Business Cycle Dynamics and the Two Margins of Labor Adjustment*

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Abstract

In a seminal paper Galí (1999) argues that a positive shock to the level of technology implies a negative impact on hours worked. Recently, Canova et al. (2008a and 2008b) extend this analysis in an important way and show that the adjustment in total hours is made both by the employment (extensive) and the hours (intensive) margin. Moreover they show that investment specific shocks imply almost exclusively adjustments along the intensive margin. In this paper we show that a simple New Keynesian model feauturing capital accumulation, two margins of labor adjustment and hiring costs is able to account for the effects of neutral and investment specific techology shocks. Nominal rigidities

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in the form of sticky prices are essential to induce a contraction in hours and employment on the impact of neutral technology shocks and an increase in the same variables on the impact of an investment specific shock.

1 Introduction

The effect of neutral technology shocks on hours worked has received much attention in the last ten years in macroeconomics. The seminal paper of Galí (1999) provides empirical evidence in favor of a negative response of hours after a positive productivity shock, which questions the relevance of technology shocks as the main driving force of aggregate fluctuations as claimed in the Real Business Cycle (RBC) literature. For in the data hours worked is pro-cyclical. Nominal rigidities (in the form of sticky prices and/or sticky wages as in Galí 1999) and real rigidities (in the form of habit persistence and capital adjustment costs as in Francis and Ramey 2005) are necessary to reconcile modern DSGE models with the empirical evidence.

The early literature focuses on the effects of technology shocks on total hours. Recently, Canova et al. (2008a and 2008b) make important contributions to the empirical evidence by allowing for two margins of labor adjustment in a vector autoregressive (VAR) model identified through long-run restrictions as in Fisher (2006). Importantly, they show that labor contracts along both margins following a positive neutral technology shocks, although the effect on the extensive margin is slightly larger (around 60% of the response of total hours).[1] In addition, Canova et al. investigate the effects of investment specific technology shocks following the methodology developed by Fisher (2006). The authors find that these shocks have an expansionary effect on total hours, but the adjustment is made almost exclusively along the intensive margin (per capita hours). The response of employment is positive but not significant. This is an interesting observation. For these shocks have received increasing attention also in the literature on estimated DSGE models. Justiniano, Primiceri and Tambalotti (2008) find that investment-specific shocks

[1] Baleer (2007) and Barnichon (2008) find a significant effect on unemployment using the same methodology. A crucial feature of these papers is that they include a trend to deal with low frequency movements in the variables, which they argue is essential for estimating the model on a long sample (1955-2000). Importantly, the results do not depend on how hours are introduced in model (in levels or in first differences). Braun et al. (2007) and Ravn and Simonelli (2008) find less clearcut results. However, none of the papers include a trend in the specification of the VAR.

are the main source of aggregate fluctuations in a standard DSGE model (similar to Smets and Wouters (2007)) estimated on US data over the period 1945-2004.

The aim of this paper is to analyze to which extent the empirical evidence described above can be rationalized within a New Keynesian set-up with labor market frictions. To this end we extend the basic New Keynesian model to include capital accumulation, since we are interested also in investment specific shocks, and labor market frictions with two margins of adjustment, since we want to study the split across the two margins. We are not aware of any model in the New Keynesian literature that combines these two elements.[2] A large and growing literature includes two margins of labor adjustment in models without capital (see, e.g., Trigari 2004 and 2006)) and there are many examples that combine capital accumulation and labor market frictions but with only the extensive margin of labor adjustment.[3] We bridge the gap and combine capital accumulation (subject to standard capital adjustment costs) and two margins of labor adjustment (modeled as in Sveen and Weinke 2007). We do that in the context of a New Keynesian model with labor market frictions following the work by Blanchard and Gali (2008).

Our main result is that our model can rationalize the empirical findings outlined above. On the impact of a productivity shock, the model features a large decline in per capita hours and in employment. Moreover, the response is larger along the extensive margin in keeping with Canova et al. (2008a and 2008b). The result relies entirely on nominal rigidities. In fact, in a flexible-price version of the model, hours and employment barely move (approximating the "neutrality result", i.e. the fact that hours and employment are invariant to neutral shocks, derived by Blanchard and Gali (2008) and Shimer (2009) in models with no capital accumulation). Under nominal rigidities instead, neutral shocks imply a contraction on hours and employment. As in Gali (1999), demand is sluggish and does not adapt to the modified

[2] Krause and Lubik (2008) have two margins of labor adjustment in a RBC model and they emphasize the importance of modelling the two margins.

[3] See, e.g., Andolfatto (1996), Merz (1996), Mandelman and Zanetti (2008), Silva and Toledo (2007), Shimer (2009) in the RBC literature, and Andres, Domenech and Ferri (2006) and Gertler, Sala and Trigari (2008) in the New Keynesian literature.

supply conditions because of sticky prices. Therefore, firms find it optimal to reduce the labor impact on both margins. The fact that new hires become productive immediately and the fact that the market for hires is continuously open, as in Blanchard and Gali (2008), are crucial for our results. Importantly, monetary policy is not optimal in our model, as in Gali (1999). However, unlike Gali (1999), our results are derived using an interest rate rule and not an exogenous money growth rule.

The model can also replicate the evidence on investment specific shocks. Both hours per capita and employment increase but the response of hours per capita is relatively larger, in keeping with Canova et al. (2008a and 2008b). Importantly, in the flexible-price version of our model hours increases less and the employment response becomes negative.

Canova et al. (2008a) rationalize their evidence in the context of a growth model featuring a vintage structure of technology shocks and search and matching frictions in the labor market. In their model only a fraction of firms can adopt the most recent technologies and only newly created jobs adopt immediately the new technology. This forces the less efficient firms to quit the market and creates a wave of Shumpeterian creative destruction. However, while the model with vintage technology can reproduce a sizeable increase in unemployment on the impact of a technology shock, the baseline version presented in Canova et al. (2008a) shows an increase in hours per employee which is counterfactual according to the empirical evidence provided in the same paper. Moreover, we believe it is interesting to analyze the question within a framework that is widely used in the profession, both in academics and in central banks.

It is important to note that our results are not obvious. As a benchmark model we take the basic model of Trigari (2006) with search and matching frictions a la Mortensen and Pissarides (1994). In the context of that model, we can not rationalize a sizeable increase in unemployment on the impact of a positive technology shock. Moreover, the bulk of the adjustment is achieved along the intensive margin which, according to Canova et al. (2008a and 2008b) is counterfactual.

The rest of the paper is organized as follows. In section 2 we present the model. In section 3 we discuss our results and we compare our model to the benchmark (Trigari, 2006). In section 4 we discuss the role of monetary policy. Finally, we conclude in section 5.

2 The model

Our model features labor market frictions à la Blanchard and Galí (2007) with two margins of labor adjustment following the work of Sveen and Weinke (2007). In addition we allow for endogenous capital accumulation subject to standard capital adjustment costs.

2.1 Households

There is a continuum of households and each of them consists of a large number of family members.[4] Each period some family members are unemployed while others work for firms.

Each member has the following period utility function

$$U\left(C_t, H_t\left(h\right)\right) = \ln C_t - \chi \frac{H_t\left(h\right)^{1+\eta}}{1+\eta}, \tag{1}$$

where $N_t\left(h\right)$ denotes hours worked in period t by household member h, and C_t is the Dixit–Stiglitz consumption aggregate. Our notation reflects the fact that heterogeneity in hours worked does not translate into consumption heterogeneity. The consumption aggregate is given by

$$C_t \equiv \left(\int_0^1 C_t\left(i\right)^{\frac{\epsilon-1}{\epsilon}} di\right)^{\frac{\epsilon}{\epsilon-1}}, \tag{2}$$

where ϵ is the elasticity of substitution between different varieties of goods $C_t\left(i\right)$.

[4] See Merz (1995) and Andolfatto (1996).

Let $P_t(i)$ is the price of good i. The associated price index is then defined as

$$P_t \equiv \left(\int_0^1 P_t(i)^{1-\epsilon} di \right)^{\frac{1}{1-\epsilon}}. \qquad (3)$$

The latter has the property that the minimum expenditure required to purchase a bundle of goods resulting in C_t units of the composite good is given by $P_t C_t$.

Households are assumed to maximize expected discounted utility of family members

$$E_t \int_0^1 \left[\sum_{k=0}^{\infty} \beta^k U\left(C_{t+k}, H_{t+k}(h)\right) \right] dh, \qquad (4)$$

where β is the subjective discount factor. The maximization is subject to a sequence of budget constraints which take the following form

$$P_t\left(C_t +_t \Psi_t^{-1} I_t\right) + D_t \leq D_{t-1}R_{t-1} + P_t W_t H_t N_t + B_t U_t + T_t + P_t R_t^K K_t. \qquad (5)$$

where I_t is the amount of the aggregate good acquired by the household for investment purposes and we have assumed that the elasticity of substitution is the same as for the consumption aggregate. Variables R_t and W_t are the gross nominal interest rate on bond holdings and the real wage, respectively, while N_t gives the fraction of employed household members and $U_t \equiv 1 - N_t$ is period unemployment. Lump-sum transfers is denoted T_t, which includes dividends resulting from ownership of firms as well as lump-sum taxes, and B_t is unemployment benefits. The latter is indexed by time as it fluctuates with neutral and investment-specific shocks to ensure stationarity in hours and employment, as in Blanchard and Gali (2008). Specifically we have $B_t = BZ_t\Psi_t^{\frac{\alpha}{1-\alpha}}$, where B is a constant, Z_t denotes the level of productivity and Ψ_t represents a shock to the marginal efficiency of investment (investment specific technology shock). Last, we let households own the capital stock, K_t, and rent it out to firm at the real rental rate R_t^K. The capital rental market is assumed to be of perfect competition.

The capital accumulation equation be given by

$$K_{t+1} = (1-\delta)K_t + S\left(\frac{I_t}{K_t}\right)K_t, \tag{6}$$

where δ is the rate of depreciation. Moreover, function $S(\cdot)$ is assumed to satisfy the following: $S(\delta) = \delta$, $S'(\delta) = 1$, $S' > 0$ and $S'' \leq 0$.

The consumer Euler equation implied by this structure takes the standard form

$$1 = R_t E_t \Lambda_{t,t+1}. \tag{7}$$

where $\Lambda_{t,t+1} \equiv \beta\left\{\left(\frac{C_t}{C_{t+1}}\right)\left(\frac{P_t}{P_{t+1}}\right)\right\}$ is the nominal stochastic discount factor.

The first-order conditions with to investment can be written as follows

$$1 = Q_t \Psi_t S^{'}\left(\frac{I_t}{K_t}\right), \tag{8}$$

where Tobin's Q_t is the real period t discounted shadow value of an additional unit of capital in period $t+1$. It is given by

$$Q_t = E_t\left\{\Lambda_{t,t+1}^R\left[R_{t+1}^K + Q_{t+1}\left(1-\delta+S\left(\frac{I_{t+1}}{K_{t+1}}\right)-\left(\frac{I_{t+1}}{K_{t+1}}\right)S^{'}\left(\frac{I_{t+1}}{K_{t+1}}\right)\right)\right]\right\}, \tag{9}$$

where $\Lambda_{t,t+1}^R = \Lambda_{t,t+1}\frac{P_{t+1}}{P_t}$.

2.2 Firms

There is a continuum of monopolistically competitive firms indexed on the unit interval and each firm is assumed to produce a differentiated good, $Y_t(i)$. Technology is Cobb-Douglas,

$$Y_t(i) = K_t(i)^\alpha \left(Z_t N_t(i) H_t(i)\right)^{1-\alpha}, \tag{10}$$

where Z_t indicates an exogenous labor-augmenting technology shock, and $K_t(i)$ denotes the period t capital stock hired by firm i. Last, $N_t(i)$ and $H_t(i)$ denote, respectively, the number of employed and the average hours worked in firm i.

We follow Blanchard and Galí (2007) in assuming restrictions on firms' hiring decisions. The law of motion of employment is given by

$$N_t(i) = (1-s) N_{t-1}(i) + L_t(i), \tag{11}$$

where parameter s denotes the rate of separation and $L_t(i)$ is the newly hired workers in firm i. Moreover, it is implicit in this formulation that workers enters into productive activity immediately when they get hired, as in Blanchard and Galí (2007).

In order to hire firms face hiring costs. They are assumed to take the form per hire

$$G_t = \Upsilon Z_t \Psi_t^{\frac{\alpha}{1-\alpha}} \left(\frac{L_t}{U_t^S}\right)^{\vartheta}. \tag{12}$$

The hiring cost depends on aggregate labor market tightness, as parameterized by parameters Υ and ϑ. Labor market tightness is measured by the fraction of aggregate new hires to the amount of search unemployment, $U_t^S \equiv 1-(1-s)N_{t-1}$, i.e. the fraction of the labor force that is searching for a job at the beginning of period t. The hiring cost fluctuates with the two shocks to insure that permanent shocks have no permanent effect on employment and hours.

Cost minimization on the part of households implies that demand for each individual good i in period t is given by

$$Y_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\epsilon} Y_t, \tag{13}$$

Finally, we assume staggered price setting à la Calvo (1983), i.e. each period a measure $(1-\theta)$ of randomly selected firms get to re-optimize their price while the remaining firms keep their prices constant. Given those assumptions each firm i solves the following problem:

$$\max \sum_{k=0}^{\infty} E_t \left\{ \Lambda_{t,t+1}^R \left[Y_{t+k}(i) \frac{P_{t+k}(i)}{P_{t+k}} - W_{t+k}(i) N_{t+k}(i) H_{t+k}(i) - R_{t+k}^K K_{t+k}(i) - G_{t+k} L_{t+k}(i) \right] \right\}$$

s.t.

$$\begin{aligned}
Y_{t+k}(i) &= \left(\frac{P_{t+k}(i)}{P_{t+k}}\right)^{-\epsilon} Y_{t+k}, \\
Y_{t+k}(i) &= K_{t+k}(i)^{\alpha}\left(Z_{t+k} N_{t+k}(i) H_{t+k}(i)\right)^{1-\alpha}, \\
N_{t+k}(i) &= (1-s) N_{t+k-1}(i) + L_{t+k}(i), \\
P_{t+k+1}(i) &= \begin{cases} P^{*}_{t+k+1}(i) & \text{with prob. } (1-\theta) \\ P_{t+k}(i) & \text{with prob. } \theta \end{cases}.
\end{aligned}$$

The first-order condition for price-setting is given by

$$\sum_{k=0}^{\infty} \theta^{k} E_{t}\left\{\Lambda^{R}_{t,t+1} \frac{Y_{t+k}(i)}{P_{t+k}}\left[P^{*}_{t}(i) - \mu P_{t+k} MC_{t+k}(i)\right]\right\} = 0, \tag{14}$$

where where $P^{*}_{t}(i)$ is the optimally chosen price, $\mu \equiv \frac{\epsilon}{\epsilon-1}$ is the frictionless markup, and $MC_{t}(i)$ denotes firm i's real marginal cost in period t. It is given by

$$MC_{t} = \frac{R^{K}_{t}}{\alpha Y_{t}(i) / K_{t}(i)}. \tag{15}$$

Note, however, that heterogeneity in prices and thereby in output does not translate into heterogeneity in the real marginal cost. The real wage is an increasing function the use of hours, as we show below. For a given level of average hours, firms have constant returns to scale in employment and capital. Therefore, since both hiring costs and the rental price of capital are exogenous to the firm, all firms must have the same marginal cost. We therefore have $MC_{t}(i) = MC_{t}\ \forall i$.[5]

Equation (14) reflects the forward-looking nature of price-setting: firms take into account not only current but also future expected marginal costs. The remaining

[5] Sveen and Weinke (2007) analyze the case where firms in addition to hiring costs face firm-specific labor-adjustment costs.

first-order conditions read

$$\begin{aligned}
\frac{R_t^K}{\alpha Y_t(i)/K_t(i)} &= \frac{W(H_t(i))\,N_t(i) + W'(H_t(i))\,N_t(i)\,H_t(i)}{(1-\alpha)\,Y_t(i)/H_t(i)}, \\
W(H_t(i))\,H_t(i) + G_t &= (1-\alpha)\,MC_t Y_t(i)/N_t(i) + (1-s)\,E_t\left\{\Lambda_{t,t+1}^R G_{t+1}\right\}.
\end{aligned}$$

The first equation states that on the margin the cost of using capital equals the cost of using hours. With wage bargaining the firm takes rationally into account that a marginal change in hours implies a change in its real wage. The second equation has the following interpretation: The left hand side gives the cost associated with hiring one additional worker. That cost includes both a wage payment and hiring costs. The right hand side gives the benefit from hiring one additional worker, i.e., the marginal savings in the cost of using capital associated with having an additional worker in place, as well as expected reductions in future hiring costs.

2.3 Wage negotiation

The household's value of a match with firm i is given by

$$\begin{aligned}
\widetilde{W}_t(i) &= W_t(i)\,H_t(i) - \chi C_t \frac{H_t(i)^{1+\eta}}{1+\eta} + E_t\Big\{\Lambda_{t,t+1}^R\Big[(1-s)\,\widetilde{W}_{t+1}(i) \\
&\quad + s\left(F_{t+1}\widetilde{W}_{t+1} + (1-F_{t+1})\,\widetilde{U}_{t+1}\right)\Big]\Big\}. \qquad (16)
\end{aligned}$$

where $\widetilde{W}_t \equiv \int_0^1 \widetilde{W}_t(i)\,\frac{L_t(i)}{L_t}di$ denotes the average value of a match and $F_t \equiv \frac{L_t}{U_t}$ is the job-finding probability. The value of a match with firm i consists of three elements. First, the real wage income resulting from working $H_t(i)$ hours at the wage $W_t(i)$. Second, the associated disutility of supplying labor (expressed in units of consumption). Third, the expected discounted value of continuing the match in the next period, or of searching for a job.

The value of being unemployed after hiring has taken place is given by

$$\widetilde{U}_t = B_t + E_t\left\{\Lambda_{t,t+1}^R\left[F_{t+1}\widetilde{W}_{t+1} + (1-F_{t+1})\,\widetilde{U}_{t+1}\right]\right\}, \qquad (17)$$

which equals the unemployment benefit and the expected discounted value of looking for a job in the next period.

We follow Blanchard and Galí (2008) in assuming that newly hired workers become productive instantaneously. This implies that the value of a match for firm i corresponds to the cost of hiring a worker

$$\widetilde{J}_t = G(F_t), \tag{18}$$

which is independent of the firm. The value of an open vacancy for firm i is zero, given our assumptions.

The wage is chosen in such a way that the Nash product is maximized, which implies the following first order condition

$$(1-\phi)\,\widetilde{J}_t = \phi\left(\widetilde{W}_t(i) - \widetilde{U}_t\right), \tag{19}$$

where $(1-\phi)$ denotes the weight of workers in the bargain. Next, we substitute for $\widetilde{J}_t$, $\widetilde{U}_t$ and $\widetilde{W}_t(i)$ in the last equation. Noting that $\widetilde{W}_t(i)$ is equal across firms allows us to find the wage resulting from the bargain in the following way

$$W_t(i) = \frac{\chi C_t \frac{H_t(i)^{1+\eta}}{1+\eta} + \Omega_t}{H_t(i)}, \tag{20}$$

where

$$\Omega_t \equiv BZ_t + \frac{1-\phi}{\phi} G(F_t) - \frac{1-\phi}{\phi} E_t\left\{\Lambda^R_{t,t+1}(1-s)(1-F_{t+1})\,G(F_{t+1})\right\}. \tag{21}$$

For future reference let us rewrite the marginal cost in the following way

$$MC_t(i) = \frac{\chi C_t H_t(i)^{\eta} N_t(i)}{Y_t(i)/H_t(i)} = \frac{MRS_t(i)}{Y_t(i)/H_t(i)\,N_t(i)}, \tag{22}$$

where $MRS_t(i)$ denotes the marginal rate of substitution of consumption for leisure, which is common to all workers hired by firm i.

2.4 Monetary policy

Following Gali and Rabanal (2005), we assume that the central bank reacts to inflation (Π_t) and output growth $\left(\frac{Y_t}{Y_{t-1}}\right)$

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho_R} \left[\left(\frac{\Pi_t}{\Pi}\right)^{\phi_\pi} \left(\frac{Y_t}{Y_{t-1}}\right)^{\phi_Y}\right]^{1-\rho_R}$$

where ρ_R denotes the degree of interest rate smoothing.

2.5 Market clearing and exogenous shocks

Market clearing for each variety i requires at each point in time that

$$Y_t(i) = Y_t^d(i). \tag{23}$$

The aggregate resource constraint is given by

$$C_t + \Psi_t^{-1} I_t + \Upsilon Z_t \Psi_t^{\frac{\alpha}{1-\alpha}} \left(\frac{L_t}{U_t}\right)^{\vartheta} L_t = Y_t$$

Finally, clearing of the bond market requires that $B_t = 0$, which holds for all t.

The exogenous shocks are described by autoregressive processes with unit roots to be consistent with the identifying assumptions in the VAR estimated by Canova et al. (2008a and 2008b):

$$\log \Psi_t = \log \Psi_{t-1} + \varepsilon_{\Psi,t}$$

$$\log Z_t = \log Z_{t-1} + \varepsilon_{Z,t}$$

2.6 Calibration

Let us now discuss the values which we assign to the model parameters in most of the quantitative analysis that we are going to conduct. The period length is one quarter. We let β be 0.99, which implies an annual steady state real interest rate of about 4 per cent.

We follow Golosov and Lucas (2007) and set the elasticity of substitution between goods, ϵ, to 7. This implies a steady-state mark-up of about 20 per cent. Our baseline value for the Calvo parameter, θ, is $2/3$, which is consistent with the recent empirical finding of Nakamura and Steinsson (2006) that firms change their prices on average every third quarter.

As far as monetary policy is concerned we set τ_π to 1.5 and τ_y to 0.5 as originally suggested by Taylor (1993) and the parameter measuring interest rate smoothing, ρ_r, is set to 0.8. These parameter values are reasonable given the empirical results in, e.g., Clarida et al. (2000).

The estimates reported by MaCurdy (1981) on the labor supply elasticity center around 0.15, which is our baseline value for $1/\eta$. We follow Shimer (2005) in setting steady state period unemployment to 0.057 and the quarterly job-finding rate to 0.71.[6] Given our model this implies a separation rate of about 0.15[7] and steady-state search unemployment of about 0.20. Following Hall (2005) the unemployment benefit, B, is set to 40% of steady state labor income. In order to calibrate the elasticity in the hiring cost function, ϑ, we follow Blanchard and Galí (2008) and use a simple relationship between the hiring cost model and the Mortensen and Pissarides (1994) model. In the latter, the matching function is given by $L = \omega V^\gamma U^{1-\gamma}$, where V denotes vacancies, γ is the elasticity of the matching function and ω is a constant. In that framework the cost of hiring an additional worker is proportional to $V/L = \omega^{-\frac{1}{\gamma}} F^{\frac{1-\gamma}{\gamma}}$. Estimates for γ are typically around 0.5 and we

[6] We compute the quarterly rate as $0.34 * \sum_{j=1}^{3} (1-0.34)^{j-1}$, where 0.34 is the corresponding monthly rate reported by Shimer.

[7] The values used in the literature range from 0.07 (Merz 1995) to 0.15 (Andolfatto 1996).

correspondingly set $\vartheta = \frac{1-\gamma}{\gamma} = 1$. We choose ϕ (the bargaining power parameter) equal to 0.5 as in Trigari (2004 and 2006). Given the elasticity of the matching function, the first-order condition for employment and the wage equation, both evaluated in steady state, imply two conditions to pin down the steady state wage income WH and parameter Υ. Last, we use χ to pin down hours in steady state to 1/3 of available time.

We set the depreciation rate (δ) at 0.025, the capital share (α) at 0.33, the second derivative of the capital adjustment cost function evaluated in steady state $\left(S''\right)$ at -3 (following Woodford (2003 chapter 5)).

3 Results

In this section we present results on the effects of two shocks and we compare our results to the ones in a model with flexible prices.

3.1 Neutral technology shocks

In figure 1 we simulate the impact of a permanent technology shock in the baseline model presented in section 2. The bold line represents the model with flexible prices whereas the dashed line represents the baseline model with sticky prices.

We first evaluate the model with flexible prices. It is well known that in a model without capital, employment and hours would be invariant to technology shocks. This is the so-called "neutrality result" discovered by Blanchard and Gali (2008) in a model with one margin of labor adjustment (employment) and recovered by Shimer (2009) in a model with two margins of labor adjustment. The "neutrality result" holds as long as there is no capital accumulation and hiring costs and unemployment benefits are indexed to productivity. In our model we model explicitly capital accumulation and therefore we expect to deviate from the "neutrality result". However, we see in figure 1 that the response of employment and hours is very limited, even though the size of capital adjustment costs is relatively small (following Woodford

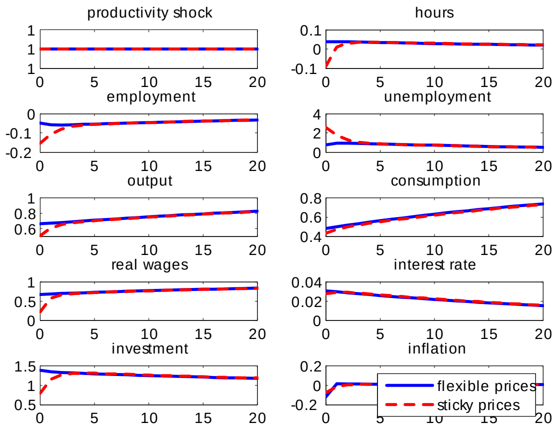

Figure 1: Neutral technology shock in the baseline model

(2003)). Since the indexation on hiring cost and unemployment benefit, although essential to preserve stationarity in employment and hours, has a limited impact on the model dynamics, we can say that our model approximates the "neutrality result" in a more complex set-up.[8]

Impulse responses are significantly different in our baseline model with sticky prices (dashed line). Both margins of labor adjustment contract and, interestingly, employment more than hours in keeping with evidence provided by Canova et al. (2008). Therefore, as in the seminal paper by Gali (1999), sticky prices can induce a contraction in labor on the impact of a neutral technology shock. This is so because sticky prices induce sluggishness in the aggregate demand response to the modified supply conditions. However, in this framework we model capital accumulation explicitly, we split the burden of the adjustment along two margins and monetary policy is modeled using an interest rate rule.

An interesting property of our model is that we can obtain a sizeable response of employment. This is an important result because employment in general fluctuates little in models with labor market frictions (Shimer 2005). In our set-up employment

[8]This implies that the unemployment volatility puzzle discussed by Costain and Reiter (2008), Shimer (2005) and Hall ( ) among others is present also in the flexible-price version of our model.

fluctuates more because we use the timing assumptions originally introduced by Blanchard and Gali (2008).

First, in our framework new hires become immediately productive (see equation 11) whereas in the standard model with search and matching frictions they become productive with a one period delay (see Trigari 2006). Thus, employment is a predetermined variable in the standard search and matching model and it cannot move on impact of the shock by assumption. This is not the case in our model.

Second, in our framework the labor market does not close once employment relationship between workers and firms have been created. Therefore, in case of separation, a firm can always go on the market and hire another worker by paying the hiring cost. This introduces more flexibility in the labor market and employment can fluctuate more.

At this point we want to empathize that our results are not obvious. For sake of comparison, we simulate as a benchmark the model of Trigari (2006). This model is considered as the reference among monetary models with labor market frictions. We used the same calibration as in Trigari (2006). From figure 2 we see that

- the employment response is small and delayed, since new hires become productive with a one period delay.
- the response of hours is large, since the expected time to fill in a vacancy is uncertain. Therefore, firms are reluctant to change employment and they conduct the adjustment along the intensive margin.

Both facts, according to Canova et al. (2008a and 2008b) are counterfactual.[9] Our model instead, using the timing assumptions as in Blanchard and Gali (2008) features results that are in line with the empirical evidence.

To sum up, we have shown that neutral technology shocks have a contractionary effect on employment and hours in the New Keynesian model. Canova et al. (2008a

[9] Importantly, these results hold also when we allow for real wage rigidities or right to manage bargaining, or when we use the calibration a la Hagerdorn-Manovskii (2008).

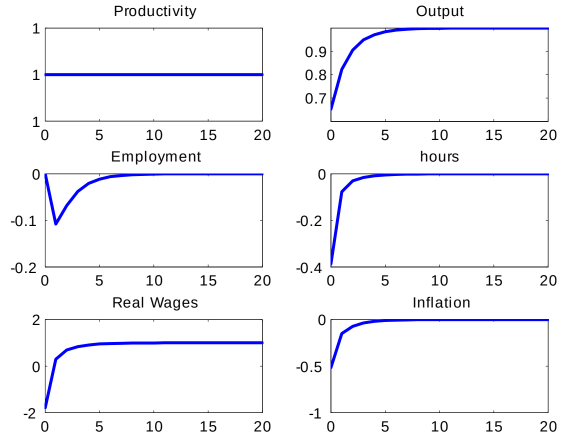

Figure 2: Neutral technology shock in the benchmark model (Trigari 2006)

and 2008b) obtain the same result in a model with Shumpeterian creative destruction effects. We provide an alternative (and not incompatible) explanation to rationalize the empirical evidence provided by the same authors (Canova et al. 2008a and 2008b).

3.2 Investment-specific technology shocks

Investment-specific technology (IST) shocks have received a lot of attention in recent years in macroeconomics, both in the VAR and in the DSGE literature. On the one hand, Fisher (2006) and Canova et al. (2008a and 2008b) show that IST shocks explain a large part of volatility in output and hours. On the other hand, many recent papers find that IST shocks are the most important drivers of aggregate fluctuations in estimated DSGE models (Justiniano, Primiceri and Tambalotti (2008) and Gertler, Sala and Trigari (2008)). Therefore, we believe it is interesting to study IST shocks in our model and see whether we can replicate the empirical evidence provided in Canova et al. (2008a and 2008b).

In figure 3 we simulate a permanent IST shock: the bold line represents the model with flexible prices whereas the dashed line shows the model with four quarters of

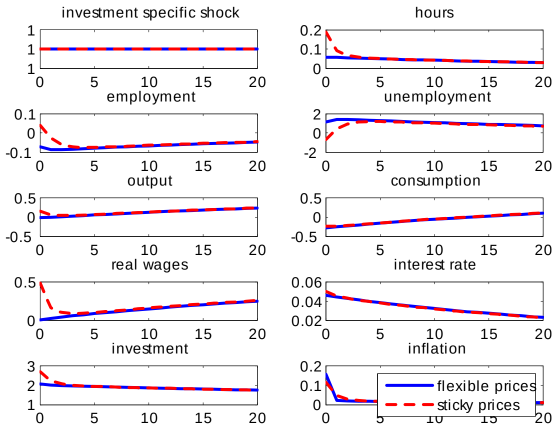

Figure 3: Investment-specific technology shock in the baseline model

price stickiness. We notice that the shock induces a slow and very persistent response in the variables: the model converges to the new steady state after several quarters.

Under flexible prices, hours and employment fluctuate very little, as it was for neutral shocks. The shock behaves like a demand shock because it induces a positive conditional correlation between output and inflation as in Justiniano, Primiceri and Tambalotti (2008). Notice that an increase in the marginal efficiency of investment makes more convenient to invest and this crowds out private consumption. This is the case also in RBC models like Greenwood, Hercowitz and Huffman (1988) and Greenwood, Hercowitz and Krussell (2000).

Under sticky prices, the slow price adjustment favors an investment boom on impact that more than compensates the crowding out of consumption. Therefore, firms have to use more labor to meet the increase in demand. Interestingly, hours grow more than employment (that actually declines slightly after the second quarters) in keeping with the evidence in Canova et al. (2008a and 2008b). The boom in investment is rather short-lived and therefore firms prefer to use hours, a current looking variable, than employment, a forward looking variable. The boom in hours affects wages that depends on labor disutility. On balance the shock is more expansionary under sticky prices with a larger increase in output and a lower increase in prices but the effect vanishes after four quarters.

4 The role of monetary policy

As in Gali (1999), the contractionary effects of neutral technology shocks are related to the central bank behavior. In our baseline model we use the rule used by Gali and Rabanal (2005) in a paper that studies the effects of technology shocks in the last fifty years. This rule can be seen as a good approximation of monetary policy in the sample but it can be quite different from the optimal monetary policy (which is, however, model dependent). To illustrate this point we consider another rule in which the interest rate responds aggressively only to inflation:

$$\frac{R_t}{R} = \left(\frac{\Pi_t}{\Pi}\right)^{\phi_\pi} \tag{24}$$

where ϕ_π is equal to 1.5. This simple rule, although not optimal, can neutralize, at least in part, the distortion coming from sticky prices by responding aggressively to inflation. In figure 4 we plot impulse responses for the neutral technology shock. We see that the sticky prices model exhibits the same dynamics as the flexible prices model and the contractionary effects on labor are reduced. Dotsey (2002) show that the same effect arises in the model by Gali (1999).

However, this is related to the simple structure of our model. In more elaborated DSGE models, many other frictions induce sluggishness in aggregate demand. As an example, we follow Francis and Ramey (2005) and we increase the degree of real rigidities in the model by allowing for habit persistence in consumption and by increasing the degree of capital adjustment costs.[10] We maintain the monetary policy rule that responds aggressively to inflation. In this extended set-up, we see in figure 5 that we obtain large contractionary effects on labor, even though the central bank accommodates strongly the shock. Thus, the main point of our

[10]We set the degree of habit persistence at 0.8 and $S^{''}$ equal to 40.

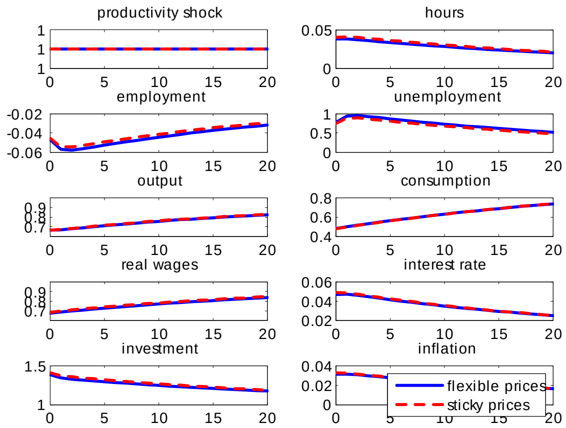

Figure 4: Neutral technology shock with aggressive monetary policy response

analysis in confirmed when monetary policy responds aggressively to inflation, as long as standard real rigidities are present in the model.

As for neutral shock, we simulate a version of the model with real rigidities and aggressive interest rate rule. In this case, the presence of real rigidities limits the initial investment boom (see figure 6). Hours and employment response is lower than in our baseline model whereas the consumption response is now almost zero on impact.

5 Conclusion

Canova et al. (2008a) show that a model with embodied technological progress can reproduce a negative response of employment on the impact of a technology shock. In this paper we provide an alternative, and not incompatible, mechanism to reproduce the same empirical evidence. We show that a simple New Keynesian model with hiring costs and two margins of labor adjustment can induce a sizeable negative response of employment and per-capita hours on the impact of a technology shock. The adjustment is achieved mainly along the extensive margin. Investment specific shocks, instead, induce a positive response along the two margins and the

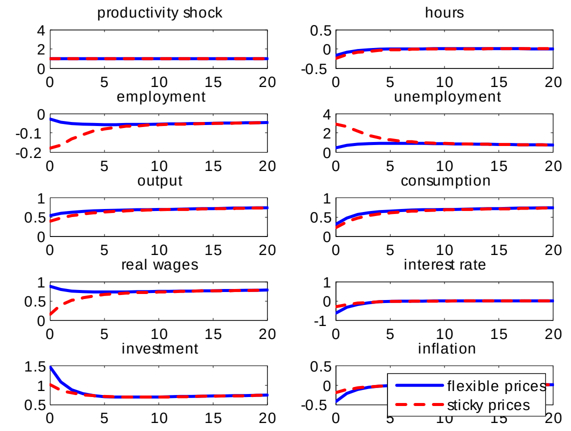

Figure 5: Neutral technology shock in the model with aggressive monetary policy response and real rigidities

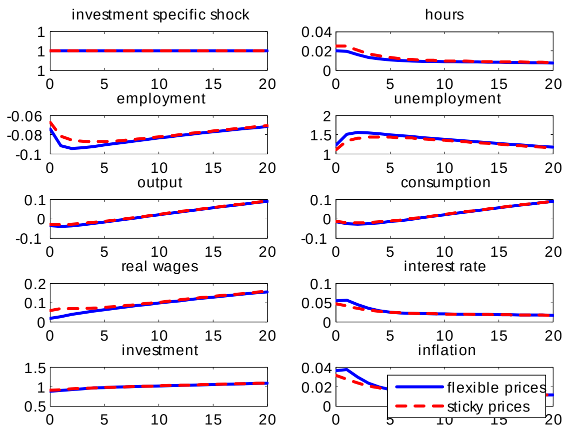

Figure 6: Investment specific technology shock in the model with aggressive monetary policy response and real rigidities

bulk of the adjustment is along the intensive margin. Nominal rigidities are crucial to obtain sizeable effects in keeping with Canova et al. (2008a and 2008b).

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Appendix: the linearized model

In what follows we consider a log-linear approximation to the equilibrium dynamics around a zero inflation steady state. Unless stated otherwise lower case letters denote the log-deviation of the original variable from its steady state value. The consumption Euler equation reads

$$c_t = E_t c_{t+1} - (r_t - E_t \pi_{t+1} - \rho), \tag{25}$$

where parameter ρ denotes the household's time preference rate. Up to the first order aggregate production is given by

$$y_t = \alpha k_t + (1 - \alpha)(z_t + n_t + h_t). \tag{26}$$

The linearized first order conditions with respect to investment and capital read as follows

$$q_t + \psi_t = -\delta S^{\prime}(i_t - k_t)$$

$$q_t = -(r_t - E_t \pi_{t+1}) + (1 - \beta(1 - \delta)) r_{t+1}^k + \beta q_{t+1} + \beta \delta \psi_{t+1}$$

The capital accumulation equation is given by

$$k_t = (1 - \delta) k_{t-1} + \delta i_t$$

Cost minimization by firms implies

$$r_t^k = mc_t + y_t - k_t$$

Aggregating the linearized law of motion of firm-level employment results in

$$n_t = (1 - s) n_{t-1} + s l_t. \tag{27}$$

Linearized unemployment reads

$$u_t = -(1-s)\frac{N}{U}n_{t-1}, \tag{28}$$

where we have used the notation that a variable without a time subscript denotes the steady state value of that variable. Period unemployment is given by

$$u_t^M = -\frac{N}{U^M}n_t. \tag{29}$$

Aggregating and linearizing the first order condition for firm-level employment implies

$$\begin{aligned} WH(w_t + h_t) &= (1-\alpha)\frac{Y}{\mu N}[mc_t + y_t - n_t] - \Upsilon(F)^{\vartheta} \\ &\left[\vartheta f_t + z_t + \frac{\alpha}{1-\alpha}\psi_t + (1-s)\beta E_t\left\{(r_t - \pi_{t+1} - \rho) - \vartheta f_{t+1} - z_{t+1} - \frac{\alpha}{1-\alpha}\psi_{t+1}\right\}\right] \end{aligned} \tag{30}$$

The following relationships holds true

$$f_t = l_t - u_t. \tag{31}$$

The real wage is given by

$$w_t = \frac{\chi C\frac{H^{1+\eta}}{1+\eta}}{WH}c_t + \left(\frac{\chi CH^{1+\eta}}{WH} - 1\right)h_t + \frac{\Omega}{WH}\omega_t, \tag{32}$$

where

$$\omega_t = \frac{(1-\phi)\Upsilon(F)^{\vartheta}}{\phi\Psi}\left[\begin{array}{c} \vartheta f_t + z_t + \frac{\alpha}{1-\alpha}\psi_t + (1-s)\beta E_t\{(1-F)(r_t - \pi_{t+1} - \rho) \\ -((1-F)\vartheta - F)f_{t+1} - \frac{\alpha}{1-\alpha}\psi_{t+1} - (1-F)z_{t+1}\} \end{array}\right] \tag{33}$$

The real marginal cost reads

$$mc_t = c_t + (1+\eta)\, h_t - y_t + n_t. \tag{34}$$

The standard New Keynesian Phillips curve for inflation is derived

$$\pi_t = \beta E_t \pi_{t+1} + \kappa mc_t, \tag{35}$$

where parameter $\kappa = \frac{(1-\beta\theta)(1-\theta)}{\theta}$.

The monetary policy rule is given by

$$r_t = \rho_r r_{t-1} + (1-\rho_r)\left[\rho + \tau_\pi \pi_t + \tau_y (y_t - y_{t-1})\right] \tag{36}$$

Finally, let us state the exogenous driving forces

$$z_t = z_{t-1} + e_{zt}, \tag{37}$$

$$\psi_t = \psi_{t-1} + e_{\psi t}, \tag{38}$$