for the entire postwar period. The results are presented in Table 2. The structural parameters of the model are estimated quite precisely. The point estimate of the coefficient of habit formation for consumption b is 0.57. The point estimate of $1/\eta_h$ in the utility function is 0.84, while that of $1/\eta_e$ is 0.14. These estimates imply an intertemporal elasticity of labor supply of about 0.9. The degree of investment adjustment costs $S''(\epsilon_a)$ is 2.75, and hence is in the range of parameter values estimated by Christiano et al. (2005). The interest-rate smoothing parameter ρ_r is 0.75, consistent with the evidence of Clarida et al. (2000). The parameter ρ_π measuring the Fed's response to deviations of inflation from its steady-state value is 1.53, close to the value advocated by Taylor (1993). The coefficient ρ_y determining the Fed's response to deviations of output growth from its steady-state value is relatively small at 0.15, consistent with the values reported by Gali and Rabanal (2004) and Smets and Wouters (2007).

Looking at the shock-generating processes, we find that the labor supply shock has the highest AR(1) coefficient with 0.8832, followed by the investment-specific shock with 0.7978, and by the consumption shock with 0.5696. The labor supply shock has the largest estimated standard error at 0.0726, followed by the investment-specific shock at 0.0343, the consumption shock at 0.0122, the technology shock at 0.0115, and the policy shock at 0.0025.

The point estimate of Γ is 0.0432. The Calvo-probability of price non-reoptimization ξ can then be recovered by assigning values to $\varepsilon(1)$ and ϵ . Table 3 reports estimates of ξ and of the average amount of time between price reoptimization for $\Gamma = 0.0432$, $\varepsilon(1) = 10$, and alternative values of ϵ . We also contrast the results with and without firm-specific labor. These variants of the benchmark model are all observationally equivalent with respect to the data.

Following Eichenbaum and Fisher (2007), we use three different values for ϵ : 0, 10 and 33. The case $\epsilon = 0$ is one corresponding to a constant elasticity of demand, while $\epsilon = 10$ or 33 implies that firms face a variable elasticity of demand. These parameter values encompass the calibration in Eichenbaum and Fisher (2007).

We look first at the results obtained with firm-specific labor. With $\epsilon = 10$, firms reoptimize prices once every 2.65 quarters on average, while with $\epsilon = 33$ prices are reoptimized once every 2.29 quarters. With a constant elasticity of demand, the average duration of price contracts is

approximately three quarters.

Dropping the assumption of firm-specific labor has a significant impact on the results. With $\epsilon = 10$, firms reoptimize prices once every 3.88 quarters on average. With $\epsilon = 33$, the frequency of price reoptimization is once every 2.79 quarters. With a constant elasticity of demand, the average amount of time between price reoptimization is 5.4 quarters. Thus, firm-specific labor significantly increases the frequency of price reoptimization.

These findings are consistent with the estimates obtained by others. Assuming firm-specific capital, a labor share of two thirds, a 10 percent markup, a 10 percent annual depreciation rate and a degree of investment adjustment costs of 3.0, Eichenbaum and Fisher (2007) find that the average duration of price contracts equals 3.6, 3.3 and 2.9 quarters for $\epsilon = 0, 10$ and 33, respectively. Altig et al. (2005) find that the average amount of time between price reoptimization lies between 2.25 and 3.5 quarters for plausible markup values.

The first two columns of Table 4 show that the benchmark model successfully reproduces the volatilities of output growth and inflation during the postwar period. It predicts a volatility of output growth of 0.0129, in comparison to 0.013 in the data. The variability of inflation predicted by the model is 0.0064, compared to 0.0069 in the data. The model also produces the right comovement between inflation and output growth with -0.0851, not far from the actual correlation which is -0.2079.

5.2 Vector Autocorrelations

Following Fuhrer and Moore (1995) and Ireland (2001, 2003), we compare the vector autocorrelation functions from a vector autoregression and from the benchmark model. We estimate an unconstrained fourth-order vector autoregression that includes the following variables: the growth rate of per capita output, the rate of change of per capita hours worked and the rate of inflation. First, we conduct a Phillips-Perron (1988) test of the presence of a unit root in per capita hours and inflation (not reported). The null hypothesis of a unit root in per capita hours is not rejected at the 5 percent level, whereas that of a unit root in the rate of inflation is rejected at the 5 percent level.

Figure 2 plots the autocorrelation functions from the vector autoregression and from the benchmark model. The diagonal elements are the univariate autocorrelation functions for inflation, the rate of change of per capita hours and the growth rate of per capita output, while the off-diagonal elements are the lagged cross correlations between these variables. Inflation is highly persistent in

the data, exhibiting positive serial correlation in the short run and the medium run. The growth rates of per capita output and hours are positively serially correlated at an horizon of one and two quarters. The benchmark model correctly predicts that inflation is more persistent than the growth rates of output and hours. Furthermore, it implies a substantial amount of inflation persistence. The model also produces positive autocorrelations in the growth rates of output and hours at a lag of one and two quarters. Thus, the benchmark model is up to the challenge of delivering plausible business-cycle dynamics. Cogley and Nason (1995) demonstrate that a large class of business cycle models fails to account for output dynamics due to their weak internal propagation mechanisms. The model also does well in matching the lagged cross correlations between inflation, output growth and the rate of change of hours.

5.3 Impulse-Response Functions

Figures 3 to 7 display the impulse responses of selected variables to each type of shock according to the benchmark model. Figure 3 summarizes the effects of a positive one percent technology shock. The model generates gradual, permanent increases in output, investment and consumption, consistent with the empirical evidence reported by Francis and Ramey (2005). Hours and effort decline in the short run and rise in the medium run. The short-run fall of hours is consistent with the empirical findings of Galí (1999), Francis and Ramey (2005) and Fernald (2007).¹⁵ The rise of hours in the medium run is consistent with the empirical finding in Basu et al. (2006).

The factors that explain the short-run decline in hours are the nominal price rigidity (e.g., Galí, 1999), habit persistence and investment adjustment costs (e.g., Francis and Ramey, 2005). The drop in inflation resulting from the improvement in technology is smaller with nominal price rigidity than it is with perfectly flexible prices, implying smaller expansionary effects on aggregate demand and output. Habit formation and investment adjustment costs also dampen the short-run increase in aggregate demand following a rise in wealth. Together, these factors imply that the rise in aggregate demand does not keep up with the increase in total factor productivity, so hours (and effort) fall in the short run. The model also predicts that the real wage rises modestly in the short run, and continues rising until it reaches a permanently higher level, consistent with the evidence in Basu et al. (2006) and Liu and Phaneuf (2007).

Figure 4 summarizes the effects of an expansionary monetary policy shock measured as a negative one percent shock to the nominal interest rate. The responses of output, consumption, invest-

¹⁵However, it is at odds with the evidence in Christiano et al. (2004) saying that hours rise following a technology improvement.

ment, hours and effort all exhibit typical hump-shaped patterns. Note, however, that the effects of a policy shock on output, hours, consumption and investment are relatively modest. The policy shock is also followed by a modest rise in inflation and a temporary increase in real wages.

Figure 5 shows that in response to a positive one percent consumption shock, both output and consumption rise temporarily, while investment falls. Baxter and King (1991) report similar findings. Hours, effort and the real wage rise. Inflation and the nominal interest rate weakly increase.

Figure 6 plots the impulse responses to a negative one percent labor supply shock. Output, hours, consumption and investment all increase sharply, and display pronounced hump-shaped responses. Effort falls. With a higher labor supply, the real wage falls. Inflation and the nominal interest rate decrease.

Lastly, Figure 7 shows that following a positive one percent investment-specific shock, output, investment, hours and effort all significantly rise in a hump-shaped fashion. After a short-run decline, consumption rises for several periods. The real wage, inflation and the nominal interest rate all rise.

5.4 Variance Decompositions

This subsection identifies the sources of the cyclical variance of output, hours and inflation during the postwar period. Table 5 features the variance decomposition of the forecast errors of output, hours worked, and inflation over different forecast horizons. The labor supply shock is the main source of output fluctuations at an horizon between one and twelve quarters, explaining from 43 to 55 percent of the variance of output. Based on vector autoregression models, Shapiro and Watson (1988) report similar percentages. Investment-specific shocks explain between 22 and 32 percent of the variance of output at similar horizons. Technology shocks explain less than 20 percent. The relatively small contribution of technology shocks predicted by our benchmark model is broadly consistent with the evidence of Galí (1999), Christiano et al. (2004) and Fisher (2006). Consumption and monetary policy shocks explain only a small percentage of the variance of output.

The variance of hours is mainly driven by labor supply shocks with 73 percent or more at all forecast horizons. This leaves only 13 percent or so to investment-specific shocks at business-cycle frequencies, and little to the other shocks.

Inflation variance is largely explained by the labor supply and investment-specific shocks. Policy shocks contribute to 11 percent of the variance of inflation at all horizons.

Summarizing the results presented in this subsection, we find that the benchmark model implies that labor supply shocks have been the most important source of output fluctuations and inflation variability during the postwar period, followed by investment-specific shocks.

6 From the Great Inflation to the Great Moderation

To what extent does the benchmark model account for the large declines in the volatilities of output growth and inflation during the Great Moderation? We answer this question by reestimating the benchmark model for the Great Inflation (1948:I to 1979:II) and for the Great Moderation (1984:I to 2006:II).

6.1 Estimation results

The estimation results are presented in Table 2. The last column reports the Andrews and Fair's (1988) Wald statistics allowing a stability test of the structural parameters of the model during the two subperiods. We find statistically significant changes in the values of some structural parameters from the first to the second subperiod. The coefficient of habit formation b decreases after 1984, whereas the parameter $S''(\epsilon_a)$ determining the degree of investment adjustment costs increases.

The estimated standard errors of structural shocks are considerably smaller after 1984. The investment-specific shock is 36 percent less volatile, followed by technology and labor supply shocks with 33 percent, by consumption shocks with 30 percent, and by monetary policy shocks with 25 percent. However, these tests show that the AR(1) coefficients of the shock-generating processes have not been significantly different between subperiods.

We also find that the Federal Reserve has fought inflation more aggressively after 1984, ρ_π increasing from 1.31 during the Great Inflation to 1.74 during the Great Moderation (see also Clarida et al., 2000). However, we find no evidence of a statistically significant change in the Fed's reaction to the measure of output. The interest-rate smoothing parameter is somewhat smaller during the second subperiod.

The estimate of Γ measuring the response of inflation to the real marginal cost is 0.0579 during the Great Inflation and 0.0341 during the Great Moderation. Table 3 reports the average amount of time between price reoptimization implied by these estimates. With $\Gamma = 0.0579$, the benchmark

model says that firms reoptimize prices once every 2.32 quarters on average with $\epsilon = 10$ and once every 2.04 quarters with $\epsilon = 33$. With $\Gamma = 0.0341$, the period of time between price reoptimization is 2.93 quarters with $\epsilon = 10$ and 2.51 quarters with $\epsilon = 33$. Therefore, the frequency of price reoptimization has slightly decreased during the Great Moderation. Smets and Wouters (2007) estimate a DSGE model with a variable elasticity of demand without firm-specific factors and report that the probability of price non-reoptimization increases from 0.55 during the Great Inflation to 0.73 during the Great Moderation.

Table 4 reports the volatilities of output growth and inflation during the two subperiods. Again, the benchmark model accounts well for these statistics. The volatility of output growth predicted by the model during the Great Inflation is 0.0142, not far from 0.0153 which is actually observed. During the Great Moderation, the actual volatility of output growth is 0.0069, while the model predicts a volatility of 0.0081. Concerning the volatility of inflation, the model predicts it is 0.008 during the Great Inflation, compared to 0.0078 in the data. During the Great Moderation, the model's prediction for the variability of inflation is 0.0035, in comparison to 0.0027 in the data.

Therefore, we conclude that the benchmark model successfully captures the severity of the declines in the volatilities of output growth and inflation during the Great Moderation. While the data tell us that the volatility of output growth has decreased by 55 percent, the model predicts a decline of 43 percent. Also, while the variability of inflation has been 65 percent smaller during the Great Moderation, the model generates a drop of 56 percent.

The benchmark model also correctly predicts that the correlation between output growth and inflation was increasingly negative from the first to the second subperiod.

6.2 What Are the Sources of the Great Moderation?

What are the sources of the reductions in the volatilities of output growth and inflation? We answer this question by performing some counterfactual experiments. We partition the model's structural parameters into three subsets of parameters. The first subset G_1 regroups the parameters pertaining to the behavior of the private sector and is given by $G_1 = \{\beta, b, 1/\eta_h, 1/\eta_e, S''(\epsilon_a), \Gamma\}$. The second, G_2 , is composed of the parameters describing the systematic portion of the Fed's policy rule and is $G_2 = \{\rho_r, \rho_\pi, \rho_g\}$. The third subset, G_3 , includes the AR(1) coefficients and the standard deviations of the structural shocks, i.e. $G_3 = \{\rho_c, \rho_h, \rho_i, \sigma_c, \sigma_h, \sigma_i, \sigma_a, \sigma_m\}$. Denote by $C_x(G_1)$, $C_x(G_2)$, and $C_x(G_3)$, respectively, the contributions of G_1 , G_2 , and G_3 to the change in the volatility of variable of interest x during the Great Moderation, where $x = \{\text{output growth,}$

inflation}. These contributions can be measured by (see also Leduc and Sill, 2007):

$$C_x(G_1) = \frac{\sigma_x(G_1^{79}, G_2^{79}, G_3^{79}) - \sigma_x(G_1^{84}, G_2^{79}, G_3^{79})}{\sigma_x(G_1^{79}, G_2^{79}, G_3^{79}) - \sigma_x(G_1^{84}, G_2^{84}, G_3^{84})}$$

$$C_x(G_2) = \frac{\sigma_x(G_1^{84}, G_2^{79}, G_3^{79}) - \sigma_x(G_1^{84}, G_2^{84}, G_3^{79})}{\sigma_x(G_1^{79}, G_2^{79}, G_3^{79}) - \sigma_x(G_1^{84}, G_2^{84}, G_3^{84})}$$

$$C_x(G_3) = \frac{\sigma_x(G_1^{84}, G_2^{84}, G_3^{79}) - \sigma_x(G_1^{84}, G_2^{84}, G_3^{84})}{\sigma_x(G_1^{79}, G_2^{79}, G_3^{79}) - \sigma_x(G_1^{84}, G_2^{84}, G_3^{84})}$$

For example, the term $\sigma_x(G_1^{84}, G_2^{79}, G_3^{79})$ measures the standard deviation of x predicted by the benchmark model during the second subperiod under the assumption that the properties of the shock-generating processes and the parameters of the policy rule are the same as they were during the first subperiod. Hence, $C_x(G_1)$ measures the variation in percentage of the standard deviation of x explained by the change in the behavior of the private sector G_1 . The denominator, which is common to all three measures, denotes the overall change in the volatility of x . A similar reasoning applies to other sources of variation in the standard deviation of x .

The results of these counterfactual experiments are reported in Table 6. Looking at the sources of the decline in the volatility of output growth during the Great Moderation, we find that smaller shocks explain almost 85 percent of the decrease in output fluctuations, leaving about 15 percent to be explained by changes in the behavior of the private sector and monetary policy. Table 7 shows that smaller labor supply shocks explain almost 50 percent of the decline in output fluctuations, followed by smaller investment-specific shocks with 22 percent.

Looking at the decline in the variability of inflation during the Great Moderation, we find that smaller shocks explain only one third of it, leaving 32.5 and 34.3 percent, respectively, to changes in the behavior of the private sector and monetary policy.

6.3 Related Literature

Other researchers, including Stock and Watson (2003), Sims and Zha (2006), Smets and Wouters (2007), Arias et al. (2007), Leduc and Sill (2007) and Justiniano and Primiceri (2008) also find that the sharp decline in the volatility of output growth during the Great Moderation results mostly from smaller structural shocks.

Smets and Wouters (2007) estimate a DSGE model with nominal rigidities, real frictions, a variable elasticity of demand and homogeneous factors. Their model overpredicts the volatility of output growth by 11.9 percent during the first subperiod and by 23.7 percent during the second subperiod. In comparison, our benchmark model underpredicts the volatility of output growth

by 7.2 percent during the Great Inflation and overpredicts it by 17.3 percent during the Great Moderation. Their model also overpredicts the variability of inflation by 47.2 percent during the first subperiod and by 36 percent during the second subperiod. In comparison, our benchmark model overpredicts the variability of inflation by a small 2.5 percent during the Great Inflation and by 29.6 percent during the Great Moderation.¹⁶

The papers by Arias et al. (2007) and Leduc and Sill (2007) identify smaller TFP shocks as the main source of the decline in output fluctuations. Based on a calibrated RBC model of the kind proposed by Burnside and Eichenbaum (1996) and featuring variable capacity utilization, variable effort and indivisible labor, Arias et al. study the sources of the decrease in the volatility of output growth without looking at the causes of the decline in the volatility of inflation. It is well known, however, that RBC models grossly overpredict the variability of inflation in response to TFP shocks as these models rest on the assumption of perfectly flexible prices (see Liu and Phaneuf, 2007). Leduc and Sill develop a sticky-price model that incorporates an energy sector and where firms face quadratic price-adjustment costs. While capturing to some extent the severity of the large decline in output fluctuations, their model considerably underpredicts the volatility of inflation which is 6.6 times smaller than found in the data.

An interesting paper by Justiniano and Primiceri (2007) estimates a DSGE model with nominal rigidities, real frictions and several types of shocks allowing for time variation in the volatility of the structural innovations. Our studies share a common result. Both papers find that changes in monetary policy and the private sector behavior have reduced the variability of inflation, but not the volatility of output growth. Their paper singles out a sharp decline in the variability of a shock specific to the equilibrium condition of investment as the source of the decrease in the volatility of output growth during the Great Moderation. We also find a significant, but somewhat smaller role for investment-specific shocks.¹⁷

¹⁶Unfortunately, their estimation results do not single out among the structural shocks included in their model which contributes most to the reduced volatility of output growth.

¹⁷Besides differences in the estimation procedures used in the two papers, our paper differs in another important respect. While the objective of reconciling the micro and macro evidence about the behavior of prices is central to our modeling strategy, it is not in Justiniano and Primiceri. So our estimated models have very different implications for the frequency of price reoptimization. While our estimates are consistent with a frequency of price reoptimization between 6 and 9 months, their estimated Calvo-probabilities of price non reoptimization generally imply that prices are reoptimized once every 2.5 years on average.

7 Conclusion

Recently, Hall (1997) has forcefully argued that the emphasis on technology shocks in business cycle theory may have been misplaced, offering evidence that the main driving force behind aggregate fluctuations are shifts in the marginal rate of substitution between goods and work. We have provided new evidence, consistent with Hall's contention and the findings of Shapiro and Watson (1988), that shifts in labor supply have been the prime driving force of postwar business cycles.

Furthermore, we have established that labor supply shocks account in large part for the decline in output fluctuations during the Great Moderation, followed by investment-specific shocks. However, we have found that the large drop in the volatility of inflation is explained almost evenly by changes in the behavior of the private sector, a less accommodative monetary policy and smaller shocks.

The DSGE framework used for the purpose of our investigation is built on the premises that price-setting firms face a variable elasticity of demand and that labor is firm-specific. These assumptions help resolve the conflicting pictures between microeconomic evidence indicating that firms reoptimize prices quite frequently with the evidence from aggregate time series that inflation is quite persistent.

References

- [1] Altig, David, Lawrence J. Christiano, Martin Eichenbaum., and Jesper Lindé. 2005. Firm-Specific Capital, Nominal Rigidities and the Business Cycle. NBER Working Paper No. 11034.
- [2] Andrews, Donald, and Fair, Ray C. 1988. Inference in Nonlinear Econometric Models with Structural Change. *Review of Economic Studies*, 55(4), 615-639.
- [3] Arias, Andres, Gary Hansen, and Lee Ohanian. 2007. Why Have Business Cycle Fluctuations Become Less Volatile? *Economic Theory*, 32(1), 43-58.
- [4] Basu, Susanto, John G. Fernald, and Miles S. Kimball, 2006. Are Technology Improvements Contractionary?. *American Economic Review*, 96(5), 1418-1448.
- [5] Baxter, Marianne, and Robert G. King. 1991. Productive Externalities and Business Cycles. Federal Reserve Bank of Minneapolis, Discussion Paper No. 53.
- [6] Bergin, Paul R., and Robert C. Feenstra. 2000. Staggered Price Setting, Translog Preferences, and Endogenous Persistence. *Journal of Monetary Economics*, 45(3), 657-680.
- [7] Bils, Mark, and Pete J. Klenow. 2004. Some Evidence on the Importance of Sticky Prices. *Journal of Political Economy*, 112(5), 947-985.
- [8] Blanchard, Olivier J., and Dany Quah. 1989. The Dynamic Effects of Aggregate Demand and Supply Disturbances. *American Economic Review*, 79(4), 655-673.
- [9] Blanchard, Olivier J., and John Simon. 2001. The Long and Large Decline in U.S. Output Volatility. *Brookings Papers on Economic Activity*, 1, 135-164.
- [10] Burnside, Craig, and Martin Eichenbaum. 1996. Factor-Hoarding and the Propagation of Business-Cycle Shocks. *American Economic Review*, 86(5), 1154-1174.
- [11] Boivin, Jean, and Marc P. Giannoni. 2006. Has Monetary Policy Become More Effective?. *Review of Economics and Statistics*, 88(3), 445-462.
- [12] Christiano, Lawrence J., Martin Eichenbaum, and Charles L. Evans. 2005. Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy. *Journal of Political Economy*, 113(1), 1-45.

- [13] Christiano, Lawrence J., Martin Eichenbaum., and Robert Vigfusson. 2004. What Happens after a Technology Shock? Mimeo.
- [14] Clarida, Richard, Jordi Galí, and Mark Gertler. 2000. Monetary Policy Rules and Macroeconomic Stability: Evidence and Some Theory. *Quarterly Journal of Economics*, 115, 147-180.
- [15] Cogley, Timothy, and James M. Nason. 1995. Output Dynamics in Real-Business-Cycle Models. *American Economic Review*, 85(3), 492-511.
- [16] Edge, Rochelle M. 2002. The Equivalence of Wage and Price Staggering in Monetary Business Cycle Models. *Review of Economic Dynamics*, 5(3), 559-585.
- [17] Eichenbaum, Martin, and Jonas D.M. Fisher. 2004. Evaluating the Calvo Model of Sticky Prices. NBER Working Papers No. 10617.
- [18] Eichenbaum, Martin, and Jonas D.M. Fisher. 2007. Estimating the Frequency of Price Re-optimization in Calvo-Style Models. *Journal of Monetary Economics*, 54(7), 2032-2047.
- Erceg, Christopher J., Dale W. Henderson, and Andrew T. Levin., 2000. Optimal Monetary Policy with Staggered Wage and Price Contracts. *Journal of Monetary Economics*, 46(2), 281-313.
- [19] Erceg, Christopher J., and Andrew T. Levin. 2003. Imperfect Credibility and Inflation Persistence. *Journal of Monetary Economics*, 50, 915-944.
- [20] Fernald, John G. 2007. Trend Breaks, Long-Run Restrictions, and Contractionary Technology Improvements. *Journal of Monetary Economics*, 54(8), 2467-2485.
- [21] Fisher, Jonas D. M. 2006. The Dynamic Effects of Neutral and Investment-Specific Technology Shocks. *Journal of Political Economy*, 114(3), 413-451.
- [22] Francis, Neville R., and Valerie A. Ramey. 2005. Is the Technology-Driven Real Business Cycle Hypothesis Dead? Shocks and Aggregate Fluctuations Revisited. *Journal of Monetary Economics*, 52(8), 1379-1399.
- [23] Fuhrer, Jeffrey C., and George Moore. 1995. Inflation Persistence. *Quarterly Journal of Economics*, 110(1), 127-159.
- [24] Galí, Jordi. 1999. Technology, Employment, and the Business Cycle: Do Technology Shocks Explain Aggregate Fluctuations?. *American Economic Review*, 89, 249-271.

- [25] Galí, Jordi, and Mark Gertler. 1999. Inflation Dynamics: A Structural Econometric Analysis. *Journal of Monetary Economics*, 44(2), 195-222.
- [26] Galí, Jordi, and Pau Rabanal. 2004. Technology Shocks and Aggregate Fluctuations: How Well Does the RBC Model Fit Postwar U.S. Data?. NBER Working Paper No. 10636.
- [27] Greenwood, Jeremy, Zvi Hercowitz, and Gregory W. Huffman. 1988. Investment, Capacity Utilization, and the Real Business Cycle. *American Economic Review*, 78(3), 402-417.
- [28] Hall, Robert E. 1997. Macroeconomic Fluctuations and the Allocation of Time. *Journal of Labor Economics*, 15(1), S223-250.
- [29] Hamilton, James D. 1994. Time Series Analysis. Princeton University Press, Princeton, NJ.
- [30] Iacoviello, Matteo, Fabio Schiantarelli, and Scott Schuh. 2007. Input and Output Inventories in General Equilibrium. Federal Reserve Bank of Boston, Working Paper No. 07-16.
- [31] Ireland, Peter N. 2001. Sticky-Price Models of the Business Cycle: Specification and Stability. *Journal of Monetary Economics*, 47, 3-18.
- [32] Ireland, Peter N. 2003. Endogenous Money or Sticky Prices?. *Journal of Monetary Economics*, 50, 1623-1648.
- [33] Justiniano, Alejandro, and Giorgio E. Primiceri. 2007. The Time Varying Volatility of Macroeconomic Fluctuations. *American Economic Review*, forthcoming.
- [34] Kahn, James, Margaret McConnell, and Gabriel Perez-Quiros. 2002. On the Causes of the Increased Stability of the U.S. Economy. *Economic Policy Review*, Federal Reserve Bank of New York, 183-202.
- [35] Kim, Chang-Jin, and Charles R. Nelson. 1999. Has the U.S. Economy Become More Stable? A Bayesian Approach Based on a Markov-Switching Model of Business Cycle. *Review of Economics and Statistics*, 81, 608-616.
- [36] Kimball, Miles S. 1995. The Quantitative Analytics of the Basic Neomonetarist Model. *Journal of Money, Credit, and Banking*, 27(4), 1241-1277.
- [37] King, Robert G., Charles I. Plosser, James Stock, and Mark W. Watson. 1991. Stochastic Trends and Economic Fluctuations. *American Economic Review*, 81(4), 819-840.

- [38] Klein, Paul. 2000. Using the Generalized Schur Form to Solve a Multivariate Linear Rational Expectations Model. *Journal of Economic Dynamics and Control*, 24, 1405-1423.
- [39] Klenow, Pete J., and Oleksiy Kryvtsov. 2008. State-Dependent or Time-Dependent Pricing: Does it Matter for Recent U.S. Inflation? *Quarterly Journal of Economics*, forthcoming.
- [40] Leduc, Sylvain, and Keith Sill. 2007. Monetary Policy, Oil Shocks, and TFP: Accounting for the Decline in U.S. Volatility. *Review of Economic Dynamics*, 10(4), 595-614.
- [41] Liu, Zheng, and Louis Phaneuf. 2007. Technology Shocks and Labor Market Dynamics: Some Evidence and Theory. *Journal of Monetary Economics*, 54(8), 2534-2553.
- [42] Matheron, Julien. 2006. Firm-Specific Labor and Firm-Specific Capital: Implications for the Euro-Data New Phillips Curve. *International Journal of Central Banking*, 33-64.
- [43] McConnell, Margaret, and Gabriel Perez-Quiros. 2000. Output Fluctuations in the United States: What Has Changed Since the Early 1980s?. *American Economic Review*, 90(5), 1464-1476.
- [44] Nakamura, Emi, and Jón Steinsson. 2007. Five Facts About Prices: A Reevaluation of Menu Cost Models. Manuscript.
- [45] Orphanides, Athanasios, and John C. Williams. 2002. Robust Monetary Policy Rules with Unknown Natural Rates. *Brookings Papers on Economic Activity*, 33, 63-146.
- [46] Phillips, Peter C.B., and Pierre Perron. 1988. Testing for a Unit Root in Time Series Regression. *Biometrika*, 75, 335-346.
- [47] Rotemberg, Julio J., and Michael Woodford. 1995. Dynamic General Equilibrium Models with Imperfectly Competitive Product Markets. in: T.F. Cooley, ed., *Frontier of business cycle research*, Princeton University Press, 243-293.
- [48] Sbordone, Argia M. 2002. Prices and Unit Labor Costs: A New Test of Price Stickiness. *Journal of Monetary Economics*, 49(2), 265-292.
- [49] Shapiro, Matthew D., and Mark W. Watson. 1988. Sources of Business Cycle Fluctuations. NBER Working Paper No. 2589.

- [50] Sims, Christopher A, and Tao Zha. 2006. Were There Regime Switches in US Monetary Policy? *American Economic Review*, 96(1), 54-81.
- Smets, Frank, and Rafael Wouters. 2003. An Estimated Dynamic Stochastic General Equilibrium Model of the Euro Area. *Journal of the European Economic Association*, 1(5), 1123-1175.
- [51] Smets, Frank, and Rafael Wouters. 2007. Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach. *American Economic Review*, 97(3), 586-606.
- [52] Stock, James H. and Mark W. Watson. 2003. Has the Business Cycle Changed? Evidence and Explanations. *Proceedings*, Federal Reserve Bank of Kansas City, 9-56.
- [53] Taylor, John B. 1993. Discretion Versus Policy Rules in Practice. *Carnegie-Rochester Conference Series on Public Policy*, 39, 195-214.
- [54] Woodford, Michael. 2003. *Interest and Prices: Foundations of a Theory of Monetary Policy*. Princeton University Press.

Appendix

This appendix briefly shows how the Phillips curve equation (16) is derived. First, recall that $\varepsilon(1)$ denotes the demand elasticity of intermediate good i evaluated at the steady state. We linearize the first-order condition for the finished-good firm's problem (9), the no-profit condition for the finished-good firm (15), and the first-order condition for the optimal price of the intermediate-good firm (14). These equations are:

$$y_{i,t+\tau} - y_{t+\tau} = -\varepsilon(1)(p_t^* - p_{t+\tau}), \quad (\text{i})$$

$$p_t^* - p_t = \frac{\xi}{(1-\xi)}\pi_t, \quad (\text{ii})$$

$$\frac{1}{(1-\beta\xi)}(p_t^* - p_t) = E_t \sum_{\tau=0}^{\infty} (\beta\xi)^\tau [mc_{i,t+\tau} + p_{t+\tau} - p_t - \varphi_1(p_t^* - p_{t+\tau})], \quad (\text{iii})$$

where

$$\varphi_1 = \left(\frac{1 + \left(1 + \frac{G'''(1)}{G''(1)}\right) \varepsilon(1)}{\varepsilon(1) - 1} \right).$$

Eichenbaum and Fisher (2004, appendix) show that $1 + \left(1 + \frac{G'''(1)}{G''(1)}\right) \varepsilon(1) = \epsilon$, where ϵ is the percent change in the elasticity of demand due to a one percent change in the relative price of the good, evaluated at the steady state. From the household's first-order conditions, we have :

$$(1 + \eta_e)e_{i,t+\tau} = (1 + \eta_h)h_{i,t+\tau}. \quad (\text{iv})$$

The real marginal cost of firm i is related to the aggregate real marginal cost by:

$$mc_{i,t+\tau} = mc_{t+\tau} - \varphi_2(p_t^* - p_{t+\tau}), \quad (\text{v})$$

where

$$\varphi_2 = (\varepsilon(1) - 1) \left[\frac{A - B}{(1 + \alpha(A - B))^{I^F}} - 1 \right], \quad A = \left(\frac{1 + \eta_h}{1 - \alpha} \right), \quad B = \left(\frac{(1 + \eta_h)^2}{(2 + \eta_h + \eta_e)(1 - \alpha)} \right),$$

and I^F is an indicator function taking a value of 1 if capital is homogenous and mobile across firms, and a value of 0 if capital is fixed. Note that as $\eta_e \rightarrow \infty$, then $B \rightarrow 0$. Substituting (i), (ii), (iv) and (v) in (iii) and rearranging, we obtain equation (16) in the paper:

$$\pi_t = \beta E_t \pi_{t+1} + \Gamma mc_t,$$

where $\Gamma = \frac{(1-\beta\xi)(1-\xi)}{\xi} \varphi^{-1}$, and $\varphi = 1 + \varphi_1 + \varphi_2$.

**Table 1: Summary Statistics on Output Growth
and Inflation**

	1948:I-2006:II	1948:I-1979:II	1984:I-2006:II
Output growth	0.0130	0.0153	0.0069
Inflation	0.0069	0.0078	0.0027
$corr(\Delta y_t, \pi_t)$	-0.2079	-0.1672	-0.3104

Table 2: Maximum Likelihood Estimates

Parameter	1948:I-2006:II		1948:I-1979:II		1984:I-2006:II		W statistic
	Estimate	S.E	Estimate	S.E	Estimate	S.E	
b	0.5713	0.0012	0.5938	0.0104	0.5598	0.0010	10.6521***
$1/\eta_h$	0.8496	0.0010	0.8204	0.2133	0.8618	0.0119	0.0377
$1/\eta_e$	0.1484	0.0081	0.1229	0.0887	0.1551	0.0018	0.1315
$S''(\epsilon_a)$	2.7520	0.0192	2.6416	0.0092	3.1621	0.2882	3.2585*
ρ_r	0.7542	0.0234	0.7861	0.0260	0.7433	0.0001	2.7278*
ρ_π	1.5295	0.1337	1.3143	0.0079	1.7401	0.1595	7.1105***
ρ_y	0.1511	0.0652	0.1739	0.0611	0.1428	0.0732	0.1060
ρ_c	0.5696	0.0461	0.5903	0.0068	0.5477	0.1530	0.0773
ρ_h	0.8832	0.0198	0.9090	0.0101	0.8621	0.0240	3.2368*
ρ_i	0.7918	0.0336	0.7536	0.0709	0.7738	0.0109	0.0789
Γ	0.0432	0.0125	0.0579	0.0004	0.0341	0.0055	18.3266***
σ_a	0.0115	0.0027	0.0128	0.0039	0.0086	0.0038	0.6016
σ_m	0.0025	0.0002	0.0020	0.0002	0.0015	0.0001	4.6748**
σ_c	0.0122	0.0010	0.0134	0.0012	0.0094	0.0014	4.7707**
σ_h	0.0726	0.0118	0.0733	0.0104	0.0488	0.0038	4.8841**
σ_i	0.0343	0.0030	0.0371	0.0040	0.0238	0.0012	9.9570***

Note: S.E denotes the standard deviation. *, **, and *** denote significance at the 10%, 5%, and 1% level, respectively.

Table 3: Implied Frequency of Price Reoptimization

	Homogeneous labor			Specific labor		
	$\epsilon = 0$	$\epsilon = 10$	$\epsilon = 33$	$\epsilon = 0$	$\epsilon = 10$	$\epsilon = 33$
1948:I-2006:II						
ξ	0.815	0.7422	0.6423	0.6563	0.6233	0.5637
$1/(1 - \xi)$	5.4052	3.8794	2.7953	2.9099	2.6544	2.2919
1948:I-1979:II						
ξ	0.7879	0.7073	0.5989	0.6035	0.5698	0.5094
$1/(1 - \xi)$	4.7149	3.4165	2.493	2.5218	2.3245	2.0383
1984:I-2006:II						
ξ	0.834	0.7674	0.6746	0.6905	0.6591	0.602
$1/(1 - \xi)$	6.0257	4.2999	3.0727	3.2313	2.933	2.5125

**Table 4: Output Growth and Inflation:
Standard Deviations and Correlations**

	1948:I-2006:II		1948:I-1979:II		1984:I-2006:II	
	Data	Model	Data	Model	Data	Model
Output growth	0.0130	0.0129	0.0153	0.0142	0.0069	0.0081
Inflation	0.0069	0.0064	0.0078	0.0080	0.0027	0.0035
$corr(\Delta y_t, \pi_t)$	-0.2079	-0.0851	-0.1672	-0.0583	-0.3104	-0.1461

Table 5: Forecast Error Variance Decompositions (1948:I-2006:II)

Output					
Horizons	Technology	Monetary policy	Consumption	Labor supply	Investment
1	9.5055	6.1120	10.1568	42.5481	31.6776
4	11.9442	2.6982	2.7433	53.8372	28.7771
8	15.6078	1.3945	1.1437	56.9637	24.8903
20	29.7602	0.7397	0.5854	50.1616	18.7531
40	49.4559	0.5009	0.3949	36.2612	13.3871
100	74.3662	0.2528	0.1992	18.3844	6.7975

Hours worked					
Horizons	Technology	Monetary policy	Consumption	Labor supply	Investment
1	6.3384	2.5617	4.2570	73.5662	13.2768
4	1.2622	1.8642	2.0406	78.8516	15.9814
8	0.8186	1.1641	1.1084	83.3553	13.5535
20	1.0844	0.9022	0.8531	86.0103	11.1501
40	1.2658	0.8945	0.8433	85.3536	11.6428
100	1.2903	0.8925	0.8410	85.2350	11.7412

Inflation					
Horizons	Technology	Monetary policy	Consumption	Labor supply	Investment
1	0.5180	11.8608	1.3689	61.9231	24.3292
4	0.4848	12.2765	1.3148	48.3301	37.5939
8	1.3026	11.8163	1.2281	45.0892	40.5638
20	2.8080	11.4288	1.1894	43.9853	40.5885
40	3.2304	10.9257	1.1383	43.7724	40.9331
100	3.2762	10.8197	1.1274	43.8799	40.8968

**Table 6: Sources of Reductions in the Volatilities
of Output Growth and Inflation (in %)**

	Private sector	Monetary policy	Shocks
Output growth	9.2	5.9	84.9
Inflation	32.5	34.3	33.2

**Table 7: Contribution of Shocks to the Reductions in the Volatilities
of Output Growth and Inflation (in %)**

	Technology	Monetary policy	Consumption	Labor supply	Investment
Output growth	0.07	0.01	0.05	49.92	21.82
Inflation	0.01	0.02	0.005	0.16	0.14

Figure 1: Output growth and inflation

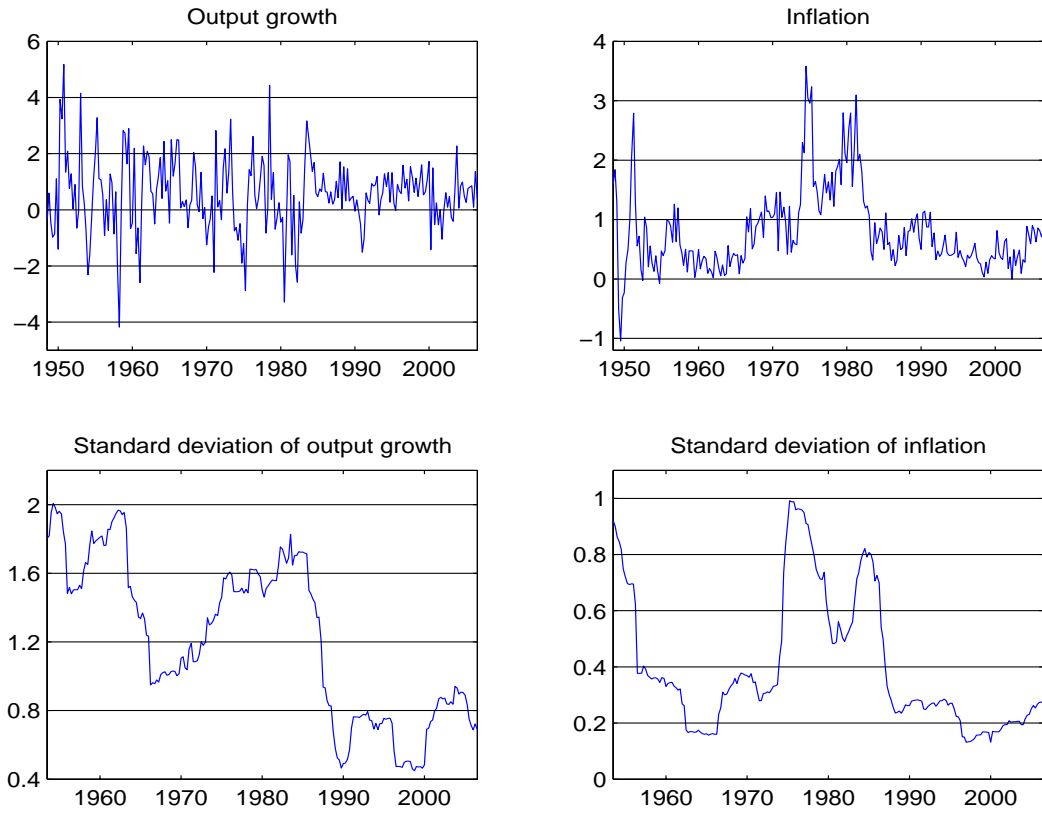
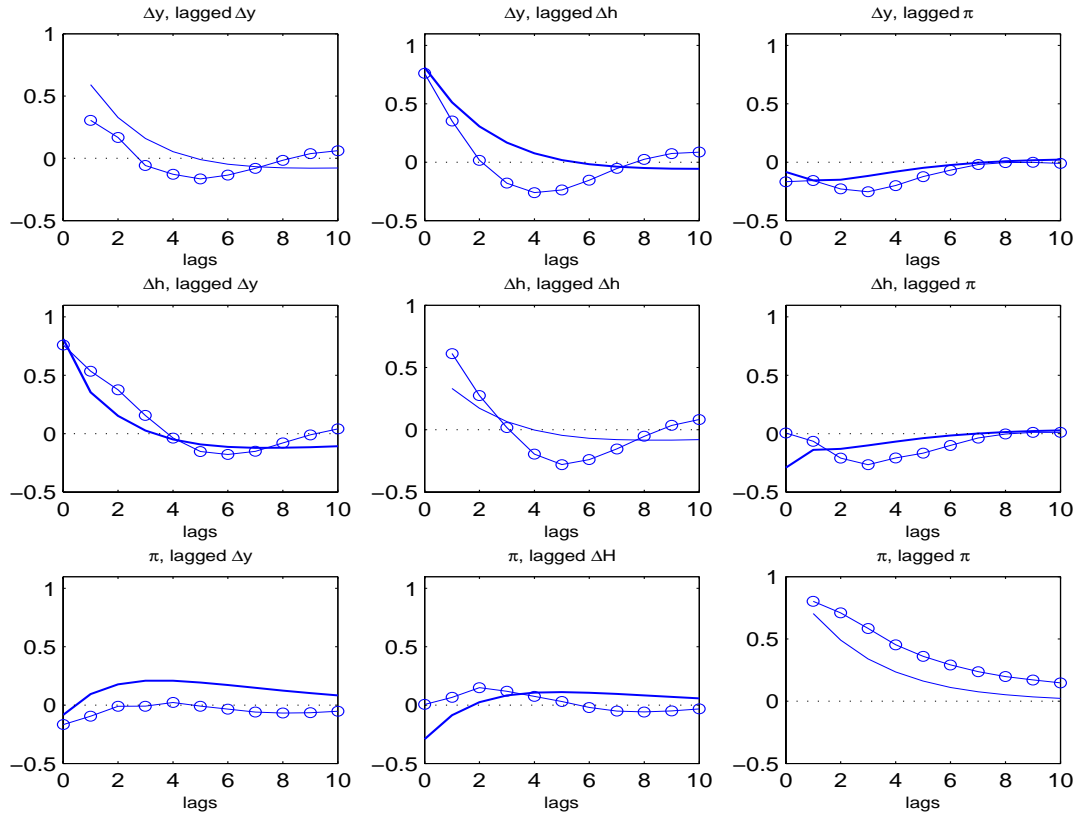


Figure 2: Vector Autocorrelation Functions: Benchmark Model vs Vector Autoregression



Note: Benchmark Model: solid line. Data: line with circles.

Figure 3: Impulse Responses to a Technology Shock

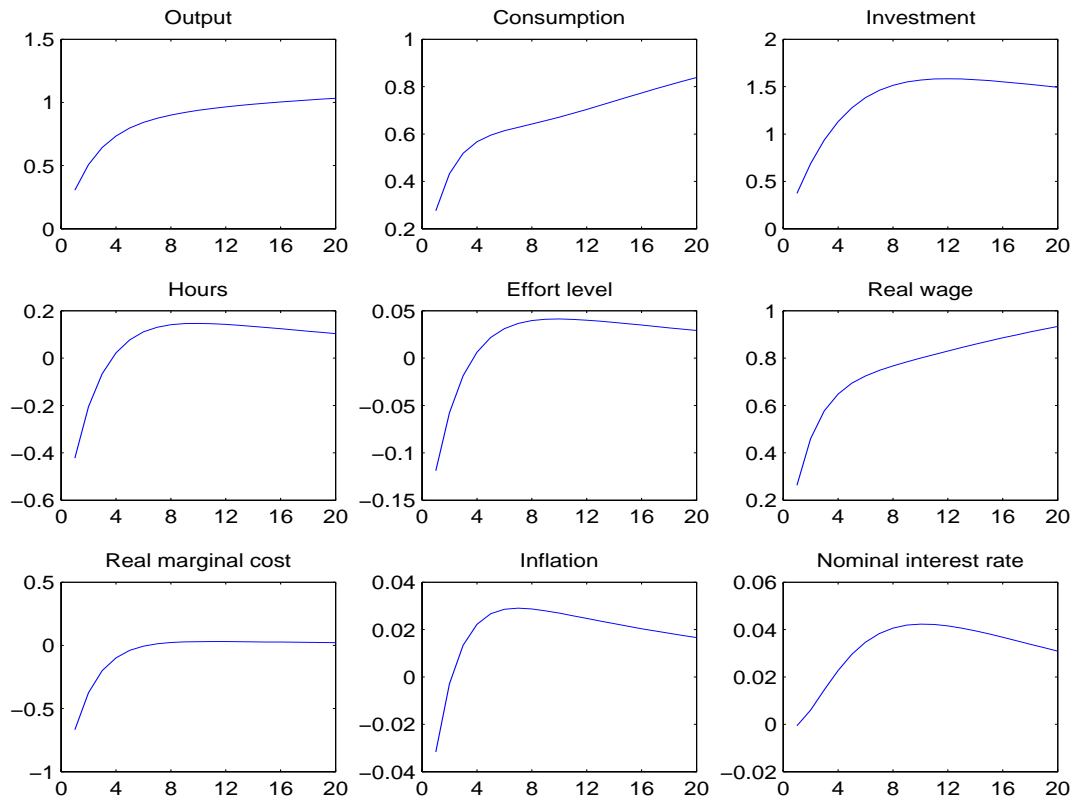


Figure 4: Impulse Responses to a Monetary Policy Shock

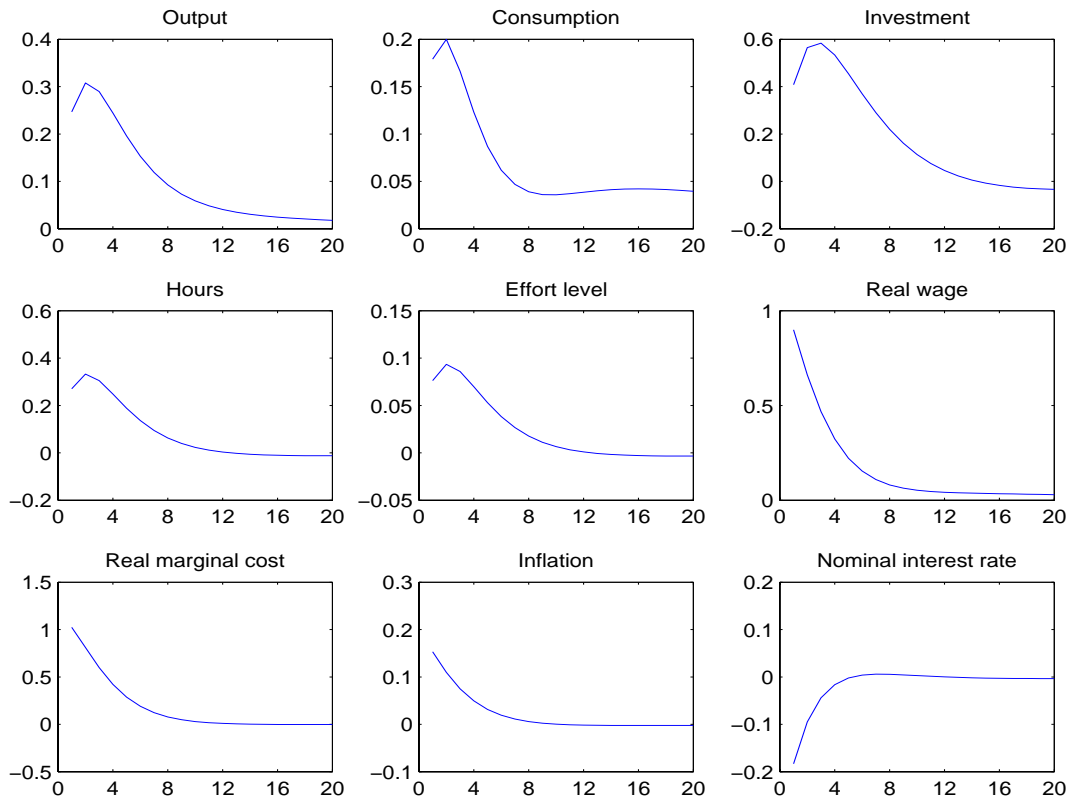


Figure 5: Impulse Responses to a Consumption Shock

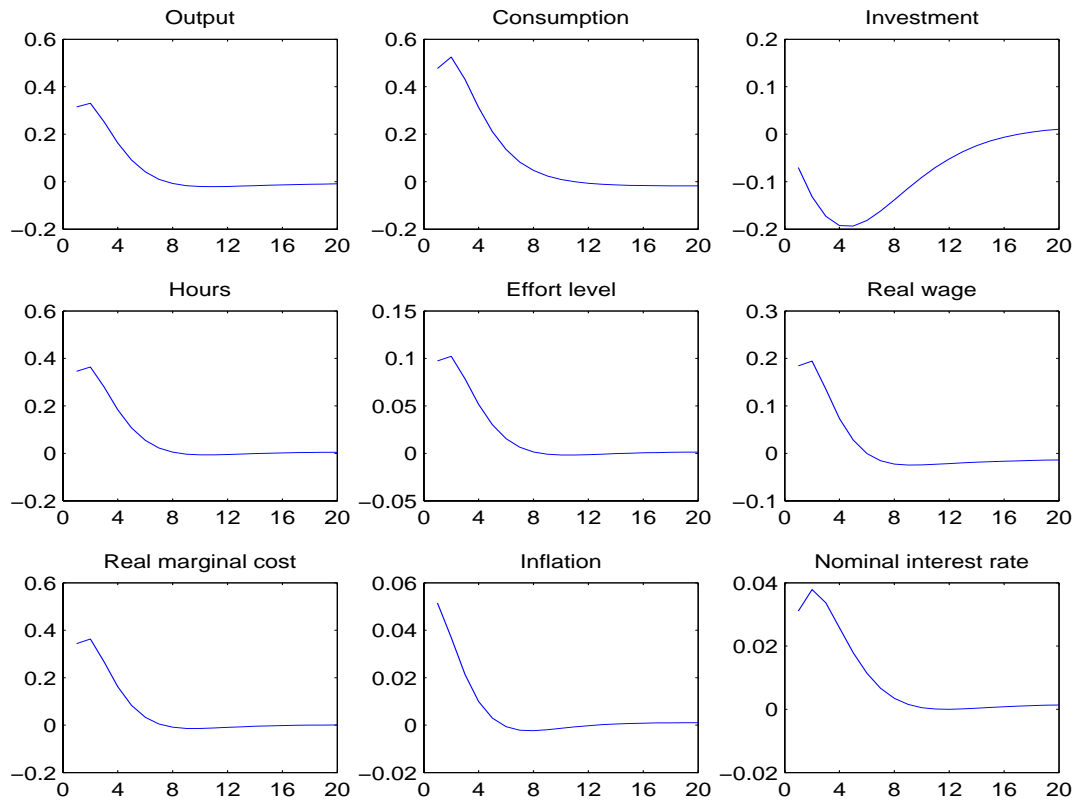


Figure 6: Impulse Responses to a Labor Supply Shock

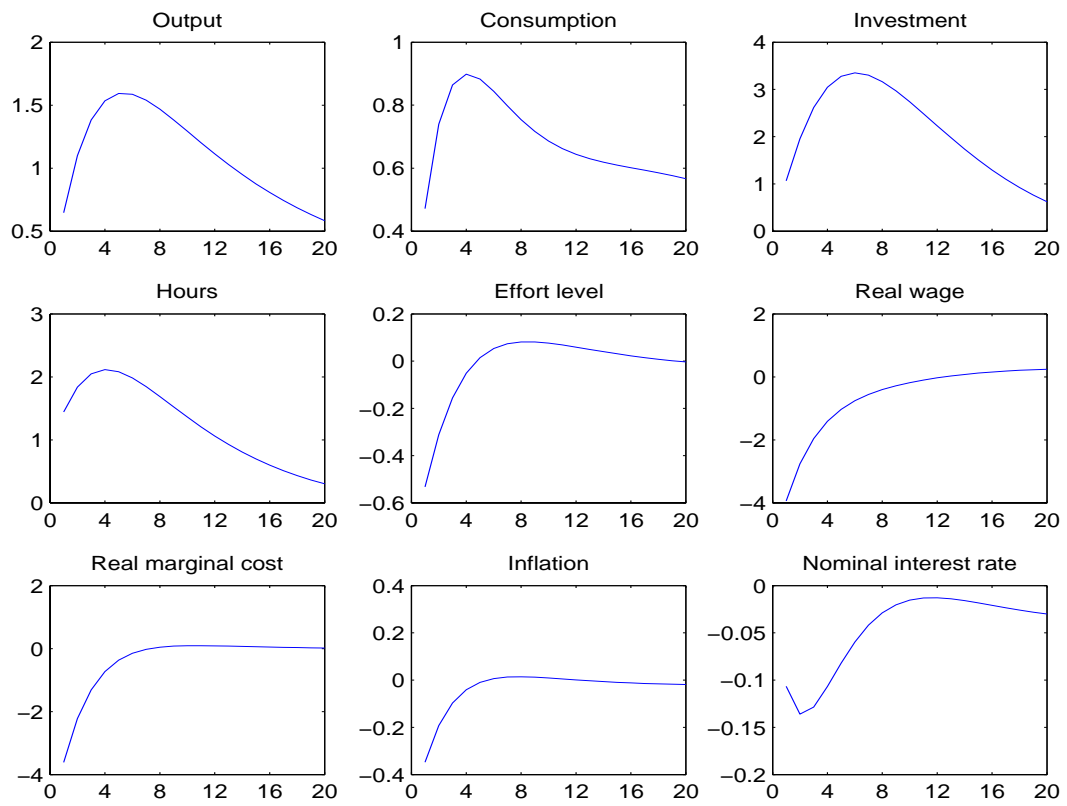


Figure 7: Impulse Responses to an Investment-Specific Shock

