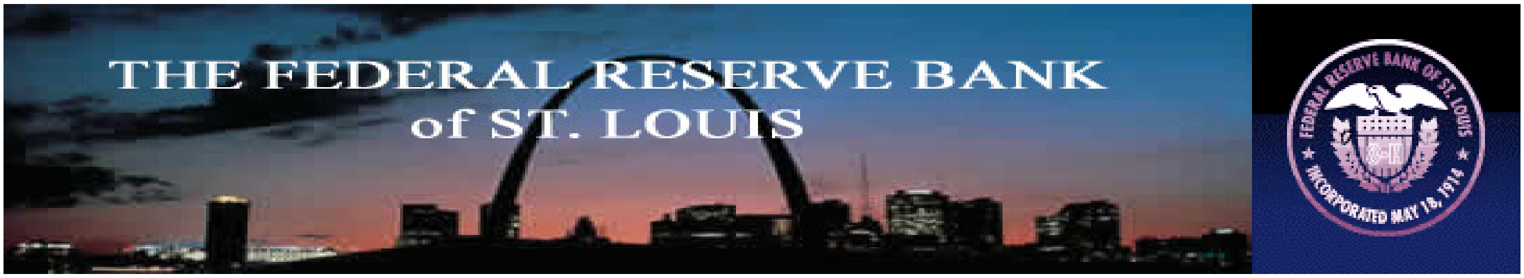

WORKING PAPER SERIES

Comovement: It's Not A Puzzle.

Riccardo DiCecio

Working Paper 2005-035B
http://research.stlouisfed.org/wp/2005/2005-035.pdf

June 2005
Revised August 2005

FEDERAL RESERVE BANK OF ST. LOUIS
Research Division
411 Locust Street
St. Louis, MO 63102

Comovement: it's not a puzzle.

Riccardo DiCecio*
FEDERAL RESERVE BANK OF ST. LOUIS

FIRST DRAFT: NOVEMBER 2003
THIS DRAFT: AUGUST 2005

Abstract

A defining feature of business cycles is the comovement of inputs at the sectoral level with aggregate activity. Standard models cannot account for this phenomenon. This paper develops and estimates a two-sector dynamic general equilibrium model that can account for this key regularity. My model incorporates three shocks to the economy: monetary policy shocks, neutral technology shocks, and embodied technology shocks in the capital-producing sector. The estimated model is able to account for the response of the US economy to all three shocks. Using this model, I argue that the key friction underlying sectoral comovement is rigidity in nominal wages.

JEL: E20, E32, O41, O42

Keywords: Comovement; Businsess cycles; Sticky wage

---

*Mail: P.O. Box 442, St. Louis, MO 63166-0442. E-mail: riccardo.dicecio@stls.frb.org
Any views expressed are my own and do not necessarily reflect the views of the Federal Reserve Bank of St. Louis or the Federal Reserve System. I am indebted to Larry Christiano and Marty Eichenbaum for their suggestions, support and guidance. I am grateful for comments from L. Barseghyan, F. Braggion, H. Braun, F. De Fiore, G. Favara, J. Fisher, N. Jaimovich, F. Molinari, A. Monge, P. Sakellaris, F. Smets and R. Vigfusson and from seminar participants at the Board of Governors of the FRS, the European Central Bank, the Kansas City FRB, Northwestern University, the Philadelphia FRB, the St. Louis FRB, University of Virgina and the 2004 SED conference. All errors are my own.

1 Introduction

Comovement refers to the fact that, empirically, the level of economic activity across different sectors of the economy tends to be similar along the business cycle. In particular when the economy is in a boom, the majority of sectors tends to use more inputs (capital and labor), and produce more output.

This paper develops and estimates a two-sector dynamic general equilibrium model which can account for this key regularity. My model incorporates three shocks to the economy: neutral technology shocks in the consumption and investment sector, embodied technology shocks in the capital producing sector, and monetary policy shocks.

Wage stickiness is the feature of the model that is crucial for obtaining comovement in response to technology shocks of either kind. Both consumption and investment increase in response to positive technology shocks. The households' desire to smooth consumption translates into a relative shift of demand from consumption to investment goods. Labor demand increases, but wage rigidities prevent the wage from fully adjusting. Firms in the consumption goods sector face an increase in demand and a (relatively small) increase in the wage rate. The first effect dominates and they hire more workers.

Standard models cannot account for comovement in response to technology shocks. In standard real business cycle (RBC) models[1] the nominal wage fully adjusts to the increase in labor demand. The effect of the higher wage offsets the increase in demand for consumption goods, and firms in the consumption goods sector hire fewer workers. Economy-wide competitive factor markets imply that the capital-to-labor ratio is equated across sectors. Hence, capital is also reallocated to the investment goods sector in response to a positive technology shock. In other words, standard RBC models predict that inputs in the consumption goods sector comove *negatively* with inputs in the investment goods sector and with aggregate output.[2]

The third source of fluctuations I consider is monetary policy. Monetary policy shocks generate an increase in economic activity in both sectors and would produce comovement even if wages were flexible. However, nominal wage rigidities play an important role in generating a persistent response of economic activity to monetary policy shocks.

A quantitative assessment of the role of sticky wages in generating co-

[1] For an exposition of the standard RBC model see Hansen (1985) and Prescott (1986).

[2] Despite using fewer resources, the consumption good sector produces more output because of the increased productivity.

movement requires a rich model. My model incorporates frictions that are standard in the literature studying the effects of monetary policy.[3] The real side of the model incorporates investment adjustment costs, variable capital utilization and habit formation preferences in consumption. Moreover, firms must borrow working capital to finance the wage bill. The model incorporates nominal price rigidities, in the form of sticky prices à la Calvo (1983).

The estimated model generates comovement of sectoral labor inputs in accordance to the data. Furthermore, my model is able to account for the response of the U.S. economy to all three shocks. The parameter estimates imply a plausible wage rigidity (3.7 quarters) and a modest degree of price stickiness. Estimates of the other parameters of the model, when comparable, and the model responses to neutral technology and monetary policy shocks are consistent with results in the literature.

Sticky wages deliver plausible empirical implications for my model by creating a countercyclical wedge between the real wage and the marginal rate of substitution between consumption and leisure. The existence of a "wage markup" over the marginal rate of substitution between consumption and leisure has been extensively documented empirically (see Galí, Gertler, and López-Salido, 2002).[4] My model generates a wage markup whose cyclical component has properties similar to its empirical counterpart.

The following section presents comovement in the U.S. data, the counterfactual implications of standard business cycle models, and shows how sticky wages generate comovement. Section 3 describes the model economy in detail. Section 4 is devoted to the model estimation and to the analysis of the comovement properties of the estimated model. Section 5 concludes. An appendix provides details on the data used.

2 The Comovement Puzzle

Comovement is a defining feature of business fluctuations. According to Burns and Mitchell (1946, pg. 3),

> " ... a cycle consists of expansions occurring at about the same time in many economic activities, followed by similarly

[3] See, for example, Christiano, Eichenbaum, and Evans (2005), Altig, Christiano, Eichenbaum, and Lindé (2002), Smets and Wouters (2003) and Smets and Wouters (2005). The last three papers also examine the effect of other shocks to the economy.

[4] See also Hall (1997) and Chari, Kehoe, and McGrattan (2004).

general recessions, contractions, and revivals which merge into the expansion phase of the next cycle ...",

a definition endorsed by Gordon (1986).[5] Lucas (1977), Long and Plosser (1983) and Christiano and Fitzgerald (1998) define business cycles in a similar way.[6]

In this section I document comovement of sectoral inputs and outputs with aggregate output at business cycle frequencies for U.S. data. I then illustrate why the standard RBC model implies negative comovement, and I show how sticky wages solve the comovement puzzle.

2.1 Comovement in the U.S. Data[7]

Figure 1 displays the cyclical components[8] of output, consumption, investment and of the corresponding labor inputs for the U.S. over the period 1964:Q1-2001:Q4.

Sectoral outputs (consumption and investment) and labor inputs comove with aggregate output. Table 1 reports correlations of sectoral outputs and labor inputs with aggregate output at business cycle frequencies (third column). The second column displays the standard deviations of sectoral outputs/inputs relative to the standard deviation of aggregate output. Consumption is half as volatile as output. Investment is 3.7 times more volatile than output. Both consumption and investment are highly correlated with output. The second moments of the corresponding labor inputs display similar properties.

[5] The NBER Business Cycle Dating Committee (Hall, Feldstein, Frankel, Gordon, Romer, Romer, and Zarnowitz, 2003), defines a recession as follows:

> "A recession is a significant decline in activity spread across the economy, lasting more than a few months, visible in industrial production, employment, real income, and wholesale-retail sales."

[6] Other authors, such as Schumpeter (1939, pg. 200), Prescott (1986, pg. 10) and Sargent (1987, pg. 282), focus on the comovement of economy-wide variables in defining business fluctuations.

[7] See Christiano and Fitzgerald (1998) for a more disaggregated analysis of the comovement properties of the US economy.

[8] The business cycle component is extracted using an HP_{1600} filter applied to the series in logs. See appendix A for a description of the data used.

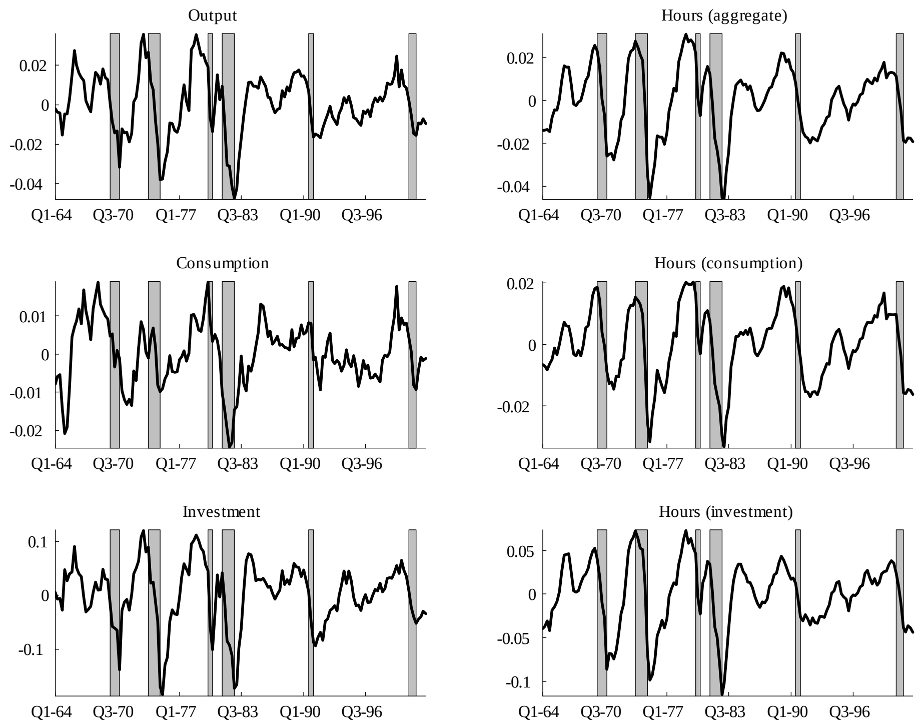

Figure 1: Cyclical components of aggregate output, sectoral outputs, and correpsonding labor inputs

Variable	$\sigma_x/\sigma_{\tilde{y}}$	$\rho_{x,\tilde{y}}$
Consumption	0.53	0.70
Hours (consumption sector)	0.74	0.85
Investment	3.69	0.92
Hours (investment sector)	2.44	0.88

Table 1: Second moments of the cyclical components of consumption, investment, and corresponding labor inputs

2.2 The Puzzle

The standard RBC model can be interpreted as a two-sector model where consumption and investment goods are produced using the same technology:

$$\begin{aligned} C_t &= e^{z_t} \left(k_{C,t}\right)^{\alpha} \left(l_{C,t}\right)^{1-\alpha}, \\ I_t &= e^{z_t} \left(k_{I,t}\right)^{\alpha} \left(l_{I,t}\right)^{1-\alpha}, \end{aligned}$$

where k_x and l_x are capital and labor employed in sector $x = C, I$. Neutral technology shocks are denoted by z.

Firms in the consumption goods sector hire labor to the point where the marginal cost, the real wage, equals the marginal product of labor:

$$w_t = (1-\alpha)\frac{C_t}{l_{C,t}} \tag{1}$$

The households' labor supply is determined by equating the marginal rate of substitution between consumption and leisure to the real wage rate:

$$w_t = \psi C_t \left(l_t\right)^{\xi} \tag{2}$$

where ψ and ξ are nonnegative constants.

Equations (1) and (2) imply that $l_{C,t}\left(l_t\right)^{\xi}$ is constant. In response to technology shocks, aggregate labor, l_t, increases. In order for $l_{C,t}\left(l_t\right)^{\xi}$ to remain constant, $l_{C,t}$ must decrease. Also, since the two sectors have identical capital-to-labor ratios,[9] capital will be moved from the consumption goods sector to the investment goods sector.[10]

Christiano and Fitzgerald (1998) show that the result is robust to the choice of functional form for the utility function within the class of preferences consistent with balanced growth (see King, Plosser, and Rebelo, 1988). Christiano and Fitzgerald (1998) also show that a non-unit elasticity of substitution between capital and labor in the production function could generate comovement. However, they argue that, for plausible values of the elasticity of substitution, a standard model does not generate comovement.

2.3 Sticky wages and comovement

In a model with sticky wages, households are not allowed to equate the marginal rate of substitution between consumption and leisure to the real

[9] This follows from the fact that there are economy-wide factor markets.

[10] For a review of the literature which addresses the comovement puzzle in real models, see Christiano and Fitzgerald (1998).

wage. Let $\mu_{H,t}$ denote the wedge between the two:

$$\mu_{H,t} = \frac{w_t}{\psi C_t \left(l_t\right)^{\xi}}. \tag{3}$$

Sticky wages create a time varying markup of the price on the marginal cost of the good supplied. The real wage can be interpreted as the price of leisure, and the marginal rate of substitution between consumption and leisure is the marginal cost, measured in consumption units. In response to a technology shock, the denominator increases but sticky wages prevent the numerator from increasing by the same amount, and $\mu_{H,t}$ decreases.

Combining the household's intratemporal equation with the first order condition for labor for firms in the consumption goods sector, (1), and rearranging:

$$\frac{1}{1-\alpha} l_{C,t} \left(l_t\right)^{\xi} = \frac{1}{\mu_{H,t}}. \tag{4}$$

A countercyclical wage markup implies that $l_{C,t} \left(l_t\right)^{\xi}$ is procyclical. Thus $l_{C,t}$ can be procyclical as well, and the puzzle is solved.

To evaluate empirically the relevance of nominal wage rigidities in generating comovement, I present in the following section a two-sector DSGE model which incorporates sticky wages and several other departures from the basic RBC model. One-sector models featuring similar frictions have been recently used to study business cycles and/or the effects of monetary policy: see Christiano, Eichenbaum, and Evans (2005), Altig, Christiano, Eichenbaum, and Lindé (2002), Smets and Wouters (2003), and Smets and Wouters (2005). A growing literature presents multi-sector DSGE models to study different issues: international monetary policy coordination (Liu and Pappa, 2005), learning and productivity shifts (Edge, Laubach, and Williams, 2004), productivity analysis in open economies (Guerrieri, Henderson, and Kim, 2005), firm-specific capital and the role of nominal rigidities over the cycle (Altig, Christiano, Eichenbaum, and Linde, 2005), to cite a few. A formal comparison with other multi-sector models is beyond the scope of this paper. However, the main point -i.e., the connection between sectoral inputs comovement and nominal wage rigidities- is quite general, as discussed above.

3 The Model

The economy is populated by a unit measure continuum of households. Each household makes consumption, investment, capital utilization, cash holding and deposit decisions. Also, each household supplies monopolistically a differentiated labor service to a competitive labor market intermediary. The homogenous composite labor is supplied to monopolist intermediate goods firms in the consumption and investment goods sectors. An intermediate firm in either sector combines labor services and capital services into an intermediate input for the production of the final good in the respective sector. Intermediate good producers need to borrow money from a competitive financial intermediary to pay for the wage bill before production takes place. Final good producers are perfectly competitive. Finally, the monetary authority implements monetary policy by setting the money growth rate.

In every period the economy is affected by three different shocks. A neutral (disembodied) technology shock increases the productivity of intermediate good producers in either sector. An investment-specific (embodied) technology shock increases the productivity only of intermediate goods producers in the investment goods sector. Monetary policy shocks affect the growth rate of money supply, beyond the endogenous response of monetary policy to realizations of the other shocks.

3.1 Timing

At the beginning of every period, embodied and disembodied technology shocks are realized. Then, prices and wages are set and households make their consumption, investment and capital utilization decisions. After this, the monetary policy shock is realized. Then, households make their portfolio decision, goods and labor markets meet and clear, and production, investment and consumption occur. To reflect the fact that different decisions are based on different information, let Ω_t be the information set including all the shock realizations up to and including time t and Ω_t^m be the information set including all the shock realizations up to t, excluding the time t realization of the monetary policy shock. The corresponding conditional expectations operators are denoted by:

$$E\left(\bullet|\Omega_t\right) = E_t\left(\bullet\right),\ E\left(\bullet|\Omega_t^m\right) = E_t^m\left(\bullet\right).$$

The timing described above ensures that the identification assumptions used to identify monetary policy shocks in the data hold by construction in the model.

3.2 Final goods firms

In either sector, final goods output is produced by competitive firms according to the technology:

$$Y_{x,t} = \left[\int_0^1 \left(Y_{x,j,t}\right)^{\frac{1}{\lambda_f}} \right]^{\lambda_f}, \ \lambda_f \in [1, +\infty), \ x = C, I, \tag{5}$$

where $Y_{j,t}^x$ denotes the time t input of intermediate good j for sector x.

Consumption and investment goods producers solve:

$$\max_{Y_{x,t}, \{Y_{x,j,t}\}_{j \in [0,1]}} P_{x,t} Y_{x,t} - \int_0^1 P_{x,j,t} Y_{x,j,t} dj, \ x = C, I, \tag{6}$$

where $P_{x,t}$ is the price of final good x.

3.3 Intermediate Goods Firms

Intermediate good $j \in [0,1]$ for the consumption goods sector is produced according to:

$$Y_{C,j,t} = \max \left\{ e^{z_{N,t}} \left[\left(K_{C,j,t}\right)^{\alpha} \left(l_{C,j,t}\right)^{1-\alpha} - \phi_C \left(Z_{t-1}\right)^{\alpha} \right], 0 \right\}, \tag{7}$$

where $\alpha \in (0,1)$, $\phi_C > 0$, $K_{C,j,t}$ and $l_{C,j,t}$ denote capital and labor services, and $z_{N,t}$ represents a neutral technology shock. The term $e^{z_{N,t}} \phi_C \left(Z_{t-1}\right)^{\alpha}$ is a "fixed" production cost which ensures that profits are zero in a non-stochastic steady state.[11]

Intermediate investment goods $j \in [0,1]$ is produced according to:

$$Y_{I,j,t} = \max \left\{ e^{z_{N,t} + z_{I,t}} \left[\left(K_{I,j,t}\right)^{\alpha} \left(l_{I,j,t}\right)^{1-\alpha} - \phi_I \left(Z_{t-1}\right)^{\alpha} \right], 0 \right\}, \tag{8}$$

where $K_{I,j,t}$ and $l_{I,j,t}$ denote capital and labor services, and $z_{I,t}$ represents a capital-embodied shock. The term $e^{z_{N,t}+z_{I,t}} \phi_I \left(Z_{t-1}\right)^{\alpha}$ is a "fixed" production cost which will ensure that profits are zero along a non-stochastic balanced growth path.

Technology shocks evolve as follows:

$$\begin{gathered} z_{x,t} = z_{x,t-1} + \mu_{x,t}, \\ \mu_{x,t} = \left(1 - \rho_x\right) \mu_x + \rho_x \mu_{x,t-1} + \varepsilon_{x,t}, \\ |\rho_x| < 1, \ \varepsilon_{x,t} \underset{iid}{\sim} N\left(0, \sigma_x^2\right), \ x = N, I. \end{gathered} \tag{9}$$

[11] The "fixed" cost is assumed to grow at the same rate as sectoral output, to ensure that it does not become negligible.

Let R_t^k and W_t denote the nominal rental rate on capital services and the wage rate. Firms need to borrow money to pay the wage bill in advance of production. Thus labor has a unit cost of $R_t W_t$.

The first-order conditions with respect to capital and labor imply that the capital-to-labor ratios across firms in each sector are identical, and they are equalized across sectors:

$$\frac{K_{x,j,t}}{l_{x,j,t}} = \frac{K_{x,t}}{l_{x,t}} = \frac{K_t}{l_t}, \forall j \in [0,1], \; x = C, I.$$

The typical intermediate goods firm's profits are:

$$\left(P_{x,j,t} - P_{x,t} s_{x,t}\right) Y_{x,j,t}, \;\; x = C, I.$$

In each period, with constant probability $\left(1 - \xi_{p,x}\right)$, a firm in sector x is allowed to reoptimize its nominal price.[12] If a firm is not allowed to reoptimize the following equations hold[13]:

$$\begin{aligned} P_{C,j,t} &= \pi_{C,t-1} P_{C,j,t-1}, \quad \pi_{C,t-1} \equiv \frac{P_{C,t-1}}{P_{C,t-2}} \\ P_{I,j,t} &= e^{-\mu_{I,t}} \pi_{I,t-1} P_{I,j,t-1}, \quad \pi_{I,t-1} \equiv \frac{P_{I,t-1}}{P_{I,t-2}} e^{\mu_{I,t-1}}. \end{aligned}$$

Firms choose $\tilde{P}_{C,t}$ and $\tilde{P}_{I,t}$ in order to maximize[14]:

$$E_t^m \sum_{l=0}^{+\infty} \left(\beta \xi_{p,C}\right)^l \eta_{t+l} \left[\tilde{P}_{C,t} X_{C,t,l} - s_{C,t+l} P_{C,t+l}\right] Y_{j,t+l}^C,$$

$$E_t^m \sum_{l=0}^{+\infty} \left(\beta \xi_{p,I}\right)^l \eta_{t+l} \left[\tilde{P}_{I,t} e^{-\left(z_{I,t+l} - z_{I,t}\right)} X_{I,t,l} - s_{I,t+l} P_{I,t+l}\right] Y_{j,t+l}^I,$$

where

$$X_{x,t,l} = \begin{cases} \Pi_{j=0}^{l-1} \pi_{x,t+j} & \text{for } l \geq 1 \\ 1 & \text{for } l = 0 \end{cases}, \;\; x = C, I.$$

η_{t+l} is the marginal value of a dollar for the household, which firms take as given; $s_{x,t}$ denotes the marginal costs for firms in sector x.

[12] Independently across firms, within and between sectors, and time.

[13] See Christiano, Eichenbaum, and Evans (2005) for a justification of this updating rule, as opposed to the standard rule $P_{x,j,t} = \pi P_{x,j,t-1}$, where π is the unconditional average of inflation.

[14] All the firms in either sector that can reoptimize will choose the same price, as shown in Woodford (1996).

The aggregate prices in the two sectors can be expressed as:

$$
\begin{aligned}
P_{C,t} &= \left[\left(1-\xi_{p,C}\right)\tilde{P}_{C,t}^{\frac{1}{1-\lambda_f}} + \xi_{p,C}\left(\pi_{C,t-1}P_{C,t-1}\right)^{\frac{1}{1-\lambda_f}}\right]^{1-\lambda_f}, &(10)\\
P_{I,t} &= \left[\left(1-\xi_{p,I}\right)\tilde{P}_{I,t}^{\frac{1}{1-\lambda_f}} + \xi_{p,I}\left(\frac{\pi_{I,t-1}P_{I,t-1}}{e^{\mu_{I,t}}}\right)^{\frac{1}{1-\lambda_f}}\right]^{1-\lambda_f}. &(11)
\end{aligned}
$$

3.4 Households

Households rank consumption, leisure and real balances streams according to[15]:

$$
E_0\sum_{t=0}^{+\infty}\beta^t\left[\log\left(C_t-bC_{t-1}\right)-\psi_l\frac{\left(h_{j,t}\right)^2}{2}+\psi_q\frac{\left(\frac{q_t}{\vartheta_t}\right)^{1-\sigma_q}}{1-\sigma_q}\right], \tag{12}
$$

$$
\beta\in(0,1),\ \sigma\in[0,+\infty),\ \psi_l\in(0,+\infty),\ \psi_q\in(0,+\infty),\ \sigma_q\in[0,+\infty),
$$

where $q_t\equiv Q_t/P_{C,t}$ are real money balances, $\vartheta_t=e^{\frac{\mu_{N,t}+\alpha\mu_{I,t}}{1-\alpha}}$ is a scaling variable, and $h_{j,t}$ is household j's labor supply.

The household's budget constraint is:

$$
\begin{aligned}
&M_{t+1}\le R_t\left[M_t-Q_t+M_{t+1}\left(\mu_t-1\right)\right]+Q_t+A_{j,t}+D_t\\
&-P_{I,t}I_t-P_{C,t}C_t-P_{C,t}a\left(u_t\right)\frac{\vartheta_t}{Z_t}\bar{K}_t+R_t^ku_t\bar{K}_t+W_{j,t}h_{j,t}, \qquad (13)
\end{aligned}
$$

where M_t is the household's beginning-of-period stock of money, $\left(\mu_t-1\right)M_{t+1}$ is a lump sum transfer from the monetary authority, Q_t denotes the nominal cash balances the household carries from the previous period, D_t denotes profits, and $A_{j,t}$ is the net cash flow from state-contingent securities.[16] The amount $\left[M_t-Q_t+\left(\mu_t-1\right)M_{t+1}\right]$ is deposited with a financial intermediary.

$\bar{K}_t$ denotes the physical stock of capital. The quantity of capital services is given by the product of physical capital and the utilization rate, u_t:

$$
K_t=u_t\bar{K}_t. \tag{14}
$$

[15] The only functional form for utility consistent with identical consumption across households and with balanced growth is logarithmic in consumption.

[16] State-contingent securities allow the households to insulate consumption and asset holdings from the realizations of idiosyncratic Calvo uncertainty.

The cost of utilizing capital is measured in consumption units and is proportional to the quantity of physical capital. In steady-state, utilization is normalized to one, and it is costless, i.e. $a(1) = 0$.

The household's stock of capital evolves according to:

$$\bar{K}_{t+1} = (1-\delta)\bar{K}_t + F(I_t, I_{t-1}), \tag{15}$$
$$F(I_t, I_{t-1}) = \left[1 - S\left(\frac{I_t}{I_{t-1}}\right)\right] I_t,$$
$$S\left(e^{\frac{\mu_N+\mu_I}{1-\alpha}}\right) = S'\left(e^{\frac{\mu_N+\mu_I}{1-\alpha}}\right) = 0,\ \varkappa \equiv e^{2\frac{\mu_N+\mu_I}{1-\alpha}} S''\left(e^{\frac{\mu_N+\mu_I}{1-\alpha}}\right) > 0.$$

The function $S(\bullet)$ gives the adjustment cost to be paid if the investment growth rate is changed from its previous-period level.[17]

3.4.1 Labor Decision

The household labor supply decision is modeled as in Erceg, Henderson, and Levin (2000). Households are monopoly suppliers of differentiated labor services, $h_{j,t}$. These services are sold to a representative, competitive firm, which aggregates them into homogeneous labor input according to:

$$n_t = \left(\int_0^1 h_{j,t}^{\frac{1}{\lambda_w}}\, dj\right)^{\lambda_w},\ \lambda_w \in [1, +\infty).$$

The aggregate wage, W_t, is related to the individual households' wage rates as follows:

$$W_t = \left(\int_0^1 W_{j,t}^{\frac{1}{1-\lambda_w}}\, dj\right)^{1-\lambda_w}. \tag{16}$$

In each period a household is allowed to reoptimize its nominal wage, with constant probability $(1-\xi_w)$,[18] taking W_t and n_t as given. If the household is not allowed to reoptimize its wage evolves according to[19]:

$$W_{j,t+1} = \pi_{C,t} e^{\frac{\mu_N+\alpha\mu_I}{1-\alpha}} W_{j,t}.$$

[17] See Christiano, Eichenbaum, and Evans (2005) for a detailed discussion of this specification of investment adjustment costs and a comparison with adjustment costs in the investment rate.

[18] Independently across households, sectors and time.

[19] The results in section 4.3 are robust to the adoption of the partial indexation of wages to past inflation used in Smets and Wouters (2005).

The first-order condition associated with the wage choice,[20] $\tilde{W}_t$, of a household that is reoptimizing is:

$$E_t^m \sum_{l=0}^{+\infty} (\beta\xi_w)^l \frac{h_{j,t+l}}{C_{t+l}} \left[\exp\left(\frac{\mu_N + \alpha\mu_I}{1-\alpha} l \right) \frac{\tilde{W}_t X_{C,t,l}}{P_{C,t+l}} - \lambda_w h_{j,t+l} C_{t+l} \right] = 0. \tag{17}$$

The aggregate wage can be expressed as:

$$W_t = \left[(1-\xi_w) \left(\tilde{W}_t \right)^{\frac{1}{1-\lambda_w}} + \xi_w \left(e^{\frac{\mu_N+\alpha\mu_I}{1-\alpha}} \pi_{C,t-1} W_{t-1} \right)^{\frac{1}{1-\lambda_w}} \right]^{1-\lambda_w}. \tag{18}$$

3.5 Loan-market clearing

Loan-market clearing requires that the demand for loans from firms to finance their working capital is equal to money deposited by the households:

$$W_t l_t = \mu_t M_t - Q_t. \tag{19}$$

3.6 Sectoral resource constraints

The resource constraints for the consumption goods sector and the investment goods sector can be expressed as[21]:

$$C_t + a(u_t) \frac{\vartheta_t}{Z_t} \bar{K}_t = e^{z_{N,t}} \left(\frac{P^*_{C,t}}{P_{C,t}} \right)^{\frac{\lambda_f}{\lambda_f-1}} \left[\left(\frac{W^*_t}{W_t} \right)^{\frac{\lambda_w(1-\alpha)}{\lambda_w-1}} K^\alpha_{C,t} h^{1-\alpha}_{C,t} - \phi_C Z^\alpha_{t-1} \right], \tag{20}$$

$$I_t = e^{z_{N,t}+z_{I,t}} \left(\frac{P^*_{I,t}}{P_{I,t}} \right)^{\frac{\lambda_f}{\lambda_f-1}} \left[\left(\frac{W^*_t}{W_t} \right)^{\frac{\lambda_w(1-\alpha)}{\lambda_w-1}} K^\alpha_{I,t} h^{1-\alpha}_{I,t} - \phi_I Z^\alpha_{t-1} \right], \tag{21}$$

where $K_{x,t}$ and $h_{x,t}$ measure capital and labor services used in sector x and

$$W^*_t = \left(\int_0^1 W_{j,t}^{\frac{\lambda_w}{1-\lambda_w}} dj \right)^{\frac{1-\lambda_w}{\lambda_w}}, \; P^*_{x,t} = \left(\int_0^1 P_{x,j,t}^{\frac{\lambda_f}{1-\lambda_f}} dj \right)^{\frac{1-\lambda_f}{\lambda_f}}, \; x = C, I.$$

[20] All the households that can reoptimize will choose the same wage.

[21] As shown in Yun (1996), the terms $\left(\frac{P^*_{x,t}}{P_{x,t}}\right)^{\frac{\lambda_f}{\lambda_f-1}}$ and $\left(\frac{W^*_t}{W_t}\right)^{\frac{\lambda_w(1-\alpha)}{\lambda_w-1}}$ do not have a first-order effect, and they disappear in the log-linearized versions of the sectoral resource constraints.

3.7 Monetary Policy

Monetary policy is modelled as a money growth rule:

$$\begin{gathered}\hat{\mu}_t \equiv \hat{\mu}_{p,t} + \hat{\mu}_{N,t} + \hat{\mu}_{I,t}, \\ \hat{\mu}_{p,t} = \rho_{\mu_p} \hat{\mu}_{p,t-1} + \varepsilon_{\mu_p,t}, \ \varepsilon_{\mu_p,t} \underset{iid}{\sim} N\left(0, \sigma^2_{\mu_p}\right) \\ \hat{\mu}_{j,t} = \rho_{\mu_j} \hat{\mu}_{j,t-1} + c_{\mu_j} \varepsilon_{j,t} + l_{\mu_j} \varepsilon_{j,t-1}, \\ \left|\rho_{\mu_p}\right|, \left|\rho_{\mu_j}\right| < 1, \ j = N, I.\end{gathered} \tag{22}$$

Here, $\varepsilon_{\mu_p,t}$ represents a monetary policy shock. The terms $\hat{\mu}_{N,t}$ and $\hat{\mu}_{I,t}$ capture the response of monetary policy to innovations in neutral and capital-embodied technology, respectively. The dynamic response of $\hat{\mu}_{j,t}$ to $\varepsilon_{j,t}$ is characterized by ARMA(1,1) processes.

3.8 Equilibrium and Solution

A textbook sequence-of-markets notion of equilibrium applies.

The model described in the previous sections can be expressed in terms of stationary variables in the obvious way. I log-linearized the scaled model in a neighborhood of its non-stochastic steady-state and I solve the log-linearized model using the algorithm described in Anderson and Moore (1985) and the method of undetermined coefficients in Christiano (2002).[22]

4 Econometric Methodology

I estimate the key parameters of the log-linearized model with a standard limited information approach. The parameters are chosen in order to minimize the distance of the impulse responses of the model to embodied, disembodied and monetary policy shocks from the impulse responses of a structural VAR representation of U.S. data.

4.1 A VAR Representation of the Data

The variables included in the VAR analysis are the growth rate of the real investment price, the growth rate of average labor productivity, the inflation rate, capacity utilization, the ratio of the real wage to average labor productivity, the consumption and investment shares of output, the federal funds rate, and the money growth rate. The sample covers the period

[22] A technical appendix is available from the author upon request.

1959:Q2-2001:Q4. The variables are required to be covariance stationary. The estimated VAR coefficients corroborate the stationarity assumption.

Consider the following reduced form VAR[23]:

$$\begin{aligned} Y_t &= A(L) Y_{t-1} + u_t, \; E u_t u_t' = V, \\ A(L) &= A_1 + A_2 L + \ldots + A_p L^p, \; p < \infty \end{aligned}$$

In the analysis that follows Y_t is defined as:

$$Y_t = \left[\begin{array}{c} \Delta \ln (p_{I,t}), \Delta \ln \left(\frac{Y_t}{l_t} \right), \pi_t, \ln \left(\frac{w_t}{Y_t / l_t} \right), \ln (u_t), \\ \ln (l_t), \ln \left(\frac{C_t}{Y_t} \right), \ln \left(\frac{I_t}{Y_t} \right), R_t, \Delta \ln (M_t) \end{array} \right]'.$$

The reduced form residuals, u_t, are related to the structural shocks, ϵ_t, by $\epsilon_t = A_0 u_t$. Also, the structural shocks are orthogonal to each other, i.e., $E \epsilon_t \epsilon_t' = I$. The first two elements of ϵ_t are the investment specific and neutral technology shocks, respectively. The last element is the monetary policy shock. The remaining elements of ϵ_t are not identified.

Following Fisher (2003), I identify embodied and disembodied technology shocks using long-run restrictions. As in the model, investment-specific technology shocks are the only shocks to have a long-run effect on the relative price of investment. Neutral technology shocks and investment-specific technology shocks are the only shocks to affect average labor productivity in the long run. The long-run effects of the structural shocks are given by:

$$\begin{gathered} Y_\infty = \Theta \epsilon_t, \\ \Theta \equiv [I - A(1)]^{-1} A_0^{-1}. \end{gathered}$$

The identifying assumptions described above boil down to assuming that the first two rows of matrix Θ have the following structure:

$$\Theta(1:2,:) = \begin{bmatrix} \theta_{11} & 0 & 0_{1 \times 8} \\ \theta_{21} & \theta_{22} & 0_{1 \times 8} \end{bmatrix}.$$

Monetary policy shocks are identified as in Christiano, Eichenbaum, and Evans (1999) by assuming that the 9^{th} column of A_0 has the following structure[24]:

$$A_0(:,9) = [0_{1 \times 8}, a_0, a_1]'.$$

[23] In the estimation, four lags (i.e., $p = 3$) and a constant were included. For ease of exposition the constant has been omitted in what follows.

[24] Notice that there are two overidentifying restrictions. The first two elements of ϵ_t would be just identified by imposing the long run restrictions. The identification of monetary policy shocks poses two additional zero restrictions.

This identification assumption can be interpreted as signifying that the monetary authority follows a Taylor-rule-like policy, which responds to all the variables ordered before the interest rate in the VAR.

Figures 2-4 report the impulse response functions (IRFs) of the VAR to the three structural shocks. The shaded areas are bootstrapped 95% confidence intervals around the point estimates. The short-run behavior of the variables in response to technology shocks is consistent with the evidence reported in Fisher (2003). Monetary policy shocks produce the patterns of responses that are well-documented in the literature. In particular, they generate persistent output and inflation responses and hump-shaped responses of consumption, investment, and hours.

4.2 Estimation

The model parameters are collected in the vector $\zeta = [\zeta_1,\ \zeta_2]'$. The elements of ζ_1 have been fixed at the same values as in Altig, Christiano, Eichenbaum, and Lindé (2002) (table 2).

Parameter in ζ_1	Value
β	$(1.03)^{-1/4}$
α	0.36
δ	0.025
μ	1.017
σ_l	1
ψ_l	s.t. $l = 1$
ψ_q	s.t. $\frac{q}{m} = 0.25$
λ_w	1.05
μ_N	0.002
μ_I	0.003

Table 2: Fixed parameters

The elements of ζ_2 are chosen to minimize the weighted distance of the

σ_q	b	λ_f	$\xi_{p,C}$	$\xi_{p,I}$	ξ_w	κ	σ_a
10.46	0.76	1.21	0.54	0.77	0.73	3.54	0.08
(2.98)	(0.03)	(0.06)	(0.06)	(0.07)	(0.02)	(0.71)	(0.04)

Table 3: Estimated economic parameters - std. errors in parentheses

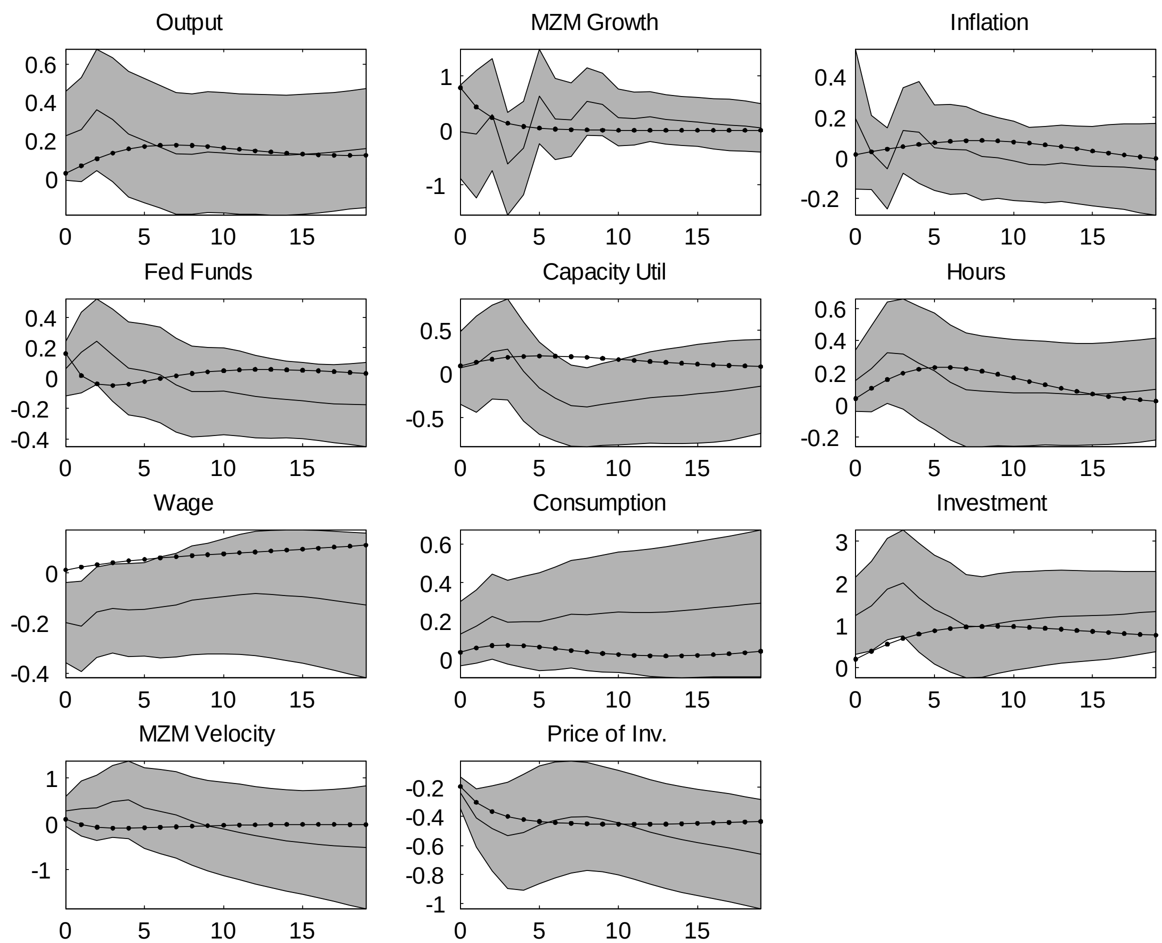

Figure 2: Model (•) and VAR-based responses to an embodied technology shock

ρ_{μ_p}	ρ_{μ_N}	c_{μ_N}	l_{μ_N}	ρ_{μ_I}	c_{μ_I}
0.13	0.30	6.96	2.70	0.69	0.53
(0.335)	(0.230)	(1.086)	(2.754)	(0.096)	(0.46)
l_{μ_I}	ρ_N	ρ_I	σ_{μ_p}	σ_N	σ_I
1.22	0.91	-0.53	0.24	0.03	0.08
(0.67)	(0.01)	(0.52)	(0.010)	(0.003)	(0.032)

Table 4: Estimated shocks parameters - std. errors in parentheses

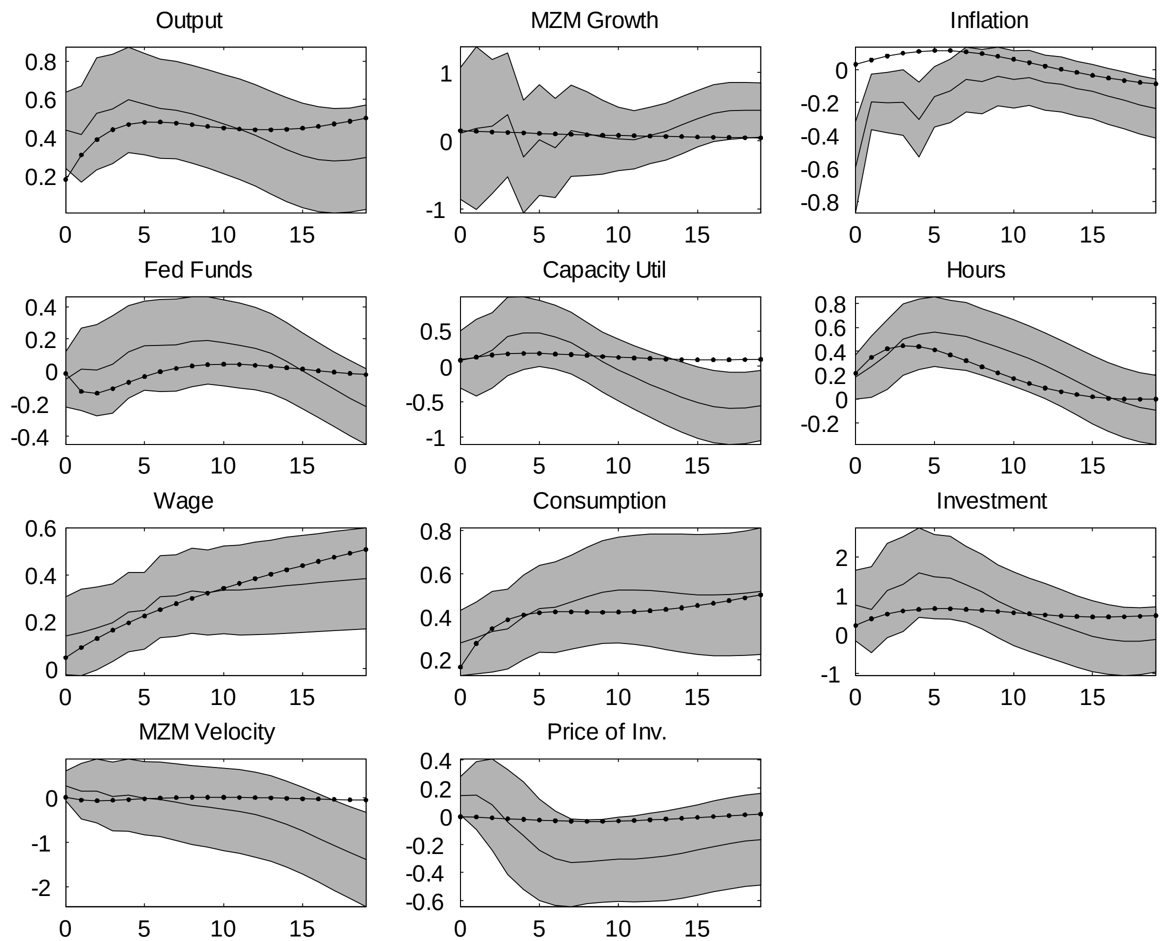

Figure 3: Model (•) and VAR-based responses to a neutral technology shock

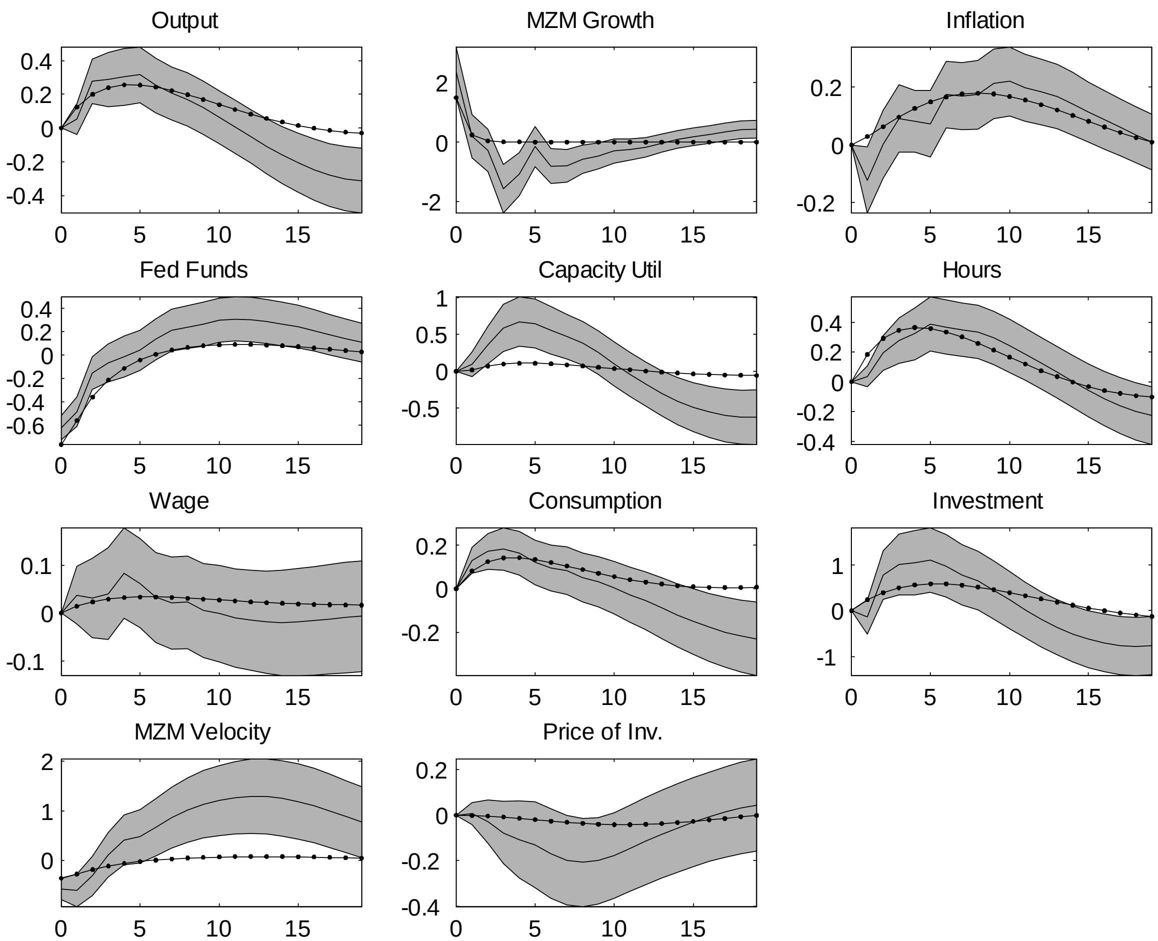

Figure 4: Model (•) and VAR-based responses to a monetary policy shock

model IRFs, $\Gamma(\zeta_2)$, from the VAR IRFs, Γ:

$$\zeta_2^* = \arg\min_{\zeta_2} (\Gamma - \Gamma(\zeta_2))' V^{-1} (\Gamma - \Gamma(\zeta_2)),$$

where V is a diagonal matrix containing the variances of the estimated VAR impulse response functions. The loss function above attributes more weight to the impulse response functions estimated more precisely.[25]

The parameter estimates are reported in tables 3 and 4. They are broadly consistent with the estimates reported by Altig, Christiano, Eichenbaum, and Lindé (2002). The estimated Calvo parameters imply an average price contract duration of 2.17 and 4.26 quarters for firms in the consumption and investment goods sectors, respectively. The average wage contract duration is 3.72 quarters.

The model impulse responses to a monetary policy shock are remarkably close to the responses in the VAR. The IRFs to technology shocks are reasonably close to those found in the data (see figures 2 and 3).

4.3 Comovement

Table 5[26] displays comovement statistics for the simulated model and the corresponding statistics for U.S. data.

The contemporaneous correlations of sectoral labor inputs with output for the model are positive and close to the corresponding values for the data. The model understates the relative volatility of labor in the investment goods sector.

Table 6[27] reports the relative volatility of sectoral labor with respect to output and the contemporaneous correlation with output for various versions of the model. The baseline model refers to the model where all frictions are operative. The other versions of the model are characterized as follows:

- no habits: $b = 0$;
- flexible prices: $\xi_{p,C} = \xi_{p,I} = 0$;

[25] This feature of the minimum distance estimator adopted explains why the estimated model does a better job at reproducing responses to monetary shocks than to technology shocks.

[26] I simulate the estimated model 10,000 times. Each time I generate artificial data of the same size as the U.S. data, I filter (HP_{1600}) the logarithms of the artificial data and compute the statistics of interests. I report the averages and the corresponding 2.5^{th} and 97.5^{th} percentiles of the 10,000 statistics.

[27] See footnote 24.

	x	$\sigma_x/\sigma_{\tilde{y}}$	$\rho_{x,\tilde{y}}$				
			-2	-1	0	1	2
Model	$\tilde{l}_C$	0.80 [0.75,0.92]	0.75 [0.48,0.89]	0.85 [0.56,0.96]	0.86 [0.58,0.97]	0.74 [0.48,0.84]	0.54 [0.34,0.65]
	$\tilde{l}_I$	1.68 [1.54,2.12]	0.61 [0.55,0.79]	0.75 [0.69,0.90]	0.83 [0.77,0.95]	0.78 [0.73,0.93]	0.67 [0.60,0.83]
U.S.	$\tilde{l}_C$	0.74	0.79	0.87	0.85	0.68	0.46
data	$\tilde{l}_I$	2.44	0.80	0.89	0.88	0.71	0.48

Table 5: Comovement statistics - 95% C.I. in paretheses

- flexible wages: $\xi_w = 0$;
- small investment adjustment costs: $\kappa = 0.05$;
- no variable capital utilization: $\sigma_a = 10,000$;
- no fixed production costs: $\lambda_f = 1$;
- no working capital: firms in the intermediate good sectors do not need to borrow their working capital, so that the unit labor cost is simply the wage rate; the loan-market-clearing equation is modified accordingly.

Demand shocks (i.e., monetary policy shocks) generate comovement independently of the frictions included in the model. A lower interest rate stimulates demand for both consumption and investment goods. With unchanged technology, the only way to satisfy the increased demand is to use more inputs in both sectors.

The key friction in generating comovement in response to technology shocks is sticky wages. The model with flexible wages generates significantly lower correlations of l_C and l_I with output in response to any shock. The flexible wages model simulated with the three shocks together displays a correlation for l_C which is less than one third of the correlation diplayed in the baseline model, and a correlation for l_I that is close to zero.

Habit formation plays a minor role in delivering comovement in response to embodied technology shocks. However, the model without habits displays a substantial amount of comovement when all the shocks are considered. This is in contrast with the results in Boldrin, Christiano, and Fisher (2001)

Model	Embodied tech. shocks				Disembodied tech. shocks			
	$\sigma_{\tilde{l}_C}/\sigma_{\tilde{y}}$	$\rho_{\tilde{l}_C,\tilde{y}}$	$\sigma_{\tilde{l}_I}/\sigma_{\tilde{y}}$	$\rho_{\tilde{l}_I,\tilde{y}}$	$\sigma_{\tilde{l}_C}/\sigma_{\tilde{y}}$	$\rho_{\tilde{l}_C,\tilde{y}}$	$\sigma_{\tilde{l}_I}/\sigma_{\tilde{y}}$	$\rho_{\tilde{l}_I,\tilde{y}}$
Baseline	0.86	0.95	2.27	0.98	0.79	0.80	0.86	0.77
No habits	1.13	0.94	1.89	0.90	1.17	0.75	0.27	-0.20
Flexible prices	0.88	0.96	2.12	0.98	0.80	0.82	1.05	0.79
Flexible wages	1.47	0.52	5.55	-0.14	0.47	0.37	2.55	0.05
Small investment adj. costs	0.54	0.93	3.14	0.99	0.66	0.77	1.35	0.58
No variable capital util.	0.94	0.95	3.22	0.97	0.59	0.67	1.43	0.64
No fixed prod. cost	1.22	0.96	2.75	0.98	1.04	0.76	0.75	0.68
No working capital	0.85	0.96	2.18	0.99	0.85	0.95	1.97	0.98
Model	Monetary policy shocks				All shocks			
	$\sigma_{\tilde{l}_C}/\sigma_{\tilde{y}}$	$\rho_{\tilde{l}_C,\tilde{y}}$	$\sigma_{\tilde{l}_I}/\sigma_{\tilde{y}}$	$\rho_{\tilde{l}_I,\tilde{y}}$	$\sigma_{\tilde{l}_C}/\sigma_{\tilde{y}}$	$\rho_{\tilde{l}_C,\tilde{y}}$	$\sigma_{\tilde{l}_I}/\sigma_{\tilde{y}}$	$\rho_{\tilde{l}_I,\tilde{y}}$
Baseline	0.83	0.95	2.23	0.97	0.81	0.86	1.69	0.83
No habits	1.15	0.94	1.70	0.87	1.13	0.83	0.27	0.59
Flexible prices	0.84	0.96	2.19	0.99	0.81	0.88	1.72	0.86
Flexible wages	0.94	0.61	3.12	0.31	0.53	0.38	2.82	0.06
Small investment adj. costs	0.53	0.92	3.10	0.99	0.57	0.84	2.55	0.84
No variable capital util.	0.84	0.96	2.53	0.96	0.69	0.76	1.95	0.75
No fixed prod. cost	1.16	0.96	2.67	0.97	1.09	0.84	1.90	0.76
No working capital	0.85	0.96	2.15	0.99	0.85	0.96	2.08	0.98

Table 6: Statistics for various versions of the model

$\tilde{\mu}_H$	$\sigma_{\tilde{\mu}_H}/\sigma_{\tilde{y}}$	Cross correlation with output				
		-2	-1	0	1	2
Model	1.51	-0.81	-0.94	-0.98	-0.87	-0.68
	[1.44,1.57]	[-0.70,-0.88]	[-0.90,-0.97]	[-0.97,-0.99]	[-0.83,-0.90]	[-0.58,-0.75]
U.S. data	1.53	-0.48	-0.68	-0.84	-0.82	-0.71

Table 7: Business cycle component of the wage markup and of the consumption-leisure MRS

who present a two-sector model driven by neutral technology shocks, with immobile capital and labor, and habit persistence. In response to technology shocks labor cannot be relocated from the consumption goods to the investment goods sector. In subsequent periods, agents are addicted to the relatively higher level of consumption.

Jin and Zeng (2002) focus on the working capital channel in a limited participation model as a rationalization of the comovement puzzle. The nominal interest rate decreases in response to both monetary policy shocks and neutral technology shocks. The general equilibrium effect of technology shocks on the nominal interest rate is due to an increase in the desired amount of savings. The reduced unit labor cost for firms in both sectors is responsible for comovement in their model. A similar channel operates in my model, but it is not essential for generating comovement.

4.3.1 Wage markup

The model generates a countercyclical wedge between the wage rate and the marginal rate of substitution between consumption and leisure[28]:

$$\tilde{\mu}_{H,t} = \tilde{w}_t - \left(\tilde{c}_t + \tilde{l}_t\right),$$

where $\tilde{w}$ is the real wage, $\tilde{c}$ is real consumption, and $\tilde{l}$ denotes hours worked (all of which have been logged and HP_{1600} filtered). The business cycle properties of the model's wedge are similar to the properties of its empirical counterpart (table 7).

[28] The model implies a more complicated expression for the wedge, due to the presence of habit persistence. Taking this into account does not change the results in table 7.

5 Conclusions

The analysis in this paper is very similar, in spirit, to the RBC literature. In the RBC literature a model is parametrized using independent information, and it is evaluated by assessing its capability to reproduce second moments of aggregate data.

My model has been parametrized by estimating the relevant parameters, instead of calibrating them, without using sectoral input variables. The model is consistent with the literature in terms of its ability to produce responses to neutral technology shocks and monetary policy shocks that are similar to those obtained in a VAR representation of U.S. data. In addition, the model is an empirically plausible account of the effects of investment-specific technology shocks. The estimated model is then simulated to assess its ability to reproduce second moments of the sectoral inputs that we observe in the data.

The model presented in this paper succeeds in generating comovement, a major hurdle for standard models. Sticky wages are the key friction in generating comovement. Nominal wage rigidities create a countercyclical markup of the real wage on the marginal rate of substitution between consumption and leisure with the same business cycle properties as its empirical counterpart. The wage markup, by keeping the cost effect of productivity shocks smaller than the demand effect, is responsible for comovement of sectoral inputs.

The modelling of sticky wages is admittedly very stylized. I interpret the evidence on the importance of wage rigidity[29] as a starting point for further research.

[29] Other authors, in different contexts, have pointed to the importance of wage rigidities. Christiano, Eichenbaum, and Evans (2005) argue that the use of sticky wages is important for obtaining a persistent response of inflation to monetary policy shocks without having to rely on inplausible amounts of price stickiness. Hall (2005) shows how wage rigidities deliver plausible volatility for unemployment, job-finding rates, and vacancies.

References

Altig, D., L. Christiano, M. Eichenbaum, and J. Linde (2005): "Firm-Specific Capital, Nominal Rigidities and the Business Cycle," NBER Working Paper No. 11034.

Altig, D., L. J. Christiano, M. Eichenbaum, and J. Lindé (2002): "Technology Shocks and Aggregate Fluctuations," manuscript, Northwestern University.

Anderson, G., and G. Moore (1985): "A Linear Algebraic Procedure for Solving Linear Perfect Foresight Models," *Economics Letters*, 17(3), 247–252.

Boldrin, M., L. J. Christiano, and J. D. M. Fisher (2001): "Habit Persistence, Asset Returns, and the Business Cycle," *American Economic Review*, 91(1), 149–166.

Burns, A. F., and W. C. Mitchell (1946): *Measuring Business Cycles.* National Bureau of Economic Research, New York, NY.

Calvo, G. A. (1983): "Staggered Prices in a Utility-Maximizing Framework," *Journal of Monetary Economics*, 12(3), 383–98.

Chari, V. V., P. J. Kehoe, and E. R. McGrattan (2004): "Business Cycle Accounting," Federal Reserve Bank of Minneapolis, Staff Report 328.

Christiano, L. J. (2002): "Solving Dynamic Equilibrium Models by a Method of Undetermined Coefficients," *Computational Economics*, 20(1-2), 21–55.

Christiano, L. J., M. Eichenbaum, and C. Evans (1999): "Monetary Policy Shocks: What Have We Learned, and to What End?," in *Handbook of macroeconomics*, ed. by J. B. Taylor, and M. Woodford, vol. 1B, pp. 1137–70. Elsevier Science, North-Holland, Amsterdam, New York and Oxford.

——— (2005): "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy," *Journal of Political Economy*, 113(1), 1–45.

Christiano, L. J., and T. J. Fitzgerald (1998): "The Business Cycle: It's Still a Puzzle," *Federal Reserve Bank of Chicago Economic Perspectives*, 22(4), 56–83.

EDGE, R. M., T. LAUBACH, AND J. C. WILLIAMS (2004): "Learning and shifts in long-run productivity growth," Board of Governors of the Federal Reserve System, Finance and Economics Discussion Series: 2004-21.

ERCEG, C. J., D. W. HENDERSON, AND A. T. LEVIN (2000): "Optimal Monetary Policy With Staggered Wage and Price Contracts," *Journal of Monetary Economics*, 46(2), 281–313.

FISHER, J. D. M. (2003): "Technology Shocks Matter," Federal Reserve Bank of Chicago, Working Paper 2002-14.

GALÍ, J., M. GERTLER, AND J. D. LÓPEZ-SALIDO (2002): "Markups, Gaps, and the Welfare Costs of Business Fluctuations," NBER Working Paper No. 8850.

GORDON, R. J. (ed.) (1986): *The American Business Cycle*. The University of Chicago Press, Chicago, IL.

GUERRIERI, L., D. HENDERSON, AND J. KIM (2005): "Investment-specific and multifactor productivity in multi-sector open economies: data and analysis," Board of Governors of the Federal Reserve System, International Finance Discussion Papers No. 828.

HALL, R., M. FELDSTEIN, J. FRANKEL, R. GORDON, C. ROMER, D. ROMER, AND V. ZARNOWITZ (2003): "The NBER's Recession Dating Procedure," http://www.nber.org/cycles/recessions.html.

HALL, R. E. (1997): "Macroeconomic Fluctuations and the Allocation of Time," *Journal of Labor Economics*, 15(1), S223–50.

——— (2005): "Employment Fluctuations with Equilibrium Wage Stickiness," *American Economic Review*, 95(1), 50–65.

HANSEN, G. D. (1985): "Indivisible Labor and the Business Cycle," *Journal of Monetary Economics*, 16(3), 309–327.

JIN, Y., AND Z. ZENG (2002): "The Working Capital Channel and Cross-Sector Comovement," *Journal of Economics*, 28(1), 51–65.

KING, R. G., C. I. PLOSSER, AND S. T. REBELO (1988): "Production, Growth and Business Cycles: I. The Basic Neoclassical Model," *Journal of Monetary Economics*, 21(2-3), 195–232.

Liu, Z., and E. Pappa (2005): "Gains from International Monetary Policy Coordination: Does It Pay to Be Different?," Emory University, unpublished manuscript.

Long, J. B., and C. J. Plosser (1983): "Real Business Cycles," *Journal of Political Economy*, 91(1), 39–69.

Lucas, R. E. J. (1977): "Understanding Business Cycles," in *Stabilization of the Domestic and International Economy*, ed. by K. Brunner, and A. H. Meltzer, vol. 5 of *Carnegie-Rochester Series on Public Policy*, pp. 7–29, Amsterdam, Holland. North-Holland Publishing Company.

Prescott, E. C. (1986): "Theory Ahead of Business Cycle Measurement," *Federal Reserve Bank of Minneapolis Quarterly Review*, 10(4), 9–22.

Sargent, T. J. (1987): *Macroeconomic Theory. Second Edition.* Academic Press, Inc., San Diego, CA.

Schumpeter, J. A. (1939): *Business Cycles*. McGraw-Hill Book Company, Inc., New York, NY.

Smets, F., and R. Wouters (2003): "An Estimated Stochastic Dynamic General Equilibrium Model of the Euro Area," *Journal of the European Economic Association*, 1(5), 1123–1175.

——— (2005): "Comparing Shocks and Frictions in US and Euro Area Business Cycles: A Bayesian DSGE Approach," *Journal of Applied Econometrics*, 20(2), 161–183.

Woodford, M. (1996): "Control of the Public Debt: A Requirement for Price Stability?," NBER Working Paper No. 5684.

Yun, T. (1996): "Nominal Price Rigidity, Money Supply Endogeneity, and Business Cycles," *Journal of Monetary Economics*, 37(2), 345–70.

Variable	Units	Haver (USECON)
Civilian Noninstitutional Population	Thousands	LN16N
Nominal GDP	Bil. $, SAAR	GDP
Real GDP	Bil. Chn. 2000 $, SAAR	GDPH
GDP: Chain Price Index	Index, 2000=100, SA	JGDP
PCE: Nondurable Goods	Bil. $, SAAR	CN
PCE: Services	Bil. $, SAAR	CS
PCE: Durable Goods	Bil. $, SAAR	CD
GPDI	Bil. $, SAAR	I
Gov't Cons. Exp. & Gross Inv.	Bil. $, SAAR	G
Federal Funds (effective) Rate	% p.a.	FFED
Hours of all persons (Nonfarm Bus. Sector)	Index, 1992=100, SA	LXFNH
Avg. weekly hours (Durable Goods Mfg.)	Hours, SA	LRDURGA
Avg. weekly hours (Nondurable Goods Mfg.)	Hours, SA	LRNDURA
Avg. weekly hours (Priv. Service-providing ind.)	Hours, SA	LRPSRVA
All Employees (Durable Goods Mfg.)	Thousands, SA	LADURGA
All Employees (Nondurable Goods Mfg.)	Thousands, SA	LANDURA
All Employees (Priv. Service-providing ind.)	Thousands, SA	LAPSRVA
Compensation per hour (NBS)	Index, 1992=100, SA	LXNFC
Capacity utilization (manufacturing)	% of capacity, SA	CUMFG
Money Stock: MZM	Bil. $, SA	FMZM
Money Stock: M2	Bil. $, SA	FM2
Money Stock: Small Time Deposits	Bil. $, SA	FMSTT

Table 8: Raw data

A Data

Table 8 describes the raw data used in the paper and provides the corresponding Haver mnemonics. The data are readily available from other commercial (e.g., DRI-WEFA) and non-commercial (e.g., the St. Louis FRB database FREDII) databases, as well as from the original sources (BEA, BLS, Board of Governors of the FRS).

The price of investment goods is measured as in Fisher (2003).[30] The price of investment is converted in real terms by dividing it by the GDP deflator (JGDP).

The monetary aggregate used is money zero maturity (after 1974), spliced

[30] I am grateful to Jonas Fisher for sharing with me his investment price data, which I updated to 2001:Q4.

with M2 minus small time deposits (before 1974).[31]

The remaining variables used in the VAR analysis are constructed from the raw data in the obvious way:

$$\frac{Y}{l}=\frac{\text{GDPH/LN16N}}{\text{LXFNH/LN16N}},\ \pi=4\Delta\log\left(\text{JGDP}\right),\ \frac{w}{Y/l}=\frac{\text{LXNFC}}{\text{JGDP}}\frac{1}{Y/l},$$
$$u=\text{CUMFG},\ l=\frac{\text{LXFNH}}{\text{LN16N}},\ \frac{C}{Y}=\frac{\text{CN+CS+G}}{\text{GDP}},\ \frac{I}{Y}=\frac{\text{CD+I}}{\text{GDP}}.$$

The variables used for constructing comovement statistics in table 1 are constructed as follows:

$$c=\frac{\text{CN+CS+G}}{\text{JGPD*LN16N}},\ l_C=\frac{\text{LRDURGA*LADURGA}}{\text{LN16N}},$$
$$i=\frac{\text{GCD+GPI}}{\text{JGPD*LN16N}},\ l_I=\frac{\text{LRNDURA*LANDURA+LRPSRVA*LAPSRVA}}{\text{LN16N}},$$
$$y=\frac{\text{GDPH}}{\text{LN16N}},\ l=l_C+l_I.$$

[31] I am grateful to Larry Christiano for suggesting the use of this monetary aggregate.