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## ABSTRACT

The origins of business cycles are still controversial among macroeconomists. This paper contributes to this debate by studying the driving forces of fluctuations in an estimated new neoclassical synthesis model of the U.S. economy. In this model, most of the variability of output and hours at business cycle frequencies is due to shocks to the marginal efficiency of investment. Imperfect competition and, to a lesser extent, technological frictions are the key to their transmission. Although labor supply shocks explain a large fraction of the fluctuations in hours at very low frequencies, they are irrelevant over the business cycle. This finding is important because the microfoundations of these disturbances are widely regarded as unappealing.

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## 1. Introduction

What is the source of economic fluctuations? This is one of the defining questions of modern dynamic macroeconomics, at least since Sims (1980) and Kydland and Prescott (1982). Yet, the literature has not reached a consensus on the answer. On the one hand, the work that approaches this question from the perspective of general equilibrium models tends to attribute a dominant role in business cycles to neutral technology shocks (see King and Rebelo, 1999 for a comprehensive assessment). On the other hand, the structural VAR literature usually points to other disturbances as the main sources of business cycles, and rarely finds that neutral technology shocks explain more than one quarter of output fluctuations (Shapiro and Watson, 1988; King et al., 1991; Cochrane, 1994; Galí, 1999; Christiano et al., 2004; Fisher, 2006).

We revisit this debate from the perspective of a New Neoclassical Synthesis model of the U.S. economy (Goodfriend and King, 1997), estimated with Bayesian methods. The model adds to a neoclassical core a rich set of nominal and real frictions, along the lines of Christiano et al. (2005), and several shocks, as in Smets and Wouters (2007), including a shock

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to total factor productivity (or neutral technology shock), as in the RBC literature; a shock to the marginal productivity of investment (or, for simplicity, investment shock), as in Greenwood et al. (1988); and a shock to desired wage markups (or, equivalently, to labor supply), as in Hall (1997). This model is an ideal laboratory for studying the driving forces of fluctuations, for three reasons. First, its fit is competitive with that of unrestricted VARs (Smets and Wouters, 2007; Del Negro et al., 2007). Second, it encompasses within a general equilibrium framework most of the views on the sources of business cycles found in the literature.<sup>1</sup> Third, its deviations from the neoclassical growth prototype give disturbances other than the neutral technology shock a fair chance to be plausible cyclical forces.

In the estimated model, *investment shocks* account for between 50 and 60 percent of the variance of output and hours at business cycle frequencies and for more than 80 percent of that of investment. The contribution of *neutral technology shocks* is smaller, but not negligible. They explain about a quarter of the movements in output and consumption, although only about 10 percent of those in hours. These numbers are close to those estimated by Fisher (2006) within a structural VAR.

*Labor supply shocks* are irrelevant over the business cycle, although they dominate the fluctuations of hours at very low frequencies. This finding is important because labor supply shocks are a key ingredient of many business cycle models, but many economists find them intellectually unappealing (see Chari et al., 2009 and especially Shimer, 2009 for an extensive discussion and references). According to our results, these disturbances can be ignored when studying business cycles, although they are necessary to account for the low level of hours worked in the 1970s and early 1980s.

Other papers in the literature study the sources of fluctuations in empirical medium-scale DSGE models. In particular, Smets and Wouters (2007) present an analysis of the driving forces of output as one of the applications of their estimated model of the U.S. economy. In contrast to our results, however, they conclude that “it is primarily two “supply” shocks, the productivity and the wage mark-up shock, that account for most of the output variations in the medium to long run,” while they find almost no role for the investment shocks beyond the shortest horizons.

These conclusions depend on the unusual definition of consumption and investment adopted by Smets and Wouters (2007). They include durable expenditures in consumption, while excluding (the change in) inventories from investment, although not from output. When the definition of investment includes inventories, but especially durables, as in most of the literature, investment becomes more volatile and more procyclical. Consequently, investment adjustment costs decline substantially and the investment shock becomes the fundamental force behind fluctuations at business cycle frequencies. To demonstrate that these conclusions are not the product of an arbitrary measurement choice, we also estimate a model with an explicit role for durable consumption goods in home production, as in Greenwood and Hercowitz (1991). In this model, investment shocks account for an even larger share of the business cycle variance of output and hours than in the baseline.

In another closely related paper, Justiniano and Primiceri (2008) find that investment shocks are the main contributors to the great moderation in output. Moreover, according to their estimated DSGE model with time-varying volatilities, the share of the variance of output growth accounted for by investment disturbances oscillates around 60 percent until the mid-1980s, and declines gradually to about 20 percent in the last years of the sample. These numbers are consistent with the 50 percent average share over the entire post-World War II period computed here.

Compared to Justiniano and Primiceri (2008), this paper abstracts from stochastic volatility, but probes deeper into the sources of fluctuations in at least three dimensions. First, it provides a more comprehensive analysis of the contribution of shocks to the variance of the observable variables, focusing in particular on the business cycle frequencies. Second, it investigates in detail why the role of investment shocks was muted in Smets and Wouters (2007). Third, it analyzes the economic mechanisms that turn these disturbances into the key driving forces of business cycles.

The crucial role of investment shocks in our baseline model is surprising, since these disturbances are unlikely candidates for generating business cycles in neoclassical environments. The reasoning was first outlined by Barro and King (1984). In an efficient equilibrium, the marginal rate of substitution between consumption and leisure—the marginal value of time—equals the marginal product of labor. With standard preferences, this equality implies that consumption and hours move in opposite directions in response to exogenous impulses that do not shift the marginal product, such as the investment shock. Therefore, this shock cannot be a significant driver of business cycles, since their distinguishing feature is the comovement of all real variables.

Our results contradict this conclusion, because the frictions included in the model transform the transmission mechanism of investment shocks with respect to the neoclassical benchmark, helping ameliorate the comovement problem. These frictions were first introduced in the literature to bring the impulse responses to monetary shocks in DSGE models closer to those from identified VARs (Christiano et al., 2005). They also play a crucial role in turning investment shocks into a viable driving force of fluctuations.

In particular, monopolistic competition with sticky prices and wages is the fundamental mechanism for the transmission of these shocks. This friction breaks the intratemporal efficiency condition described above, by driving an endogenous wedge between the marginal product of labor and the marginal value of time. As a result, the relative movements of consumption and hours are not as tightly constrained as in a perfectly competitive economy.

<sup>1</sup> We do not analyze the role of news shocks, which have recently received much attention in the literature (e.g. Beaudry and Portier, 2006 and Jaimovich and Rebelo, 2009).

The rest of the paper is organized as follows. Section 2 outlines our baseline model and Section 3 describes the approach to inference and the parameter estimates. Section 4 presents the implications of these estimates for the sources of fluctuations. Section 5 compares our results to those of Smets and Wouters (2007). Section 6 discusses the role of frictions in the transmission of investment shocks, both qualitatively and quantitatively. Section 7 concludes.<sup>2</sup>

## 2. The model economy

This section outlines our baseline model of the U.S. business cycle. It is a medium-scale DSGE model with a neoclassical growth core, augmented with several frictions—departures from the simplest assumptions on tastes, technology and market structure—now common in the literature.

The economy is populated by five classes of agents: producers of a final good, intermediate goods producers, households, employment agencies and a government. Their optimization problems are presented below.

### 2.1. Final good producers

At every point in time  $t$ , perfectly competitive firms produce the final consumption good  $Y_t$  combining a continuum of intermediate goods  $\{Y_t(i)\}_i$ ,  $i \in [0, 1]$ , according to the technology

$$Y_t = \left[ \int_0^1 Y_t(i)^{1/(1+\lambda_{p,t})} di \right]^{1+\lambda_{p,t}}. \quad (1)$$

The elasticity  $\lambda_{p,t}$  follows the exogenous stochastic process

$$\log(1+\lambda_{p,t}) = (1-\rho_p)\log(1+\lambda_p) + \rho_p \log(1+\lambda_{p,t-1}) + \varepsilon_{p,t} - \theta_p \varepsilon_{p,t-1}, \quad (2)$$

where  $\varepsilon_{p,t}$  is *i.i.d.*  $N(0, \sigma_p^2)$ . The literature refers to this as a *price markup shock*, since  $\lambda_{p,t}$  is the desired markup of price over marginal cost for intermediate firms. As in Smets and Wouters (2007), the ARMA(1,1) structure helps capture the moving average, high frequency component of inflation.

Profit maximization and the zero profit condition imply that the price of the final good,  $P_t$ , is a CES aggregate of the prices of the intermediate goods,  $\{P_t(i)\}_i$

$$P_t = \left[ \int_0^1 P_t(i)^{1/\lambda_{p,t}} di \right]^{\lambda_{p,t}} \quad (3)$$

and that the demand function for the intermediate good  $i$  is

$$Y_t(i) = \left( \frac{P_t(i)}{P_t} \right)^{-(1+\lambda_{p,t})/\lambda_{p,t}} Y_t. \quad (4)$$

### 2.2. Intermediate goods producers

A monopolist produces the intermediate good  $i$  according to the production function

$$Y_t(i) = \max\{A_t^{1-\alpha} K_t(i)^\alpha L_t(i)^{1-\alpha} - A_t F; 0\}, \quad (5)$$

where  $K_t(i)$  and  $L_t(i)$  denote the amounts of capital and labor employed by firm  $i$ .  $F$  is a fixed cost of production, chosen so that profits are zero in steady state (Rotemberg and Woodford, 1995; Christiano et al., 2005).  $A_t$  represents exogenous technological progress. Its growth rate ( $z_t \equiv \Delta \log A_t$ ) follows a stationary AR(1) process

$$z_t = (1-\rho_z)z + \rho_z z_{t-1} + \varepsilon_{z,t}, \quad (6)$$

with  $\varepsilon_{z,t}$  *i.i.d.*  $N(0, \sigma_z^2)$ , which implies that the level of technology is non stationary. This is our *neutral technology shock*.

As in Calvo (1983), every period a fraction  $\xi_p$  of intermediate firms cannot choose its price optimally, but resets it according to the indexation rule

$$P_t(i) = P_{t-1}(i) \pi_{t-1}^{1-p} \pi^{1-p}, \quad (7)$$

where  $\pi_t \equiv P_t/P_{t-1}$  is gross inflation and  $\pi$  is its steady state. The remaining fraction of firms chooses its price  $P_t(i)$  optimally, by maximizing the present discounted value of future profits

$$E_t \left\{ \sum_{s=0}^{\infty} \xi_p^s \frac{\beta^s A_{t+s}}{A_t} \left[ P_t(i) \left( \prod_{k=1}^s \pi_{t+k-1}^{1-p} \pi^{1-p} \right) Y_{t+s}(i) - W_{t+s} L_{t+s}(i) - r_{t+s}^k K_{t+s}(i) \right] \right\} \quad (8)$$

<sup>2</sup> Technical details and additional results on the models estimated in the paper are available in the online version at doi:10.1016/j.jmoneco.2009.12.008.

subject to the demand function (4) and to cost minimization. In this objective,  $\lambda_t$  is the marginal utility of nominal income for the representative household that owns the firm, while  $W_t$  and  $r_t^k$  are the nominal wage and the rental rate of capital.

### 2.3. Employment agencies

Firms are owned by a continuum of households, indexed by  $j \in [0, 1]$ . Each household is a monopolistic supplier of specialized labor,  $L_t(j)$ , as in Erceg et al. (2000). A large number of competitive “employment agencies” combine this specialized labor into a homogenous labor input sold to intermediate firms, according to

$$L_t = \left[ \int_0^1 L_t(j)^{1/(1+\lambda_{w,t})} dj \right]^{1+\lambda_{w,t}}. \quad (9)$$

As in the case of the final good, the desired markup of wages over the household’s marginal rate of substitution,  $\lambda_{w,t}$ , follows the exogenous stochastic process

$$\log(1+\lambda_{w,t}) = (1-\rho_w)\log(1+\lambda_w) + \rho_w\log(1+\lambda_{w,t-1}) + \varepsilon_{w,t} - \theta_w\varepsilon_{w,t-1}, \quad (10)$$

with  $\varepsilon_{w,t} \text{ i.i.d. } N(0, \sigma_w^2)$ . This is the wage markup shock. We also refer to it as a *labor supply shock*, since it has the same effect on the household’s first order condition for the choice of hours as the shock to the preference for leisure popularized by Hall (1997).

Profit maximization by the perfectly competitive employment agencies implies the labor demand function

$$L_t(j) = \left( \frac{W_t(j)}{W_t} \right)^{-(1+\lambda_{w,t})/\lambda_{w,t}} L_t, \quad (11)$$

where  $W_t(j)$  is the wage received from employment agencies by the supplier of labor of type  $j$ , while the wage paid by intermediate firms for their homogenous labor input is

$$W_t = \left[ \int_0^1 W_t(j)^{1/\lambda_{w,t}} dj \right]^{\lambda_{w,t}}. \quad (12)$$

### 2.4. Households

Each household maximizes the utility function

$$E_t \left\{ \sum_{s=0}^{\infty} \beta^s b_{t+s} \left[ \log(C_{t+s} - hC_{t+s-1}) - \varphi \frac{L_{t+s}(j)^{1+v}}{1+v} \right] \right\}, \quad (13)$$

where  $C_t$  is consumption,  $h$  is the degree of habit formation and  $b_t$  is a shock to the discount factor, which affects both the marginal utility of consumption and the marginal disutility of labor. This *intertemporal preference shock* follows the stochastic process

$$\log b_t = \rho_b \log b_{t-1} + \varepsilon_{b,t}, \quad (14)$$

with  $\varepsilon_{b,t} \sim \text{i.i.d. } N(0, \sigma_b^2)$ . Since technological progress is non stationary, utility is logarithmic to ensure the existence of a balanced growth path. Moreover, consumption is not indexed by  $j$  because the existence of state contingent securities ensures that in equilibrium consumption and asset holdings are the same for all households.

As a result, the household’s flow budget constraint is

$$P_t C_t + P_t I_t + T_t + B_t \leq R_{t-1} B_{t-1} + Q_t(j) + \Pi_t + W_t(j) L_t(j) + r_t^k u_t \bar{K}_{t-1} - P_t a(u_t) \bar{K}_{t-1}, \quad (15)$$

where  $I_t$  is investment,  $T_t$  is lump-sum taxes,  $B_t$  is holdings of government bonds,  $R_t$  is the gross nominal interest rate,  $Q_t(j)$  is the net cash flow from household’s  $j$  portfolio of state contingent securities, and  $\Pi_t$  is the per-capita profit accruing to households from ownership of the firms.

Households own capital and choose the capital utilization rate,  $u_t$ , which transforms physical capital into effective capital according to

$$K_t = u_t \bar{K}_{t-1}. \quad (16)$$

Effective capital is then rented to firms at the rate  $r_t^k$ . The cost of capital utilization is  $a(u_t)$  per unit of physical capital. In steady state,  $u = 1$ ,  $a(1) = 0$  and  $\chi \equiv a''(1)/a'(1)$ . In the log-linear approximation of the model solution this curvature is the only parameter that matters for the dynamics.

The physical capital accumulation equation is

$$\bar{K}_t = (1-\delta)\bar{K}_{t-1} + \mu_t \left( 1 - S \left( \frac{I_t}{I_{t-1}} \right) \right) I_t, \quad (17)$$

where  $\delta$  is the depreciation rate. The function  $S$  captures the presence of adjustment costs in investment, as in [Christiano et al. \(2005\)](#). In steady state,  $S = S' = 0$  and  $S'' > 0$ .<sup>3</sup>

The *investment shock*  $\mu_t$  is a source of exogenous variation in the efficiency with which the final good can be transformed into physical capital, and thus into tomorrow's capital input. [Justiniano et al. \(2009\)](#) show that this variation might stem from technological factors specific to the production of investment goods, as in [Greenwood et al. \(1997\)](#), but also from disturbances to the process by which these investment goods are turned into productive capital. Here, we ignore that distinction and maintain an agnostic stance on the ultimate source of these disturbances.

The investment shock follows the stochastic process

$$\log \mu_t = \rho_\mu \log \mu_{t-1} + \varepsilon_{\mu,t}, \quad (18)$$

where  $\varepsilon_{\mu,t}$  is *i.i.d.*  $N(0, \sigma_\mu^2)$ .

As in [Erceg et al. \(2000\)](#), every period a fraction  $\xi_w$  of households cannot freely set its wage, but follows the indexation rule

$$W_t(j) = W_{t-1}(j)(\pi_{t-1} e^{z_{t-1}})^{1-\omega} (\pi e^{\eta})^{1-\omega}. \quad (19)$$

The remaining fraction of households chooses instead an optimal wage  $W_t(j)$  by maximizing

$$E_t \left\{ \sum_{s=0}^{\infty} \xi_w \beta^s \left[ -b_{t+s} \varphi \frac{L_{t+s}(j)^{1+\nu}}{1+\nu} + A_{t+s} W_t(j) L_{t+s}(j) \right] \right\} \quad (20)$$

subject to the labor demand function (11).

## 2.5. The government

A monetary policy authority sets the nominal interest rate following a feedback rule of the form

$$\frac{R_t}{R} = \left( \frac{R_{t-1}}{R} \right)^{\rho_R} \left[ \left( \frac{\pi_t}{\pi} \right)^{\phi_\pi} \left( \frac{X_t}{X_t^*} \right)^{\phi_X} \right]^{1-\rho_R} \left[ \frac{X_t/X_{t-1}}{X_t^*/X_{t-1}^*} \right]^{\phi_{dX}} \eta_{mp,t}, \quad (21)$$

where  $R$  is the steady state of the gross nominal interest rate. As in [Smets and Wouters \(2007\)](#), interest rates responds to deviations of inflation from its steady state, as well as to the level and the growth rate of the GDP gap ( $X_t/X_t^*$ ).<sup>4</sup> The monetary policy rule is also perturbed by a *monetary policy shock*,  $\eta_{mp,t}$ , which evolves according to

$$\log \eta_{mp,t} = \rho_{mp} \log \eta_{mp,t-1} + \varepsilon_{mp,t}, \quad (22)$$

where  $\varepsilon_{mp,t}$  is *i.i.d.*  $N(0, \sigma_{mp}^2)$ .

Fiscal policy is fully Ricardian. The government finances its budget deficit by issuing short term bonds. Public spending is determined exogenously as a time-varying fraction of output

$$G_t = \left( 1 - \frac{1}{g_t} \right) Y_t, \quad (23)$$

where the *government spending shock*  $g_t$  follows the stochastic process

$$\log g_t = (1 - \rho_g) \log g + \rho_g \log g_{t-1} + \varepsilon_{g,t}, \quad (24)$$

with  $\varepsilon_{g,t} \sim \text{i.i.d. } N(0, \sigma_g^2)$ .

## 2.6. Market clearing

The aggregate resource constraint,

$$C_t + I_t + G_t + a(u_t) \bar{K}_{t-1} = Y_t \quad (25)$$

can be derived by combining the government's and the households' budget constraints with the zero profit condition of the final goods producers and of the employment agencies.

## 2.7. Solution

In this model, consumption, investment, capital, real wages and output fluctuate around a stochastic balanced growth path, since the level of technology  $A_t$  has a unit root. Therefore, the solution involves the following steps. First, rewrite the model in terms of detrended variables. Second, compute the non-stochastic steady state of the transformed model, and

<sup>3</sup> [Lucca \(2007\)](#) shows that this formulation of the adjustment cost function is equivalent (up to first order) to a generalization of the time to build assumption.

<sup>4</sup> The GDP gap is the difference between actual GDP ( $C_t + I_t + G_t$ ) and its level under flexible prices and wages, and no markup shocks ([Woodford, 2003](#)).

log-linearly approximate it around this steady state. The details of these steps can be found in the online appendix. Third, solve the resulting linear system of rational expectation equations to obtain its state space representation. This representation forms the basis for the estimation procedure, which is discussed in the next section.

### 3. Bayesian inference

We use Bayesian methods to characterize the posterior distribution of the structural parameters (see [An and Schorfheide, 2007](#) for a survey). The posterior distribution combines the likelihood function with prior information.

The likelihood is based on the following vector of observable variables:

$$\left[ \Delta \log X_t, \Delta \log C_t, \Delta \log I_t, \log L_t, \Delta \log \frac{W_t}{P_t}, \pi_t, \log R_t \right], \quad (26)$$

where  $\Delta$  denotes the temporal difference operator. The data are quarterly and span the period from 1954QIII to 2004QIV. The online appendix includes all the details on the dataset used to construct the likelihood function, and on the prior densities and posterior estimates of the structural coefficients.<sup>5</sup>

Two parameters are fixed using level information not contained in our dataset: the quarterly depreciation rate of capital ( $\delta$ ) to 0.025 and the steady state ratio of government spending to GDP ( $1-1/g$ ) to 0.22, which corresponds to the average value of  $G_t/X_t$  in our sample. The priors on the other coefficients are fairly diffuse and broadly in line with those adopted in previous studies (e.g. [Del Negro et al., 2007](#); [Levin et al., 2005](#)).

The prior distribution of all but one persistence parameters is a Beta, with mean 0.6 and standard deviation 0.2. The exception is the prior on the autocorrelation of the monetary policy shocks, which is centered at 0.4 because the policy rule already allows for interest rates inertia.

The intertemporal preference, price and wage markup shocks are normalized to enter with a unit coefficient in the consumption, price inflation and wage equations respectively (see the online appendix for details). The priors on the innovations' standard deviations are quite disperse and chosen to generate volatilities for the endogenous variables broadly in line with the data. Their covariance matrix is diagonal.

To evaluate jointly the economic content of the priors on the exogenous processes and the structural parameters, it is useful to look at the implications of these priors for the variance decomposition of the observable variables. This representation of the prior information is more useful than a series of comments on the distributions for specific coefficients, given the focus of the paper on the sources of fluctuations. The view of business cycles built a priori in the estimation is in line with the RBC tradition. In particular, the neutral technology shock accounts on average for 34, 38, 43 and 29 percent of the variability of output, consumption, investment and hours, and the 90 percent a priori credible intervals include values of these shares between roughly 1 and 90 percent for output and hours. The second most important shock for output and hours is the government spending shock (see the online appendix for the full prior variance decomposition). On the contrary, the a priori role of investment shocks for all variables is negligible, with essentially no mass on the variance decomposition that emerges a posteriori. This divergence may be a concern for model comparison, but it also indicates that our results are not driven by the prior.

The posterior estimates of the structural coefficients imply a substantial degree of price and wage stickiness, habit formation in consumption and adjustment costs in investment, in line with previous studies (e.g. [Altig et al., 2005](#); [Del Negro et al., 2007](#); [Smets and Wouters, 2007](#)).

### 4. Shocks and business cycles

This section analyzes the driving forces of fluctuations by looking at the variance decomposition of the main macroeconomic variables implied by the estimated model.

[Table 1](#) reports the contribution of each shock to the variance of the *level* of the observable variables at business cycle frequencies, which encompass periodic components with cycles between 6 and 32 quarters, as in [Stock and Watson \(1999\)](#).<sup>6</sup> The fourth column of the table makes clear that investment shocks account for 50 percent of the fluctuations in output, almost 60 percent of those in hours and more than 80 percent of those in investment, by far the largest shares. On the basis of this evidence, we conclude that investment shocks are the leading source of business cycles.

One qualification to this result comes from consumption. Investment shocks are responsible for only a small fraction of its variability, which is instead driven largely by the otherwise irrelevant intertemporal preference shock. This is a symptom of the well-known failure of standard consumption Euler equations to capture the empirical relationship between consumption and interest rates, as argued in [Primiceri et al. \(2006\)](#) (see also [Canzoneri et al., 2007](#); [Atkeson and Kehoe, 2008](#)).

<sup>5</sup> The results do not change when estimating the model by maximum likelihood (i.e. with flat priors), as shown in the online appendix.

<sup>6</sup> We compute the spectral density of the observable variables implied by the DSGE model and transform it to obtain the spectrum of the level of output, consumption, investment and wages.

**Table 1**

Posterior variance decomposition at business cycle frequencies in the baseline model.

Series/shock	Medians and [5th, 95th] percentiles						
	Policy	Neutral	Government	Investment	Price mark-up	Wage mark-up	Preference
Output	0.05 [0.03, 0.08]	0.25 [0.19, 0.33]	0.02 [0.01, 0.02]	0.50 [0.42, 0.59]	0.05 [0.03, 0.07]	0.05 [0.03, 0.08]	0.07 [0.05, 0.10]
Consumption	0.02 [0.01, 0.04]	0.26 [0.20, 0.32]	0.02 [0.02, 0.03]	0.09 [0.04, 0.16]	0.01 [0.00, 0.01]	0.07 [0.04, 0.12]	0.52 [0.42, 0.61]
Investment	0.03 [0.02, 0.04]	0.06 [0.04, 0.10]	0.00 [0.00, 0.00]	0.83 [0.76, 0.89]	0.04 [0.02, 0.06]	0.01 [0.01, 0.02]	0.02 [0.01, 0.04]
Hours	0.07 [0.04, 0.10]	0.1 [0.08, 0.13]	0.02 [0.02, 0.03]	0.59 [0.52, 0.66]	0.06 [0.04, 0.09]	0.07 [0.04, 0.11]	0.08 [0.06, 0.12]
Wages	0.00 [0.00, 0.01]	0.4 [0.30, 0.52]	0.00 [0.00, 0.00]	0.04 [0.02, 0.07]	0.31 [0.23, 0.41]	0.23 [0.16, 0.32]	0.00 [0.00, 0.01]
Inflation	0.03 [0.02, 0.06]	0.14 [0.09, 0.21]	0.00 [0.00, 0.00]	0.06 [0.02, 0.13]	0.39 [0.29, 0.50]	0.34 [0.26, 0.42]	0.02 [0.01, 0.04]
Interest rates	0.17 [0.13, 0.22]	0.09 [0.06, 0.12]	0.01 [0.00, 0.01]	0.47 [0.37, 0.56]	0.05 [0.03, 0.07]	0.04 [0.03, 0.07]	0.16 [0.11, 0.23]

*Note:* Business cycle frequencies correspond to periodic components with cycles between 6 and 32 quarters. The decomposition is obtained using the spectrum of the DSGE model and an inverse first difference filter for output, consumption, investment and wages to reconstruct the levels. The spectral density is computed from the state space representation of the model with 500 bins for frequencies covering that range of periodicities. Medians need not add up to one.

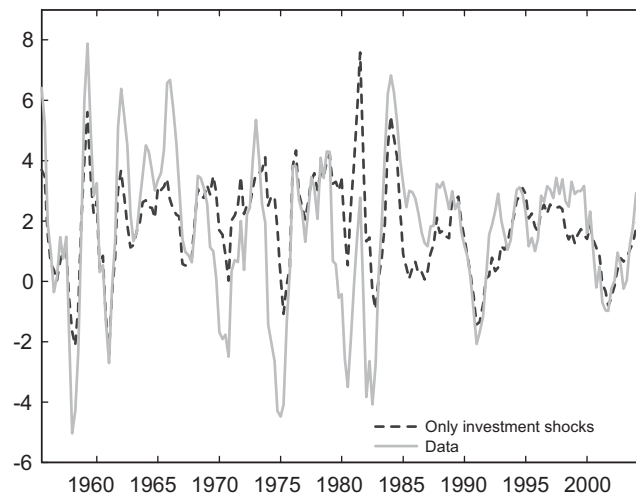
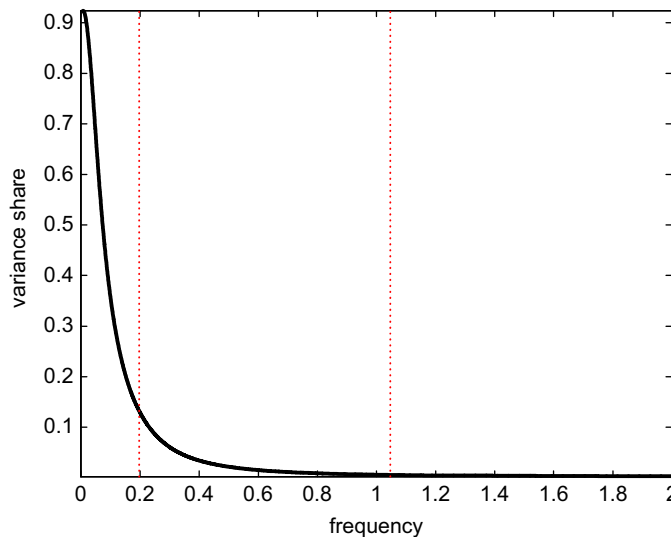
**Fig. 1.** Year-over-year output growth in the data and in the model with only investment shocks.

Fig. 1 provides a time series decomposition of the contribution of investment shocks to the variance of output by plotting year-to-year GDP growth in the data (the gray line) and in the model, conditional on the estimated sequence of the investment shocks alone (the black line). The comovement between the two series is striking. In particular, investment shocks appear largely responsible for “dragging” GDP growth down at business cycle troughs, a pattern especially evident in the last two downturns, as well as in the recessions of the 1960s. The main exceptions are the “twin” recessions of the early 1980s, in which monetary factors are in fact believed to have played a fundamental role.

Two results stand out from the other shocks and variables in Table 1. First, the neutral technology shock remains fairly important. It explains around one quarter of the volatility of output and consumption, and 40 percent of the variance of real wages. This contribution is more limited than usually found in the RBC literature mainly because, in our estimated model, positive productivity shocks have a negative effect on hours (see Justiniano et al., 2008, Fig. 6). This fall in hours is consistent with the findings of Smets and Wouters (2007) and with a large empirical literature (Galí, 1999; Francis and Ramey, 2009; Canova et al., 2006; Fernald, 2007; Basu et al., 2006), although it remains controversial (Christiano et al., 2004; Uhlig, 2004; Chang and Hong, 2006).

The second result to highlight in Table 1 is that wage markup shocks explain only 5 and 7 percent of the volatility of output and hours. Interestingly, the contribution of these shocks to fluctuations in hours is much higher (58 percent) when considering their overall variance, rather than focusing on business cycle frequencies alone. Fig. 2 studies the source of this





**Fig. 2.** Variance share of hours due to wage markup shocks as a function of the spectrum frequencies. The vertical dashed lines mark the frequency band associated with business cycles, which includes frequencies between  $2\pi/32 = 0.19$  and  $2\pi/6 = 1.05$ .

discrepancy by plotting the share of the variance of hours due to the wage markup shock, as a function of the spectrum frequencies. Business cycles correspond to the band within the dotted vertical lines. The contribution of wage markup shocks is substantial at very low frequencies, but declines steeply towards the business cycle range, where it is mostly below 10 percent.

This spectral profile of the contribution of labor supply shocks is consistent with the forecast error variance decomposition for GDP presented by Smets and Wouters (2007), in which the share of variance associated with this shock increases monotonically with the forecast horizon. The advantage of the spectral decomposition in Fig. 2 is that it isolates more clearly the contribution of labor supply shocks at business cycle frequencies.<sup>7</sup> This clarification is important, because medium scale DSGE models à la Smets and Wouters (2007) have been criticized as tools for both monetary policy and business cycle analysis, since they need large labor supply shocks to fit the data (e.g. Chari et al., 2009; Shimer, 2009). These critiques become less stringent if these shocks are important only for low frequency movements in hours, which might be due for example to demographic developments largely unrelated to the business cycle.

In summary, our analysis proposes a parsimonious view of the sources of business cycles. Investment shocks impart the main impetus to fluctuations, which spread from investment to output and hours. Consumption, however, is largely insulated from these disturbances and its comovement with the rest of the economy is driven mainly by neutral technology shocks. Finally, labor supply shocks account for a large fraction of the movements in hours, but these are concentrated at very low frequencies.

As for wages and prices, their movement is mainly driven by exogenous variation in desired markups, as would be expected in an economy in which monetary policy is well calibrated. In this respect, it is especially remarkable that inflation and wages are almost completely insulated from investment shocks. However, the significant contribution of these shocks to the movements in nominal interest rates suggests that achieving this degree of nominal stabilization required a fair amount of activism on the part of monetary policy.

## 5. A comparison with Smets and Wouters

The prominent role of investment shocks in our variance decomposition is at odds with some findings in a very influential paper by Smets and Wouters (2007, SW hereafter). Although SW also study the forces driving output fluctuations in their DSGE model, they find that their investment shock accounts for less than 25 percent of the forecast error variance in GDP at any horizon. Our estimates of the contribution of this shock to output are twice as large. This section documents the sources of this discrepancy.

Our baseline model and that of SW differ in several respects, both in the details of the theoretical specification and in the measurement of the observable variables. The first two columns of Table 2 show that the differences in specification play a negligible role in reconciling the two results. In fact, the estimation of our model with SW's dataset attributes only

<sup>7</sup> Even the Smets and Wouters (2007) interpretation of the role of labor supply shocks is unclear. They write in the introduction: "While 'demand' shocks such as the risk premium, exogenous spending, and investment-specific technology shocks explain a significant fraction of the short-run forecast variance in output, both wage mark-up (or labor supply) and, to a lesser extent, productivity shocks explain most of its variation in the medium to long run."



**Table 2**

Variance share of output and hours at business cycles frequencies due to investment shocks, comparison with Smets and Wouters.

Model	Smets and Wouters	Baseline			Durables in home production
Definition of observables	Smets and Wouters	Smets and Wouters	Investment includes consumer durables but not inventories	Baseline	Baseline with consumption of durable goods observable
Series					
Output	0.23	0.19	0.42	0.50	0.65
Hours	0.26	0.22	0.47	0.59	0.74

Note: Business cycle frequencies correspond to periodic components with cycles between 6 and 32 quarters. Variance decompositions are performed at the mode of each specification.

19 and 22 percent of the business cycle variance of output and hours to investment shocks. These numbers are close to those obtained estimating SW's model with the same dataset (23 and 26 percent), and much lower than the 50 and 59 percent in our baseline estimation. Therefore, the discrepancy in the variance decompositions stems largely from differences in measurement.<sup>8</sup>

Compared to our baseline, SW's dataset excludes (the change in) inventories from investment—although not from output—and includes purchases of consumer durables in consumption.<sup>9</sup> As a result, our investment series is more volatile and procyclical, while consumption is less so. Moreover, the comovement between the two series is less pronounced in our dataset. This result is not surprising, since durables and inventories are both volatile and procyclical components of GDP (Stock and Watson, 1999).

Of course, these differences in sample autocovariances translate into changes in parameter estimates. Most strikingly, the inferred investment adjustment cost parameter more than doubles (from 2.85 to 6.47) when moving to SW's definition of the observables. This change dampens the impact of investment shocks on investment, but also on output and hours. At the same time, the habit persistence parameter declines (from 0.78 to 0.66), making consumption and investment more countercyclical in response to investment and intertemporal preference shocks respectively. Moreover, the standard deviation of the latter shock increases substantially (from 0.04 to 0.08), while that of the former, perhaps surprisingly, hardly changes (from 6.03 to 6.07).<sup>10</sup>

Overall, the parameter estimates obtained with our dataset imply two main changes in the transmission of shocks: first, a more powerful amplification of investment shocks, without exacerbating the countercyclicality of consumption; and second, a weaker response of output and hours to intertemporal preference shocks, but with a more pronounced countercyclical reaction of investment. As a consequence of these changes, investment shocks account for a higher share of the variance of output and hours and a correspondingly lower share to the intertemporal preference shock.

Our definition of investment differs from SW's in two respects: it includes both the change in inventories and the expenditures on durable goods. However, the latter difference accounts for about two thirds of the discrepancy between our variance decomposition and SW's. In fact, the estimation of our model with durables included in (fixed) investment, rather than in consumption, increases the contribution of investment shocks to business cycle fluctuations from 19 to 42 percent for output and from 22 to 47 percent for hours (third column of Table 2). The inclusion of inventories accounts for the rest of the gap (8 and 12 percentage points for output and hours).

Our treatment of consumer durables as a form of investment is standard in the business cycle literature (see for example Cooley and Prescott, 1995; Christiano et al., 2005; Del Negro et al., 2007). However, this measurement choice requires a stronger argument in its defense, given its consequences for the answer to the central question of the paper. One such argument comes from the estimation of a generalized version of the baseline model, with a more explicit role for durable goods.<sup>11</sup> In this model, as in Greenwood and Hercowitz (1991) and Chang and Schorfheide (2003), households consume nondurable goods and the service flow of durables. This flow is produced by a home-production technology that combines durables and non-market hours. Households' new purchases of durable goods increase their stock through an accumulation equation that is affected by two shocks: the same investment shock that impinges on the standard capital accumulation and a shock specific to the accumulation of durables. This assumption captures the idea that shocks to the marginal efficiency of firms' investment are correlated with shocks to the efficiency of consumer durables, although not

<sup>8</sup> "SW's dataset" uses their definition of the seven observable variables, applied to our sample period, from 1954QIII to 2004QIV.

<sup>9</sup> SW also use different series for hours and wages, but this does not have any material impact on the results.

<sup>10</sup> Detailed results for our model estimated using SW's dataset are included in the online appendix. These results include posterior parameter estimates and business cycle variance decompositions, as well as a comparison of the impulse responses implied by this estimation with those in the baseline. Also included is the autocovariance structure for output, consumption, and investment in the two datasets.

<sup>11</sup> We thank Frank Schorfheide (the associate editor) for this suggestion.

perfectly. This version of the model is estimated with the growth rate of consumer durables as an additional observable variable.

A formal description of the model with durables, details on its estimation and on the implied variance decomposition are available in the online appendix. The main finding is that this model attributes to investment shocks an even larger share of the business cycle volatility of output and hours than our baseline (last column of Table 2). This result does not change when measuring household investment as the sum of consumer durables and residential investment, as in Greenwood and Hercowitz (1991). We conclude that the treatment of durables as one component of investment, as in our the baseline model, delivers more reliable results on the sources of fluctuations than their inclusion in consumption, as in SW.

## 6. Inspecting the mechanism: how investment shocks become important

In standard neoclassical environments, neutral technology shocks are the most natural source of business cycles, since they can easily produce the typical comovement of macroeconomic variables. In fact, Barro and King (1984) show that generating this kind of comovement in response to most other shocks is problematic. In particular, they explicitly identify investment shocks as an unlikely driving force of business cycles. Intuitively, a positive shock to the marginal productivity of investment increases the rate of return, giving households an incentive to save more and postpone consumption. With lower consumption, the marginal utility of income increases, shifting labor supply to the right—an intertemporal substitution effect. Along an unchanged labor demand schedule, this supply shift raises hours and output, but depresses wages and labor productivity.

In our estimated model, on the contrary, investment shocks trigger procyclical movements in all key macroeconomic variables, as shown in Fig. 3.<sup>12</sup> This effect is due to a significant change in the transmission mechanism, relative to the neoclassical benchmark, that allows investment shocks to emerge as the single most important source of business cycle fluctuations. This section considers more closely how the frictions included in the baseline model contribute to this result. Some of these frictions, such as endogenous capital utilization and investment adjustment costs, have been analyzed before in a similar context, most prominently by Greenwood et al. (1988, 2000). Others, such as monopolistic competition with sticky prices and wages, have not.<sup>13</sup>

To organize this discussion, start from the efficiency equilibrium condition that must hold in a neoclassical economy:

$$MRS(C, L) = MPL(L). \quad (27)$$

With standard preferences and technology, the marginal rate of substitution (*MRS*) depends positively on consumption (*C*) and hours (*L*), while the marginal product of labor (*MPL*) is decreasing in hours. As a result, any shock that boosts hours on impact, without shifting the marginal product of labor schedule, must also generate a fall in consumption for (27) to hold at the new equilibrium. This is precisely what happens in response to investment shocks in a neoclassical model, as was discussed above.

Eq. (27) also highlights the three margins on which the frictions included in our baseline model must be operating to make the transmission of investment shocks more conformable with the typical pattern of business cycles. Departures from the standard assumptions on tastes affect the form of the *MRS*, technological frictions affect the form of the *MPL*, and departures from perfect competition create a wedge between the two.

For instance, with internal habit formation, the *MRS* also becomes a function of past and future expected consumption. Intuitively, households become reluctant to adjust their consumption sharply, which reduces their willingness to substitute over time. As a consequence, consumption is less likely to fall significantly in response to a positive investment shock.

Endogenous capital utilization, instead, acts as a shifter of the *MPL*, as first highlighted by Greenwood et al. (1988). By increasing the utilization of existing capital, investment shocks increase the marginal product of labor on impact, shifting labor demand. Along a fixed labor supply schedule, this shift implies a rise in hours and wages, as well as in consumption.

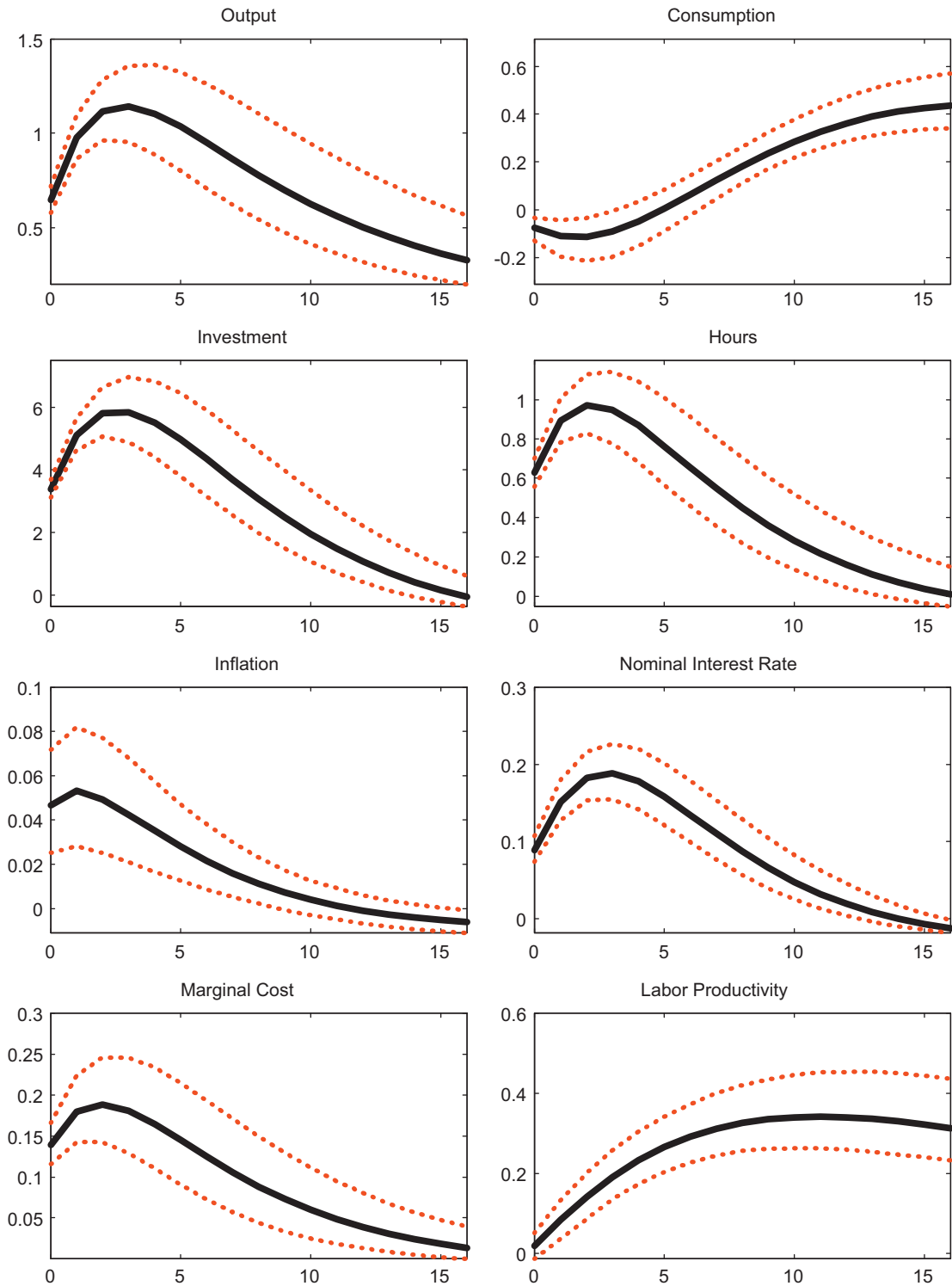
Finally, monopolistic competition in goods and labor markets drives a wedge between the *MRS* and the *MPL*. Sticky prices and wages make this wedge endogenous, so that Eq. (27) becomes

$$\omega(L)MRS(C, L) = MPL(L), \quad (28)$$

where  $\omega$  denotes the wedge. In our model,  $\omega$  is the sum of two equilibrium markups, that of price over marginal cost and that of real wages over the marginal rate of substitution. If this markup is countercyclical (i.e. it falls when hours rise, as suggested for example by Rotemberg and Woodford, 1999; Galí et al., 2007), consumption and hours can move together in response to an investment shock, without violating the equilibrium condition (28).

<sup>12</sup> Consumption is flat initially and increases with a delay of about one year. This response explains why investment shocks account for a small fraction of the movements in consumption. Eusepi and Preston (2009), Furlanetto and Seneca (2009), Guerrieri et al. (2009) and Khan and Tsoukalas (2009) explore several mechanisms that enhance the procyclicality of consumption in response to investment shocks.

<sup>13</sup> Rotemberg and Woodford (1995) point out that endogenous markup variation is an additional channel through which aggregate shocks might affect fluctuations, especially in employment. However, they do not consider investment shocks in their analysis.



**Fig. 3.** Impulse responses to a one standard deviation investment shock. The dashed lines represent 90 percent posterior probability bands around the posterior median.

More specifically, in our estimated model, a positive investment shock produces a drop in the price markup, as evident from the fact that the real marginal cost rises in Fig. 3. This fall in the markup induces a positive shift in labor demand, which amplifies the shift associated with changes in utilization. At the same time, the wage markup also falls, shifting the

**Table 3**

Variance share of output and hours at business cycle frequencies due to investment shocks, restricted models.

	Baseline	No habits <sup>a</sup>	No investment costs and variable capital utilization <sup>b</sup>	Perfectly competitive goods and labor markets <sup>c</sup>	Perfectly competitive goods markets <sup>d</sup>	Perfectly competitive labor market <sup>e</sup>	No frictions <sup>f</sup>
Series							
Output	0.50	0.39	0.23	0.04	0.30	0.31	0.02
Hours	0.59	0.51	0.30	0.08	0.51	0.42	0.03
Log							
Marginal likelihood	−1176.3	−1302.6	−1283.3	−1457.1	−1415.1	−1274.7	−1512.0

Notes: Business cycle frequencies correspond to periodic components with cycles between 6 and 32 quarters. Variance decompositions are performed at the mode of each specification.

<sup>a</sup>  $h$  calibrated at 0.01.

<sup>b</sup>  $S''$  calibrated at 0.01,  $1/\chi$  calibrated at 0.001.

<sup>c</sup>  $\lambda_w$ ,  $\xi_w$ ,  $\iota_w$ ,  $\lambda_p$ ,  $\xi_p$ , and  $\iota_p$  calibrated at 0.01.

<sup>d</sup>  $\lambda_w$ ,  $\xi_w$  and  $\iota_w$  calibrated at 0.01.

<sup>e</sup>  $\lambda_p$ ,  $\xi_p$  and  $\iota_p$  calibrated at 0.01.

<sup>f</sup> Combines the calibration for all specifications above, except baseline.

labor supply schedule to the right. Unlike in the perfectly competitive case, though, this shift in labor supply is consistent with an increase in hours at an unchanged level of consumption.

In our economy, the endogeneity of markups is due to price and wage stickiness. However, Eq. (28) suggests that any other friction resulting in countercyclical markups would propagate investment shocks in a similar way.

The rest of this section investigates the quantitative role of all these frictions in turning investment shocks into the dominant source of fluctuations. For this purpose, we re-estimate several restricted versions of the baseline model, shutting down one category of frictions at-a-time, and study the resulting variance decomposition. The restricted models under consideration are the following: first, a model with no habit in consumption, which corresponds to  $h = 0$ ; second, a model with no capital utilization margin and investment adjustment costs, obtained by setting  $1/\chi = 0.001$  and  $S'' = 0$ ; third and fourth, models with (nearly) competitive labor and goods markets, in which  $\xi_w = 0.01$ ,  $\iota_w = 0$ ,  $\lambda_w = 1.01$  and  $\xi_p = 0.01$ ,  $\iota_p = 0$ ,  $\lambda_p = 1.01$ , respectively; and finally, a model with no frictions, which corresponds to the neoclassical core embedded in the baseline specification.

The results of this exercise are reported in Table 3. The table focuses on the contributions of investment shocks to the volatility of output and hours at business cycle frequencies. The first result to note is that removing any of the frictions reduces the contribution of investment shocks to fluctuations, as expected, given the preceding discussion of how these frictions alter the transmission mechanism.

In terms of relative contributions, imperfect competition has the most significant marginal impact. In the perfectly competitive model, the contribution of investment shocks to fluctuations in output and hours drops to 4 and 8 percent respectively. Shutting down imperfect competition in goods and labor markets separately produces a roughly equal decline in the importance of investment shocks. Endogenous utilization and adjustment costs come next. Their exclusion reduces the contribution of investment shocks to fluctuations in both hours and output by more than half, compared with the baseline. The friction that plays the smallest role at the margin is time non-separability.

Finally, the last column in Table 3 shows that the contribution of the investment shock disappears entirely in the frictionless model. This result suggests that the estimation procedure is not affecting our findings on the role of this shock in business cycles. In the estimated version of the neoclassical model obtained by restricting the baseline specification, investment shocks do not play any role in fluctuations, as should be expected in light of the theoretical analysis of Barro and King (1984) and Greenwood et al. (1988).<sup>14</sup>

The models in Table 3 encompass a wide range of views on the sources of business cycles. In this paper, we proposed investment shocks as the key driving force. Other researchers might look at Table 3 and conclude otherwise if, for instance, they prefer the neoclassical growth model to our baseline. However, one compelling reason for preferring the latter is that its fit is far superior to that of any of the alternatives considered here, as shown by the marginal data densities (or marginal likelihoods) reported in the last row of Table 3. The marginal likelihood of the baseline model is more than 100 log-points higher than that of the next best model, implying overwhelming posterior odds in its favor.<sup>15</sup>

<sup>14</sup> In the estimated frictionless model, the neutral technology and labor supply shocks explain 43 and 45 percent of the variance of output and 4 and 77 percent of that of hours at business cycle frequencies.

<sup>15</sup> Del Negro and Schorfheide (2008) discuss reasons why posterior odds should be interpreted with some care when priors are not adjusted as the model specification is altered.

## 7. Concluding remarks

What is the source of business cycle fluctuations? We revisited this fundamental question of macroeconomics from the perspective of an estimated new neoclassical synthesis model. The main finding is that investment shocks—shocks to the marginal efficiency of investment—are the main drivers of movements in hours, output and investment over the cycle. Imperfect competition with endogenous markups is crucial for the transmission of these shocks. Neutral technology shocks also retain a non negligible role in the fluctuations of consumption and output and are mainly responsible for their comovement. Shocks to labor supply account for a large share of the variance of hours at very low frequencies, but their contribution over the business cycle is negligible.

One qualification to these results is that the estimated volatility of our investment shock is larger than that of the price of investment relative to consumption measured in the data. In a simple two-sector representation of our model, in which the sector producing investment goods is perfectly competitive, the two would be the same. As we argue in Justiniano et al. (2009), however, important sources of variation in the marginal efficiency of investment are not captured by changes in the relative price. One example is frictions in the capital accumulation process, perhaps related to the intermediation ability of the financial sector. Models that explicitly include these type of frictions, such as that in Christiano et al. (2007), therefore represent a promising avenue for future research.

## Appendix A. Supplementary materials

Supplementary materials associated with this article can be found in the online version at doi:10.1016/j.jmoneco.2009.12.008.

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