Journal of Economic Dynamics & Control 36 (2012) 47–62

Contents lists available at SciVerse ScienceDirect

Journal of Economic Dynamics & Control

journal homepage: www.elsevier.com/locate/jedc

Endogenous business cycle propagation and the persistence problem: The role of labor-market frictions

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A R T I C L E I N F O

Article history:
Received 6 September 2010
Received in revised form
23 June 2011
Accepted 14 July 2011
Available online 24 August 2011

JEL classification:
E32
E62

Keywords:
Business cycle propagation
Persistence problem
Sticky wages
Costly labor adjustment

A B S T R A C T

Contrasting sharply with a recent trend in DSGE modeling, we propose a business cycle model where frictions and shocks are chosen with parsimony. The model emphasizes a few labor-market frictions and shocks to monetary policy and technology. The model, estimated from U.S. quarterly postwar data, accounts well for important differences in the serial correlation of the growth rates of aggregate quantities, the size of aggregate fluctuations and key comovements, including the correlation between hours and labor productivity. Despite its simplicity, the model offers an answer to the persistence problem (Chari et al., 2000) that does not rely on multiple frictions and adjustment lags or *ad hoc* backward-looking components. We conclude modern DSGE models need not embed large batteries of frictions and shocks to account for the salient features of postwar business cycles.

1. Introduction

A recent trend in dynamic stochastic general equilibrium (DSGE) modeling has seen frictions and shocks proliferate to improve the fit of macro models.[1] This modeling strategy has been prone to criticism. Among the new frictions, some like the rule-of-thumb behavior of price-setters and the backward indexing of wages and prices lack a convincing microfoundation (Woodford, 2007; Cogley and Sbordone, 2008), whereas of the many shocks now driving these models, some are dubiously structural and do not have a clear economic interpretation (Chari et al., 2009).[2] But do DSGE models really need to rely on heavy batteries of frictions and shocks to account for the salient features of the postwar U.S. business cycle? The answer we provide in this paper is no.

Our approach differs sharply from the recent trend. We show that a parsimonious DSGE model featuring just a few labor market frictions goes a long way matching several stylized facts that have characterized the postwar U.S. business cycle. While doing so, our model also offers a solution to the so-called *output persistence problem* unveiled by Chari et al. (2000) (CKM).

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[1] A notable example of a DSGE model with numerous frictions is Christiano et al. (2005) where aggregate fluctuations are driven by a shock to monetary policy. Smets and Wouters (2007) and Justiniano and Primiceri (2008) use more or less the same set of frictions, but include many types of shocks, Justiniano and Primiceri emphasizing the conditional volatility of shocks.

[2] In some DSGE models, adjustment lags in the response of macroeconomic variables to a monetary policy shock are added to frictions to match the short-run restrictions used in structural vector autoregressions (SVAR) to identify a monetary policy shock (see Rotemberg and Woodford, 1997; Christiano et al., 2005; Boivin and Giannoni, 2006; Altig et al., 2011). When tested, however, these restrictions turn out to be invalid (Normandin and Phaneuf, 2004).

0165-1889/$ - see front matter
doi:10.1016/j.jedc.2011.07.003

Several DSGE models developed in reaction to CKM's findings have produced more persistent, but monotonically declining responses of output following a monetary policy shock (see Section 5.3). In contrast, our framework delivers persistent *and* hump-shaped responses of aggregate quantities to a monetary policy shock. Our model's responses are consistent with evidence both from the empirical literature on monetary policy (see among others Galí, 1992; Bernanke and Mihov, 1998; Christiano et al., 1999, 2005; Normandin and Phaneuf, 2004; Romer and Romer, 2004) and from structural vector autoregressions in Cogley and Nason (1995) and Galí (1999) about the effects of nontechnology shocks on output. Furthermore, in contrast to the handful of models which have produced hump-shaped responses of output to a policy shock (e.g., Walsh, 2005; Christiano et al., 2005; Smets and Wouters, 2007), our model is able to do so with a small number of frictions and without the use of *ad hoc* backward-looking elements. Our findings are thus fully consistent with the optimizing behavior of households and firms.

Relative to a perfectly competitive real business cycle (RBC) model, the only frictions used in our framework are a cash-credit structure to motivate money, Calvo-style staggered nominal wage contracts and labor adjustment costs.[3] The flexible price assumption is motivated by recent U.S. micro level evidence by Bils and Klenow (2004), who show that for several categories of consumer goods and services, prices adjust much more frequently than most observers previously thought, with a mean of 3.3 months and a median waiting time between price adjustments of 4.3 months. The sticky-wage assumption follows from micro level evidence pointing to substantial rigidity in U.S. nominal wages. Using data from the Survey of Income and Program Participation (SIPP), Barattieri et al. (2010) show that, once corrected for measurement error, nominal wages are very slow to adjust, with adjustment probabilities of 18% per quarter or lower. They also find that the hazard function for wage changes has a clear peak at 12 months, consistent with the general impression that wages and salaries are reviewed annually. Therefore, according to micro data on wages and prices, wage stickiness is substantially more pervasive than price stickiness. The second type of friction embedded in our model is costly labor adjustment and is supported by plant-level evidence in Cooper and Willis (2004, 2009), among others.[4]

While these structural ingredients are not new, the evidence they help produce is. Indeed, we show that once combined into a single DSGE framework, these frictions deliver a surprisingly high number of findings consistent with the salient features of the postwar business cycle. We estimate our model with U.S. postwar quarterly data using the generalized method of moments (GMM) with overidentifying restrictions. Given our emphasis on labor market frictions, we require in the estimation of the model that it matches a set of moments composed of the following labor-market related observations (see section 4.3, Table 2), among others:

- The short-run autocorrelations of differenced hours worked have been significantly higher than the autocorrelations of the growth rates of aggregate quantities. Specifically, while the first and second-order autocorrelations of differenced hours are 0.58 and 0.36, they are 0.38 and 0.29 for output growth, followed by 0.31 and 0.27 for investment growth, and by 0.23 and 0.19 for consumption growth. Beyond the second order, the autocorrelations decay rapidly.
- The autocorrelations of nominal wage inflation have been high and positive at short and medium horizons.
- Wage inflation has been somewhat less volatile than output growth with a ratio of 0.83.
- The volatility of first differenced hours has been slightly smaller than the volatility of output growth with a ratio of 0.92.
- Differenced hours have comoved positively with output growth.
- The correlation between differenced hours and differenced labor productivity has been weakly negative.

The first observation points to significant differences in the postwar dynamics of employment, output, investment and consumption growth. It will guide our assessment of the realism and strength of internal propagation induced by our frictions. Kydland and Prescott (1982) and King et al. (1988a) have shown that the standard neoclassical growth model can easily match the autocorrelations of most aggregate quantities when these variables are detrended with the Hodrick–Prescott filter and technology shocks are generated through an AR(1) process. But in the event that the level of technology is non-stationary, the standard RBC model dramatically fails to account for the positive short-run serial correlation in real GDP growth, investment growth and hours growth, with the autocorrelations of differenced investment and differenced hours predicted by the standard RBC model being negative (King et al., 1988b, Table 1). Focusing on the short-run autocorrelations of output growth and an important trend-reverting component in real GDP in response to a nontechnology shock, Cogley and Nason (1995) show that a wide range of RBC models fail to account for output dynamics. This leads them to the conclusion that RBC models embody weak endogenous propagation mechanisms.

A notable exception is a paper by Wen (1998), who looks at the dynamics of output, consumption, investment and employment using the empirical procedure proposed by Watson (1993). Wen argues that a RBC model augmented to include habit formation on leisure choice and an employment externality accounts well for the dynamics of aggregate

[3] The labor adjustment costs we have in mind include those for advertising a job, screening, testing, and training new workers when the workforce expands, and the costs of legal requirements and regulations when the workforce shrinks. Varying labor input may also be costly because of changes in the input mix or because a restructuring of the workforce may be called upon within working plants, giving rise to planning and organizational costs. Also, along an increase in employment, firms may have to buy new equipment, giving rise to costs of getting access to financial capital.

[4] The aggregate consequences of costly labor adjustment have been analyzed by Sargent (1979), Kydland and Prescott (1991), Mendoza (1991), Fairise and Langot (1994), Cogley and Nason (1995) and Janko (2008), among others.

quantities, except for consumption growth. However, his main findings rely on an externality channel which is much too strong in light of evidence in Baxter and King (1991), Caballero and Lyons (1992) and Cooper and Johri (1997). Furthermore, in his model, aggregate fluctuations are driven only by a technology shock which follows an AR(1) process. The richer dynamics implied by his model reflect pronounced, hump-shaped and trend-reverting responses of output, investment and hours to a technology shock. In the broader macroeconomic literature, however, technology shocks are treated as permanent, for example in the structural vector autoregression literature where the response of output to a technology shock does not display a trend-reverting pattern (Shapiro and Watson, 1988; Blanchard and Quah, 1989; Galí, 1992, 1999; Christiano et al., 2004; Francis and Ramey, 2005; Basu et al., 2006; Fisher, 2006).

We follow more closely the approach proposed by Cogley and Nason (1995) and Galí (1999). We assume a non-stationary level of technology and attribute the trend-reverting component of output to a nontechnology shock. But while Cogley and Nason (1995) assume that the nontechnology shock is a government spending shock, we model it as a monetary policy shock. We show that our parsimonious framework accounts very well for the positive short-run autocorrelations of output growth, consumption growth, investment growth and employment growth, and also for the differences in the pattern of these autocorrelations, confirming the relevance of our frictions. To the best of our knowledge, this is the first time a DSGE model goes so far in explaining serially correlated movements in the growth rates of aggregate quantities.

Adding the serial correlation of wage inflation (second observation) to the serial correlation of hours growth is a way to convey useful information about two critical parameters we need to estimate: the labor-adjustment parameter and the coefficient governing the response of nominal wages to the employment gap in the wage contract. Furthermore, accounting for serial correlation of wage inflation can serve to assess the plausibility of the wage contracting arrangement assumed in our framework.

Following Taylor (1980) and Calvo (1983), we assume staggered, multiperiod nominal wage contracts. We show that these contracts act as a significant source of nonneutrality and persistence in wage inflation. They differ from other contracting arrangements found in the literature. One such arrangement is Boldrin and Horvath's (1995) optimal contracts. Based on optimal contract theory, these authors propose one-period-ahead labor contracts that break the link between real wages and productivity to better explain labor market variables. This type of contract, however, does not generate wage inertia.[5] While preserving the link between real wages and productivity, the wage contracts used in our model give rise to plausible labor market dynamics, including significant wage inertia. Another type of arrangement is found in the search and matching literature. Typically, search and matching models assume period-by-period Nash bargaining between firms and workers, which implies high wage volatility, low employment volatility and little persistence in wage inflation. Gertler and Trigari (2009) lower wage volatility and increase employment volatility by incorporating multiperiod staggered Nash bargaining into the conventional Mortensen–Pissarides model. Unlike us, however, they study a non-monetary economy.

The fourth observation directs attention toward a weakness that has affected several business cycle models following Kydland and Prescott (1982). The standard RBC model predicts movements of hours which are small compared to output fluctuations. To increase employment volatility, Hansen (1985) and Rogerson (1988) incorporate indivisible labor in the RBC model. While increasing the volatility of hours, indivisible labor significantly reduces the volatility of average labor productivity which then becomes much too small. In contrast, our model avoids the tradeoff between the volatilities of hours and labor productivity, while generating a strong positive comovement between hours and output (fifth observation).

The sixth observation stands as "a litmus test for aggregate economic models" in the words of Christiano and Eichenbaum (1992). It is at odds with technology-driven RBC models which predict a strong positive correlation between hours and productivity. Unlike Braun (1994) and McGrattan (1994) who lower this correlation by introducing multiple tax, government spending and technology shocks, we obtain a weakly negative correlation between hours and productivity just by combining technology and monetary policy shocks.

While accounting for these observations, our model generates one more substantive finding. We show that labor-market frictions also imply positive short-run autocorrelations of investment growth, reflecting a persistent and hump-shaped response of investment to a monetary policy shock. We obtain this finding without any investment and financial frictions. In our model, investment dynamics result from strong interactions of capital and labor input, as emphasized by Baxter and King (1993).

The rest of the paper is organized as follows. Section 2 provides a model description. Section 3 describes the estimation procedure. Section 4 reports the estimation results and discusses our main findings. Section 5 reexamines the persistence problem through the lens of our model. Section 6 contains concluding remarks.

2. The model

Our framework is a standard one-sector model with variable labor and endogenous capital accumulation. A representative firm produces a final good using a constant-returns-to-scale technology and has to incur a cost when varying its labor input. Households are imperfectly competitive with respect to labor skills. They purchase two types of consumption goods: a cash good and a credit good. Money is held due to the cash-in-advance constraint for the cash good

[5] See Table 3 of their paper.

(e.g., Lucas and Stokey, 1987; Cooley and Hansen, 1989). Households rent capital and labor services to the representative firm. Nominal wages are set through Calvo contracts, while prices are reoptimized every period.

2.1. The representative firm

The representative firm's technology is a production function given by

$$Y_t = A_t K_t^{1-\alpha} N_t^{\alpha}, \tag{1}$$

where Y_t is final output, K_t is the stock of physical capital, N_t is total hours worked and A_t is the level of technology.

The stock of physical capital evolves according to

$$K_{t+1} = (1-\delta)K_t + I_t, \tag{2}$$

where δ is the rate of depreciation of physical capital.

The natural log of technological progress is assumed to follow a random walk with drift,

$$(1-L)\ln(A_t) = \ln(A) + \varepsilon_t, \tag{3}$$

where L is the lag operator and ε_t is an i.i.d. shock.

Each period the firm maximizes its profits given by

$$Y_t - \frac{W_t}{P_t} N_t - Q_t K_t - \frac{\alpha_n}{2} A_t (N_t - N_{t-1})^2, \tag{4}$$

subject to (1), taking the price and wage as given. W_t is the aggregate nominal wage, Q_t is the real rental rate of capital, P_t is the aggregate price level and α_n is a labor-adjustment parameter. The last term in (4) stands for the cost paid by the representative firm when varying labor hours.[6]

2.2. Households

A continuum of households are monopoly suppliers of differentiated labor services indexed by $h \in (0,1)$. Each period, household h receives a lump-sum transfer from the government. It decides its consumption purchases, how much capital to invest, its purchases of securities,[7] its holdings of cash, and its notional labor supply which differs from its actual hours which is determined by labor demand at the contractual wage rate.

Household h's preferences are described by

$$E_t^h \sum_{i=0}^{\infty} \beta^i [(\omega \ln(C_{1t+i}) + (1-\omega)\ln(C_{2t+i})) + \phi \ln(1 - N(h)_{t+i})], \tag{5}$$

where E_t^h denotes the expectations operator conditional on information up to time t, C_{1t} is the cash-good, C_{2t} is the credit-good, and $N(h)_t$ represents the hours worked of household h. Total time endowment is normalized to one.

At the beginning of period t, household h has currency holdings denoted by $M_t + (1+R_{t-1})B(h)_t + T_t$; M_t is the household's beginning-of-period stock of money, $(1+R_{t-1})B(h)_t$ is the principal plus interest from government bond holdings, and T_t is the lump sum money transfer from the monetary authority. Household h acquires bonds during period t, which it carries into the next period, $B(h)_{t+1}$. The purchase of cash goods during period t must satisfy the following cash-in-advance constraint:

$$P_t C_{1t} \le M_t + T_t, \tag{6}$$

whereas household h's allocations must satisfy the following sequence of budget constraints:

$$C_{1t} + C_{2t} + I_t + \frac{M_{t+1}}{P_t} + \frac{B(h)_{t+1}}{P_t} \le \frac{W(h)_t}{P_t} N(h)_t + Q_t K_t + \frac{T_t}{P_t} + \frac{M_t}{P_t} + \frac{(1+R_{t-1})B(h)_t}{P_t}, \tag{7}$$

where I_t represents gross investment and $W(h)_t$ is household h's nominal wage in period t. Household h maximizes (5) subject to (6) and (7), and the non-negativity constraints.[8]

[6] This cost is proportional to the level of technology to ensure the existence of a balanced growth path.

[7] We suppose that there are state-contingent financial contracts that make it possible to insure each household against the idiosyncratic income risk that may arise from asynchronized wage adjustment. These financial arrangements ensure that, in equilibrium, consumption, investment and holdings of real money balances are identical across households, although nominal wages and hours may differ (cf. Rotemberg and Woodford, 1997; Erceg et al., 2000; Huang et al., 2004; Christiano et al., 2005).

[8] Government bonds and nominal balances are the only assets whose net supply is non-zero. All other assets are suppressed without loss of generality.

2.3. The wage decision

The representative competitive firm transforms differentiated labor services into an aggregate labor input N_t, using the following aggregator:

$$N_t = \left(\int_0^1 N(h)_t^{1/(1+\theta_w)} \, dh \right)^{(1+\theta_w)}. \tag{8}$$

The demand for labor skill of type h is

$$N(h)_t = \left(\frac{W(h)_t}{W_t} \right)^{-(1+\theta_w)/\theta_w} N_t, \tag{9}$$

where $(1+\theta_w)/\theta_w$ represents the substitution elasticity between differentiated labor skills and the aggregate wage index is related to $W(h)_t$ by the aggregator:

$$W_t = \left(\int_0^1 W(h)_t^{-1/\theta_w} \, dh \right)^{-\theta_w}. \tag{10}$$

Household h takes N_t and W_t as given.

As in Calvo (1983), households can reoptimize nominal wages upon receiving a signal that arrives with probability $(1-d)$. The ability to reoptimize its wage is independent across households and time. The optimal nominal wage rate is a constant markup over a weighted average of the *MRS*'s for the periods during which the wage rate will remain effective. The optimal wage rate of household h at time t satisfies the first-order condition:

$$E_t \sum_{i=0}^{\infty} (\beta d)^i \left(\frac{1}{1+\theta_w} \frac{W(h)_t}{P_{t+i}} \lambda_{t+i} + V(h)_{N,t+i} \right) N(h)_{t+i} = 0, \tag{11}$$

where λ_{t+i} is the marginal utility of consumption which is identical across households and

$$V(h)_{N,t+i} \equiv \frac{-\phi}{(1-N(h)_{t+i})}. \tag{12}$$

After the contracting wage rate has been set, the amount of labor services of type h is determined by (9).

Using a linear approximation in the neighborhood of the steady-state equilibrium, equation (11) is expressed as the following law of motion for household h's nominal wage in time t:

$$\tilde{W}(h)_t = dE_t \tilde{W}(h)_{t+1} + (1-d)\tilde{W}_t + (1-d)\gamma(\tilde{N}_t - \tilde{N}_t^*), \tag{13}$$

where γ is a parameter which determines together with $(1-d)$ the sensitivity of the contracting wage to the employment gap $(\tilde{N}_t - \tilde{N}_t^*)$

$$\gamma \equiv \frac{\frac{NV_{NN}}{V_N}}{1+\frac{NV_{NN}}{V_N}\frac{(1+\theta_w)}{\theta_w}}, \quad \text{and}$$

$$V_{NN} \equiv -\phi(1-N)^{-2}.$$

The employment gap is the difference between $\tilde{N}_t$, measuring the proportional deviation of actual aggregate hours N_t from the steady state, and $\tilde{N}_t^*$ denoting the proportional deviation of aggregate hours with flexible (market-clearing) wage decisions from the steady state. Variables without subscripts represent steady-state levels.

Eq. (13) is similar to Taylor's (1980) wage contract, except that it is cast within an explicit optimization problem. In the present context, the composite parameter γ has a clear structural interpretation. The higher the elasticity of substitution between differentiated labor skills, the lower is the sensitivity of the contracting wage to the employment gap. Alternatively, the higher the relative risk aversion for labor hours NV_{NN}/V_N, the higher is the sensitivity of wages to the employment gap.

2.4. The monetary authority

The monetary authority transfers of cash balances to households are given by the flow budget constraint:

$$M_{t+1} - M_t = T_t, \tag{14}$$

M_t denoting the per capita stock of money.

The gross growth rate of money supply is given by

$$\ln(g_t) = (1-\rho_m)\mu_m + \rho_m \ln(g_{t-1}) + \upsilon_t, \tag{15}$$

where $\ln(g_t) \equiv \ln(M_t/M_{t-1})$, $0 < \rho_m < 1$, μ_m is the steady-state growth rate of money, and υ_t is a white noise shock to the money growth process.

2.5. Model solution

The definition of equilibrium is standard. In an appendix which is available upon request, we discuss the computational strategy for approximating the equilibrium which involves taking a linear approximation around the nonstochastic steady state of the economy. Real variables are divided by the non-stationary level of technology to ensure their stationarity. Nominal variables are divided by the money stock. All variables are measured as proportional deviations from the steady state.

We use a state-space representation of the dynamics of the economy from which forward-looking variables are eliminated using the techniques described in King et al. (1987) and Blanchard and Kahn (1980). The log-linearized version of the model is expressed in its state-space form as follows:

$$H_{t+1} = A(\theta)H_t + D(\theta)\overline{\varepsilon}_{t+1}, \tag{16}$$

$$Z_t = C(\theta)H_t, \tag{17}$$

where H_t stands for the vector of state variables, Z_t represents a vector of endogenous variables, $\overline{\varepsilon}_{t+1}$ is a vector of innovations to the technology and money growth processes, and $A(\theta)$, $D(\theta)$ and $C(\theta)$ are matrices that are functions of the structural parameters of the model. The state-space representation and assumptions about the variance–covariance properties of $\overline{\varepsilon}_{t+1}$ can be used to derive analytical expressions for the asymptotic covariance matrices of the state and endogenous variables. The unconditional second moments of the model can thus be computed without having to simulate the model's exogenous processes.

3. Estimation method

3.1. Econometric procedure

Our model is estimated and tested using a two-step GMM procedure. We first choose a set of moment conditions that help identify the structural parameters of our model. Then, since the dimension of the vector of moment conditions used in the estimation is greater than that of the vector of structural parameters we seek to estimate, we can test the overidentifying restrictions implied by the model. As shown by Dridi et al. (2007), non-rejection of the overidentifying restrictions is equivalent to an encompassing test guaranteeing a consistent estimation of structural parameters. Having in hand consistent parameter estimators, the model can be judged from its ability to match a set of moments in the data.

The estimator of the vector of parameters θ is the solution to the following problem:

$$\hat{\theta}_T = \arg\min_{\theta \in \Theta} \left(\frac{1}{T} \sum_{t=1}^{T} f(z_t,\theta) \right)' W_T \left(\frac{1}{T} \sum_{t=1}^{T} f(z_t,\theta) \right), \tag{18}$$

where W_T is a random non-negative symmetric matrix, z_t is a vector composed of selected variables, and $f(z_t,\theta)$ is a q-vector of unconditional moment restrictions. Several moment restrictions are defined as the difference between sample unconditional moments and their model counterparts. The model's predictions are generated using Eqs. (16) and (17) without having to simulate the model. The optimal weighting matrix W_T represents the inverse of the variance–covariance matrix of the moment conditions evaluated at a set of first-step estimates, W_T being equal to the identity matrix. This matrix is consistently estimated using the estimator of Newey and West (1994).

The present method has the advantage of avoiding poorly measured variables, the stock of physical capital for example. Both the model's structural parameters and the parameters of the stochastic processes generating the forcing variables can be estimated after the state transition equations (16) have been augmented with the equations describing the stochastic processes. It is then possible to generate estimates of the forcing variable processes although we cannot observe them directly.[9]

Our estimation procedure differs from other simulated moment methods which fix the laws of motion of forcing variables through preliminary estimates (e.g., Jonsson and Klein, 1996). It also differs from the estimation method used by Christiano et al. (2005) (CEE) which minimizes the distance between the impulse response functions of macroeconomic variables to a monetary policy shock from a structural vector autoregression (SVAR) and from a DSGE model.

The reasons we do not follow this approach are twofold. First, monetary policy shocks in SVARs are identified by imposing short-run restrictions. These restrictions must also be imposed in the model in the form of adjustment lags of variables to a policy shock. In CEE, output, consumption, investment, the real wage, labor productivity and prices all adjust to a policy shock with a one-quarter lag. These adjustment lags are added to the already large number of nominal and real frictions included in the model, making it very difficult to assess which factors are mainly responsible for their findings. We see no other reasons than the anecdotal "Friedman's lags" to justify the use of such restrictions. Furthermore, Normandin and Phaneuf (2004) provide evidence showing that the short-run restrictions that are typically imposed in SVARs to identify a monetary policy shock are statistically invalid.

[9] Bansal et al. (1995) propose a similar method.

Second, Canova and Sala (2009) look at identification issues and their consequences for parameter estimation and model evaluation when the objective function measures the distance between VAR-based and model-based impulse responses. They argue that problems of observational equivalence, partial and weak identification are widespread and typically produced by an ill-behaved mapping between the structural parameters and the coefficients of the solution. They conclude that due to identifiability problems the "peculiarities of the procedure make existing theoretical conclusions inapplicable" (p. 432). According to them, maximum likelihood and Bayesian methods are prone to similar problems.

3.2. Calibration

We are unable to estimate all the parameters of our model. The probability of wage non-reoptimization d and the composite parameter γ in Eq. (13) cannot be simultaneously identified. We set the value of d, and estimate γ which is critical in determining real persistence as shown by Chari et al. (2000) and Huang and Liu (2002).

One source of information that helps calibrate d is a survey by Taylor (1999) indicating the average waiting time between wage adjustments has been about 12 months for the U.S. postwar period, implying $d=0.75$. A recent micro level study by Barattieri et al. (2010) also suggests that wages and salaries are reviewed annually. Therefore, we set the expected spell of wage contracts to be 12 months, implying $d=0.75$.

We also need to fix ω, determining the relative importance of cash and credit goods in the utility function. We rely on a recent study by Klee (2008) who provides evidence on the share of transactions by types of payment and reports that 54% of transactions at grocery stores were in cash. Therefore, we set $\omega=0.54$.

3.3. Vector of moments used in the estimation

The structural parameters we seek to estimate are:

$$\Psi=\{\ln(A),\alpha,\delta,\alpha_n,\beta,\phi,\gamma,\mu_m,\rho_m,\sigma_\varepsilon,\sigma_\upsilon\}.$$

We must choose the moments composing $f(z_t,\theta)$ in (18) which our model will be asked to match to estimate the structural parameters in Ψ. However, we must limit the number of moments to insert in $f(z_t,\theta)$. Since one of our objectives is to identify endogenous sources of business-cycle propagation, we include the short-run autocorrelations of output growth, hours growth and consumption growth in $f(z_t,\theta)$. Later, we also look at the autocorrelations of investment growth. Recall that the evidence in King et al. (1988b) and Cogley and Nason (1995) shows that with a non stationary level of technology, the standard neoclassical growth model and several of its variants fail to generate positive serial correlation in the growth rates of aggregate quantities. We also add the autocorrelations of wage inflation which, together with the autocorrelations of differenced hours, help identify the labor-adjustment parameter α_n in Eq. (4), and the parameter determining the sensitivity of nominal wages to the employment gap γ in Eq. (13).

Other moments included in $f(z_t,\theta)$ are the volatility measures (σ_{dy}, σ_{dc}/σ_{dy}, σ_{di}/σ_{dy}, σ_{dn}/σ_{dy}, σ_{dw}/σ_{dy}), and the correlations ($\mathrm{corr}_{dc,dy}$, $\mathrm{corr}_{di,dy}$, $\mathrm{corr}_{dn,dy}$, $\mathrm{corr}_{dw,dy}$, $\mathrm{corr}_{dn,d(y/n)}$).

The following moment restrictions complete $f(z_t,\theta)$:

$$E(\ln N_t-\ln N(\Psi))=0, \tag{19}$$

$$E[\Delta\ln Y_t-\ln(A)]=0, \tag{20}$$

$$E[\Delta(\ln Y_t-\ln(A))^2-\sigma_y^2(\Psi)]=0, \tag{21}$$

$$E(\Delta\ln M_t-\mu_m)=0, \tag{22}$$

$$E[(\ln(g_{t-1})-\mu_m)((\ln(g_t)-\mu_m)-\rho_m(\ln(g_{t-1})-\mu_m))]=0, \quad \text{and} \tag{23}$$

$$E[((\ln(g_t)-\mu_m)-\rho_m(\ln(g_{t-1})-\mu_m))^2-\sigma_\nu^2]=0. \tag{24}$$

Eq. (19) imposes that the mean of the log of hours worked in the data be equal to the nonstochastic steady-state level of employment implied by the model parameters, and helps estimate ϕ, the weight on leisure in (5). Eq. (20) imposes that the mean of output growth be equal to the nonstochastic steady-state output growth, which helps identify $\ln(A)$. Eq. (21), by matching the actual variance of output growth and that implied by the model, serves to identify the variance of the technology shock σ_ε^2. Eq. (22) imposes that the sample mean of the gross growth rate of money be equal to the nonstochastic steady-state growth rate of money, which allows estimating μ_m. The moment restriction in Eq. (23) helps estimate the AR(1) parameter ρ_m in the money growth Eq. (15). Finally, Eq. (24) serves to identify σ_ν^2.

4. Estimation results

4.1. Data

We use U.S. quarterly data from 1959:I to 2006:II. Consumption C_t denotes the sum of consumption expenditures on nondurable goods and services. Investment I_t denotes the sum of consumption expenditures on durable goods, gross nonresidential investment (structures and equipment) and residential investment. Output Y_t is the sum of C_t and I_t. The price level P_t is the deflator corresponding to our measure of output. N_t represents total hours worked in the non-farm business sector. W_t is the average hourly compensation in the non-farm business sector. The nominal money stock M_t is measured by M1. Output, consumption, investment, hours, and the nominal money stock are expressed as per capita variables after they have been divided by the civilian non-institutional population aged 16 and over. All series are taken from the Haver database.

4.2. Parameter estimates

The parameter estimates of our model are reported in Table 1. We are unable to reject the overidentifying restrictions of our model based on Hansen's (1982) J test. This confirms that our model successfully accounts for the set of moment conditions included in $f(z_t,\theta)$. The parameters are estimated with accuracy.

The estimate of $\ln(A)$ implies an annual growth rate of productivity of 2.1%. The estimated labor share α is 0.628, and is consistent with calibration normally used in business cycle studies. The rate of depreciation of physical capital δ is 0.023, corresponding to an annual rate of depreciation of 9.2%. The labor-adjustment parameter α_n is estimated at 13.7, and is consistent with the calibration assumed in Cogley and Nason (1995) after adjusting for differences in the functional forms of labor adjustment costs. The estimated discount factor β is 0.994. The parameter ϕ, which determines the weight of leisure in the utility function is 2.8, consistent with a steady-state fraction of hours of about 0.24. The composite parameter γ in the wage contract equation is estimated at 0.08. The estimates of μ_m, the steady-state growth rate of money, and ρ_m, the AR(1) coefficient in the money growth process are respectively 0.009 and 0.81. The technology innovation σ_ε is estimated at 0.01 and the money growth innovation σ_υ at 0.006. All these estimates are within the range of existing evidence and intuition.

Table 1
Parameter estimates, benchmark model.[a]

Parameters	Benchmark
$\ln(A)$	0.0051 (0.0003)
α	0.6280 (0.0354)
δ	0.0228 (0.0062)
α_n	13.71 (3.87)
β	0.9937 (0.0034)
ϕ	2.805 (0.169)
γ	0.0810 (0.0162)
μ_m	0.0092 (0.0011)
ρ_m	0.8130 (0.0334)
σ_ε	0.0105 (0.0008)
σ_υ	0.0064 (0.0005)
J test (p-value)	17.17 (0.374)

[a] Standard errors are in parentheses next to parameter values, while p-value appears in parentheses for the J test.

4.3. How well does the estimated model match the stylized facts?

With this set of parameter estimates in hand, we can ask how our model matches the moments included in $f(z_t,\theta)$. This comparison is made in Table 2. Despite its parsimony, the model does very well on many dimensions. First, we find that labor market frictions are an important source of endogenous business cycle propagation. Our model generates positive short-run autocorrelations in the growth rates of aggregate quantities unlike the models examined by King et al. (1988b) and Cogley and Nason (1995).

Interestingly, it also accounts for differences in the pattern of autocorrelations of aggregate quantities. As we have seen, the autocorrelations in the data have been significantly higher at lags of 1 and 2 quarters for hours growth (0.578 and 0.355) than for output growth (0.381 and 0.295) and consumption growth (0.23 and 0.19).[10] Our model delivers autocorrelations of

[10] We look at the autocorrelations of investment growth in Table 3.

Table 2
Moment conditions versus benchmark.[a]

Moments	Model	Data (s.e.)
σ_y	0.0097	0.0087 (0.0008)
$\sigma_{c/y}$	0.5057	0.5820 (0.0386)
$\sigma_{i/y}$	2.5485	2.5380 (0.0801)
$\sigma_{n/y}$	0.9657	0.9220 (0.0742)
$\sigma_{w/y}$	0.8833	0.8310 (0.0728)
$corr_{c,y}$	0.7513	0.7070 (0.0484)
$corr_{i,y}$	0.9533	0.9260 (0.0154)
$corr_{n,y}$	0.7402	0.6610 (0.0414)
$corr_{w,y}$	0.3223	−0.1740 (0.0152)
$corr_{n,y/n}$	−0.3180	−0.3290 (0.0298)
$corr_{y_t,y_{t-1}}$	0.2909	0.3810 (0.0787)
$corr_{y_t,y_{t-2}}$	0.1759	0.2950 (0.0609)
$corr_{y_t,y_{t-3}}$	0.0974	0.1990 (0.0624)
$corr_{n_t,n_{t-1}}$	0.6354	0.5780 (0.0579)
$corr_{n_t,n_{t-2}}$	0.3741	0.3550 (0.0726)
$corr_{n_t,n_{t-3}}$	0.1894	0.1730 (0.1348)
$corr_{w_t,w_{t-1}}$	0.9050	0.5130 (0.1424)
$corr_{w_t,w_{t-2}}$	0.8114	0.5240 (0.0974)
$corr_{w_t,w_{t-3}}$	0.7218	0.4400 (0.1207)
$corr_{c_t,c_{t-1}}$	0.1578	0.2334 (0.0961)
$corr_{c_t,c_{t-2}}$	0.1449	0.1906 (0.0560)
$corr_{c_t,c_{t-3}}$	0.1315	0.1239 (0.0645)

[a] Standard errors (s.e.) appearing in the table are calculated using the data-driven procedure proposed by Newey and West (1994).

0.635 and 0.374 for hours, followed by 0.291 and 0.176 for output, and 0.158 and 0.145 for consumption. We interpret this evidence as supporting the relevance of labor market frictions inserted in our model.

Our model also accounts for the size of aggregate fluctuations. The volatility of output growth predicted by the model is not statistically different from the actual volatility. Furthermore, the model replicates the volatility of consumption growth, investment growth, hours growth and wage inflation relative to the volatility of output growth.

The model also captures key comovements. Empirically, the correlation of output growth and investment growth is the strongest at 0.926, followed by the correlation of consumption growth and output growth at 0.707, and by the correlation of hours growth and output growth at 0.661. The predictions of the model are broadly consistent with this pattern of correlations, with a correlation of 0.953 for investment growth and output growth, 0.751 for consumption growth and output growth, and 0.74 for hours growth and output growth.

Our estimated model is not affected by the ''employment-productivity puzzle'' predicting a correlation between hours and productivity of −0.318, which almost perfectly matches that found in the data at −0.329. This can be explained as follows. In our model, the weakly negative correlation between hours and productivity is shaped by two opposing forces. One is the technology shock which has a positive impact on this correlation,[11] while the other is the monetary policy shock which has a negative impact because of sticky wages.[12] But one correlation for which there is room for improvement is that between wage inflation and output growth. While this correlation is weakly negative in the data, the model predicts it is weakly positive.

The autocorrelations of wage inflation implied by our model, unlike those of aggregate quantities, are high and positive beyond the third-order lag (not reported) as they are in the data. Therefore, the contracting arrangement embedded in our model generates substantial inertial behavior in wage inflation.[13]

4.3.1. Broadening the set of facts to explain

We can only use a restricted number of moments in $f(z_t,\theta)$. But since our model easily survives a test of its overidentifying restrictions, we ask how well our estimated model accounts for other moments than those in $f(z_t,\theta)$. The results are presented in Table 3.

[11] There is a debate concerning the response of hours to a technology shock, with evidence in Christiano et al. (2004) saying hours rise, and evidence in Galí (1999) saying hours fall. Liu and Phaneuf (2007) show that a sticky-wage model is not necessarily inconsistent with a decline of hours if consumption habit is also included.

[12] The evidence about the effect of monetary policy shocks on the real wage (and productivity) is inconclusive, with evidence in Christiano et al. (1997, 2005) saying it weakly rises, and evidence in Fleischman (1999) saying it falls. We are grateful to Susanto Basu who brought this point to our attention.

[13] The autocorrelations of wage inflation implied by our model are somewhat too high. Note, however, that they are much higher in the data when measured from the average hourly earnings, with 0.79, 0.78, 0.76, 0.73, 0.70 and 0.70 at lags of 1–6 quarters, respectively.

Table 3
Widening the set of facts.[a]

Moments	Model	Data (s.e.)
$corr_{i_t,i_{t-1}}$	0.3735	0.3139 (0.0734)
$corr_{i_t,i_{t-2}}$	0.2109	0.2659 (0.0693)
$corr_{i_t,i_{t-3}}$	0.0995	0.1681 (0.0626)
$\sigma_{y,y/n}$	0.7092	0.7948 (0.0631)
$\sigma_{n,y/n}$	1.3617	1.1601 (0.0909)
$corr_{y,m}$	0.2312	0.1582 (0.0710)
$corr_{inf,m}$	0.5311	0.1656 (0.1941)

[a] Standard errors (s.e.) appearing in the table are calculated using the data-driven procedure proposed by Newey and West (1994).

One striking result is that our model is also able to generate positive serial correlation in investment growth. The actual autocorrelations are 0.314, 0.266 and 0.168 at lags of 1–3 quarters, whereas the theoretical autocorrelations are 0.373, 0.211 and 0.1. This finding could seem surprising at first since we make complete abstraction of investment and financial frictions. Huang et al. (2004), Christiano et al. (2005), Smets and Wouters (2007) and Justiniano and Primiceri (2008) generate plausible investment dynamics through investment adjustment costs, whereas Carlstrom and Fuerst (1997) assume endogenous agency costs. In our model, the marginal product of an input increases with the other input. As we later show, the adjustment of hours to a monetary policy shock imparts on the marginal product schedule for capital and investment, inducing rich investment dynamics in the model.

Note also that the model does quite well matching the volatility of productivity growth to the volatility of output growth, and the volatility of hours growth to the volatility of productivity growth. Technology-driven business cycle models with market-clearing wages must rely on a highly elastic labor supply to generate the right volatility of hours. These models also imply a volatility of labor productivity to the volatility of output (or hours) which is counterfactually low. Since households are not required to be on their notional labor supply curves at all times due to nominal wage stickiness, our model does not face this problem.

Finally, we report the correlations between money growth and output growth, and between money growth and inflation. In both cases, the correlations implied by the model are not far from those found in the data.

4.4. Autocorrelations of output growth conditional on the types of shocks and frictions

We have found that our model delivers strong endogenous business cycle propagation. Both types of shocks and frictions are essential for this finding. To support this claim, we ask what the autocorrelations of output growth are in our model conditional on each type of shock and friction. These correlations are reported in Table 4.

With technology shocks only, the autocorrelations of output growth at lags of 1–3 quarters are too low at 0.096, 0.052 and 0.029, whereas with monetary policy shocks only, they are too high at 0.655, 0.407 and 0.227. Therefore, the model needs both types of shocks to account for the unconditional autocorrelations of output growth. With staggered wage contracts only, the autocorrelations of output growth are 0.105, 0.06 and 0.029, whereas with labor adjustment costs only, they are 0.077, 0.044 and 0.028. Clearly, both types of frictions are needed in the model to match the serial correlation of output growth. We return to this point later.

Table 4
Conditional output dynamics and the role of labor-market frictions.

	A. Conditional output dynamics	
Moments	Technology shock	Monetary shock
$corr_{y_t,y_{t-1}}$	0.0957	0.6554
$corr_{y_t,y_{t-2}}$	0.0522	0.4070
$corr_{y_t,y_{t-3}}$	0.0285	0.2267
	B. Role of labor-market frictions	
Moments	Sticky wages	Costly labor adjustment
$corr_{y_t,y_{t-1}}$	0.1049	0.0766
$corr_{y_t,y_{t-2}}$	0.0603	0.0440
$corr_{y_t,y_{t-3}}$	0.0285	0.0282

We briefly summarize the findings in this section. We find that a DSGE model featuring nominal wage contracts and costly labor adjustment easily survives a test of its overidentifying restrictions. It generates positive serial correlation in the growth rates of aggregate quantities, while delivering the right pattern in the serial correlation of these variables. It also induces substantial wage inflation inertia. It closely matches the volatility of key aggregates and their comovements, and is not affected by the employment-productivity puzzle. It does not exploit a plethora of frictions and shocks to generate these findings.

5. The persistence problem revisited

5.1. Accounting for persistence and timing in the response of output in the wake of a monetary policy shock

Gray (1976), Fischer (1977) and Phelps and Taylor (1977), among others, have established that rational expectations notwithstanding, systematic monetary policy can give rise to significant nonneutralities with sticky wages and prices. Taylor (1980) goes even farther, arguing that multiperiod staggered nominal contracts can be a source of persistent output fluctuations. But a recent paper by CKM (2000) argues that staggered price contracts do not yield persistent output fluctuations in response to monetary policy shocks once they are incorporated into a macro model with intertemporal general-equilibrium foundations.

CKM (2000) estimates the response of output to the shock in a *univariate* autoregression for detrended output. They measure output persistence by its half-life or length of time after the shock before the deviation of output shrinks to half of its impact value. They summarize the amount of output persistence generated by staggered price-contracts by the *contract multiplier* or ratio of the half-life of output deviations following a monetary shock with staggered price setting to the corresponding half-life with flexible price decisions. The contract multiplier conveys information about the *longevity* of the response of output in the aftermath of a monetary policy shock.

One possible interpretation of the single shock in CKM's univariate autoregression is that it is proportional to a monetary policy shock. However, under this interpretation output fluctuations would be driven only by monetary shocks, which is unlikely. Another interpretation is that this single disturbance reflects a mixture of shocks, in which case the contract multiplier would be a misleading measure of real persistence induced by a monetary policy shock.

Throughout the years, the empirical literature on monetary policy has also stressed the timing in the response of output following a monetary policy shock. Evidence from a variety of studies suggests that output gradually rises during 4–6 quarters following an expansionary monetary policy shock, and then slowly returns to its pre-shock level at the end of 4–5 years. Barro (1978) and Mishkin (1982) provide early evidence of persistent and hump-shaped responses of output in the aftermath of monetary policy shocks using estimation procedures consistent with the rational expectations hypothesis. This finding has subsequently been confirmed in the broader literature on monetary policy for different sample periods and with different estimation and identification procedures (see among others Blanchard and Quah, 1989; Galí, 1992; Bernanke and Mihov, 1998; Christiano et al., 1999, 2005; Romer and Romer, 1989, 2004; Normandin and Phaneuf, 2004). Therefore, while being persistent as CKM and the subsequent literature on the persistence problem emphasize, it is well established empirically that the response of output is delayed and hump-shaped in the aftermath of a monetary policy shock. This is important considering that most models developed in reaction to findings in CKM have failed along this dimension, predicting monotonically declining responses of output in the wake of a monetary policy shock (see the discussion below).

Fig. 1 displays the impulse response of output to a 1% expansionary shock to monetary policy based on our estimated model. Output initially rises by 0.4%, with a maximum increase occurring four quarters after the shock, and then slowly returns to its stochastic trend at the end of 20 quarters or so. While offering an answer to the persistence problem, our model is also consistent with evidence about the timing of the output response from the broader empirical literature on monetary policy.

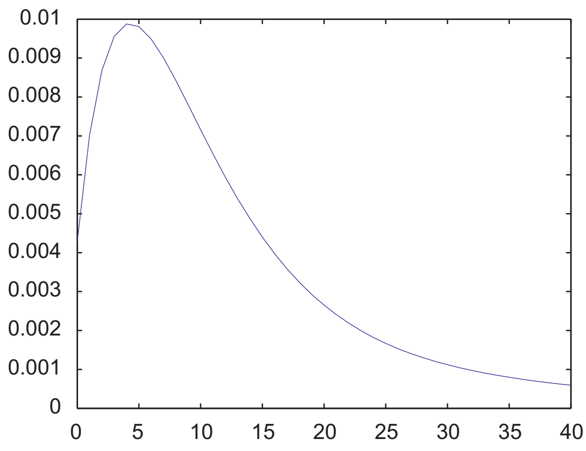

Fig. 1. Output response to a monetary shock (Benchmark Model).

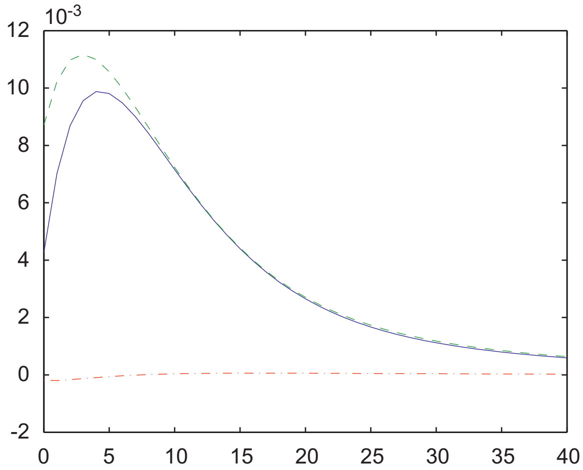

Fig. 2. The persistence problem. The figure contains impulse responses of output following a monetary shock. The straight line corresponds to the benchmark model, the dashed line to the model with sticky wages only and the dash-dotted line to the model with costly labor adjustment only.

Both frictions are important for this finding. To prove this point, we look at the response of output if the only friction in the model is costly labor adjustment, and alternatively if there is only nominal wage stickiness. The responses are displayed in Fig. 2. With flexible wage decisions and costly labor adjustment, the policy shock operates mainly through the inflation tax (Cooley and Hansen, 1989). Because the inflation tax is an insignificant source of monetary nonneutrality, costly labor adjustment cannot generate a plausible response of output by itself. On the other hand, whereas sticky wages are an important source of monetary nonneutrality, they do not by themselves generate a pronounced hump-shaped response of output. Note that with wage contracts alone, the model delivers only a short delay in the response of output compared to the version of the model with both types of frictions. This explains the weak serial correlation of output growth reported in Table 4 with sticky wages only. With both frictions, the wage contracts yield strong monetary nonneutrality, and labor adjustment costs lengthen the delay in the response of output.

5.2. *Investment and the dynamic interaction of capital and labor*

We now take a closer look at the dynamic interaction of capital and labor in our model. We show that it is the source of positive serial correlation of investment growth despite the absence of investment, capital and financial frictions. Our framework is a one-sector model with variable labor and endogenous capital accumulation. Variations in labor input shift the marginal product schedule for capital. This, in turn, shapes the response of investment.

Fig. 3 shows that wage contracts and labor adjustment costs induce a persistent and hump-shaped response of hours to a monetary policy shock. This triggers persistent and hump-shaped responses of the marginal product of capital and

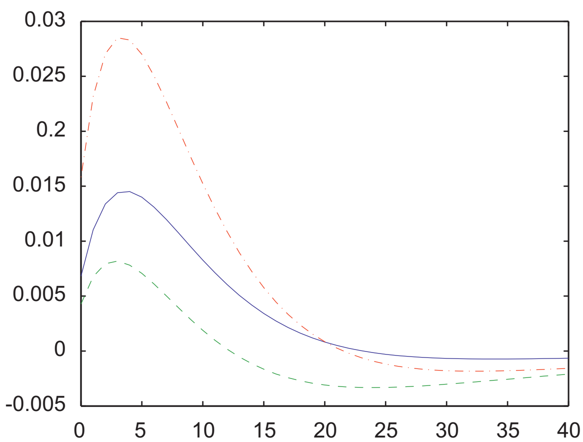

Fig. 3. Dynamic interactions of capital and labor. The figure contains impulse responses following a monetary shock in the benchmark model. The straight line corresponds to the impulse response of hours worked, the dashed line to the impulse response of the marginal product of capital and the dashed-dotted line to the impulse response of investment.

investment following a monetary policy shock. The delayed and hump-shaped response of investment is the source of positive short-run serial correlation of investment growth implied by our model.[14] Interestingly, Baxter and King (1993) have shown that the interaction between capital and labor input matters greatly for the effect of fiscal policy in general equilibrium.

5.3. Related literature

Here, we briefly discuss how our findings relate to the recent literature on the effects of monetary policy shocks in DSGE settings. Following CKM (2000), several researchers have tried to find new channels of monetary transmission in DSGE models. However, in our view, these efforts have only been partially successful. There are two reasons for this.

First, while delivering higher contract multipliers than the models examined by CKM, the new monetary transmission channels have generally failed to generate a significant hump-shaped response of output following a monetary policy shock. Consequently, they do not match the actual positive short-run serial correlation of output growth and other aggregate quantities. Second, to generate higher contract multipliers, these models rely on structural ingredients which either lack microfoundations, are empirically implausible, or both.

Bergin and Feenstra (2000) argue that the interactions between staggered price setting, a non-CES aggregation technology and a roundabout input–output structure increase the contract multiplier. However, in their model, prices adjust only once every 2 years, while the share of material inputs lies between 0.8 and 0.9, which is implausible judging by the calibrations proposed by Basu (1995), Huang et al. (2004) and Nakamura and Steinsson (2008). Also, while generating a higher output persistence, these features do not generate a hump-shaped response of output following a monetary policy shock.

Dotsey and King (2006) also work from a model with a roundabout production structure, which is combined with an assumption that prices stay put during four quarters. Their model includes variable capacity utilization, capital adjustment costs and labor variations at the intensive and extensive margins. This combination of nominal and real frictions increases output persistence, but generates only a small hump-shaped response of output following a monetary policy shock, implying weak positive serial correlation of output growth.

An alternative avenue explored by Huang and Liu (2002) is to show that staggered-wage contracts work differently from staggered-price contracts in general equilibrium.[15] Working with Taylor-type contracts, they show that while wage and price contracts produce similar dynamic wage-setting and price-setting equations, both link output persistence to the underlying preferences and technologies in different ways, wage contracts producing a higher output persistence in the aftermath of a monetary policy shock than price contracts. But while implying a higher output persistence, Taylor-contracts also yield a dampened, monotonically declining response of output following a monetary policy shock, which is inconsistent with evidence. Relaxing the assumption of homogeneous factor markets assumed in Huang and Liu (2002) in favor of one of firm-specific factors, Edge (2002) establishes the equivalence of models with staggered wage contracts and staggered price contracts.

Neiss and Pappa (2005) propose a sticky-price model with variable capital utilization, costly capital adjustment, variable labor effort and habit formation on leisure. While these features increase the half-life in the response of output, no combination of frictions can successfully account for the timing in the response of output following a monetary policy shock.

Bouakez et al. (2005) estimate a DSGE model with sticky prices, habit formation on consumption and capital adjustment costs using maximum-likelihood techniques. They report an estimate of the habit parameter which is close to 1.0, and one of the Calvo-probability of price reoptimization implying that prices adjust only once every 19.5 months on average, which is empirically implausible. Even with such high estimates, the model delivers only small hump-shaped responses of output and hours following a monetary policy shock, and no hump-shaped response of investment.

A few exceptions of models that generate persistent, hump-shaped responses of aggregate quantities to a monetary policy shock are those by Christiano et al. (2005) (CEE) and Smets and Wouters (2007). CEE incorporate sticky wages, sticky prices, full indexation of prices to past inflation by firms not allowed to reoptimize their prices, full indexation of wages to past inflation by households not allowed to reoptimize their wages, a working capital channel, nonseparable consumption, investment adjustment costs, and an obligation on the part of firms to borrow the wage bill ahead of production. To this extensive list of frictions, CEE must embed adjustment lags in the model to match those used in the SVAR to identify the monetary policy shock. Hence, output, consumption, investment, real wages, labor productivity and prices are all assumed to adjust to a monetary policy shock only with a one-period lag. These frictions, combined with adjustment lags, make it difficult to assess which particular features of the model are driving their results. Furthermore, wage and price indexation lacks a convincing microfoundation and is inconsistent with evidence from micro level studies on wage and price behavior (Bils and Klenow, 2004; Nakamura and Steinsson, 2008; Barattieri et al., 2010). Smets and Wouters (2007) work with a similar choice of frictions, estimating their model with a Bayesian procedure. In contrast to those models, our approach allows a clean and simple reading of the role played by labor-market frictions in U.S. business-cycle dynamics.

[14] The theoretical autocorrelations of investment growth at lags of 1–3 quarters are 0.37, 0.19 and 0.07 conditional on a monetary policy shock, while they are 0.1, 0.03 and 0.0 conditional on a technology shock.

[15] See also Andersen (1998) and Ascari (2000).

One final concern would be to ask whether our findings could not have been inferred from the existing literature, especially that on the role of search and matching frictions in models with nominal rigidities. Walsh (2005) offers the only example we know of a DSGE model incorporating labor market search and monetary policy that implies persistent, hump-shaped responses of aggregate quantities to a monetary policy shock. His model is very different from ours as it emphasizes the interactions between labor market search, sticky prices, habit persistence and monetary policy. Furthermore, his model also incorporates full indexation of prices to last-period inflation by firms which are not allowed to reoptimize their prices as in CEE (2005). For reasons which we have already explained, we have decided we would not use backward indexation in our model. Furthermore, in contrast to Walsh's model ours stresses the interactions between labor market frictions, sticky wages and monetary policy. Most other types of search and matching models assume flexible price decisions with period-by-period Nash bargaining, with the exception of Gertler and Trigari (2009) who study a non-monetary environment.

6. Conclusion

This paper has proposed a parsimonious approach to study business cycle dynamics. It differs sharply from the recent trend in DSGE modeling which has seen the number of frictions and shocks increase considerably to improve the fit of macro models. We have offered evidence showing that the interactions between sticky wages, costly labor adjustment and monetary policy have several important macroeconomic implications.

It helps account for important differences in the dynamics of employment, output, consumption and investment growth. It is also consistent with the actual size of aggregate fluctuations and several key comovements, including that between hours and productivity.

We have shown that despite its parsimonious choice of frictions, our model offers an answer to the persistence problem, delivering persistent, hump-shaped responses of aggregate quantities in the aftermath of a monetary policy shock. In contrast to recent models like those of Christiano et al. (2005), Walsh (2005) and Smets and Wouters (2007), we do not require the use of multiple frictions or shocks, or backward indexation to generate this finding.

One natural extension would be to account for variations in the long-run trend component of inflation along the lines suggested by Ireland (2007) and Cogley and Sbordone (2008).

Acknowledgment

We thank the editor Christopher Otrok, an anonymous referee, Giuseppe Bertola, Leif Danziger, Peter Ireland, Zheng Liu, Francisco Ruge-Murcia, Michael Woodford, and seminar participants at the Bank of Canada, York University, the University of Alberta, the University of Toronto, and the European University Institute for discussions and suggestions. The authors also acknowledge financial support from FQRSC and SSHRC.

Appendix A. Data sources

The series are from the Haver database and the (quarterly) sample is 1959:I to 2006:II, with definitions as follows.

- C_t: private consumption, composed of consumption of non-durables (*gcnq*) and services (*gcsq*).
- I_t: private investment, defined as gross private domestic investment (*gpiq*) and consumption of durable goods (*gcdq*).
- Y_t: output, measured as private consumption plus private investment.
- P_t: the price level, which is just the deflator for our measure of output, measured as $((gcn+gcs+gcd+gpi)/(gcnq+gcsq+gcdq+gpiq))$, where the series in the numerator are nominal values and the series in the denominator are measured in constant dollars.
- N_t: total hours worked (*lhours*).
- W_t: compensation per hour, nonfarm business sector (*lbpur*).
- M_t: M1.

Consumption, investment, output, hours worked, and the money supply are deflated by total civilian population aged 16 and over ($p16$).

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