Finance and Economics Discussion Series
Divisions of Research & Statistics and Monetary Affairs
Federal Reserve Board, Washington, D.C.

The Shimer puzzle and the Identification of Productivity Shocks

Regis Barnichon

2009-04

The Shimer puzzle and the Identification of Productivity Shocks*

Regis Barnichon

Federal Reserve Board

25 October, 2008

(First Draft: April 2007)

Abstract

Shimer (2005) argues that the Mortensen-Pissarides (MP) model of unemployment lacks an amplification mechanism because it generates less than 10 percent of the observed business cycle fluctuations in unemployment given labor productivity shocks of plausible magnitude. This paper argues that part of the problem lies with the identification of productivity shocks. Because of the endogeneity of measured labor productivity, filtering out the trend component as in Shimer (2005) may not correctly identify the shocks driving unemployment. Using a New-Keynesian framework to control for the endogeneity of productivity, this paper estimates that the MP model can account for a third, and possibly as much as 60 percent, of fluctuations in labor market variables.

JEL classifications: E32, E37, J63, J64

Keywords: Unemployment Fluctuations, Labor productivity, Search and matching model, New-Keynesian model

*I would like to thank Stephanie Cheng, Jordi Gali, Wouter den Haan, Barbara Petrongolo, Chris Pissarides, Silvana Tenreyro and seminar participants at the 2008 EEA/ESEM conference in Milan for helpful comments. Any errors are my own. E-mail: <r.o.barnichon@lse.ac.uk>.

1 Introduction

In a very influential paper, Shimer (2005) argues that the Mortensen-Pissarides (MP) search model of unemployment lacks an amplification mechanism because it generates less than 10 percent of the observed business cycle fluctuations in unemployment given labor productivity shocks of plausible magnitude. In this paper, I argue that Shimer's (2005) estimate may be biased downward because of the endogeneity of labor productivity, and I estimate that a third, and possibly as much as 60 percent, of the Shimer puzzle is simply due to the misidentification of productivity shocks.

The Shimer puzzle has attracted a lot of interest in the literature, and a number of researchers have focused on ways to create more amplification so that small exogenous productivity movements generate large fluctuations in unemployment.[1] However, there is substantial evidence that, perhaps due to labor hoarding and variable capacity utilization, some of the movements in productivity are in fact endogenous.[2] For example, when the firm is demand constrained in the short-run, firms can respond to changes in demand by adjusting their level of capacity utilization of inputs (capital or labor), and measured labor productivity fluctuates *endogenously* with aggregate demand and hence unemployment.[3] By filtering out the trend component of output per hour to identify productivity shocks, Shimer (2005) may not identify the true productivity shocks but rather the endogenous response of productivity to unobserved disturbances. And because this endogenous response is small, this may explain why the cyclical component of measured labor productivity fluctuates less than unemployment.

To estimate the impact of exogenous changes in productivity on labor market variables, I impose long-run restrictions in a structural VAR model along the line of Gali (1999), and I find that a permanent productivity increase temporarily lowers labor market tightness (the vacancy-

[1] See, among others, Hagedorn and Manovski (2005) , Hall (2005), Hall and Migrom (2005), Shimer (2004), and Mortensen and Nagypal (2005) for a review of recent efforts.

[2] See, among others, Bils and Cho (1994), Burnside, Eichenbaum and Rebelo (1993), Burnside and Eichenbaum (1996) and Basu and Kimball (1997).

[3] This idea is given empirical support in Barnichon (2008), following Gali (1999).

unemployment ratio), while the MP model implies the opposite.[4] Hence, before assessing the amplification properties of the MP model, I embed the search and matching model in a New Keynesian framework. In this set-up, a permanent increase in productivity (i.e. a positive productivity shock) may temporarily raise unemployment and lower labor market tightness because aggregate demand does not adjust immediately to the new productivity level in the presence of nominal rigidities, and hence firms use less labor. The model also generates endogenous movements in productivity. Because hiring firms are demand constrained, an aggregate demand shock generates a transitory movement in productivity as firms vary their level of capacity utilization.

To estimate the proportion of Shimer's puzzle due to the endogeneity of productivity, I use a calibrated version of the model to control for endogenous productivity movements unrelated to productivity shocks, and I reproduce Shimer's (2005) exercise on data simulated from my model. With a standard calibration, simulated labor market tightness is 9 times more volatile than the cyclical component of labor productivity, while the ratio comes at about 26 in US data. I conclude that the MP model can account for about a third, rather than 10 percent, of labor market tightness fluctuations, and a sensitivity analysis suggests that this share could be as high as 60 percent.

The remainder of the paper is organized as follows: Section 2 discusses Shimer's (2005) puzzle; Section 3 presents and calibrates a New-Keynesian model with search unemployment and replicates Shimer's (2005) exercise on model generated data; and Section 4 offers some concluding remarks.

[4] Barnichon (2008) and Canova, Lopez-Salido and Michelacci (2008) come to similar conclusions, albeit with different labor market variables.

2 The Shimer puzzle

2.1 Shimer's (2005) evidence

In this section, I reproduce Shimer's exercise (2005), and Table 1 presents summary statistics for unemployment, vacancies, labor market tightness and productivity.[5] As originally argued by Shimer (2005), the volatility of productivity is only a fraction (here less than 4%) of the volatility of labor market tightness. Turning to the correlation matrix, unemployment and labor market tightness are weakly correlated with productivity with correlations of respectively -0.23 and 0.19.

In the context of a standard MP model where productivity movements are the central driving force of unemployment fluctuations, Shimer (2005) shows that the standard deviations of unemployment, vacancies and productivity are of the same order of magnitude, i.e. $\sigma(u) \approx \sigma(v) \approx \sigma(p)$. By estimating that productivity shocks are only 10% as volatile as unemployment fluctuations, Shimer (2005) concludes that the MP model can only account for less than 10% of unemployment fluctuations. Furthermore, Shimer (2005) notes that the MP model exhibits virtually no propagation as it implies a contemporaneous correlation between unemployment and productivity of -1 when the data show a contemporaneous and peak unemployment-productivity correlation of respectively only -0.23 and -0.50.

2.2 Fixing the model to add more amplification

One way to reconcile the MP framework with the data is to modify the model so that it generates more amplification, i.e. that a given shock to productivity has a larger impact

[5] I use quarterly data taken from the U.S. Bureau of Labor Statistics (BLS) covering the period 1951:Q1 to 2005:Q4. Labor productivity is measured as real average output per hour in the non-farm business sector, and unemployment is the quarterly average of the monthly unemployment rate series constructed by the BLS from the Current Population Survey. Labor market tightness is defined as the vacancy-unemployment ratio and vacancies are the quarterly average of the monthly Conference Board help-wanted advertising index. I remove low-frequency movements using a standard HP-filter with $\lambda = 1600$. Alternatively, using $\lambda = 10^5$ as in Shimer (2005a) does not change any of the results presented in this paper.
I measure productivity as output per hour as in Shimer (2004) instead of output of worker as in Shimer (2005). The Shimer puzzle is present with the same magnitude using both measures, and all the results in this paper hold for both measures.

on unemployment. Mortensen and Nagypal (2006) provide a detailed review of the current effort in that direction, and I will only emphasize two influential examples. A first possibility, suggested by Hall (2005) and Shimer (2005), is to introduce real wage rigidity. In the standard MP model, the Nash bargaining real wage responds so much to movements in productivity that it effectively absorbs most of the changes in productivity. As a result, the surplus of the match responds only weakly to fluctuations in productivity. By introducing a degree of real wage rigidity, movements in productivity have a more substantial impact on the match surplus, on the incentives of firms to post vacancies and hence on equilibrium unemployment.

Another possibility, suggested by Hagedorn and Manovskii (2004), does not rely on real wage rigidity but uses a standard MP model with a different calibration than the one used in Shimer's. Hagedorn and Manovskii (2004) show that when the opportunity cost of employment is high, the job finding rate becomes very responsive to changes in productivity, and the MP model can quantitatively account for the magnitude of unemployment fluctuations. While this approach is different from the one proposed by Hall (2005) and Shimer (2005), the underlying philosophy is the same: one needs to modify the MP model (either its equations or its calibration) so that the surplus of the match becomes more responsive to changes in productivity.

2.3 The conditional volatilities of productivity and labor market tightness

The aforementioned literature generally considers productivity movements as exogenous. However, there is substantial evidence that, perhaps due to labor hoarding and variable capacity utilization, some of the movements in productivity are in fact endogenous.[6]

To identify the impact of exogenous changes in productivity, I follow Galí (1999) and Blanchard and Quah (1989) and impose long-run restrictions in structural VAR models to identify technological disturbances. Technology shocks are the only shocks with a permanent impact on productivity, and I interpret transitory productivity movements as variations in

[6] See, among others, Bils and Cho (1994), Burnside, Eichenbaum and Rebelo (1996) and Basu and Kimball (1997).

capacity utilization. Specifically, I am interested in estimating the system

$$\begin{pmatrix} \Delta ln \; \frac{y_t}{h_t} \\ ln \; \theta_t \end{pmatrix} = C(L) \begin{pmatrix} \varepsilon_t^a \\ \varepsilon_t^m \end{pmatrix}$$

where $\frac{y_t}{h_t}$ is labor productivity defined as output per hours, θ_t the vacancy-unemployment ratio, $C(L)$ an invertible matrix polynomial and the vector of structural orthogonal innovations comprises technology shocks ε_t^a and non-technology shocks ε_t^m.[7]

Figure 1 presents the impulse response functions. The Shimer puzzle is clearly apparent for both shocks: the standard deviation over the first two years after a technology shock is 16 times larger for labor market tightness than for output per hour, and after a non-technology shock, the ratio is 21. However, as similarly emphasized in Gali (1999), Barnichon (2008) and Canova, Lopez-Salido and Michelacci (2008) a positive technology shock temporarily lowers labor market tightness, while the MP model implies the opposite.[8] This implies that it is difficult to draw conclusions regarding the amplification properties of the baseline MP model since its transmission mechanism is likely to be incomplete.

3 The Shimer puzzle in a New-Keynesian setting

To reassess the extent of Shimer's puzzle, it is important to extend the search and matching model so that it can (i) rationalize endogenous productivity movements, and (ii) account for the fact that permanent productivity increases temporarily lower labor market tightness. To do so, I follow Gali (1999) and Barnichon (2008), and I extend the MP model so that hiring

[7] I use quarterly data taken from the U.S. Bureau of Labor Statistics (BLS) covering the period 1951:Q1 to 2005:Q4. Labor productivity x_t is measured as real average output per hour in the non-farm business sector, and labor market tightness $\theta_t = v_t / u_t$ is the ratio of the quarterly average of the monthly unemployment rate series constructed by the BLS from the Current Population Survey over the Conference Board help advertising index. Following Fernald (2007), I allow for two breaks in $\Delta \ln \left(\frac{y}{h}\right)_t$, 1973:Q1 and 1997:Q1, and I filter the unemployment series with a quadratic trend. Fernald (2007) showed that the presence of a low-frequency correlation between labor productivity growth and unemployment, while unrelated to cyclical phenomena, could significantly distort the estimates of short run responses obtained with long run restrictions.

[8] See Barnichon (2008) for a discussion about the positive impact of technology shocks on unemployment and its implications for the modeling of unemployment fluctuations.

firms are demand constrained in a New-Keynesian fashion.

In a neoclassical setting, firms post vacancies depending on the return of the match. However, this needs not be the case when firms have to satisfy a given level of demand for their products. In a New-Keynesian setting with monopolistically competitive firms and nominal rigidities, firms may have to hire more workers when demand is unexpectedly high even if productivity (and hence the match surplus) does not increase. Put differently, the number of posted vacancies could increase without any change in productivity. In practice, firms also respond to higher demand by increasing capacity utilization of inputs (capital or labor). As a result, measured labor productivity fluctuates with aggregate demand and hence unemployment.

A permanent increase in productivity (i.e. a technology shock) may temporarily raise unemployment because with nominal rigidities, aggregate demand does not adjust immediately to the new productivity level, and firms use less labor.

In the next subsections, I present and calibrate a New-Keynesian model with search unemployment, and I replicate Shimer's exercise on model generated data.

3.1 A New-Keynesian model with search unemployment

Following Barnichon (2008) and Krause and Lubik (2007), I extend the MP model by introducing nominal frictions so that hiring firms are demand constrained in a New-Keynesian fashion. In addition, I make a distinction between the extensive (number of workers) and the intensive (hours and effort) labor margins. In this framework, unemployment fluctuations are the product of two disturbances: technology shocks and monetary policy (or aggregate demand) shocks. A positive technology shock permanently raises productivity but may also temporarily raise unemployment and lower labor market tightness. A positive monetary policy shock decreases unemployment and increases measured productivity temporarily, because firms increase labor effort to satisfy demand in the short run. As a result, measured labor productivity is the product of two components: permanent and temporary disturbances.

The main ingredients of the model are monopolistic competition in the goods market, hiring frictions in the labor market and nominal price rigidities. There are three types of agents: households, firms and a monetary authority.

3.1.1 Households

I consider an economy populated by a continuum of households of measure one and a continuum of firms of measure one. With equilibrium unemployment, ex-ante homogenous workers become heterogeneous in the absence of perfect income insurance because each individual's wealth differs based on his employment history. To avoid distributional issues, I follow Merz (1995) and Andolfatto (1996) in assuming that households form an extended family that pools its income and chooses per capita consumption and assets holding to maximize its expected lifetime utility. There are $1 - n_t$ unemployed workers who receive unemployment benefits b in units of utility of consumption, and n_t employed workers who receive the wage payment w_{it} from firm i for providing hours h_{it} and effort per hour e_{it}.[9] Denoting $g(h_{it}, e_{it})$ the individual disutility from working, the representative family seeks to maximize

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\ln (C_t) + \lambda_m \ln(\frac{M_t}{P_t}) - n_t \int_0^1 g(h_{it}, e_{it}) di \right]$$

subject to the budget constraint

$$\int_0^1 P_{jt} C_{jt} dj + M_t = \int_0^1 n_t w_{it} di + (1 - n_t) b C_t + \Pi_t + M_{t-1}$$

with λ_m a positive constant, M_t nominal money holdings, Π_t total transfers to the family and C_t the composite consumption good index defined by $C_t = \left(\int_0^1 C_{it}^{\frac{\varepsilon-1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}}$ where C_{it} is the quantity of good $i \in [0, 1]$ consumed in period t and P_{it} is the price of variety i. $\varepsilon > 1$ is the elasticity of substitution among consumption goods. The aggregate price level is defined as

[9] I introduce variable effort per hour in order to generate procyclical productivity movements.

$P_t = \left(\int_0^1 P_{it}^{1-\varepsilon} di \right)^{\frac{1}{1-\varepsilon}}$. The disutility from supplying hours of work h_t and effort per hour e_t is the sum of the disutilities of the members who are employed. Following Bils and Cho (1994), the individual period disutility of labor takes the form:

$$g(h_{it}, e_{it}) = \frac{\lambda_h}{1+\sigma_h} h_{it}^{1+\sigma_h} + h_{it} \frac{\lambda_e}{1+\sigma_e} e_{it}^{1+\sigma_e}$$

where $\lambda_h,\ \lambda_e,\ \sigma_h$ and σ_e are positive constants. The last term reflects disutility from exerting effort with the marginal disutility of effort per hour rising with the number of hours. An infinite value for σ_e generates the standard case with inelastic effort.

3.1.2 Firms and the labor market

Each differentiated good is produced by a monopolistically competitive firm using labor as the only input. There is a continuum of large firms distributed on the unit interval. At date t, each firm i hires n_{it} workers to produce a quantity $y_{it} = A_t n_{it} L_{it}^{\alpha}$ where A_t is an aggregate technology index, L_{it} the effective labor input supplied by each worker and $0 < \alpha < 1$.[10] I define effective labor input as a function of hours h_{it} and effort per hour e_{it} such that $L_{it} = h_{it} e_{it}$. Total effective labor input can be adjusted through three channels: the extensive margin n_{it}, and the two intensive margins: hours h_{it} and effort per hour e_{it}. With variable effort, the model will be able to generate endogenous procyclical movements in productivity.

Being a monopolistic producer, the firm faces a downward sloping demand curve $y_{it}^d = (\frac{P_{it}}{P_t})^{-\varepsilon} Y_t$ and chooses its price P_{it} to maximize its value function given the aggregate price level P_t and aggregate output Y_t. As is standard in New-Keynesian models, firms are subject to Calvo-type price setting and can only reset their price at random dates. Each period a fraction ν of randomly selected firms cannot reset its price.

[10] This production function can be rationalized by assuming a constant capital-worker ratio and a standard Cobb-Douglas production function $y_{it} = A_t (nL_{it})^{\alpha} K_{it}^{1-\alpha}$. Note however, that the main message of the paper does not rely on this particular choice of the production function, and that the model could accommodate other functional forms.

In a search and matching model of the labor market, workers cannot be hired instantaneously and must be hired from the unemployment pool through a costly and time-consuming job creation process. Firms post vacancies at a unitary cost, $c_t = cA_t$, and unemployed workers search for jobs. I assume that the matching function takes the usual Cobb-Douglas form so that the flow m_t of successful matches within period t is given by $m_t = m_0 u_t^{\eta} v_t^{1-\eta}$where m_0 is a positive constant, $\eta \in (0,1)$, u_t denotes the number of unemployed and $v_t{=}\int_0^1 v_{it} di$ the total number of vacancies posted by all firms. Accordingly, the probability of a vacancy being filled in the next period is $q(\theta_t) \equiv m(u_t, v_t)/v_t = m_0 \theta^{-\eta}$ where $\theta_t \equiv \frac{v_t}{u_t}$ is the labor market tightness. Similarly, the probability for an unemployed to find a job is $m(u_t, v_t)/u_t = m_0 \theta_t^{1-\eta}$. Matches are destroyed at a constant rate λ, and the law of motion for a representative firm is given by $n_{it+1} = (1-\lambda) n_{it} + q(\theta_t) v_{i,t}$.

When a firm and a worker meet, they must decide on the allocation of hours and effort to satisfy demand. I assume that both parties negotiate the hours/effort decision by choosing the optimal allocation and set hours and effort per hour to satisfy demand at the lowest utility cost for the worker. More precisely, they solve

$$\min_{h_{it}, e_{it}} \frac{\lambda_h}{1+\sigma_h} h_{it}^{1+\sigma_h} + h_{it} \frac{\lambda_e}{1+\sigma_e} e_{it}^{1+\sigma_e}$$

subject to satisfying demand $A_t n_{it} h_{it}^{\alpha} e_{it}^{\alpha} = y_{it}^d$ at date t, and this implies that effort per hour is a function of total hours

$$e_{it} = e_0 h_{it}^{\frac{\sigma_h}{1+\sigma_e}}$$

where $e_0 = \left(\frac{1+\sigma_e}{\sigma_e} \frac{\lambda_h}{\lambda_e} \right)^{\frac{1}{1+\sigma_e}}$ is a positive constant. Thus, changes in hours can proxy for changes in effort, and I can write a reduced-form relationship between output and hours

$$y_{it} = y_0 A_t n_{it} h_{it}^{\varphi}$$

with $y_0 = e_0^{\alpha}$ and $\varphi = \alpha\left(1+\frac{\sigma_h}{1+\sigma_e}\right)$. For $\varphi > 1$, the production function displays short run increasing returns to hours, and endogenous labor productivity (i.e. output per hour) movements are procyclical.

3.1.3 Wage bill setting

As is usual in the search literature, firms and workers bargain individually about the real wage and split the surplus in shares determined by an exogenous bargaining weight γ. Denoting $J_i(w_{it})$ the value of a matched worker to firm i at date t, and $W_i(w_{it})$ and $U(w_{it})$ the value for a worker of being respectively employed by firm i and unemployed, the equilibrium wage w_{it} satisfies $w_{it} = \underset{w_{it}}{\text{argmax}} \ (W_i(w_{it}) - U(w_{it}))^{\gamma} (J_i(w_{it}))^{1-\gamma}$ and is a solution of the first-order differential equation

$$w_{it} = \gamma\left(\frac{h_{it}}{\varphi}\frac{\partial w_{it}}{\partial h_{it}} + \frac{c_t}{\lambda_t}\theta_t\right) + (1-\gamma)\left(\frac{b_t}{\lambda_t} + \frac{g(h_t, e_t)}{\lambda_t}\right) \tag{1}$$

with $\lambda_t = \frac{1}{C_t}$.[11] A solution is given by

$$w_{it} = \gamma\frac{c_t}{\lambda_t}\theta_t + (1-\gamma)\frac{b_t}{\lambda_t} + (1-\gamma)\varkappa\frac{h_{it}^{1+\sigma_h}}{\lambda_t} \tag{2}$$

with $\varkappa = \frac{\lambda_h \frac{1+\sigma_h+\sigma_e}{(1+\sigma_h)\sigma_e}}{1-\frac{\gamma}{\varphi}(1+\sigma_h)} > 0$.[12]

3.1.4 The firm's problem

Given the market wage and aggregate price level, firm i will choose a sequence of price $\{P_{it}\}$ and vacancies $\{v_{it}\}$ to maximize the expected present discounted value of future profits subject

[11] While the wage equation (1) is a weighted average of both parties surpluses and is similar to other bargained wages derived in e.g. Trigari (2004), Walsh (2004) or Krause and Lubik (2007), the firm's surplus is *not* given by the marginal product of labor. Indeed, once the firm has chosen its price, it is demand constrained and a marginal worker will not increase the firm's revenue. Instead, the first term of (1) is given by $-\frac{\partial w_{it}}{\partial n_{it}} = \frac{h_{it}}{\varphi}\frac{\partial w_{it}}{\partial h_{it}}$, the change in the wage bill caused by substituting the intensive margin (hours and effort) with the extensive one (employment). See Barnichon (2008) for more details.

[12] The model is well behaved only if $\varkappa > 0$. This imposes that $1 - \frac{\gamma}{\varphi}(1+\sigma_h) > 0$, which will be verified by the calibrated parameters.

to the demand constraint, the Calvo price setting rule, the hours/effort choice and the law of motion for employment. Formally, the firm maximizes its value

$$E_t \sum_j \beta^j \frac{u'(C_{t+j})}{u'(C_t)} \left[\frac{P_{i,t+j}}{P_{t+j}} y^d_{i,t+j} - n_{i,t+j} w_{i,t+j} - \frac{c}{\lambda_{t+j}} v_{i,t+j} \right]$$

subject to the demand constraint

$$y^d_{it} = y_0 A_t n_{it} h^{\varphi}_{it} = (\frac{P_{i,t}}{P_t})^{-\varepsilon} Y_t$$

the law of motion for employment

$$n_{it+1} = (1-\lambda) n_{it} + q(\theta_t) v_{it}$$

and the bargained wage

$$w_{it} = \gamma \frac{c_t}{\lambda_t} \theta_t + (1-\gamma) \frac{b_t}{\lambda_t} + (1-\gamma) \varkappa \frac{h^{1+\sigma_h}_{it}}{\lambda_t}.$$

3.1.5 Technological progress and the central bank

Consistent with the long run identifying assumption made in Section 2, the technology index series is non-stationary with a unit root originating in technological innovations. Hence, technology is comprised of a deterministic and a stochastic component: $A_t = e^{a.t+a_t}$ with $a_t = a_{t-1} + \varepsilon^a_t$ and $\varepsilon^a_t \sim N(0, \sigma^a)$ is a technology shock with a permanent impact on productivity.

Consistent with a growing economy and zero inflation in "steady-state", the money supply evolves according to $M_t = e^{a.t+m_t}$ with $\Delta m_t = \rho_m \Delta m_{t-1} + \varepsilon^m_t + \tau^{cb} \varepsilon^a_t$, $\rho_m \in [0, 1]$ and $\varepsilon^m_t \sim N(0, \sigma^m)$. I interpret ε^m_t as an aggregate demand shock.

3.1.6 Closing and solving the model

Averaging firms' employment, total employment evolves according to $n_{t+1} = (1-\lambda)n_t + v_t q(\theta_t)$. The labor force being normalized to one, the number of unemployed workers is $u_t = 1 - n_{t.}$ Finally, as in Krause and Lubik (2007), vacancy posting costs are distributed to the aggregate households so that $C_t = Y_t$ in equilibrium. To solve the model, I log-linearize the first-order conditions around the (zero-inflation) long run equilibrium.[13]

3.2 Calibration

I now discuss the calibration of the parameters of the model, and Table 2 lists the parameter values. Whenever possible, I use values typically used in the literature. I set the quarterly discount factor β to 0.99 and the returns to efficient labor α to 0.64. I assume that the markup of prices over marginal costs is on average 10 percent, which amounts to setting ε equal to 11. I choose $\nu = 0.5$ so that firms reset their price every 2 quarters, consistent with Bils and Klenow (2004). I set the growth rate of technology (and money supply) to $a = 0.5\%$ a quarter so that the economy is growing by 2% on average each year. I use a money growth autocorrelation parameter ρ_m of 0.5 following Krause and Lubik (2007). Turning to the labor market, I use a middle value for the matching function elasticity $\eta = 0.5$ and set the bargaining weight $\gamma = \eta$ following the Hosios (1990) condition. The scale parameter of the matching functions m_0 is chosen such that, as reported in den Haan, Ramey and Watson (2000), a firm fills a vacancy with a quarterly probability $q(\theta) = 0.7$ and, as used in Thomas (2008), a worker finds a job with probability $\theta q(\theta) = 0.6$. Following Shimer (2005), the separation rate is 10% so jobs last for about 2.5 years on average, and the income replacement ratio is set to 40%. I choose $\sigma_h = 2$ (i.e. an hours per worker elasticity of 0.5) and need to decide on σ_e to fix a value for φ. Bils and Cho (1994) build a model to account for the procyclicality of labor productivity. In doing so, they allow for variable effort *and* variable capital utilization. The present model does not consider capital explicitly but implicitly if one assumes a constant capital-labor ratio. A key

[13] The equations are presented in the Appendix.

hypothesis of Bils and Cho (1994) is that the capital utilization rate is proportional to hours. If a worker works longer hours and at a more intense pace, the utilization of the capital he operates will also tend to increase. As a result, changes in hours per worker proxy not only for variations in effort but also for unobserved changes in capital utilization. In that case, Schor's (1997) estimate for the elasticity of effort with respect to hours $\frac{\sigma_h}{1+\sigma_e} = 0.5$ delivers a value for φ of 1.5. I set σ_e accordingly in order to match this estimate.[14] Finally, and consistent with the aim of the paper to reassess Shimer's puzzle while controlling for the endogeneity of productivity, I set the standard deviations of technology and monetary policy shocks σ^a and σ^m equal to the standard deviations of technology and non-technology shocks estimated with the structural VAR.[15]

3.3 Simulation

Figure 2 and 3 show the impulse response functions after technology shocks and monetary policy (or aggregate demand) shocks. A first observation is that this New Keynesian MP model fulfills the two necessary conditions to reassess Shimer's puzzle: it is successful at replicating the productivity responses to both shocks (or put differently, it can be used to control for the endogeneity of productivity), and it gets the sign of labor market tightness responses right. Nonetheless, the Shimer puzzle is apparent after both shocks: model labor market tightness moves a lot less than its empirical counterpart.

However, after a non-technology shock, the standard deviation of model labor market tightness over the first two years after a technology shock is almost 9 times larger than for model output per hour. Since the empirical ratio is 21, the MP model explains in fact 40% of labor market tightness fluctuations following an aggregate demand shock. This back-of-the-envelope calculation suggests that the misidentification of productivity shocks and the endogeneity of productivity may be responsible for some of the Shimer puzzle.

Using a calibrated version of the model, I simulate 50 years of data, and I repeat the exercise

[14] This calibration is consistent with Basu and Kimball (1997) evidence that φ ranges between 1.28 to 1.6.
[15] With this calibration, the model matches the persistence and volatility of the US output per hour series.

5000 times. Following Shimer (2005), I detrend the model generated productivity series, and in Table 2, I report the summary statistics for the simulated labor market variables. Despite a baseline Mortensen-Pissarides structure of the labor market and a standard calibration, simulated θ is 9 times more volatile than the cyclical component of labor productivity, while the ratio comes at about 26 in US data. I conclude that the MP model can account for about a third, rather than 10 percent, of labor market tightness fluctuations.

In other dimensions, the model performs remarkably well as the cross-correlations have the right signs and are not far off the true values. In particular, unemployment is only weakly correlated with productivity (-0.24) and matches quite closely its empirical counterpart (-0.23). However, the autocorrelation of model vacancies is 0.42 instead of 0.90 for US data. This is due to the excessively rapid response of vacancies. This problem was already pointed out by Fujita and Ramey (2004) and incorporating sunk costs for vacancy creation as in Fujita and Ramey (2004) would presumably correct this shortcoming. Similarly, this excess sensitivity of vacancies can explain the slightly too high vacancy-productivity and labor market tightness-productivity correlations (both 0.49, compared with empirical values of 0.25 and 0.19).

3.4 Robustness

Since the main result of this paper comes out of a calibration exercise, I present in Table 4 the influence of key parameters on the ability of the extended MP model to generate fluctuations in labor market variables. First, I span the range of plausible values for the elasticity of the matching function from $\eta = 0.24$ (Hall, 2005) to 0.72 (Shimer, 2005) and find that the MP model explains between roughly 25 and 50 percent of fluctuations in θ.[16] The return to hours coefficient is also an important parameter, and Basu and Kimball (1998) estimates that it ranges between 1.3 and 1.6. Within this interval, the MP model accounts for between 30 and 60 percent of unemployment fluctuations. With a higher degree of price stickiness (one year),

[16] It is important to note that the elasticity of the matching function has a large impact on the performance of the New Keynesian MP model. However, Mortensen and Nagypal (2005) show that this is not the case for the baseline MP model: a value $\sigma = 0.44$ instead of $\sigma = 0.72$ barely changes the elasticity of market tightness with respect to productivity and does not help to overturn Shimer's conclusion.

the MP model accounts for almost 50% of fluctuations in θ. Finally, varying the value of the income replacement ratio from 0.4 (Shimer, 2005) to the high value used in Hagedorn and Manovskii (2005) of $b = 0.9$ improves the "amplification properties" of the New Keynesian MP model so much that it generates too much volatility in θ. Similarly, lowering the worker's bargaining weight improves the performance of the MP model, and a low value $\gamma = 0.05$ as in Hagedorn and Manovskii (2005) allows the MP model to account for 40% of labor market tightness fluctuations.[17]

4 Conclusion

In a very important paper, Shimer (2005) argues that the Mortensen-Pissarides search model of unemployment lacks an amplification mechanism because it cannot generate the observed business cycle fluctuations in unemployment given labor productivity shocks of plausible magnitude.

In this paper, I show that because of the endogeneity of measured labor productivity, filtering out the trend component of output per hour as in Shimer (2005) may not correctly identify the shocks driving unemployment. In fact, using long-run restrictions in a structural VAR model to isolate exogenous productivity shocks, I find that a permanent increase in productivity lowers the vacancy-unemployment ratio, while the MP model implies the opposite. I embed the MP model in a New-Keynesian framework to (i) account for this empirical evidence, and (ii) control for the endogeneity of productivity, and I estimate that the MP model can account for a third, and possibly as much as 60 percent, of fluctuations in labor market variables.

Interestingly, this finding is in line with the work by Pissarides (2007) who reconsiders the Shimer puzzle in the context of an MP model with endogenous job destruction. Pissarides (2007) reestimates the unemployment volatility puzzle downwards and claims that "with endogenous job destruction, the model fails to account for about half to two thirds of the volatility

[17] Interestingly, this implies that Hagedorn and Manovskii's (2005) calibration with a high income replacement ratio and low worker's bargaining weight generates too much volatility in θ.

in unemployment” instead of the 90% originally estimated by Shimer (2005). If a third of the Shimer puzzle is due to the misidentification of productivity shocks and another 30 to 50 percent is due to the omission of endogenous job destruction, the low volatility of unemployment relative to that of productivity may be less of a problem than originally thought.

Appendix

Log-linearized equilibrium dynamics

To analyze the behavior of the economy, I log-linearize the first-order conditions around the (zero-inflation) long run equilibrium.

The optimal vacancy posting condition takes the form

$$\frac{c_t}{q(\theta_t)} = E_t \beta_{t+1} \left[\chi_{it+1} + \frac{c_{t+1}}{q(\theta_{t+1})}(1-\lambda) \right] \tag{3}$$

with χ_{it}, the shadow value of a marginal worker, given by

$$\chi_{it} = -w_{it} + (1-\gamma)\varkappa \frac{1+\sigma_h}{\varphi} \frac{h_{it}^{1+\sigma_h}}{\lambda_t}$$

Since $\frac{1}{q(\theta_t)}$ is the expected duration of a vacancy, equation (3) has the usual interpretation: each firm posts vacancies until the expected cost of hiring a worker $\frac{c_t}{q(\theta_t)}$ equals the expected discounted future benefits $\{\chi_{it+j}\}_{j=1}^{\infty}$ from an extra worker. Because the firm is demand constrained, the flow value of a marginal worker is not his contribution to revenue but his reduction of the firm's wage bill. The first term of χ_{it} is the wage payment going to an extra worker, while the second term represents the savings due to the decrease in hours and effort achieved with that extra worker.

Log-linearizing the vacancy posting condition equation around the (zero-inflation) steady state, I get for any $t > 0$

$$\frac{c\eta}{q(\theta^*)}\hat{\theta}_t = E_t \beta \left[\chi^* \hat{\chi}_{it+1} + \frac{c(1-\lambda)\eta}{q(\theta^*)}\hat{\theta}_{t+1} \right]$$

with the value of a marginal worker $\hat{\chi}_{it+1}$ given by

$$\chi^* \hat{\chi}_{it+1} = -\gamma c \theta \hat{\theta}_t + \frac{1}{n\mu}\left(\frac{1+\sigma_h}{\varphi} - 1\right)(\hat{y}_{it+1} - \hat{n}_{it+1})$$

With Calvo-type price setting, a firm resetting its price at date t will satisfy the standard Calvo price setting condition:

$$E_t \sum_{j=0}^{\infty} \nu^j \beta_j \left[\frac{P_{it}^*}{P_{t+j}} - \mu s_{it+j} \right] Y_{t+j} P_{t+j}^{\varepsilon} = 0$$

where the optimal mark-up is $\mu = \frac{\varepsilon}{\varepsilon - 1}$ and the firm's real marginal cost

$$s_{it} = \frac{1+\sigma_h}{\varphi} (1-\gamma) \varkappa \frac{Y_t}{A_t} h_{it}^{1+\sigma_h-\varphi}$$

The firm will choose a price P_{it}^* that is, in expected terms, a constant mark-up μ over its real marginal cost for the expected lifetime of the price.

To derive the New-Keynesian Phillips curve, I log-linearize around the zero inflation equilibrium. However, because of firms' ex-post heterogeneity, the derivation is not as straightforward as with costly price adjustment. I follow Woodford's (2004) similar treatment of endogenous capital in a New-Keynesian model with Calvo price rigidity. In my case, employment is the state variable and plays the role of capital in Woodford's model. The price-setting condition becomes

$$\sum_{k=0}^{\infty} (\nu\beta)^k \hat{E}_t^i \left[\tilde{p}_{it+k} - \hat{s}_{it+k} \right] = 0 \tag{4}$$

with

$$\hat{s}_{it+k} = \hat{n}_{it+k} + \frac{1+\sigma_h}{\varphi} \left(\hat{y}_{it+k} - \hat{n}_{it+k} \right) - \hat{y}_{it+k} + \hat{y}_{t+k} \tag{5}$$

The notation $\hat{E}_t^i$ denotes an expectation conditional on the state of the world at date t but integrating only over future states in which firm i has not reset its price since period t. $\tilde{p}_{it} \equiv \log\left(\frac{P_{it}}{P_t}\right)$ is the firm's relative price.

Denoting log prices by lower-case letters and p_{it}^* the optimal (log) price for firm i at t, the demand curve for firm i at date $t+1$ can be written $\hat{y}_{it+1} = \hat{y}_{t+1} - \varepsilon(p_{it} - p_{t+1})$ if it cannot reset its price at $t+1$ and $\hat{y}_{it+1} = \hat{y}_{t+1} - \varepsilon(p_{it+1}^* - p_{t+1})$ if it can reset its price.

Averaging across all firms, I get

$$\begin{aligned}\int_0^1 \hat{y}_{it+1}di &= \hat{y}_{t+1} - \varepsilon\left[\nu(\int_0^1 p_{it}di - p_{t+1}) + (1-\nu)(\int_0^1 p^*_{it+1}di - p_{t+1})\right] \\ &= \hat{y}_{t+1} - \varepsilon\left[\nu(p_t - p_{t+1}) + (1-\nu)(p^*_{t+1} - p_{t+1})\right] \qquad (6)\end{aligned}$$

where $p^*_{t+1} = \int_0^1 p^*_{it+1}di$ is the average price chosen by all price setters at date $t+1$.

With Calvo price-setting, I can write

$$p_{t+1} = \left((1-\nu)p^{*1-\varepsilon}_{t+1} + \nu p_t^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}$$

or

$$1 = (1-\nu)\left(\frac{p^*_{t+1}}{p_{t+1}}\right)^{1-\varepsilon} + \nu\left(\frac{p_t}{p_{t+1}}\right)^{1-\varepsilon}.$$

Log-linearizing around the zero-inflation equilibrium gives $-\nu(p_{t+1} - p_t) = (1-\nu)(p^*_{t+1} - p_{t+1})$ and combining with (6) gives $\int_0^1 \hat{y}_{it+1}di = \hat{y}_{t+1}$. Further, $\int_0^1 \hat{n}_{it}di = \hat{n}_t$.

Averaging (5) across all firms, I can rewrite the real marginal cost as

$$\hat{s}_{it+k} = \hat{s}_{t+k} + \left(\frac{1+\sigma_h}{\varphi} - 1\right)(-\varepsilon\tilde{p}_{it+k} - \tilde{n}_{it+k}) \qquad (7)$$

where $\tilde{n}_{it+k} = n_{it+k} - n_{t+k}$ is the relative employment of firm i.

Using that $\hat{E}^i_t\tilde{p}_{it+k} = p_{it} - E_t p_{t+k}$ and (7) in (5) yields

$$\left(1 + \varepsilon\left(\frac{1+\sigma_h}{\varphi} - 1\right)\right)p^*_{it} = (1-\nu\beta)\sum_{k=0}^{\infty}(\nu\beta)^k\hat{E}^i_t\left[\hat{s}_{t+k} + \left(1 + \varepsilon\left(\frac{1+\sigma_h}{\varphi} - 1\right)\right)p_{t+k} - \left(\frac{1+\sigma_h}{\varphi} - 1\right)\tilde{n}_{it+k}\right] \qquad (8)$$

Moreover, subtracting (**??**) from its average, I get

$$\begin{aligned}
\tilde{n}_{it+1} &= E_t(\hat{y}_{it+1} - \hat{y}_{t+1}) \\
&= -\varepsilon E_t\left[\nu(p_{it} - p_{t+1}) + (1-\nu)(p^*_{it+1} - p_{t+1}\right] \\
&= -\varepsilon\nu\tilde{p}_{it} - \varepsilon(1-\nu)(p^*_{it+1} - p^*_{t+1})
\end{aligned} \tag{9}$$

since $p_{t+1} = \nu p_t + (1-\nu)p^*_{t+1}$.

The firm's pricing decision depends on its employment level and the economy's aggregate state. But to a first order, the log-linearized equations are linear so that the difference between p^*_{it} and p^*_t, the average price chosen by all price setters, is independent from the economy's aggregate state and depends only on the relative level of employment $n_{it} - n_t = \tilde{n}_{it}$. So as in Woodford (2004), I guess that the firm's pricing decision takes the form

$$p^*_{it} - p^*_t = -\epsilon\tilde{n}_{it} \tag{10}$$

with ϵ a constant to be determined. Hence, (9) becomes

$$\tilde{n}_{it+1} = \frac{-\varepsilon\nu}{1-\varepsilon(1-\nu)\epsilon}\tilde{p}_{it} = -f(\epsilon)\tilde{p}_{it}$$

Since this was shown for any $t > 0$, I also get $\tilde{n}_{it+k} = -f(\epsilon)\tilde{p}_{it+k-1}$, $\forall k > 0$ so that I can rewrite (8) as

$$\phi p^*_{it} = (1-\nu\beta)\sum_{k=0}^{\infty}(\nu\beta)^k\hat{E}^i_t\left[\hat{s}_{t+k} + \left(1+\varepsilon\left(\frac{1+\sigma_h}{\varphi} - 1\right)\right)p_{t+k}\right] - (1-\nu\beta)\left(\frac{1+\sigma_h}{\varphi} - 1\right)\tilde{n}_{it} \tag{11}$$

with $\phi = \left(1+\varepsilon\left(\frac{1+\sigma_h}{\varphi} - 1\right) - \nu\beta\left(\frac{1+\sigma_h}{\varphi} - 1\right)f(\epsilon)\right)$.

Subtracting (11) from its average, I obtain

$$\phi(p^*_{it} - p^*_t) = -(1-\nu\beta)\left(\frac{1+\sigma_h}{\varphi} - 1\right)\tilde{n}_{it}. \tag{12}$$

This equation is of the conjectured form (10) if and only if ϵ satisfies

$$\epsilon = \frac{(1-\nu\beta)\frac{1+\sigma_h}{\varphi} - 1}{1 + \varepsilon\left(\frac{1+\sigma_h}{\varphi} - 1\right) - \nu\beta\left(\frac{1+\sigma_h}{\varphi} - 1\right) f(\epsilon)}. \tag{13}$$

Finally, averaging (11) and using $\pi_t = \frac{1-\nu}{\nu}(p_t^* - p_t)$, I obtain the New-Keynesian Phillips curve

$$\pi_t = \delta.\hat{s}_t + \beta E_t \pi_{t+1}$$

with $\delta = \frac{(1-\nu)(1-\nu\beta)}{\nu\phi}$.

References

[1] Andolfatto, D. “Business Cycles and Labor-Market Search,” *American Economic Review*, 86(1), 1996.

[2] Barnichon, R. “Productivity, Aggregate Demand and Unemployment Fluctuations,” Finance and Economics Discussion Series 2008-47, Board of Governor of the Federal Reserve System, 2008.

[3] Basu, S. and M. Kimball. “Cyclical Productivity with Unobserved Input Variation,” *NBER Working Papers* 5915, 1997.

[4] Bils, M. and J. Cho. “Cyclical Factor Utilization,” *Journal of Monetary Economics*, 33, 319-354, 1994.

[5] Burnside, C., Eichenbaum, M. “Factor-Hoarding and the Propagation of Business-Cycle Shocks,” *American Economic Review,* 86(5), pp. 1154-1174, 1996.

[6] Burnside, C., Eichenbaum, M. and S. Rebelo. “Labor Hoarding and the Business Cycle,” *Journal of Political Economy*, 01(2), pp. 245-73, 1993.

[7] Canova, F., C. Michelacci and D. López-Salido, “Schumpeterian Technology Shocks,” mimeo CEMFI, 2007.

[8] Fujita, S. and G. Ramey. “Job Matching and Propagation,” *Journal of Economic Dynamics and Control*, Forthcoming.

[9] Galí, J. “Technology, Employment and The Business Cycle: Do Technology Shocks Explain Aggregate Fluctuations?,” *American Economic Review*, 89(1), 1999.

[10] Galí, J and P. Rabanal. “Technology Shocks and Aggregate Fluctuations: How Well Does the RBC Model Fit Postwar U.S. Data?,” *NBER Macroeconomics Annual*, 2004.

[11] Hagedorn, M. and I. Manovskii. "The Cyclical Behavior of Equilibrium Unemployment and Vacancies Revisited," Univerity of Pennsylvania mimeo.

[12] Hall, R. "Employment Fluctuations with Equilibrium Wage Stickiness," *American Economic Review*, 95(1), pp. 50-65, 2005.

[13] Hall, R. "Job Loss, Job Finding, and Unemployment in the U.S. Economy over the Past Fifty Years," *NBER Macroeconomics Annual*, pp. 101-137, 2005.

[14] Hall, R. and P. Milgrom. "The Limited Influence of Unemployment on the Wage Bargain," *American Economic Review*, 98(4), pp. 1653-1674, 2008.

[15] Krause, M and T. Lubik. "The (Ir)relevance of Real Wage Rigidity in the New Keynesian Model with Search Frictions", *Journal of Monetary Economics*, 54(3), 2007.

[16] Mertz, M. "Search in the Labor Market and the Real Business Cycle," *Journal of Monetary Economics*, 49, 2002.

[17] Mortensen, D. and E. Nagypal. "More on Unemployment and Vacancy Fluctuations," *NBER Working Papers* 11692, 2005.

[18] Mortensen, D and C. Pissarides. "Job Creation and Job Destruction in the Theory of Unemployment," *Review of Economic Studies*, 61, 397-415, 1994.

[19] Pissarides, C. "The Unemployment Volatility Puzzle: Is Wage Stickiness the Answer?," The Walras-Bowley lecture, North American Summer Meetings of the Econometric Society, Duke University, June 21-24, 2007

[20] Schor J., "Does Work Intensity Respond to Macroeconomic Variables? Evidence from British Manufacturing," Working Paper, 1987.

[21] Shimer, R. "The Consequences of Rigid Wages in Search Models," *Journal of the European Economic Association (Papers and Proceedings)*, 2: 469-479, 2004.

[22] Shimer, R. "The Cyclical Behavior of Equilibrium Unemployment and Vacancies," *American Economic Review*, 95(1), pp. 25-49, 2005.

Table 1: Summary Statistics, Quarterly US Data, 1951-2005

		u	*v*	θ	*p*
Standard deviation		0.125	0.139	0.257	0.010
Quarterly autocorrelation		0.87	0.90	0.89	0.69
Correlation matrix	*u*	1	-0.95	-0.97	-0.23
	v	-	1	0.98	0.25
	θ	-	-	1	0.19
	p				1

Notes: Seasonally adjusted unemployment *u* is constructed by the BLS from the Current Population Survey (CPS). The seasonally adjusted help-wanted advertising index *v* is constructed by the Conference Board. Labor market tightness is the vacanc-unemployment ratio. Average labor productivity *p* is seasonally adjusted real average output per person in the non-farm business sector, constructed by the Bureau of Labor Statistics (BLS) from the National Income and Product Accounts and the Current Employment Statistics. All variables are reported in logs as deviations from an HP trend with smoothing parameter 1600.

Table 2: Calibration

Discount rate	β=0.99	
Matching function elasticity	σ=0.5	
Bargaining weight	γ=σ	Hosios (1990)
Probability vacancy is filled	q(θ)=0.7	den Haan, Ramey and Watson (2000)
Job finding probability	θq(θ)=0.6	Thomas (2008)
Separation rate	λ=0.1	Shimer (2005)
Income replacement ratio	b=0.4	Shimer(2005)
Returns to scale to efficient hours	α=0.64	
Disutility of hours	σ_h=2	
Short-run increasing returns to hours	φ=1.5	Schor (1997)
Growth rate of 2% a year	a_0=0.5%	
Degree of price stickiness	ν=0.5 (2 quarters)	Bils and Klenow (2004)
Mark-up of 10%	ε=11	
AR(1) process for money growth	ρ_m=0.5	Krause and Lubik (2007)
Standard-deviation of monetary policy shock	σ_m=0.0226	
Standard-deviation of technology shock	σ_a=0.006	

Table 3: Summary Statistics, Model

		u	v	θ	p
Standard deviation		0.042 (0.004)	0.065 (0.004)	0.089 (0.008)	0.010 (0.001)
Quarterly autocorrelation		0.85 (0.03)	0.42 (0.06)	0.74 (0.05)	0.69 (0.05)
Correlation matrix	u	1	-0.35 (0.07)	-0.72 (0.04)	-0.24 (0.10)
	v	-	1	0.90 (0.01)	0.49 (0.07)
	θ	-	-	1	0.49 (0.08)
	p	-	-	-	1

Notes: Standard errors-the standard deviation across 5000 model simulations-are reported in parentheses.

Table 4: Robustness

		Parameter value	$\sigma^{MP}(\theta)$	*Share of $\sigma^{US}(\theta)$ explained by MP model*
Matching function elasticity	η	0.24 0.72	0.11 0.61	47% 25%
Return to hours	φ	1.3 1.6	0.15 0.07	60% 27%
Degree of price stickiness	ν	0.75	0.12	47%
Income replacement ratio	b	0.2 0.9	0.61 0.29	25% 116%
Worker's bargaining weight	γ	0.5 0.05	0.85 0.10	33% 40%

Notes: $\sigma^{MP}(\theta)$ is the model generated standard-deviation of labor market tightness and $\sigma^{US}(\theta)$ is its empirical counterpart.

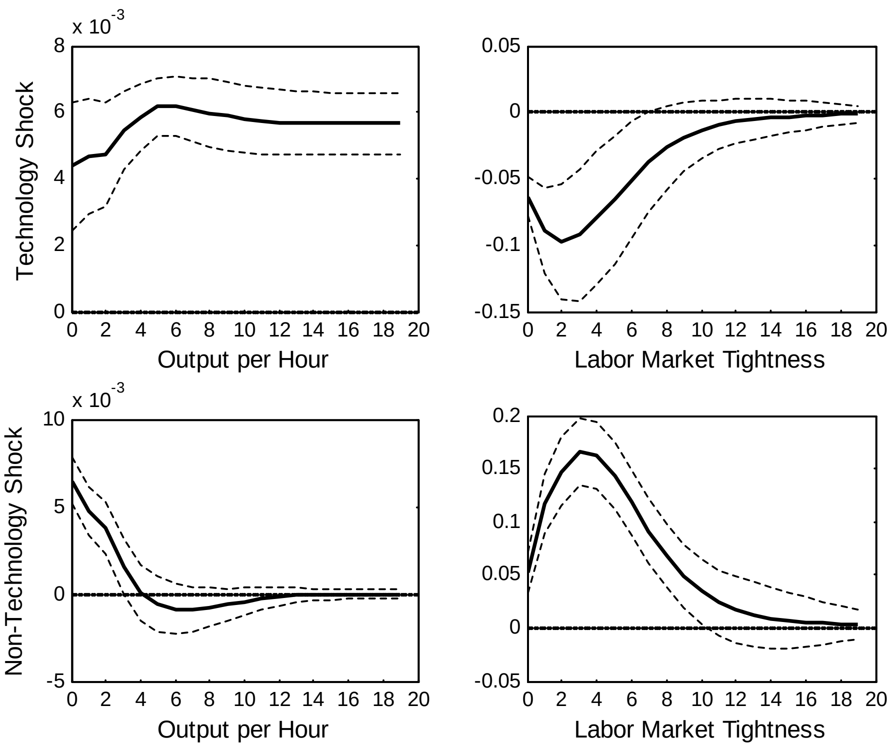

Figure 1: Impulse response functions to one s.d. shocks. Dashed lines represent the 95% confidence interval.

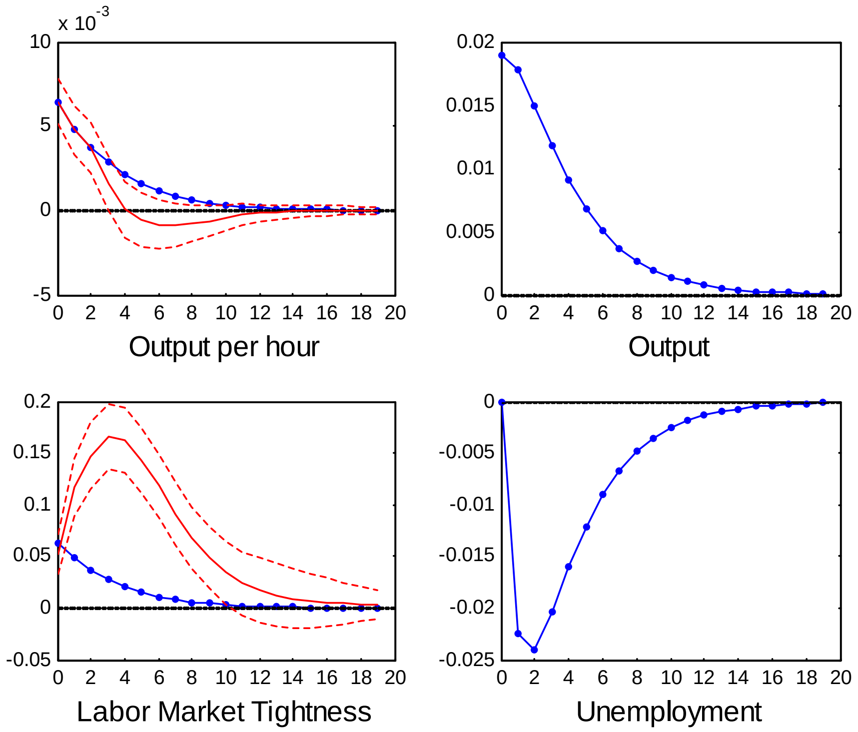

Figure 2: Model (dotted line) and Empirical (plain line) impulse response functions to a positive monetary policy shock. Dashed lines represent the 95% confidence interval.

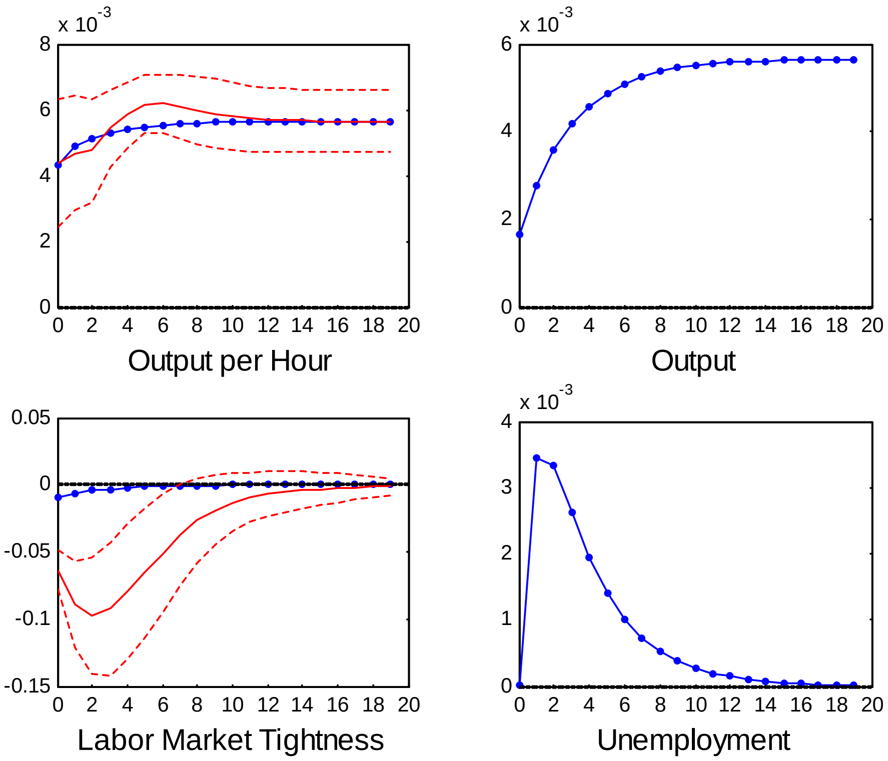

Figure 3: Model (dotted line) and Empirical (plain line) impulse response functions to a positive technology shock. Dashed lines represent the 95% confidence interval.