Stage-specific technology shocks and employment: Could we reconcile with the RBC models?

Chahnez Boudaya

Stage-Specific Technology Shocks and

Employment!: Could we Reconcile

with the RBC Models!?

Chahnez BOUDAYA

2006.43

Stage-Specific Technology Shocks and Employment: Could We Reconcile with the RBC Models? *

Chahnez Boudaya†

†Centre d'Economie de la Sorbonne (EUREQua), Université Paris1-Sorbonne, Maison des Sciences Economiques 106-112 Bd de l'Hôpital 75013 Paris. E-mail: Boudaya@univ-paris1.fr.

Résumé

L' auteur examine la dynamique d' un modèle à deux stades de production rattachés par une structure verticale input-output, et où chaque stade est sujet à un choc technologique qui lui est propre. Par ailleurs, le modèle présente des rigidités nominales de prix et de salaires ainsi que des coûts d'ajustement d'emploi et de capital. Les résultats de l'estimation sur des données d'après-guerre révèlent que les prédictions du modèle au chapitre de l'ajustement de l'emploi aux chocs technologiques sont variées: i) Les heures travaillées baissent de façon persistante suivant un choc technologique positif au stade final et ii) augmentent suite à un choc technologique positif au stade intermédiaire.

Classification JEL:E24, E32, E52

Mots-clés: Modèles RBC, Rigidités de prix et de salaires, Stades de production, Chocs technologiques.

Abstract

This paper analyses the response of labor input to technology shocks in an estimated two-stage production framework with both price and wage stickiness and stage-specific shocks to productivity. The model features a vertical input-output structure with imperfect mobility of labor across stages. The estimation uses the maximum likelihood technique applied to the post-war US data. the main findings could easily match the standard RBC models predictions: A shock to productivity in the intermediate good production stage i) leads to an increase in both stage-specific labor and the aggregate labor and ii) explains a large proportion of the volatility of both the real GDP and the aggregate labor. Besides, regarding the output-labor correlation, the model does a very good job in matching the data.

JEL classification: E24, E32, E52

Keywords: RBC models, Sticky prices, Sticky wages, Production chain, Employment, Technology shocks, Sectoral comovements.

1 Introduction

It is an old idea presented at least from Means (1935) that,

> "...in an industrialized economy the relationship between money, prices and output is tied to the interdependence of firms at each stage of production. This led many to conclude that there is a conjunction between aggregate fluctuations and an input-output structure..." (Huang and Liu 2001)

In lines with Means' claim, a large strand of literature emerging from multi-sector models has attracted a growing interest about the transmission of business cycle shocks through a horizontal (vertical) roundabout input-output structure within a single (multiple) stage(s) of production. For instance, Long and Plosser (1983,1987) specified a six-sector model of the economy with intermediate input linkages and uncorrelated sector-specific shocks to examine the transmission mechanisms of real shocks. Besides, Bergin and Feenstra (2000) show that the interactions between staggered-price setting and the real rigidity introduced through a non-CES aggregation technology and a roundabout input-output structure help generate real persistence following monetary shocks. Also, Basu (1995) focused on the transmission of monetary shocks in a roundabout input-output production structure. In the same vein, Huang, Liu and Phaneuf (2004) examine the cyclical behavior of real wages in response to monetary shocks in a DSGE model with either nominal wage and/or price rigidities and a horizontal input-output structure with a single stage of production. By contrast, Boudaya (2005) focuses on technology shocks effects on hours worked in a New Keynesian framework with staggered price settings à la Calvo. It sorts out from the interest about the horizontal input-output structure that i) it improves the models' ability to generate variables responses persistence; and ii) it reinforces the rigidities effects in the model. Recent papers on this topic were interested instead, in the shocks transmission in models with vertical input-output structure. For instance, Blanchard (1983) was interested to explain the sluggish adjustment of prices. Huang and Liu (2001) propose a model that features a vertical input-output structure with staggered price contracts at each stage of production to generate the observed persistence of aggregate output in response to monetary shocks. Also, Huang and Liu (2004) exmines the optimal monetary policy in a DSGE framework with two stages of production. Recently,

another strand of literature follows the lead of Gali (1999) and was concerned to investigate the controversial effects of a technology improvement on output, labor and other economic variables. The seminal paper of Gali (1999) identifies technology shocks as the only shocks that have an effect on labor productivity in the long run and estimates a persistent decline of hours in response to a positive technology shock. As Gali points out, this result is more consistent with the predictions of a dynamic stochastic general equilibrium model (DSGE) with sticky prices than those of standard Business Cycle models, as long as monetary policy is not too accommodative for technology shocks. There have been other attempts that have reached similar conclusions (see for example Kiley (1998), Basu, Fernald and Kimball (1998), Francis and Ramey (2001) and others). For instance, Francis and Ramey (2003) concluded that "...technology-driven real business cycle hypothesis is dead...". In a recent paper, Christiano, Eichenbaum and Vigfusson (2003) challenge these empirical results. Using the same identifying assumption as Gali (1999), they find evidence that a technology shock drives hours worked up, not down. In the same way, Langot (1997) examines the effects of both aggregate and sectoral productivity shocks in a job-serach model with two sectors. While an aggregate shock increases employment in both sectors, a sectoral shock have opposite effects depending on sector hit by the shock.

Both strands of literature have motivated this empirical work. The purpose of the present paper is twofold. First, it tries to investigate whether stage-specific technology shocks in a dynamic general equilibrium model with both price and wage rigidities and two stages linked by a vertical input-output production structure, could reconcile with the standard RBC theory in terms of aggregate variables patterns. The prediction of a positive short run comovement between productivity, output and employment in response to technology shocks lies at the root of the ability of an RBC model to replicate some central features of observed aggregate fluctuations, while relying on exogenous variations in technology as the only (or, at least the dominant) driving force. Second, I focus on whether technology shocks could be considered as the main source of fluctuations in aggregate output and other main variables.

I build on Boudaya (2005) and Huang and Liu (2001, 2004). The first one uses an horizontal input-output production structure within one stage of production to show that i) for plausible values of the intermediate input share, a favorable technology shock leads to a short-run decline in labor in-

4

put regardless of monetary policy considered and that ii) the initial decline becomes more important as the intermediate input share grows because of a strong substitution effect between the intermediate goods and the labor input. In fact, taking into account the presence of intermediate goods introduces on one hand, more price rigidities in the model and thus makes variables adjust more slowly to the shocks; and on the other hand yields to a substitution mechanism between intermediate goods and labor which causes the later to fall in response to a favorable technology shock, when combined with more price rigidities. Huang and Liu (2001) consider the production of a final good through multiple stages of processing and introduce staggered price contracts at each stage to show that output response to a monetary shock is more persistent, the greater the number of stages of production and the larger the share of intermediate inputs. On the other hand, Huang and Liu (2004) introduce two stages in the production scheme to examine the optimal monetary policy in a model without capital accumulation. The present paper, however differs from Boudaya (2005) and Huang and Liu (2001, 2004) in several points. First, it takes into account the two-stages productive framework but with capital accumulation. Second, as in Boudaya (2005), I focus on a Taylor rule. Besides, I introduce nominal wage rigidities in addition to staggered price settings.

In order to achieve my goal, I construct a two-stage productive dynamic stochastic general equilibrium model that features monopolistic competition in both the final goods market and the labor market, with firms setting nominal prices for their products and households setting nominal wages for their labor skills.

The main findings can be briefly summarized as follows. First, a 1% shock to technology in the intermediate-good sector leads to a persistent increase in labor input in both sectors. Second, it explains the major part of the volatility of final output, intermediate good, investment, real wages, inflation and labor input in the intermediate-good sector. Consequently, if I consider a productivity shock in the intermediate-good sector as the only source of business fluctuations, my model of price rigidities could reconcile with the predictions of standard business cycle models!! So, technology shocks do matter as the driving force of aggregate fluctuations. Furthermore, a productivity shock in both final goods and intermediate goods stage could explain about 65% of output variations and 90% of aggregate employment fluctuations despite all rigidities in my model. This result contrasts sharply with Gali (1999) conclusions that only non-technological shocks could explain output variability

in a price rigidities framework.

The paper is organized into five sections. Section II presents the model within two productive stages, a productivity shock specific to each stage, a money-demand shock. Besides, I introduce labor adjustment costs, staggered prices and wages setting à la Calvo. The monetary policy is governed by a Taylor rule. Section III reports the estimation procedure and the results. In section IV, I provide the impulse responses and report the performance of the model via moment comparisons. Section V concludes.

2   The model

The economy is composed by a large number of infinitely lived households with different labor skills, which are imperfect substitutes for each other in the production process, and two stage-production linked by a vertical input-output structure. Thus, final consumption goods are produced through two stages of processing, from intermediate goods to finished goods. At each stage, there is a continuum of monopolistically competitive firms producing differentiated goods. There is one shock to technology at each stage. Following Huang and Liu (2004), I assume that monetary authorities cannot distinguish the source of technological innovation when it happens.

2.1   Households

Households offer differentiated labor skills. I consider a continuum of different households indexed by i. Besides, household i has preferences defined over real consumption, $C_t(i)$, real money balances, $\frac{M_t(i)}{P_t}$ and leisure, $1 - N_t(i, .)$. The expected utility function of a representative consumer-worker i is specified as:

$$U_0 = E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{\gamma}{\gamma - 1} \log \left(C_t(i)^{\frac{\gamma-1}{\gamma}} + b_t^{\frac{1}{\gamma}} \left(\frac{M_t(i)}{P_t} \right)^{\frac{\gamma-1}{\gamma}} \right) + \eta \log(1 - N_t(i, .)) \right]$$

where γ and η are positive structural parameters denoting the constant elasticity of substitution between consumption and real balances, and the weight on leisure in the utility function, respectively and $\beta \in (0, 1)$ is the discount factor. Total time available to the household in the period is normalized to one.

Shock b_t is interpreted as a shock to money demand , and it follows the first-order autoregressive process:

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

where $\rho_b \in (-1, 1)$, and the serially uncorrelated shock ε_{bt} is normally distributed with zero mean and standard deviation σ_b.

The representative household i carries real balances and bonds $B_t(i)$ into period t. At the beginning of the period, she receives lump-sum nominal transfer $T_t(i)$ from monetary authority in addition to work revenues, capital returns and nominal profits $D_t(i)$ as a dividend from each intermediate goods-producing firm j. Next, the household's bonds mature, providing it with $B_t(i)$ additional units of money. The household uses some of this money to purchase $B_{t+1}(i)$ new bonds at the nominal cost $\frac{B_t(i)}{R_{t-1}}$; hence, R_{t-1} denotes the gross nominal interest rate between *t-1* and *t*. Besides, household i uses some of her funds to purchase final good consumption at price P_t. Moreover, I assume that it is costly to intertemporally adjust the capital stock, since there are adjustment costs specified as:

$$CAC_t(i) = \frac{\kappa}{2} \left(\frac{K_{t+1}(i)}{K_t(i)} - 1 \right)^2 K_t(i)$$

where $\kappa > 0$ is the capital-adjustment cost parameter.

The budget constraint of household i is given by:

$$C_t(i) + \frac{M_t(i)}{P_t} + \frac{B_{t+1}(i)}{P_t} + K_{t+1}(i) - (1 - \delta)K_t(i) + CAC_t(i)$$
$$= \frac{W_t(i)}{P_t} N_t(i) + \frac{R_{k,t}}{P_t} K_t(i) + \frac{M_{t-1}(i)}{P_t} + R_{t-1} \frac{B_t(i)}{P_t} + \frac{T_t}{P_t} + \frac{D_t}{P_t}$$

where $\delta \in (0, 1)$ denotes the constant capital depreciation rate.

Each household chooses $C_t(i)$, $M_t(i)$, $B_{t+1}(i)$, $K_{t+1}(i)$ and $W_t(i)$ (if the household is allowed to change its wage) to maximize the expected discounted sum of her utility flows subject to the budget constraint and to firms' demand for her labor type i.

The effective labor input in the production process of a typical firm is given by a CES function of the quantities of the different types of labor hired:

$$N_t = \left(\int_0^1 N_t(i,.)^{\frac{\sigma-1}{\sigma}} di \right)^{\frac{\sigma}{\sigma-1}},$$

where $\sigma \succ 1$ denotes the elasticity of substitution between differentiated labor skills. The total demand of all firms for labor skill i is given by:

$$N_t(i,.) = \left(\frac{W_t(i)}{W_t} \right)^{-\sigma} N_t, \tag{1}$$

N_t is the aggregate employment and W_t is the aggregate wage index given by:

$$W_t = \left(\int_0^1 W_t(i)^{1-\sigma} di \right)^{\frac{1}{1-\sigma}}$$

Households are price takers in the goods market and monopolistic competitors in the labor market. They set wages for their labor skills, taking the labor demand schedule 1 as given.

The first-order conditions for this problem are:

$$\frac{C_t(i)^{\frac{-1}{\gamma}}}{C_t(i)^{\frac{\gamma-1}{\gamma}} + b_t^{\frac{1}{\gamma}} \left(\frac{M_t(i)}{P_t} \right)^{\frac{\gamma-1}{\gamma}}} = \lambda_t \tag{2}$$

$$\frac{b_t^{\frac{1}{\gamma}} \left(\frac{M_t(i)}{P_t} \right)^{\frac{-1}{\gamma}}}{C_t(i)^{\frac{\gamma-1}{\gamma}} + b_t^{\frac{1}{\gamma}} \left(\frac{M_t(i)}{P_t} \right)^{\frac{\gamma-1}{\gamma}}} = \lambda_t \left(1 - \frac{1}{R_t} \right) \tag{3}$$

$$\beta E_t \frac{\lambda_{t+1}}{\lambda_t} \left[r_{kt+1} + 1 - \delta + \kappa \left(\frac{K_{t+2}(i)}{K_{t+1}(i)} - 1 \right) \frac{K_{t+2}(i)}{K_{t+1}(i)} - \frac{\kappa}{2} \left(\frac{K_{t+2}(i)}{K_{t+1}(i)} - 1 \right)^2 \right] = 1 + \kappa \left(\frac{K_{t+1}(i)}{K_t(i)} - 1 \right) \tag{4}$$

$$\lambda_t = \beta R_t E_t \left(\frac{\lambda_{t+1}}{\pi_{y,t+1}} \right) \tag{5}$$

where λ_t is the Lagrangian multiplier associated with the budget constraint.

Following Ireland (1997) and Kim (2000), equations (1) and (2) can be combined with equation (5) to approximate a real money-demand function of the form:

$$\log\left(\frac{M_t}{P_t}\right) = \log(C_t) + \frac{1}{1-\gamma}\log(b_t) - \frac{1}{\gamma-1}\log(r_t) \qquad (6)$$

where r_t is the net nominal interest rate between t and $t+1$ ($r_t = R_t - 1$), $\frac{1}{\gamma-1}$ is the interest elasticity of money-demand.

In addition, there is a first-order condition for setting the nominal wage when the household is allowed to do so. This happens with probability d_w at the beginning of each period.

$$\widetilde{W}_t(i) = \left(\frac{\sigma}{\sigma-1}\right)\frac{E_t\sum_{m=0}^{\infty}(\beta d_w)^m\frac{\eta N_{t+m}(i)}{1-N_{t+m}(i)}}{E_t\sum_{m=0}^{\infty}(\beta d_w)^m N_{t+m}(i)\Lambda_{t+m}(i)\frac{1}{P_{t+m}}} \qquad (7)$$

Therefore, the household's optimal wage is a constant markup over the ratio of weighted marginal utilities of leisure to marginal utilities of income within the duration of wage contracts.

The wage index evolves over time according to the recursive equation given by:

$$W_t = [d_w W_{t-1}^{1-\sigma} + (1-d_W)\widetilde{W}_t^{1-\sigma}]^{\frac{1}{1-\sigma}} \qquad (8)$$

where $\widetilde{W}_t$ is the average wage of those workers who revise their wage at time t.

This condition together with (7) allows to derive the following Phillips curve:

$$\hat{\pi}_{w,t} = \beta E_t\hat{\pi}_{w,t+1} + \frac{(1-d_w)(1-d_w\beta)}{d_w}\left[\frac{N}{1-N}\hat{N}_t - \hat{\lambda}_t - \hat{w}_t\right] \qquad (9)$$

The term in square brackets measures the marginal rate of substitution (the real marginal cost to workers of their work effort) minus the real wage.

The wage inflation is defined by

$$\pi_{w,t} \equiv \frac{W_t}{W_{t-1}} \qquad (10)$$

9

2.2 Firms

I consider two types of monopolistically competitive firms: intermediate goods-producing firms and materials-producing firms. Final goods sector and intermediate goods sector are linked by a vertical input-output structure. The prices of both intermediate production inputs and final consumption goods are determined by staggered nominal contracts à la Calvo with probabilities d_z and d_y of survival in each period. Therefore, both the price index of intermediate goods (which corresponds broadly to the PPI) and that of finished goods (which corresponds to the CPI) are sticky in the model.

The final good, Y_t, is a composite of differentiated finished goods. In particular,

$$Y_t = \left(\int_0^1 Y_t(j)^{\frac{\theta_y-1}{\theta_y}} dj \right)^{\frac{\theta_y}{\theta_y-1}}$$

where $\theta_y \in (1, \infty)$ denotes the elasticity of substitution between the differentiated finished goods, $Y_t(j)$ is the output of finished good j.

To produce a type j ($j \in [0,1]$) finished good requires inputs of labor, $N_{y,t}(i,j)$, capital, $K_{y,t}(j)$, and a composite of intermediate goods (materials), $Z_t(j)$ with a constant returns to scale technology given by:

$$Y_t(j) = Z_t(j)^\phi \left[A_{y,t} K_{y,t}^{\alpha_y} N_{y,t}(i,j)^{1-\alpha_y} \right]^{1-\phi} \tag{11}$$

where $Z_t = \left(\int_0^1 Z_t(l)^{\frac{\theta_z-1}{\theta_z}} dl \right)^{\frac{\theta_z}{\theta_z-1}}$ denotes the input of composite intermediate goods used by j, $\theta_z > 1$ is the elasticity of substitution between differentiated intermediate goods, and $A_{y,t}$ is a productivity shock to the finished good sector.

The parameters α_y and ϕ are positive and less than one.

Intermediate firm l rents capital, $K_{z,t}(l)$, hires workers, $N_{z,t}(l)$ and combines the two factors to produce a quantity $Z_t(l)$ of intermediate good following the constant-return-to-scale technology:

$$Z_t(l) = A_{z,t} K_{z,t}^{\alpha_z} N_{z,t}(i,l)^{1-\alpha_z} \tag{12}$$

$A_{y,t}$ is a productivity shock to the intermediate good sector, $\alpha_z \in (0,1)$ is the share of capital.

The productivity shocks evolve following a stationary exogenous process:

$$\log(A_{k,t}) = (1 - \rho_{A,k})\log(A_k) + \rho_{A,k}\log(A_{k,t-1}) + \varepsilon_{k,t}, \ k \in \{y, l\}, \quad (13)$$

where $\varepsilon_{y,t}$ and $\varepsilon_{z,t}$ are mean-zero, *i.i.d.* normal processes that are mutually independent, with finite variances given by σ_y^2 and σ_z^2, respectively.

Firms are price-takers in the input markets and monopolistic competitors in the product markets. At each processing stage, prices are set optimally in a randomly staggered fashion as suggested by Calvo (1983). More specifically, firms in the finished good sector and the intermediate good sector can reset their prices in any given period only with the probability $(1- \theta_y)$ and $(1-\theta_z)$, respectively, independently of other firms and of the time elapsed since the last adjustment. Thus, a measure $(1- \theta_k)$, $k \in \{y, z\}$ of producers reset their prices each period , while a fraction θ_k keeps their prices unchanged.

The maximization problem for the intermediate goods-producing firm j is :

$$\max_{\{K_{y,t}(j), N_{y,t}(.,j)\}} E_t \sum_{q=0}^{\infty} (\beta d_y)^q \frac{\lambda_{t+q}}{\lambda_t} \frac{D_{y,t+q}(j)}{P_{t+q}}$$

subject to:

$$D_{y,t}(j) = P_t(j)Y_t(j) - R_{k,t}K_{y,t}(j) - \int_0^1 W_t(i)N_{y,t}(i,j)di - LAC_{y,t}(j) - P_{z,t}Z_t(j)$$

$$Y_t(j) = \left(\frac{P_t(j)}{P_t}\right)^{-\theta_y} Y_t$$

and (11)

where λ_t is the marginal utility of wealth for a household i and $LAC_t(j)$ is the labor adjustment cost in terms of proportional loss of output. I assume a convex form with respect to labor increase.

$$LAC_{y,t}(j) = \frac{\varphi_y}{2}\left(\frac{N_{y,t}(j)}{N_{y,t-1}(j)} - 1\right)^2 Y_t(j), \qquad \varphi_y \geqslant 0$$

Labor adjustment costs are introduced to prevent from perfect mobility of labor between the two sectors.

The first order conditions for this maximization problem are:

$$w_t = \frac{(1-\alpha_y)(1-\phi)}{\mu_{y,t}(j)}\frac{Y_t(j)}{N_{y,t}(j)} - \frac{\varphi_y Y_t(j)}{N_{y,t-1}(j)^2}\left(N_{y,t}(j) - N_{y,t-1}(j)\right)$$
$$+ \beta\varphi_y E_t\left[\frac{\lambda_{t+1}}{\lambda_t}(N_{y,t+1}(j) - N_{y,t}(j))\frac{Y_{t+1}(j)}{N_{y,t}(j)^2}\right] \tag{14}$$

$$r_{k,t} = \alpha_y(1-\phi)\frac{1}{\mu_{y,t}(j)}\frac{Y_t(j)}{K_{y,t}(j)} \tag{15}$$

$$p_{z,t} = \frac{1}{\mu_{y,t}(j)}\phi\frac{Y_t(j)}{Z_t(j)} \tag{16}$$

where $\frac{W_t}{P_t} = w_t$ is the real wage, μ_{yt} is the real markup, $r_{k,t}$ is the real capital return, and $p_{z,t}$ is the real price for the intermediate input, Z_t.

I assume that prices $\tilde{P}_{y,t}(j)$ are determined by a Calvo contract with a probability d_y that the firm j keeps its price unchanged at period t. In that case, the aggregate price level is given by:

$$P_{y,t} = \left[d_y P_{y,t-1}^{1-\theta_y} + (1-d_y)\tilde{P}_{y,t}^{1-\theta_y}\right]^{\frac{1}{1-\theta_y}} \tag{17}$$

where $P_{y,t}$ is the logarithm of aggregate price level in the final good sector and $P_{y,t}^*$ is the logarithm of the price fixed by the firms adjusting their prices in t. The optimization problem of the firm adjusting its price is the following:

$$\max_{P_{y,t}^*}\sum_{q=0}^{\infty}(\beta d_y)^q E_t\left[\frac{\lambda_{t+q}}{\lambda_t}\frac{P_{y,t}(j) - \frac{1}{\mu_{y,t+q}(j)}}{P_{y,t+q}}Y_{t+q}(j)\right]$$

subject to (11) and the following demand function:

$$Y_{t+q}(j) = \left(\frac{P_{y,t}(j)}{P_{y,t+q}}\right)^{-\varepsilon}Y_{t+q}$$

$P_{y,t}(j)$ determines $\tilde{P}_{y,t}$ at the optimum. The first order condition with respect to $P_{y,t}(j)$ is:

$$\tilde{P}_{y,t}(j) = \frac{\theta_y}{\theta_y - 1}\frac{E_t\sum_{q=0}^{\infty}(\beta d_y)^q\frac{\lambda_{t+q}}{\lambda_t}Y_{t+q}(j)\frac{1}{\mu_{yt+q}(j)}}{E_t\sum_{q=0}^{\infty}(\beta d_y)^q\frac{\lambda_{t+q}}{\lambda_t}Y_{t+q}(j)\frac{1}{P_{y,t+q}}} \tag{18}$$

The previous equation relates the optimal price to the expected future price of the final good and to the expected future real marginal costs.

This condition, together with (17) allow to derive the following log-linearized New Phillips Curve at the symmetric equilibrium:

$$\hat{\pi}_{y,t} = \beta E_t \hat{\pi}_{y,t+1} - \frac{(1-d_y)(1-d_y\beta)}{d_y}\hat{\mu}_{y,t}, \tag{19}$$

where $\pi_{y,t} = \frac{P_{y,t}}{P_{y,t-1}}$ is the inflation rate in the final-good sector, and $\hat{\pi}_{y,t}$ corresponds to the percentage deviation of the inflation rate in the final-good sector from its steady state level.

Similarly, the intermediate goods-producing firm l maximizes:

$$Max E_t \sum_{q=0}^{\infty} (\beta d_z)^q (\frac{\lambda_{t+q}}{\lambda_t}) \frac{D_{z,t+q}(l)}{P_{z,t+q}}$$

subject to:

$$D_{z,t}(l) = P_{z,t}(l)Z_t(l) - R_{k,t}K_{z,t}(l) - \int_0^1 W_t(i)N_{z,t}(i,l)di - LAC_{z,t}(l),$$

and the equation (12)

Labor adjustment costs, $LAC(l)$, are defined by

$$LAC_{z,t}(l) = \frac{\varphi_z}{2}\left(\frac{N_{z,t}(l)}{N_{z,t-1}(l)} - 1\right)^2 Z_t(l), \qquad \varphi_z \geqslant 0.$$

The first order conditions for this maximization problem are:

$$
\begin{aligned}
w_t &= (1-\alpha_z)\frac{1}{\mu_{z,t}(l)}\frac{Z_t(l)}{N_{z,t}(l)} - \varphi_z \frac{Z_t(l)}{N_{z,t-1}(l)^2}\left(N_{z,t}(l) - N_{z,t-1}(l)\right) \\
&\quad + \beta\varphi_z E_t[\frac{\lambda_{t+1}}{\lambda_t}(N_{z,t+1}(l) - N_{z,t}(l))\frac{Z_{t+1}(l)}{N_{z,t}(l)^2}]
\end{aligned}
\tag{20}
$$

$$r_{k,t} = \alpha_z \frac{1}{\mu_{z,t}(l)}\frac{Z_t(l)}{K_{z,t}(l)} \tag{21}$$

I assume that prices $\tilde{P}_{z,t}(l)$ are determined by a Calvo contract with a probability d_z that the firm l keeps its price unchanged at period t. In that case, the aggregate price level is given by:

13

$$P_{z,t} = \left[d_z P_{z,t-1}^{1-\theta_z} + (1-d_z)\tilde{P}_{z,t}^{1-\theta_z} \right]^{\frac{1}{1-\theta_z}} \tag{22}$$

where $P_{z,t}$ is the logarithm of aggregate price level and $\tilde{P}_{z,t}$ is the logarithm of the price fixed by the firms adjusting their prices in t. The optimization problem of the firm adjusting its price is the following:

$$\tilde{P}_{z,t}(l) = \frac{\theta_z}{\theta_z - 1} \frac{E_t \sum_{q=0}^{\infty} (\beta d_z)^q \frac{\lambda_{t+q}}{\lambda_t} Z_{t+q}(l) \frac{1}{\mu_{zt+q}(l)}}{E_t \sum_{q=0}^{\infty} (\beta d_z)^q \frac{\lambda_{t+q}}{\lambda_t} Z_{t+q}(l) \frac{1}{P_{z,t+l}}} \tag{23}$$

This condition, together with (22) allow to derive the following log-linearized New Phillips Curve:

$$\hat{\pi}_{z,t} = \beta E_t \hat{\pi}_{z,t+1} - \frac{(1-d_z)(1-d_z\beta)}{d_z}\hat{\mu}_{z,t} \tag{24}$$

where

$$\pi_{z,t} = \frac{P_{z,t}}{P_{z,t-1}} \tag{25}$$

2.3   The monetary authority

The central bank manages the short-term nominal interest rate, R_t, in response to fluctuations in final-good inflation, $\pi_{y,t}$, and output, y_t. The interest rate reaction function of the central bank is given by:

$$\log\left(\frac{R_t}{R}\right) = \varrho_\pi \log\left(\frac{\pi_{y,t}}{\pi_y}\right) + \varrho_y \log\left(\frac{y_t}{y}\right) + v_t, \tag{26}$$

and

$$v_t = \varrho_v v_{t-1} + \varepsilon_{Rt}, \tag{27}$$

where π_y and y are the steady-state values of $\pi_{y,t}$ and y_t, R is the steady-state value of the gross nominal interest rate, and v_t is a zero-mean, serially correlated monetary policy shock with standard deviation σ_v. The error term, ε_{Rt}, arises from the fact that the central bank can control short-term interest rates only indirectly by setting the bank rate. The error term thus reflects developments in money and financial markets that are not explicitly captured by my model which is assumed to be i.i.d. with a standard deviation σ_R.

14

2.4 Closing the model

When I consider the symmetric equilibrium, the market cleaning condition requires:

$$K_t = K_{y,t} + K_{z,t} \tag{28}$$

$$N_t = N_{y,t} + N_{z,t} \tag{29}$$

$$Y_t = C_t + I_t \tag{30}$$

2.5 Equilibrium

For $h = y, z$, an equilibrium consists of the following set of allocations: $\{C_t, N_t, B_t, m_t, K_{t+1}, Y_t, I_t, Z_t, K_{h,t}, N_{h,t}, \pi_{h,t}, \pi_{w,t}, p_{z,t}, w_t, r_{k,t}, \mu_{h,t}, R_t\}$, that satisfy the following conditions: (i) the household's allocations solve its utility maximization problem; (ii) each finished good producer's allocations and price solve its profit maximization problem taking the wage and all prices but its own as given; (iii) each intermediate good producer's allocations and price solve its profit maximization problem; and (iv) all markets clear.

Steady state details are reported in appendix A. The full-system of log-linearized equations is reported in appendix B.

3 Estimation

3.1 Estimation methodology and data

To solve the model, I log-linearize the equilibrium conditions around a symmetric steady state where all variables are constant. In particular, I assume that the steady-state domestic gross inflation is equal to 1. Standard techniques are then used to solve the linearized system, which leads to the following state space representation:

$$\mathcal{S}_t = \mathbf{A}\mathcal{S}_{t-1} + \mathbf{B}\epsilon_t, \tag{31}$$
$$\mathcal{Y}_t = \mathbf{C}\mathcal{S}_t, \tag{32}$$

where the vector $\mathcal{S}_t$ keeps track of the model's predetermined and exogenous variables, and the vector $\mathcal{Y}_t$ includes remaining endogenous variables. I use

the Kalman filter to evaluate the likelihood function associated with the state space solution. The structural parameters are estimated by maximizing the likelihood function.[1] The series used in the estimation are the nominal interest rate, the inflation rate, the real consumption, the real money balances, and the real wages.[2]

The model is estimated using U.S. quarterly data running from 1964Q1 through 2004Q4. The nominal interest rate is measured by the 3-month Treasury Bill Rate. Inflation is calculated as the changes in the consumer price index, considered as a the final-good price. Consumption is measured by real personal consumption expenditures. Real money balances are calculated by dividing the M2 money stock by the consumer price index. The real wage is measured by the ratio of the average hourly earnings over the consumer price index. All these data, except for the interest rate, are seasonally adjusted. Consumption and real money balances are divided by the number of the civilian population. All series except for the interest rate and the inflation rate, are logged and detrended using the HP filter.

3.2 Parameter estimates

As is typically the case with the maximum-likelihood estimation of relatively large structural models, it is difficult to obtain sensible estimates of all structural parameters, either because some of them are poorly identifiable or because the complexity of the objective function is such that the optimization algorithm fails to locate the maximum and eventually crashes. To deal with this issue, some parameters have to be calibrated prior to the estimation. Particularly, the subjective discount rate, β, is set to 0.995, which implies an annual real interest rate of 2 per cent in the steady state. The intertemporal elasticity of substitution for labor is set to 1, then the weight on leisure in the utility function, η, is calibrated so that the representative household spends about one third of its total time working in the steady state. The constant

---

[1] The maximum likelihood technique uses the methods outlined by Hamilton (1994, Ch. 13).

[2] Note that the number of variables included in the estimation procedure is five, however we only consider four shocks in the model. With more than four observable variables, the system becomes stochastically singular and the maximum likelihood procedure fails. See Ingram, Kocherlakota and Savin (1994).To make the estimation exercise feasible we need the same number of observed variables as the number of shocks. Therefore, we include an additional measurment error, corresponding to the CPI inflation rate variable, as in Ireland (2003).

elasticity of substitution between real consumption and real balances, γ, is calibrated to 0.1 which is consistent with the estimates of Ireland (1997) and Kim (2000). The depreciation rate of physical capital is chosen to be 0.025. Setting $\theta = \vartheta = 8$ gives a steady-state markup of 14 per cent. This corresponds well to the estimates in the empirical literature between 10 per cent and 20 per cent (see, for example, Basu 1995). The σ parameter gives the elasticity of substitution across different labour types in the production of individual domestic intermediate goods. The value $\sigma = 6$ corresponds to estimates from microdata in Griffin (1992).[3]

Estimation results are reported in Table 1. Looking first at the auto-correlation coefficients for the exogenous variables, the one governing the persistence for the final-good technology shock is smaller than the one for the intermediate-good shock. The data seem to prefer a version of the model where the supply shock on the production of materials is closer to a unit root. This can lead to some extent to a way of identifying sectoral supply shocks in a purely empirical framework. The estimate of $\varrho_v = 0.5545$ tells that the unpredictable intervention of the monetary authority is mildly persistent. Moreover, the money demand is very persistent which is consistent with the results by Kim (1999). Note that, all the standard deviations of shocks are moderate and statistically significant. In addition, the shock on $A_{y,t}$ is almost three times as volatile as the shock on $A_{z,t}$.

The large and significant estimate of $d_w = 0.8295$, corresponding to a wage contract of slightly less than 6 quarters in average, suggests that the main nominal rigidity in the model is coming from the wage side. This result echoes the one reported by Christiano, Eichenbaum, and Evans (2003), a study that relies on an other technique of estimation.[4] Finally, and interestingly, the estimates of $d_y = 0.4341$ and $d_z = 0.3677$ all appear small compared to the literature. The latter result shows that, on the one hand, a model combining both wage and price stickiness leads to lower price contract length. On the other hand, when I include vertical input-output structure of the production process I need less stickiness in the goods pricing side to fit

---

[3]It also agrees with the value estimated in Ambler, Guay, and Phaneuf (2003) using aggregate time-series data. They succeed in estimating the value of the equivalent parameter in their model by calibrating the equivalent of the d_w parameter.

[4]Christiano, Eichenbaum, and Evans (2003) use a different technique based on matching conditional moments corresponding to impulse-response function to a monetary shock identified in a structural VAR, and they estimate simultaneously the degrees of wage and price stickiness.

the data.

The capital adjustment cost parameter estimate is statistically significant and equal to 4.2646, which is reasonable in terms of matching the volatility of investment in my model. The estimates of $\varphi_y = 0.5533$ and $\varphi_z = 6.4969$ imply that the final-good firms can adjust more easily labor factor than the intermediate-sector ones. Unfortunately, as far as I know data on sectoral labor is not available to corroborate this result, but given that my model is estimated I can interpret the result as a fact even if there is no similar conclusions in some micro studies. Finally, the shares of capital estimates in both final good sector and intermediate good sector, α_y and α_z are equal to 0.3025 and 0.2567 respectively. These values appear to be consistent with the calibrated values assigned to these parameters in Kydland and Prescott (1982), Cooley and Hansen (1989), and other business cycles studies.

4   Dynamic effects of the structural shocks

4.1   Variance decomposition

The best starting point is the set of variance decompositions, the contribution of each source of innovations to the variance of each endogenous variable. Two main results emerge from table 1: i) innovations to technology in the intermediate-good sector account for most of the variance of final output (54%), intermediate good (80%), investment (66%), aggregate (50%) and intermediate-good sector (57%) employment, real wages (78%), nominal interest rates (98%) and inflation (88% for $\pi_{y,t}$, 96% for $\pi_{z,t}$ and 99% for $\pi_{w,t}$); while ii) innovations to final-good sector technology explains the most of the variance of consumption (42%).

4.2   Impulse-response functions

Given the results for variance decompositions, I focus mainly on the responses to innovations to technology in both the final-good sector and the intermediate-good one. I will discuss briefly responses to other innovations. Figure 1 plots the impulse response functions of final output, intermediate input, consumption, investment, aggregate and sector-specific labor input, real wages, nominal interest rates and inflation to a 1% shock to technology in the final good sector. The final output and the real wages show a persis-

tent increase (the response of real wages is hump-shaped). In the presence of intermediate input production structure, a positive supply shock leads to a persistent decline in the inputs demand level in the final-good sector (see Boudaya (2005)). In fact, all inputs become more productive such that the final good-producing firms could reach the same level of final output with less input. With labor adjustment cost, the firms adjust their labor demand gradually (the impulse-response is hump-shaped). Consequently, the increase in real wages following a positive technology shock is less important (0.25% initially), then the wealth effect dominates the substitution effect. Thus, labor supply is reduced in the short run. Besides, less demand for intermediate good needs less labor in the materials sector. As a result, the aggregate employment level drops sharply. Moreover, as a favorable technology shock reduces both the firms price level and their real marginal cost, the final-good sector and the real wages inflation decrease. The monetary authorities react by lowering the nominal interest rate.

Figure 2 plots the responses of the considered variables to a 1% shock to productivity in the intermediate-good sector. The intermediate good shows a persistent increase. This needs more labor input. I should note that the estimate of the degree of price stickiness in the intermediate-good sector is too weak (0.36) which corresponds to a one quarter contract duration. Figure 7 displays the labor input sensitivity to variations in the degree of price stickiness. It sorts out from the bottom right panel that labor input $L_{z,t}$ could decline in response to a positive technology shock in the intermediate-good sector only for high and implausible values of d_z. Besides, a favorable productivity shock in the materials sector, $A_{z,t}$ represents a positive supply shock in the market for intermediate goods and should result in a reduction of the relative price of intermediate goods. As a result, real wages increase. Moreover, labor would move to the sector in which productivity is higher (in that case to the intermediate-good sector) which reinforces the increase in labor input $N_{z,t}$. As the sector-specific employment levels are given to move together (as shown by the unconditional correlations with aggregate employment)[5], the final-good sector employment increases but by less than the increase in that of intermediate-good sector.

Figure 3 shows the dynamic effects of a monetary policy shock on the key variables. An expansionary monetary policy shock of 1% tends to decrease

---

[5]This fact is also emphasized by Hornstein and Prachnik (1997), in a two-sector model with both durable and nondurable goods.

the investment level, the output, the intermediate goods, the consumption and the labor input. The real wages are countercyclical.

In figure 4, I plot the impulse-responses to a 1% money demand shock. All variables, excepting real wages and nominal interest rates show a persistent decrease.

4.3   Unconditional moments

In the postwar U.S. observed data, output, consumption, investment, real wages and employment move together, with investment being much more volatile than output (3 times as volatile). Table 3 reports some second order unconditional moments predicted by the model. While it does a good job to replicate the observed comovement and the volatility of consumption and investment for the postwar U.S data, the model economy exaggerates the qualitative pattern of relative volatilities of output, employment and real wages. However, I also show that the model economy is broadly consistent with the observed unconditional positive correlation between output and labor input.

4.4   Sectoral Comovements

In table 4 I report simulated contemporaneous correlations for final output, intermediate input, aggregate employment and sector-specific employment. The model economy predicts a strong positive contemporaneous correlation for aggregate employment and labor input in the intermediate-good sector (0.9913). Besides, according to table 4, intermediate input and labor input in the materials sector are highly correlated (0.9608) while the correlation between final output and employment in the final-good sector is only 0.5593. Also, I should notice that final output is more correlated with intermediate input than with labor input in the final-good sector.

4.5   Data fit

Figure 5 compares the model simulated data versus the true ones. The model does a good job in replicating the data for both consumption and interest rates, while it tends to exaggerate the magnitude of the data for the inflation rate, the money balances and the real wage.

4.6 Patterns of shocks

Figure 6 shows the historical pattern of each estimated shock. While studying the shocks, it is important to keep in mind the recession dates during the Post-War period as identified by the National bureau of Economic research (NBER): 1973-1974 and 1980-1981. We should note that technology shocks tend to be negative around recession dates. There are two years with the most negative shocks to technology in the two sectors: 1974 and 1980.

1980 is a year with very negative technology and monetary shocks.

During the 1990's, a period characterized by high productivity growth rates, there is no remarkable positive technology shocks. Rather, this period experienced a series of small positive and negative technology shocks.

The period 1980-1983 is marked by a succession of very negative then very positive monetary shocks.

Money-demand shocks tend to be positive between 1970 and 1990 while they become negative from 1990.

Finally, a noticeable feature of the shocks in figure 6 is that series appear to be less volatile outside the recession periods and especially after 1982.

5   Conclusion

This paper examines whether I could reconcile with the standard RBC frictionless theory in terms of matching the patterns of variables in response to technology shocks, in a two-stage productive framework with both price and wage rigidities. While a positive shock to productivity in the final good sector leads to a persistent decrease in labor input and thus a negative correlation between aggregate output and labor, a positive shock to productivity in the intermediate input sector provides a good support to the RBC models predictions. In fact, it emerges from the estimation results that a positive shock to technology in the intermediate good sector produces a permanent increase in labor input in both sectors and in the aggregate labor input. Moreover, this shock explains the largest part of both aggregate output and employment fluctuations and thus could be considered as the driving force of the fluctuations in this model.

Appendix A

Steady state

Since there is no trend-growth in productivity, a steady state obtains if $A_y = A_z = 1$. In this steady state, the optimal pricing rules, (17), (22) and (23) reduce to:

$$\mu_y = \frac{\theta_y}{\theta_y - 1},$$

and

$$\mu_z = \frac{\theta_z}{\theta_z - 1},$$

$$r_k = \frac{1}{\beta} - 1 + \delta,$$

$$R = \frac{\pi_y}{\beta},$$

$$\frac{K_y}{Y} = \frac{\alpha_y(1 - \phi)}{r_k \mu_y},$$

$$\frac{K_z}{Z} = \frac{\alpha_z}{r_k \mu_z},$$

$$\frac{N_z}{Z} = \left(A_z \left(\frac{K_z}{Z} \right)^{\alpha_z} \right)^{\frac{-1}{1 - \alpha_z}},$$

$$\frac{N_y}{Y} = \left(\frac{Z}{Y} \right)^{\frac{-\phi}{(1 - \alpha_y)(1 - \phi)}} \left(\frac{K_y}{Y} \right)^{\frac{\alpha_y}{\alpha_y - 1}},$$

$$w = \frac{(1 - \alpha_z)}{\mu_z} \left(\frac{N_z}{Z} \right)^{-1},$$

Besides,

$$w = \frac{(1-\alpha_y)(1-\phi)}{\mu_y}\frac{Y}{N_y} \implies \frac{Y}{N_y} = \frac{\mu_y}{\mu_z}\frac{(1-\alpha_z)}{(1-\alpha_y)(1-\phi)}\left(\frac{N_z}{Z}\right)^{-1},$$

This gives,

$$\frac{Z}{Y} = \left(\frac{N_y}{Y}\right)^{\frac{-(1-\alpha_y)(1-\phi)}{\phi}}\left(\frac{K_y}{Y}\right)^{\frac{\alpha_y(1-\phi)}{\phi}},$$

$$P_z = \frac{\phi}{\mu_y}\left(\frac{Z}{Y}\right)^{-1},$$

$$\frac{N_z}{N_y} = \frac{N_z}{Z}\frac{Z}{Y}\left(\frac{N_y}{Y}\right)^{-1},$$

$$N_y = \frac{N}{1+\frac{N_z}{N_y}},$$

$$N_z = N - N_y,$$

$$Z = N_z * \left(\frac{N_z}{Z}\right)^{-1},$$

Then,

$$Y = Z * \left(\frac{Z}{Y}\right)^{-1},$$

$$K_y = Y * \left(\frac{Y}{K_y}\right)^{-1}, K_z = Z * \left(\frac{Z}{K_z}\right)^{-1}, K = K_z + K_y$$
$$I = \delta K, C = Y - I, m = Cb(1-\beta)^{-\gamma}$$
$$\Lambda = C^{\frac{\gamma-1}{\gamma}} + b^{\frac{1}{\gamma}}m^{\frac{\gamma-1}{\gamma}}.$$

Log-linearized system

For any variable x_t, I define $\widehat{x}_t = \log(\frac{x_t}{x})$ as the deviation of x_t from its steady-state value.

$$-\frac{1}{\gamma}\hat{C}_t = \hat{\lambda}_t + \hat{\Lambda}_t,$$

$$\frac{1}{\gamma}\hat{b}_t - \frac{1}{\gamma}\hat{m}_t = \hat{\lambda}_t + \hat{\Lambda}_t + \left(\frac{1}{R-1}\right)\hat{R}_t,$$

$$\Lambda\hat{\Lambda}_t = \left(\frac{(\gamma-1)}{\gamma}C^{\frac{\gamma-1}{\gamma}}\right)\hat{C}_t + \left(\frac{1}{\gamma}b^{\frac{1}{\gamma}}m^{-\frac{1}{\gamma}}\right)\hat{b}_t + \left(-\frac{1}{\gamma}b^{\frac{1}{\gamma}}m^{-\frac{1}{\gamma}}\right)\hat{m}_t,$$

$$\hat{\lambda}_t = \hat{R}_t + \hat{\lambda}_{t+1} - \hat{\pi}_{y,t+1},$$

$$\hat{\lambda}_t + \kappa(1+\beta\delta)\hat{K}_{t+1} + (-\kappa)\hat{K}_t = \hat{\lambda}_{t+1} + (\beta r_k)\hat{r}_{k,t+1} - (\beta\kappa\delta)\widehat{I}_{t+1},$$

$$\hat{\pi}_{w,t} = \beta\widehat{\pi}_{w,t+1} + \frac{(1-\beta d_w)(1-d_w)}{d_w}\left(\frac{N}{1-N}\hat{N}_t - \hat{\lambda}_t - \hat{w}_t\right),$$

$$\hat{\pi}_{w,t} = \hat{w}_t - \hat{w}_{t-1} + \hat{\pi}_{y,t},$$

$$\hat{r}_{k,t} = -\hat{\mu}_{y,t} + \hat{Y}_t - \hat{K}_{y,t},$$

$$\hat{w}_t = -\hat{\mu}_{y,t} + \hat{Y}_t - [1+(1+\beta)\varphi_y\frac{\mu_y}{(1-\alpha_y)(1-\phi)}]\hat{N}_{y,t} + \varphi_y\frac{\mu_y}{(1-\alpha_y)(1-\phi)}[\hat{N}_{y,t-1}+\beta E_t\hat{N}_{y,t+1}],$$

$$\hat{p}_{z,t} = -\hat{\mu}_{y,t} + \hat{Y}_t - \hat{Z}_t,$$

$$\hat{\pi}_{y,t} = \beta E_t \hat{\pi}_{y,t+1} - \frac{(1-d_y)(1-d_y\beta)}{d_y}\hat{\mu}_{y,t},$$

$$\hat{Y}_t = (1-\phi)\hat{A}_{y,t} + \phi\widehat{Z}_t + \alpha_y(1-\phi)\hat{K}_{y,t} + (1-\alpha_y)(1-\phi)\hat{N}_{y,t},$$

$$\hat{r}_{k,t} = -\hat{\mu}_{z,t} + \hat{Z}_t - \hat{K}_{z,t},$$

$$\hat{w}_t = -\hat{\mu}_{z,t} + \hat{Z}_t - [1 + \varphi_z\frac{\mu_z}{1-\alpha_z}(1+\beta)]\hat{N}_{z,t} + \varphi_z\frac{\mu_z}{1-\alpha_z}[\hat{N}_{z,t-1} - \beta\hat{N}_{z,t+1}],$$

$$\hat{Z}_t = \hat{A}_{z,t} + \alpha_z\hat{K}_{z,t} + (1-\alpha_z)\hat{N}_{z,t},$$

$$\hat{\pi}_{z,t} = \beta E_t \hat{\pi}_{z,t+1} - \frac{(1-d_z)(1-d_z\beta)}{d_z}\hat{\mu}_{z,t},$$

$$\hat{\pi}_{z,t} = \hat{p}_{z,t} - \hat{p}_{z,t-1} + \hat{\pi}_{y,t},$$

$$\hat{Y}_t = \frac{C}{Y}\hat{C}_t + \frac{I}{Y}\hat{I}_t,$$

$$\hat{R}_t = \varrho_\pi\hat{\pi}_{y,t} + \varrho_y\widehat{y}_t + \widehat{v}_t,$$

$$\widehat{v}_t = \varrho_v\widehat{v_{t-1}} + \varepsilon_{R,t} \tag{33}$$

25

$$\hat{I}_t = \frac{1}{\delta}\hat{K}_{t+1} - (\frac{1}{\delta} - 1)\hat{K}_t,$$

$$\hat{K}_t = \frac{K_y}{K}\hat{K}_{y,t} + \frac{K_z}{K}\hat{K}_{z,t},$$

$$\hat{N}_t = \frac{N_y}{N}\hat{N}_{y,t} + \frac{N_z}{N}\hat{N}_{z,t}.$$

26

References

[1] Ambler, Steven, Guay, Alain and Phaneuf, Louis. "Labor Market Imperfections and the Dynamics of Postwar Business Cycles "

[2] Basu, Susanto. "Intermediate Goods and Business Cycles: Implication for Productivity and Welfare." American Economic Review 3: 512-531 (1995).

[3] Basu, Susanto. "Technology and Business Cycles: How Well Do Standard Models Explain The Facts?" in "Beyond Shocks: What Causes Business Cycles?" Conferences Series No.42, Federal Reserve Bank of Boston (June 1998).

[4] Basu, Susanto; Fernald, John and Kimball, Miles. "Are Technology Improvements Contractionary?" International Finance Discussion Papers No 625, Board of Governors of the Federal Reserve System (1998).

[5] Bergin, P.R., Feenstra, R.C. "Staggered Price Setting , Translog Preferences and Endogenous Persistence." Journal of Monetary Economics 45: 657-680 (2000).

[6] Blanchard, Olivier Jean. "Price Asynchroniszation and Price Level Inertia." in Dornbush , R., Simonsen, M.H. (Eds), Inflation, Debt, and Indexation. Cambridge, Massachusetts: 3-24 (1983).

[7] Blanchard, Olivier Jean and Kahn, Charles M. "The Solution of Linear Difference Equations Under Rational Expectations." Econometrica 48: 1305-1311 (1980).

[8] Blanchard, Olivier Jean and Kiyotoki, Nobuhiro. "Monopolistic Competition and the Effects of Aggregate Demand." American Economic Review 77: 647-666 (1987).

[9] Boudaya, Chahnez. "The Effects of Technological Innovations on Employment: A New Explanation." Cahiers de la MSE No.2005.13 (2005).

[10] Calvo, Guillermo A. "Staggered Prices in a Utility Maximizing Framework." Journal of Monetary Economics 12: 383-398 (1983).

[11] Carlsson, Mikael. "Measures of Technology and the Short-Run Responses to Technology Shocks: Is the RBC-Model Consistent with Swedish Manufacturing Data?" (2000)

[12] Chang, Yongsung and Hong, Jay H. "On the Employment Effect of Technology: Evidence from US Manufacturing for 1958-1996." Federal Reserve Bank of Richmond Working Papers No 03-06 (2003).

[13] Christiano, L., Eichenbaum, M. and Vigfusson, R. "What Happens After a Technology Shock?" Board of Governors of the Federal Reserve System, International Finance Discussion Paper , 768 (2003).

[14] Cooley, Thomas F. and Gary D. Hansen. "The Inflation Tax in a Real Business Cycle Model." American Economic Review vol.79 No.4: 733-748 (1989).

[15] Dib, Ali and Phaneuf, Louis. "An Econometric U.S Business Cycle Model with Nominal and Real Rigidities." CREFE, Université du Québec à Montréal, Working Paper No.137 (2001).

[16] Dotsey, Michael. "Structure from Shocks." mimeo, Federal Reserve Bank of Richmond (1999a).

[17] Francis, Neville and Ramey, Valerie A. "Is the Technology-Driven Real Business Cycle Hypothesis Dead? Shocks and Aggregate Fluctuations Revised." manuscript, UCSD (2001).

[18] Gali, Jordi. "Technology, Employment, and the Business Cycle:Do Technology Shocks Explain Aggregate Productivity?" American Economic Review 89: 249-271 (1999).

[19] —————. "New Perspectives on Monetary Policy, Inflation and the Business Cycle." NBER Workin Paper w8767 (February 2002).

[20] Griffin, Peter. "The Impact of Affirmative Action on Labor Demand: A Test of Some Implications of the Le Chatelier Principle." Review of Economics and Statistics 74: 251-260 (1992).

[21] —————. "Input Demand Elasticities for Heterogenous Labor: Firm-Level Estimates and an Investigation into the Effects of Aggregation." Southern Economic Journal 62: 889-901 (1996).

[22] Hamilton, James D. "Times Series Analysis." Princeton University Press, Princeton, New jersey (1994).

[23] Hornstein, Andreas and Praschnik, Jack. "Intermediate Inputs and sectoral Comovement in the Business Cycle." Federal Reserve Bank of Richmond Working Paper No.97-6 (1997).

[24] Huang, Kevin X.D.and Liu, Zheng. "Production Chains and General Equilibrium Aggregate Dynamics." Journal of Monetary Economics 48:437-462 (2001).

[25] —————————————————."Staggered Contracts and Business Cycle Persistence." Institute for Empirical Macroeconomics Discussion Paper 127, Federal Reserve Bank of Minneapolis (1998).

[26] —————————————————."Inflation Targeting: What Inflation to Target?" Federal Reserve Bank of Philadelphia Working Paper No.04-6 (July 2004).

[27] Huang, Kevin X.D.; Liu, Zheng and Phaneuf, Louis. "On the Transmission of Monetary Policy Shocks".CREFE Working Papers 112 (2000).

[28] Ireland, Peter N." A Small, Structural, Quarterly Model for Monetary Policy Evaluation." Carnegie-Rochester Conference Series on Public Policy 47: 83-108 (1997).

[29] Ireland, Peter N."Interest Rates, Inflation, and Federal Reserve Policy Since 1980." Journal of Money, Credit and Banking 32: 417-431 (2000).

[30] Ireland, Peter N. "Endogenous Money or Sticky Prices?" Journal of Monetary Economics 50: 1623-1648 (2003).

[31] Jermann, Urban."Asset Pricing in Production Economies." Journal of Monetary Economics: 257-275 (1998).

[32] Kiley, Michael T."Partial Adjustment and Staggered Price Setting." Manuscript, Federal Reserve Board (1998).

[33] Kim, J."Constructing and Estimating a Realistic Optimizing Model of Monetary Policy." Journal of Monetary Economics 45: 329-59 (2000).

[34] King, Robert G., and Wolman, Alexander. "Inflation Targeting in a St. Louis Model of the 21st Century." Federal Reserve Bank of St. Louis Review 78: 83-107 (1996).

[35] Kydland, Finn and Edward Prescott. " Time to Build and Aggregate Fluctuations." Econometrica vol.50 No.6 (November 1982).

[36] Long, J and Plosser, C. "Real Business Cycles." Journal of Political Economics 91: 39-69 (1983).

[37] ——————————-. "Sectoral vs Aggregate Shocks in the Business Cycle." American Economics Review: Papers and Proceedings 77: 333-336 (1987).

[38] Longot, F. "Sectoral Shocks and Employment Reallocation in a Two-Sector Dynamic General Equilibrium Model." First Version May 1997.

[39] Marchetti, Domenico J. and Nucci, Francesco. "Price Stickiness and the Contractionary Effect of Technology Shocks." European Economic Review, forthcoming.

[40] Means, G.C. "Industrial prices and their relative inflexibility." U.S. Senate Document 13, 74th Congress, 1st Session, Washington DC (1935).

[41] Rotemberg, Julio. "Prices, Output, and Hours: An Empirical Analysis Based on a Sticky Price Model." Journal of Monetary Economics 37: 505-533 (1996).

[42] Shea, John. "What Do Technology Shocks Do?" NBER Working Papers 6632 (1998).

[43] Taylor John. "Discretion Versus Policy Rules in Practice." Carnegie-Rochester Conference Series on Public Policy 39: 195-214 (1993).

[44] —————. "An Historical Analysis of Monetary Policy Rules." NBER Working Paper No.6768 (October 1998).

[45] —————. "Monetary Policy Rules." University of Chicago Press and NBER (1999).

Table 1: Maximum likelihood estimates

Parameter definition	Parameter	Estimate	Std	t-stat	p-value
Autoc. tech. finished good sector	$\rho_{A,y}$	0.8633	0.0628	13.7532	0.0000
Autoc. tech. intermediate good sector	$\rho_{A,z}$	0.9900	0.0090	110.552	0.0000
Autoc. monetary policy	ϱ_v	0.5545	0.0358	15.4829	0.0000
Autoc. money demand	ρ_b	0.9411	0.0199	47.2776	0.0000
Autoc. measurment error	ρ_{merror}	0.9375	0.0236	39.6937	0.0000
std. tech. finished good sector	$\sigma_{A,y}$	0.0087	0.0011	7.9813	0.0000
std. tech. intermediate good sector	$\sigma_{A,z}$	0.0028	0.0002	12.3175	0.0000
std. monetary policy	σ_R	0.0038	0.0002	21.9383	0.0000
std. money demand	σ_b	0.1286	0.0052	24.8684	0.0000
std. measurment error	σ_{merror}	0.0068	0.0003	20.4247	0.0000
Policy reaction to inflation	ϱ_π	1.0074	0.0108	93.0324	0.0000
Policy reaction to output gap	ϱ_y	0.0752	0.0169	4.4529	0.0000
Degree of wage stickiness	d_w	0.8295	0.0319	26.038	0.0000
Degree of price stick. final sector	d_y	0.4341	0.0451	9.6198	0.0000
Degree of price stick. intermediate sector	d_z	0.3677	0.1708	2.153	0.0401
Capital adj. cost	κ	4.2646	0.9718	4.3884	0.0000
Labor adj. cost final sector	φ_y	0.5533	1.5379	0.3598	0.3731
Labor adj. cost intermediate sector	φ_z	6.4969	1.9596	3.3154	0.0019
Interm. share in final secor	ϕ	0.2997	0.0066	45.2947	0.0000
Labor share final sector	α_y	0.3025	0.0256	11.8049	0.0000
Labor share intermediate sector	α_z	0.2567	0.0371	6.9142	0.0000
Average money demand	b	0.1938	0.0615	3.1511	0.0032

Table 2: Variance decomposition

Variable	$A_{y,t}$	$A_{z,t}$	R_t	b_t	$merror_t$
Y_t	10.7539	54.0584	35.1816	0.0061	0.0000
Z_t	15.4560	80.6244	3.9187	0.0008	0.0000
C_t	42.8075	36.8819	20.1907	0.1200	0.0000
I_t	4.7563	66.6808	28.5543	0.0087	0.0000
N_t	33.1152	57.4004	9.4824	0.0020	0.0000
$N_{y,t}$	7.3087	12.6376	80.0364	0.0173	0.0000
$N_{z,t}$	32.3165	50.3449	17.3349	0.0037	0.0000
w_t	16.6865	78.3459	4.9659	0.0017	0.0000
R_t	1.1747	98.7156	0.1091	0.0006	0.0000
$\pi_{y,t}$	1.2056	88.3280	0.4312	0.0004	10.0349
$\pi_{z,t}$	1.3102	96.7788	1.9095	0.0014	0.0000
$\pi_{w,t}$	0.8959	99.0047	0.0991	0.0003	0.0000

Table 3: Some Second Order Unconditional Moments

Moments	Post-war US data		Model prediction
$std(Y)$	0.0170 (0.0023)		0.0260
$std(C)$	0.0123 (0.0017)		0.0121
$std(I)$	0.0509 (0.0073)		0.0523
$std(N)$	0.0042 (0.0003)	0.0395* (0.0080)	0.0480
$std(w)$	0.0110 (0.0026)		0.0218
$Corr(Y,C)$	0.9305 (0.2526)		0.3295
$Corr(Y,I)$	0.8908 (0.2374)		0.9698
$Corr(Y,w)$	0.7399 (0.3696)		0.5277
$Corr(Y,N)$	0.6813 (0.1548)	0.0880* (1.1121)	0.6994
$Corr(N,w)$	0.4442 (0.1652)	0.0559* (2.2928)	0.2057

*: Labour is HP filtered in the first column and measured in level in the second column.

Table 4: Sectoral Comovements

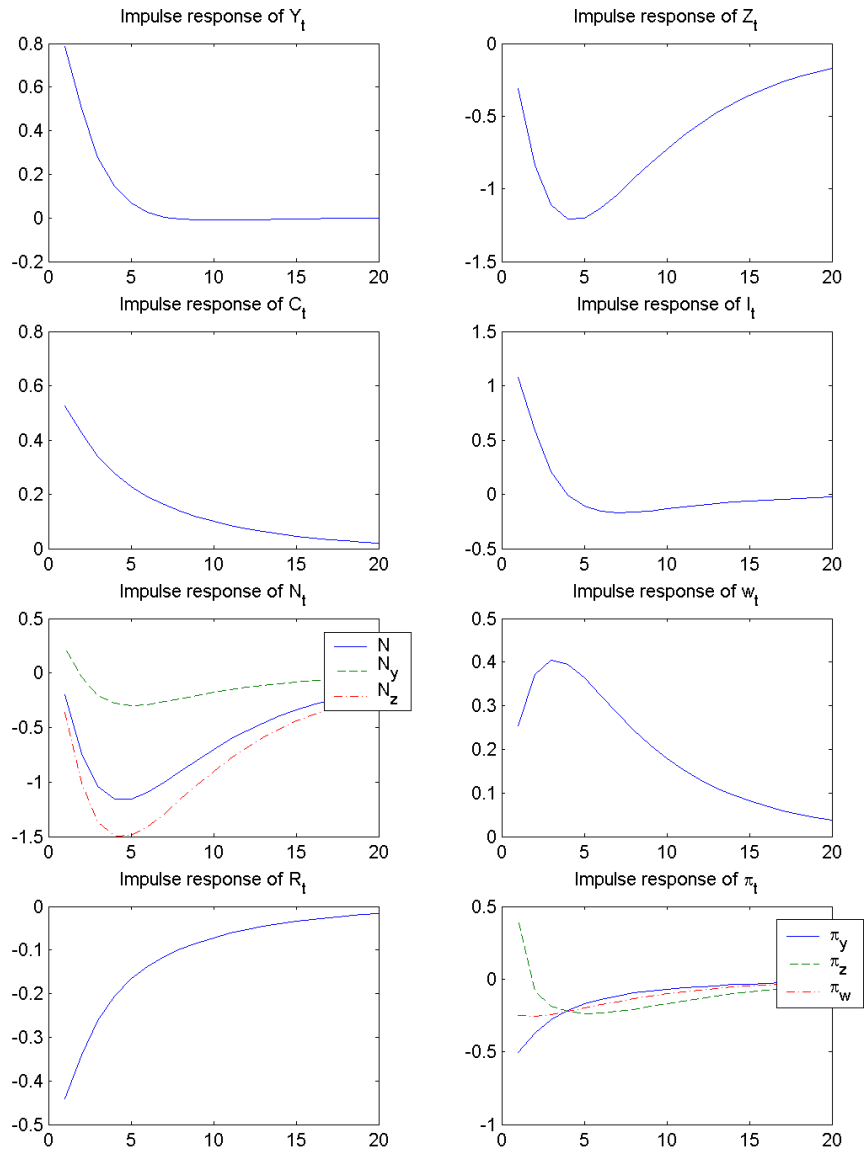| Simulated moment	Value
$Corr(Y, Z)$	0.7259
$Corr(Y, N)$	0.6994
$Corr(Y, N_y)$	0.5593
$Corr(Y, N_z)$	0.6670
$Corr(Z, N)$	0.9289
$Corr(Z, N_y)$	0.2736
$Corr(Z, N_z)$	0.9608
$Corr(N, N_y)$	0.5644
$Corr(N, N_z)$	0.9913

Figure 1: Final-stage technology shock
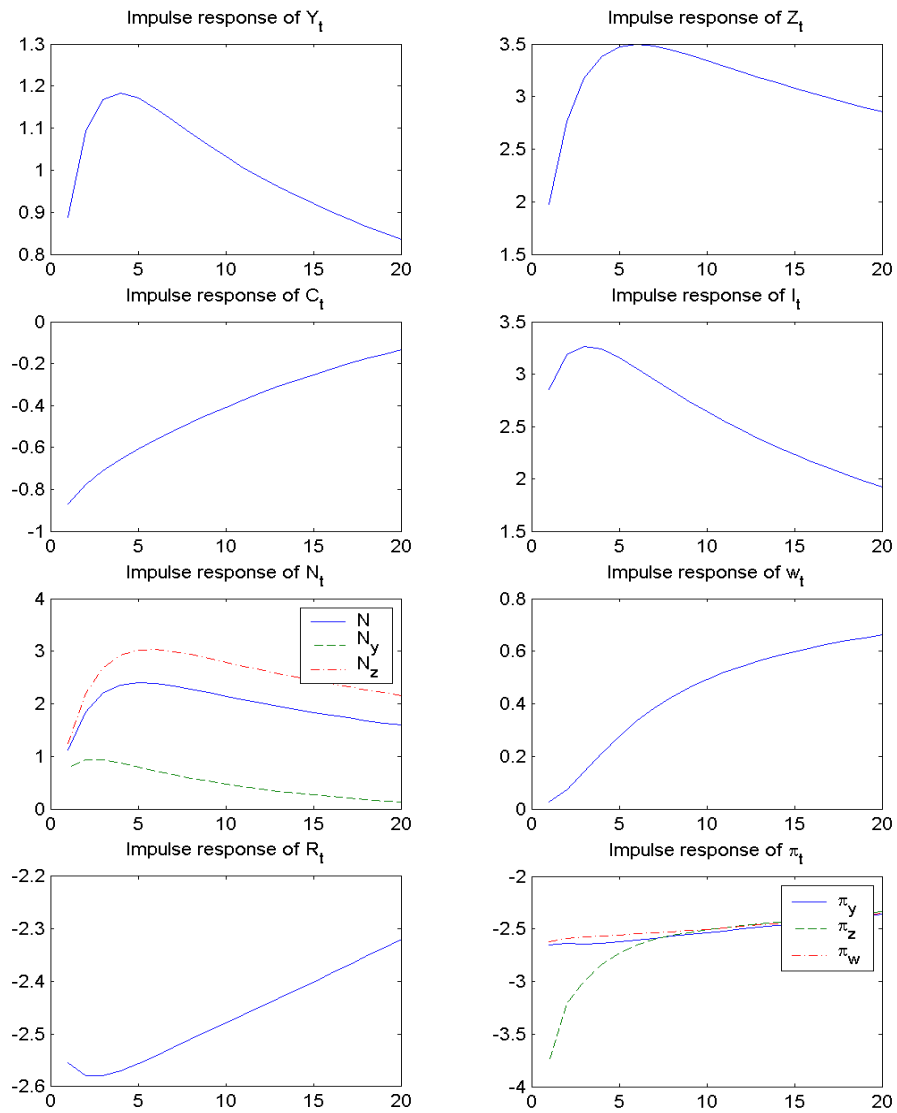
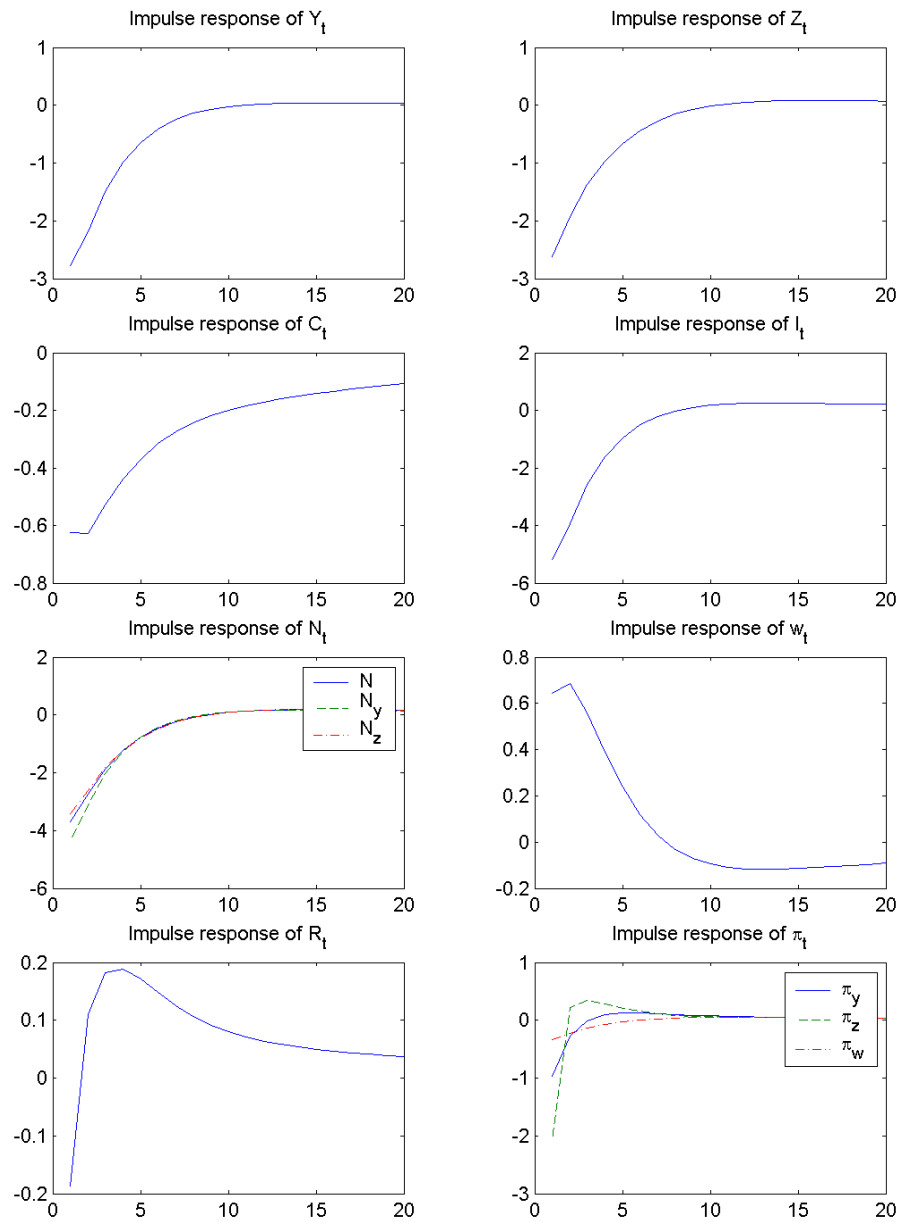Figure 2: Intermediate-stage technology shock

Figure 3: Monetary policy shock

Figure 4: Money demand shock
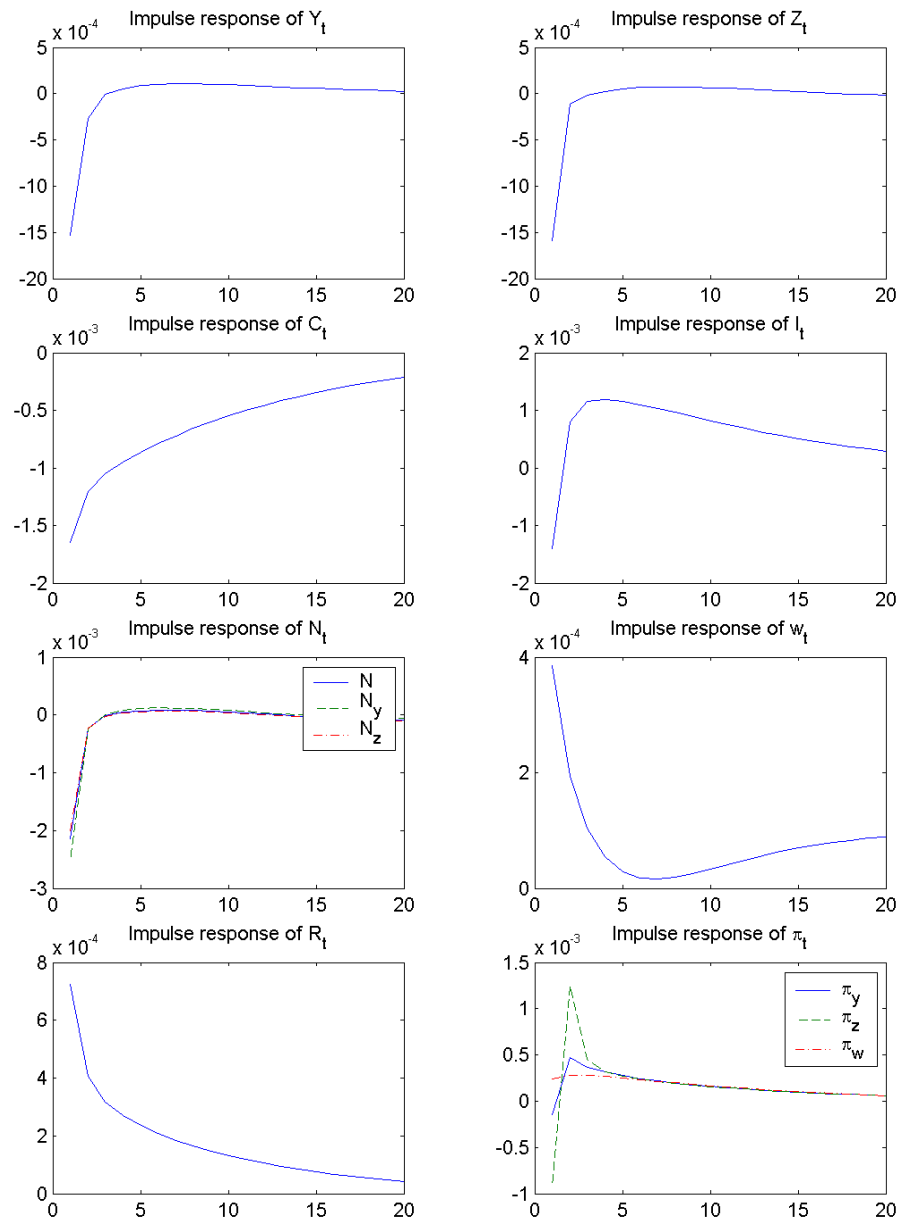
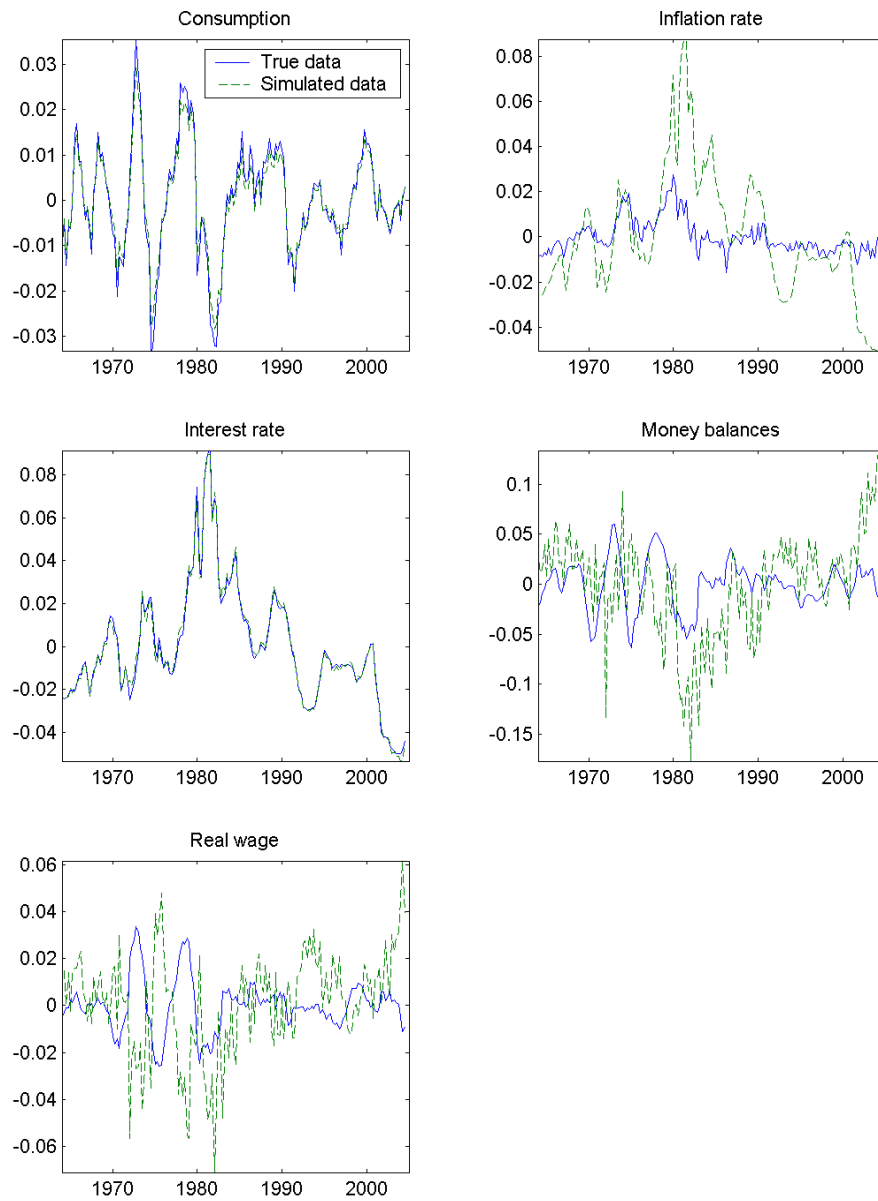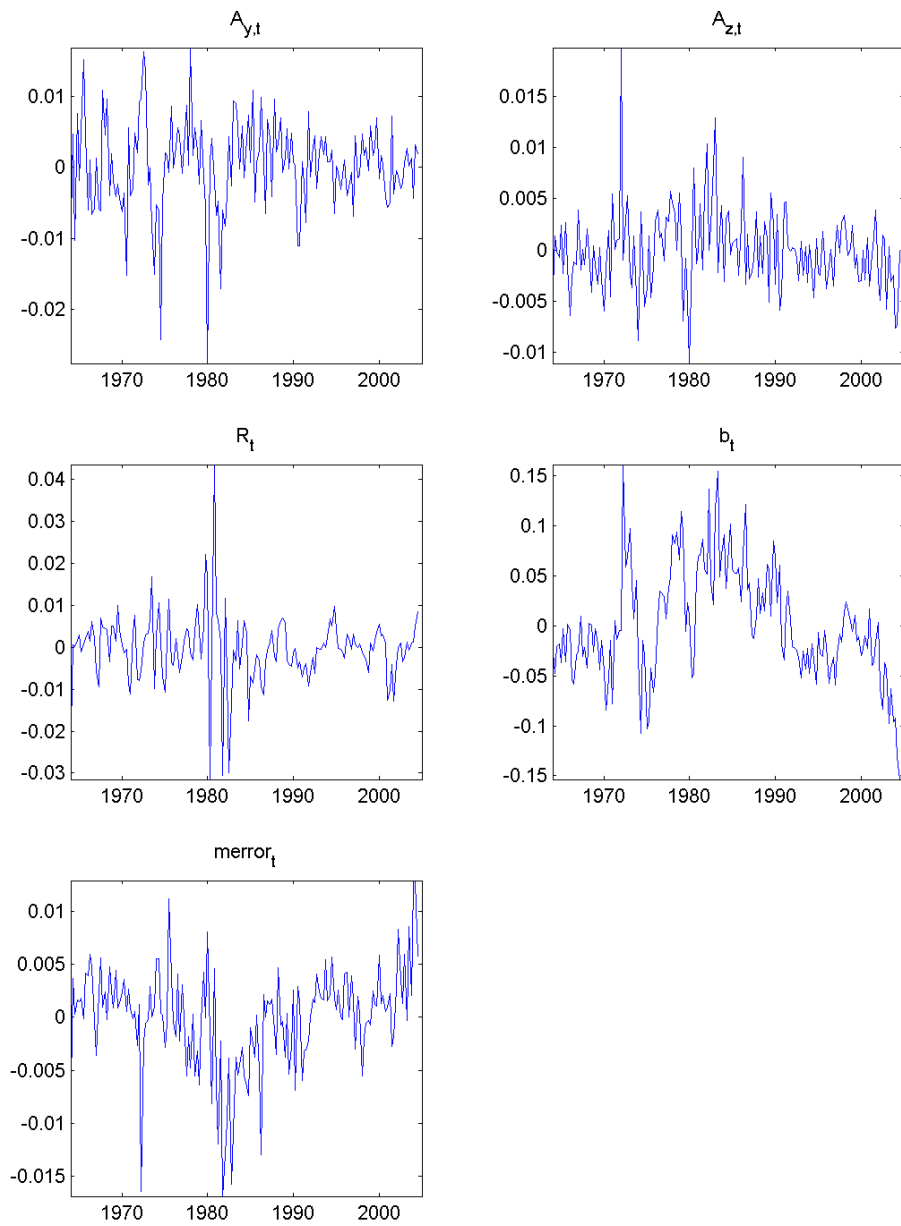Figure 5: Simulated data versus true data

Figure 6: Model generated structural shocks

Figure 7: Labor response sensitivity