A New Keynesian Model with Overtime Labor

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Paper number 08/15

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October 2008

Abstract

This paper extends the standard New Keynesian model by incorporating labor adjustment costs and overtime work. I show that labor frictions help reconcile the frequent price changes found in the microdata with the degree of sluggishness in inflation adjustment to output changes at the macro level.

The introduction of labor frictions affects the dynamic behavior of economic variables (particularly employment and inflation) and implies that firms marginal costs should be measured in overtime costs. Marginal costs measured in overtime hours are procyclical and are predicted by inflation as suggested by theory.

JEL Classification: E30, E31, E32.

Keywords: New Keynesian Phillips Curve, business cycle models, labor frictions, inflation dynamics.

1 Introduction

Models that combine price stickiness with monopoly power at the firm level (New Keynesian Phillips Curve models) have become standard specifications and contributed greatly to a better understanding of short-run inflation dynamics. It is normally assumed, in this class of models, that production factors are purchased in a spot market. Altig, Christiano, Eichenbaum and Linde (2005), Woodford (2005), Sveen and Weinke (2004) have departed from this and studied the implications for sticky price models of standard restrictions to capital formation conventional in investment theory (capital becomes productive with a one period delay and is subject to adjustment costs).

In this paper I extend the departure from rental spot markets to the labor input. Following Hall (1996), I assume that firms must commit to the number of workers they will employ before observing shocks to the economy, but are free to adjust the number of employees working overtime in response to economic changes[1]. I differ from Hall by assuming that firms have monopoly power, are subject to Calvo price stickiness and face convex adjustment costs in changing their full time workers[2]. The introduction of labor frictions significantly alters employment and inflation dynamics. In labor frictions model, inflation rises on impact in response to a TFP and government expenses shock (the opposite happens in the absence of labor frictions). In this model, hours rise in response to a positive TFP shock. Suggesting that a sticky price model that is consistent with the micro evidence on price stickiness may no longer be characterized by a negative response from labor to productivity shocks. In the case of a government expenses or monetary policy shock, most of the fluctuations in hours is due to changes in overtime work and not employment numbers. Labor frictions also significantly increases the effect of exogenous shocks in economic variables. Both models seem to have difficulty in matching the volatility of overtime employment observed in the data. The model

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[1]Overtime employment appears to adjust more rapidly than full time employment to output innovations (Hansen and Sargent (1988)). Other empirical studies (Hamermesh (93)) confirm that hours per worker are adjusted more rapidly than employment.

[2]Empirical studies at the micro level indicate that labor adjustment costs are quite significant (see Hamermesh and Pfann (96) for a survey), with some suggesting they amount to as much as one year payroll for the average worker.

with no adjustment costs is not able to make overtime work sufficiently volatile (its volatility is always the same as regular employment) and the model with labor adjustment costs it seems to be too much volatile.

Perhaps of even greater importance, the introduction of labor frictions allows a reinterpretation of econometric estimations of the New Keynesian Phillips curve, which were thought to imply implausible large periods of price stickiness. My analysis indicates that if labor frictions are taken into account then low estimates of the marginal cost coefficient of the NKPC are perfectly compatible with frequent price adjustments by firms. The same effect can be seen in the firm-specific capital models but to a much smaller extent. The reason for this is that labor represents a much larger share of firms costs than capital.

The intuition is as follows: with a rental market in labor employment increases in demand in one part of the economy bid up the price of inputs for all firms. If firm specific factor markets are introduced - either in capital or labor - then an increase in demand in one part of the economy increases the shadow value of capital or labor there but has no immediate effect in other parts of the economy. This induces price adjusting firms to keep their relative price close to the non-adjusters. Hence, a given degree of sluggishness in the adjustment of inflation to changes in output, can be reconciled with a greater degree of firm-level flexibility of prices, in the cases where one assumes more specific factors of production.

At the empirical level, Batini, Jackson and Nickell (2005), had already presented evidence of a great importance of labor adjustment costs in NKPC estimation, by correcting the labor share, as a marginal cost measure, using changes in employment. However, when employment is predetermined, marginal costs should be measured in terms of overtime costs. I construct marginal cost measures based on overtime costs[3] and use them to estimate the NKPC. The resulting coefficient estimates do not significantly differ from those obtained using the labor share. Unlike the labor

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[3]Bills (87) also considers marginal costs to be a function of overtime work. Bills constructs his measure of marginal costs using data on average hours per worker (which includes part time workers) in the manufacturing industry and estimating the marginal wage schedule.

In the model considered here, it is assumed that all workers are full time workers (an assumption Bills does not make) and marginal costs are computed from data on overtime work in nonagricultural industries. In this case, there is no need to specify the derivative of overtime hours with respect to average hours and estimate the marginal wage schedule.

share, marginal costs measured in overtime are procyclical and seem to be Granger caused by inflation as predicted by the NKPC model. Regressions using forecasted values of marginal costs using overtime also seem to fit the data significantly better than using the labor share.

The remainder of the paper is organized as follows. Section 2, presents a brief analysis of employment and hours worked. Section 3 describes my new Keynesian model with overtime work and labor adjustment costs. Section 4 displays my calibration assumptions. Section 5 contains the implications of labor frictions for price frequency adjustment. In section 6, I estimate the NKPC using marginal cost measures based on overtime costs. In section 7, I simulate and compare a model with labor frictions with a model with no labor frictions. Section 8 summarizes the paper's findings. The appendix contains a description of the data used, all tables, figures and more detailed derivations of some of my results.

2　A quick look at the empirical evidence on hours worked

In this analysis I make use of aggregate data on U.S. nonagricultural industries. N0 denotes the number of partial-time workers (persons who worked between 1 and 34 hours in a week), N1 the number of full time workers (persons who worked 35 hours and over), N2 corresponds to overtime employment (number of persons who worked 41 hours and over) and N will denote total employment (N=N0+N1, since N2 is a subset of N1).

In figure 1 of the appendix, we see total hours corresponding to these categories plotted over time. We can see, without surprise, that the bulk of total hours worked[4] is composed mainly by the variable N1_hrs (total hours worked by full time workers, during the straight shift - which is assumed to be constant at 40 hours a week), with full time workers representing more than 75% of the workforce (table 1)[5]. It is also this variable that explains most of the total hours volatility (with a covariance of 84% with total hour worked), as can be seen in table 3, implying that most fluctuation in aggregate hours worked comes from the extensive margin, i.e., from workers moving in and out of the labor force. Whereas in standard versions of the New Keynesian model all fluctuations in employment are along the intensive margin (that is, all the variation is in hours

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[4]N_hrs=N0_hrs+N1_hrs+N2_hrs

[5]The model developed here assumes that all workers are full time workers, does representing accurately the vast majority of the workforce.

per worker)[6]. The numbers in table 3 also clearly show that employment changes explain most of the fluctuation in hours in each category (95% for part time hours, 100% for full time hours (by assumption) and 79% for overtime hours).

Despite the fact that employment fluctuations causes most of the changes in total hours, overtime work has important cyclical properties that make it particularly relevant for business cycle study. Overtime employment appears to adjust more rapidly than straight time employment to economic changes (Hansen and Sargent (1988)). Indicating that many firms are very likely constrained in the short run in adjusting their total employment and resort to overtime work in order to respond to unexpected fluctuations. This makes overtime employment, maybe a better candidate to proxy firms marginal cost than total hours worked.

To make this more clear, I make use of the HP filter to isolate the cyclical components of real GDP, N0, N1 and N2 (in this analysis, all variables are in logarithms and in per capita terms). The cyclical component of overtime employment is almost twice as volatile as that of full time workers (and more than twice of the volatility of real GDP - see table 4) and seems to be much more responsive to HP detrended output changes than any of the other employment variables (table 5).

Another reason to introduce overtime work to NKPC models is their inability to amplify and propagate shocks (see Chari, Kehoe and McGratten (2000)). Hall (1996) shows that the differentiation from straight time and overtime is a more successful mechanism than effort in doing so. It is also relevant to note, that overtime employment has the advantage over effort of being observable and measurable.

Taken together these facts indicate that it is important to differentiate straight time employment from overtime employment in the study of business cycles. The model developed in the following section, allows agents to move in and out of the workforce and by introducing labor frictions in total employment, it is also compatible with an important role for cyclical overtime employment fluctuations.

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[6]Among the few exceptions are: Walsh (2005), Trigari (2005) and Blanchard and Gali (2006).

3 The Model Economy: An overtime model with labor frictions

3.1 Agents

Consider an economy with a continuum of infinitely lived agents on the interval [0,1].

Their utility is:

$$\sum_{t=0}^{\infty} \beta^t (\frac{1}{1-\sigma}C_t^{1-\sigma} + v\frac{1}{1-\chi}L_t^{1-\chi}) \qquad (1)$$

Each household is endowed with T units of time each period. L can take one of three values[7]:

-T if the agent is unemployed;

-T-t1 if the agent is employed but works the straight shift only;

-T-t1-t2 if the agent works both the straight and overtime shift.

I follow Hansen (1985) and Rogerson (1988) and employ lotteries to convexify the commodity space. The end result is the utility specification below (see appendix for details), similar to the one used by Hansen and Sargent (1988) and Hall (1996):

$$\sum_{t=0}^{\infty} \beta^t [\frac{1}{1-\sigma}C_t^{1-\sigma} - a_1(N_{1,t} - N_{2,t}) - a_2 N_{2,t} - a_0(1 - N_{1,t})] \qquad (2)$$

Where $a_0 = -v\frac{1}{1-\chi}, a_1 = -v\frac{1}{1-\chi}(1-h_1)^{1-\chi}, a_2 = -v\frac{1}{1-\chi}(1-h_1-h_2)^{1-\chi}$, $h_1 = $ t1/T, $h_2 = $ t2/T (in order to normalize to unity the household's time endowment), $N_{1,t}$ is the share of agents who work the straight time shift (full time employment) and $N_{2,t}$ is the share of workers who work both shifts (overtime employment). This representative agent is subject to the following sequences of budget constraints:

$$C_t = (D_t + W_{1,t}h_1 N_{1,t} + W_{2,t}h_2 N_{2,t} + T_t + TR_t - E_t\{Q_{t,t+1}D_{t+1}\})/P_t \qquad (3)$$

C_t is the consumption of the final good, P_t is the price of the final good, W_{1t} is the nominal hourly wage of the straight shift, W_{2t} is the nominal hourly wage of the overtime shift, D_t is the nominal payoff of the portfolio held at the end of period t, $Q_{t,t+1}$ is the stochastic discount factor, TR_t are government transfers and T_t denotes firms profits. The price of a one period bond is given by $R_t^{-1} = E_t Q_{t,t+1}$ where R_t denotes the gross nominal interest rate.

The resulting first order conditions are:

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[7]The fact that employment changes explain most of the fluctuation in hours in each category (table 3) indicates this is not a very limiting assumption.

$$Q_{t,t+1} = \beta(C_{t+1}/C_t)^{-\sigma}(P_t/P_{t+1}) \qquad (4)$$

$$C_t^{-\sigma}w_{2,t}h_2 + a_1 - a_2 = 0 \qquad (5)$$

$$C_t^{-\sigma}w_{1,t}h_1 + a_0 - a_1 = 0 \qquad (6)$$

with

$$w_{2,t} = W_{2,t}/P_t \qquad (7)$$

$$w_{1,t} = W_{1,t}/P_t \qquad (8)$$

3.2 Firms

3.2.1 Final Good Firms

The final consumption good, Y_t, is produced by a perfectly competitive representative firm. The firm produces the final good by combining a continuum of intermediate goods ($Y_i, i \in [0,1]$) using a Dixit-Stiglitz technology:

$$Y_t = [\int_0^1 Y_{it}^{(\epsilon-1)/\epsilon} di]^{\epsilon/(\epsilon-1)} \qquad (9)$$

Profit maximization implies the following demand for the ith good:

$$Y_{it} = (P_t/P_{it})^{\epsilon}Y_t \qquad (10)$$

where P_t is an index cost of buying a unit of Y:

$$P_t = [\int_0^1 P_{it}^{1-\epsilon} di]^{1/(1-\epsilon)} \qquad (11)$$

3.2.2 Intermediate Good Firms

Each intermediate good is produced by a monopolist firm according to the following production function:

$$Y_{i,t} = A_t N_{i,t} \qquad (12)$$

$$N_{i,t} = (h_1 N_{1,t}^{1-\alpha}(i) + h_2 N_{2,t}^{1-\alpha}(i)) \qquad (13)$$

The above production function is similar to the one used by Hall (1996). Like Hall, I assume $N_{1,t}(i)$ must be chosen before the shocks to the economy are known[8]. Intermediate good producers

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[8]Studies using aggregate quarterly data, summarized in Hamermesh (93), show the average lag in adjusting employment demand to be three to 6 months.

are subject to Calvo price staggering. They also face labor adjustment costs to total employment[9], according to:

$$H_{it} = H(\frac{N_{1,t+1}(i)}{N_{1,t}(i)}) \qquad (14)$$

Where H_{it} represent purchases by the firm of the final good. The function H(.) is an increasing and convex function, of the usual kind assumed in neoclassical investment theory, which satisfies near a zero growth rate of employment, H(1)=δ_{N1}, H'(1)=1 and H"(1)=$\epsilon_{\psi N1}$, where δ_{N1} is an exogenous separation rate and the parameter $\epsilon_{\psi N1}$ measures the employment adjustment costs in a log-linear approximation to the equilibrium dynamics. This implies that in the steady state (assumed constant, as I abstract from economic growth) to which the economy converges in the absence of shocks, the rate of hiring required to maintain the economy's employment is δ_{N1} times the steady state employment N1 (so that δ_{N1} can be interpreted as the exogenous quit rate in employment). It also implies that near the steady state, a marginal unit in hiring expenses increases employment by an equal amount (as there are locally no adjustment costs). These assumptions are similar to those made by Woodford (2005) and Sveen and Weinke(2004) in a context of investment adjustment costs.

The present discounted value of profits is:

$$E_t \sum_{j=0}^{\infty} Q_{t,t+j}[P_{i,t+j}Y_{i,t+j} - P_{t+j}w_{1,t+j}h_1 N_{1,t+j}(i) - P_{t+j}w_{2,t+j}h_2 N_{2,t+j}(i) - P_{t+j}H_{i,t+j}] \qquad (15)$$

The ith intermediate good firm chooses $P_{i,t+j}, Y_{i,t+j}, N_{1,t+j+1}(i), N_{2,t+j}(i)$ to maximize profits subject to (10), (12), (14), as well as its price setting constraints. The firm takes $P_{t+j}, Y_{t+j}, W_{1,t+j}, W_{2,t+j}$ as given.

The resulting first order conditions are:

$$E_t \sum_{j=0}^{\infty} (\theta\beta)^j \Lambda_{t,j} \frac{P_{t+j}}{P_{t+j+1}} Y_{i,t+j}[P_{i,t+j} - (1+\mu)MC_{i,t+j}] = 0 \qquad (16)$$

$$\frac{w_{2t}}{(1-\alpha)A_t N_{2,t}^{-\alpha}(i)} = MC_{it} \qquad (17)$$

$$H'(\frac{N_{1,t+1}(i)}{N_{1,t}(i)}) = E_t\beta\Lambda_{t,1}[\rho_{i,t+1} + \frac{N_{1,t+2}(i)}{N_{1,t+1}(i)}H'(\frac{N_{1,t+2}(i)}{N_{1,t+1}(i)}) - H(\frac{N_{1,t+2}(i)}{N_{1,t+1}(i)})] \qquad (18)$$

with:

$$\rho_{i,t+1} = -w_{1,t+1}h_1 + w_{2,t+1}h_2\frac{MPN_{1,t+1}(i)}{MPN_{2,t+1}(i)} \qquad (19)$$

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[9]Sargent (78) and Shapiro (86) using aggregate data estimated adjustment costs for overtime to be much smaller than for employment levels. For this reason I assume that overtime can be adjusted without adjustment costs.

$$\frac{MPN_{1,t+1}(i)}{MPN_{2,t+1}(i)} = N_{2,t+1}^{\alpha}(i)\frac{h_1}{h_2}N_{1,t+1}^{-\alpha}(i) = [\frac{1}{h_2}Y_{i,t+1}A_{t+1}^{-1} - \frac{h_1}{h_2}N_{1,t+1}^{1-\alpha}(i)]^{\alpha/(1-\alpha)}\frac{h_1}{h_2}N_{1,t+1}^{-\alpha}(i) \qquad (20)$$

and $\Lambda_{t,j} = (\lambda_{t+j}/\lambda_t) = (C_{t+j}/C_t)^{-\sigma}, \mu = \epsilon/(\epsilon - 1)$ is the steady state markup if price over marginal cost, θ is the probability the firm will not be able to optimally reset its price this period.

It is worth some time to look at equation (17). When the straight time employment is pre-determined, the relevant measure of a firm's marginal cost is its overtime labor costs and not its total labor input. The empirical literature (Gali and Gertler (1999) for example) has so far focused on the labor share or output gap to proxy marginal costs. In chapter 6 I construct measures of marginal cost based on overtime costs. The estimates however do not prove to be significantly different from those obtained using the labor share.

The first order condition for the firm's price setting behavior is similar to the standard Calvo model (price is a function of all future expected marginal costs). However, since a firm's choice of full time employment is among the determinants of its marginal product of labor, I cannot solve the price setting problem without considering the firm's optimal employment behavior. The reason for this is that N1 is not purchased on a spot market. Workers are contracted to one firm only and the existence of convex adjustment costs prevents a more rapid adjustment of a firm's number of workers. A firm's marginal cost therefore depends on its present full time employment numbers and these depend on the firm's decisions in previous periods, including its price-setting decisions. The firm's choices here are more complex than in standard sticky price models (which typically assume rental markets for production factors) but the problem is very similar to the case of firm-specific capital solved by Woodford (2005).

Equation (18) takes a similar form to the F.O.C. for the firm's investment decision found in Sveen and Weinke (2004) or Woodford (2005). It is noteworthy that a firm's marginal return to N1 is measured by the marginal savings in its overtime costs as opposed to its marginal productivity. This arises from the firms being demand constrained, which implies that the firm's benefit from having an additional worker derives from the fact that this allows to produce the quantity demanded with less overtime work.

3.3 Aggregate resource constraint

The economy's resource constraint is:

$Y_t = C_t + G_t + H_t \qquad (21)$

where

$$H_t = [\int_0^1 H_{it} di] \qquad (22)$$

and G_t denotes government expenses.

3.4 Inflation Dynamics

From now on, I will use lower case letters to denote variables in log deviation from the steady state.

The economy's price inflation equation takes the form (see appendix for details):

$$\pi_t = \beta E_t \pi_{t+1} + \gamma mc_t \qquad (23)$$

Where $\pi_t = p_t - p_{t-1}$ and the parameter γ is a function of the model's structural parameters ($\gamma = \frac{(1-\theta)(1-\theta\beta)}{\theta}\phi_{N1}^{-1}$, in the homogeneous factors model $\phi_{N1} = 1$) which is computed numerically using the method developed in Woodford (2005). Woodford (2005) shows that a non-explosive solution to the firm's decision problem exists in the case of large enough adjustment costs. The introduction of labor frictions does therefore not imply any important change in the dynamic relationship between inflation and average real marginal cost in comparison to the baseline NKPC model (see Yun (1996)).

3.5 Monetary Policy Rule

When prices are sticky the equilibrium path of real variables cannot be determined independently of monetary policy. In other words: monetary policy is non-neutral. The model is closed by assuming the central bank follows a simple interest rule (often referred to as a "Taylor" rule) of the form:

$$i_t = \gamma_\pi \pi_t + \gamma_y y_t + e_t^v \qquad (24)$$

This rule has desirable stabilizing properties[10] and also some empirical appeal as a description of what central banks do in practice.

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[10]The central bank chooses a target for the short term interest rate, as a function of economic conditions. To attain that rate, the central bank adjusts the money supply to meet the quantity on money demanded at the target interest rate. This is preferable than doing the reverse (set the nominal money stock and let the interest rate adjust), due to the potential instability of money demand suggested by the evidence. Under monetary targeting, this instability would translate into interest rate volatility that could harm the real economy.

3.6 Exogenous Shocks

It is assumed that the monetary policy shock, government spending and technology follow an exogenous process AR(1) process:

$$e^v_{t+1} = \varpi_v e^v_t + \varepsilon_{t+1} \qquad (25)$$

$$g_{t+1} = \varpi_g g_t + e^g_{t+1} \qquad (26)$$

$$a_{t+1} = \varpi_a a_t + e^a_{t+1} \qquad (27)$$

Where ε_t, e^g_t and e^a_t represent shocks distributed independently N(0, 1).

3.7 An overtime model with no labor adjustment costs

For comparison I consider a model where N1 is not predetermined and without labor adjustment costs in total employment. Only equations 18 and 21 are different. These are replaced by:

$$\frac{w_{1t}}{(1-\alpha)A_t N_{1,t}^{-\alpha}(i)} = MC_{it} \qquad (28)$$

$$Y_t = C_t + G_t \qquad (29)$$

In this model γ equals $\frac{(1-\theta)(1-\theta\beta)}{\theta}\frac{1-\alpha}{1-\alpha+\alpha\epsilon}$. Under the assumption of constant returns to scale ($\alpha = 0$) there is no difference between this case and standard NKPC model with homogeneous factors.

4 Calibration

The period length is one quarter. I assume a value of one for σ, the intertemporal elasticity of substitution. I set the discount rate $\beta = 0.99$ and choose $\epsilon = 7.6667$ which implies a frictionless steady state markup of 15%. The agents time endowment T is set at 1369, implying agent's have 15 hours per day available for work and leisure activities.

The parameters regarding work hours and employment are set equal to their time series sample means (see tables 1 and 2). Therefore the steady state values of t1, t2, N1 and N2 equal 516, 155, 0.42 and 0.16 respectively. The representative agent's leisure utility parameter v and labor supply elasticity are calibrated so that N1=0.42 and N2=0.16. The capital share α is 0.33 and the GDP share of government expenses equals 0.2, both are standard values in the business cycle literature. The quit rate in employment (δ_{N1}) is chosen to be 0.1 (consistent with the empirical evidence for

the U.S., see Shimmer (2005)) and $\epsilon_{\psi N1}$, the curvature on labor adjustment costs, to be 2^{11} (a value consistent with Cooper and Willis (2002) estimates).

For the Taylor rule I choose the inflation and output weights (γ_π, γ_y) to be 1.5 and 0.5/4 respectively. These parameters are roughly consistent with observed variations in the Federal Funds rate over the Greenspan era (see Taylor (1999)).

The shock processes parameters were obtained by OLS estimation[12]. The autoregressive parameters are set at $\varpi_a = 0.99, \varpi_g = 0.99$ and $\varpi_v = 0.73^{13}$.

Finally the New Keynesian Phillips curve coefficient for marginal cost γ is set to be 0.02, which is consistent with empirical estimates (see Gali and Gertler (1999)).

5   Implications for the frequency of price adjustment

The non-linear estimates of the NKPC imply a period of price stickiness much larger than that found using micro data. The Calvo price staggering assumption implies an average time period for which a price is fixed of $1/(1-\theta)$. The typical value estimated, $\theta=0.8$, then implies an average period of price stickiness of 5 quarters. Klenow and Kryvstov (2005), estimate the mean monthly fraction of items changing prices, using micro data collected from the three largest metropolitan areas (New York, Los Angeles and Chicago), I report these estimates in table 6. These estimates imply an average time period between price changes of 3.4 months (average period lengths are calculated by 1/fr) for all prices (4.3 months if we exclude sales). These imply values of θ of 0.12 for all prices and 0.3 if one exclude sales (table).

In this section, I explore how the labor rigidities introduced[14], help reconcile this apparent

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[11]This implies, that for a 5% change in employment, adjustment costs are about 4.2% of output per quarter. This is about twice larger than the estimates by Shapiro (86). However, it falls considerably short of what accounting studies indicate (reviewed in Hamermesh and Pfann (96)).

[12]A TFP measure is obtained by $A_t = \frac{\text{real } GDP_t}{h_1 N_{1,t}^{1-\alpha} + h_2 N_{2,t}^{1-\alpha}}$. G is goverment current expenditures. All variables were converted to per capita terms. The OLS regressions consist of : $\log(A_t) = c + (\log A_{t-1}) + e_t^a$;$\log(G_t) = c + (\log G_{t-1}) + e_t^g$. The resulting estimates are standard and close to Hall's (96).

[13]A series for the monetary policy shock e_t^v was obtained by: $e_t^v = FF_t - 1.5\pi_t - 0.125y_t$.Where FF correspondes to the federal funds rate, π to inflation and y to HP detrended real GDP per capita. ϖ_v was then obtained by means of the OLS regression: $e_{t+1}^v = \varpi_v e_t^v + \varepsilon_t$.

[14]The results in this section aren't necessarily linked to marginal costs measured in overtime. One could still have

discrepancy between macro and micro estimations. Table 7 shows the implied values of θ for several values of γ for the homogeneous factor markets, the firm-specific capital model, a model with a decreasing returns to scale production function (capital is absent from canonical versions of the New Keynesian model) and the model with labor frictions. We can see that allowing capital to be firm-specific implies a significant reduction in the implied price stickiness value (the values of θ vary between 0.7 and 0.6), yet it still falls very far behind the values in the micro estimations, especially for the lowest values of γ. Adding labor frictions, has a much larger effect, with θ varying between 0.4 and 0.3. Even for the lowest values of γ, the average price duration implied by the labor frictions model seems to be quite consistent with the micro evidence. In the same table we can see that while the use of a decreasing returns to scale production function in this model, implies by itself a reduction in price stickiness in comparison to the homogeneous factors case, the largest contribution is due to the introduction of labor frictions.

The intuition is as follows: with a rental market in labor employment increases in demand in one part of the economy bid up the price of inputs for all firms. If firm specific factor markets are introduced - either in capital or labor - then an increase in demand in one part of the economy increases the shadow value of capital or labor there but has no immediate effect in other parts of the economy. This induces price adjusting firms to keep their relative price close to the non-adjusters. Hence, a given degree of sluggishness in the adjustment of inflation to changes in output, can be reconciled with a greater degree of firm-level flexibility of prices, in the cases where one assumes more specific factors of production.

I perform some experiments in order to discover why the results of the labor-frictions model differ from the firm-specific capital model. I hold the value of γ fixed at 0.02 and test the sensitivity of the labor frictions model solution to different parameter calibrations. My analysis indicates that the explanation lies in the output share of the constrained production factor (in the firm-specific capital model, the constrained factor share is only a third, whereas in the labor frictions model described in section 3 it represents more than 80%). I find that the labor adjustment cost parameters, $\epsilon_{\psi N1}$ and δ_{N1}, have a very small effect.

The output share of the constrained production factor was found to have a greater influence on

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a model with predetermined employment but in which firms are free to adjust the use of raw materials, instead of overtime, to react to unexpected fluctuations.

θ, it seems that capital does not represent a large enough proportion of a firm's costs, in order for the introduction of realistic levels of frictions in this factor, to reduce sufficiently the elasticity of the desired price with respect to output. Table 8 shows that if the capital share in the firm-specific capital model were to be double of the labor share (the unconstrained production factor in this model) it would imply $\theta = 0.569$, a significantly smaller value. Alternatively, reducing the size of the full time labor input relative to the overtime input (the factor free of frictions) in the labor frictions model leads to a great rise in the implied period between price adjustments. Lowering the steady state value of N1 to 0.20 and t1=200 results in a value of θ equal to 0.634.

Table 9, shows the results of alternative parameter specifications of the labor adjustment cost function. Price frequency seems to be practically unaffected by these.

6 Estimation of the NKPC with overtime costs

6.1 Constructing a marginal cost measure based on overtime work

I start by describing how I constructed a measure of real marginal cost in log deviations from the steady state. I obtain overtime wages by multiplying W (compensation per hour in the nonfarm business sector) by 1.5 (assuming a constant 50% wage premium for overtime). I then multiply overtime wages by N_2 and $h_2 = 155$, and divide the resulting series by GDP. This gives a measure of real marginal cost consistent with the model described in chapter 3. Finally, I take the log of the resulting series and subtract its mean. Assuming the overtime shift and the overtime premium to be constant may appear to be a serious limitation, but the results are indifferent to the choice of value (since I later demean the series). I also construct an alternative measure of real marginal cost that uses average overtime hours (this series is plotted in figure 3) , instead of assuming a constant h_2. The differences between these measures and labor share can be better seen below:

labor share$=\frac{WN\_hrs}{GDP}$,

overtimeshare_h2$=\frac{1.5Wh_2N_2}{GDP}$,

overtimeshare_hrs$=\frac{1.5W(overtimehours\_average)N_2}{GDP}$.

Where N_hrs denotes total hours worked in nonagricultural industries and N2 the number of persons who worked 41 hours or more.

Table 10 presents some summary statistics regarding inflation and these marginal cost measures.

The overtime marginal costs measures are about 4 times more volatile than the labor share. Unlike the labor share, these measures are procyclical (consistent with Bills (86) results). As Woodford (2003) pointed out, increases in output that are not driven by increases in technological efficiency will tend

to raise nominal marginal costs more than prices in a broad class of standard models, as workers require a higher real wage in order to be induced to supply extra hours. For this reason, several authors[15] have argued that the labor share is not a good proxy for marginal costs. Using overtime data to construct marginal cost measures seems to address this criticism.

Preliminary analysis indicates that assuming overtime hours to be constant is not a significant limitation. Figure 4 shows us that these marginal cost measures follow each other quite closely. These series correlation coefficient is 0.832.

6.2   Estimation of the NKPC

I estimate the NKPC by GMM, making use of the orthonogonality condition:

$$E_t \left\{ (\theta \pi_t - (1 - \theta)(1 - \theta\beta)mc_t - \theta\beta\pi_{t+1})z_t \right\} \qquad (30)$$

This allows the direct estimation of the of the structural parameters θ and β, using aggregate data. The instrument set z_t is composed of four lags of inflation, the marginal cost variable, the output gap (HP detrended real GDP), the log-short interest rate spread, wage inflation and commodity price inflation.

The results for both marginal cost measures considered can be found in table 11 and seem to indicate that assuming overtime hours to be constant is not a serious limitation (the unrestricted regression using overtime hours yields a beta value superior to one, but restricting the value to one does not affect the estimation of θ). The results for the nonlinear estimations are very similar (θ is about 0.8) to those obtained by Gali and Gertler (1999) using the labor share as a measure of marginal cost and a similar set of instruments.

These estimates are not valid under the assumptions regarding labor frictions (predetermined employment and convex adjustment costs) made in chapter 3. In this case it is only possible to

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[15]Rudd and Whelan (2007), point out that the labor share tends to jump upward and reach a local peak near the onset of the NBER recessions. For the labor share to be a good proxy for real marginal costs and for real marginal cost to be positively correlated with the output gap, would imply that output was actually above potential during each postwar recession.

obtain direct estimates of β and γ (this is also the case when capital is firm-specific). I now estimate these parameters directly, using the moment condition:

$$E_t\left\{(\pi_t - \gamma mc_t - \beta\pi_{t+1})z_t\right\} \qquad (31)$$

The linear regressions (table 12) using overtime marginal cost measures yield a small negative coefficient (not significant) for γ, but positive values fall within the confidence interval.

Overall, these results are not very different from those reported by Gali and Gertler (1999) who reported similarly high coefficients for θ (which varied between 0.829 and 0.915) and low values of γ (which varied between 0.007 and 0.047).

Perhaps a better way to assess the empirical performance of the NKPC is to construct explicit measures of $E_t mc_{t+j}$ and then estimate the model:

$$\pi_t = \gamma \sum_{j=0}^{\infty} \beta E_t mc_{t+j} \qquad (32)$$

using a VAR to forecast the values of mc_{t+j} in a manner similar to Campbell and Shiller's (1987) methodology, the discounted sum of expected marginal costs is then obtained using a value of β equal to 0.99.

Can inflation be used to construct forecasts of future values of the driving term? If the NKPC model is correct then lagged inflation would embody preceding periods expectations about future marginal costs, and thus should probably add useful forecasting value to the VAR. Rudd and Whelan (2007) show that the hypothesis that inflation Granger causes the labor share is clearly rejected by the data. In table 13, I show the results of an OLS regression of the labor share on 4 lags of inflation. The R2 is only 0.015 and the F-statistic, with a value of 0.477, confirms Rudd and Whelan's results that lagged inflation does not Granger cause employment. In this aspect, the results for the overtimeshare_h2 are remarkably different (see table 14). An OLS regression of this variable on 4 lags of inflation, yields an R2 of 0.206 and the F-statistic value is zero, which clearly supports the hypothesis that inflation Granger causes the overtimeshare_h2 marginal cost measure. These are encouraging results in favor of using a marginal cost measure based on overtime costs and may account for the presence of lagged inflation in conventional empirical Phillips curves.

This suggests that forecasting values of $E_t mc_{t+j}$ using a VAR in overtimeshare_h2 and inflation may prove useful. The Schwarz criterion selects a lag order of two for both the overtimeshare_h2 variable and the labor share (despite the absence of Granger causality in the labor share case, I perform the same exercise for comparison purposes). The OLS regression again yields a small

estimate of γ in both cases (see results in table 15 and 16). With this method a significant coefficient for the overtimeshare_h2 is estimated, although with the wrong expected sign (γ=-0.017). In the case of the labor share, the coefficient has the right sign but is not significant (γ=0.014). Another great difference, is the Adj. R2 of the two regressions, the labor share's is only 0.002 while in the overtimeshare_h2 case it is 0.741.

Estimating the same equation in first differences yields γ=0.015 for both marginal cost measures (again, only significant for the overtimeshare_h2). In this case also, the Adj. R2 of the regression with the overtimeshare_h2 (Adj. R2=0.17) is much higher than for the labor share (Adj. R2=0.001).

The analysis made in this section indicates that marginal costs measured in overtime have a more robust link to the output gap, inflation and changes in inflation.

7 Impulse response functions and business cycle statistics

The introduction of labor frictions significantly alters employment and inflation dynamics. In labor frictions model, inflation rises on impact in response to a TFP and government expenses shock (the opposite happens in the absence of labor frictions). In this model, hours rise in response to a positive TFP shock. Suggesting that a sticky price model that is consistent with the micro evidence on price stickiness may no longer be characterized by a negative response from labor to productivity shocks. In the case of a government expenses or monetary policy shock, most of the fluctuations in hours is due to changes in overtime work and not employment numbers. Labor frictions also significantly increases the effect of exogenous shocks in economic variables. Both models seem to have difficulty in matching the volatility of overtime employment observed in the data. The model with no adjustment costs is not able to make overtime work sufficiently volatile (its volatility is always the same as regular employment) and the model with labor adjustment costs it seems to be too much volatile.

7.1 Business cycle statistics

The business cycle statistics for the TFP shock, government expenses shock and monetary shock are displayed in tables 17-19. Several key differences can be observed between the model with and

without labor frictions.

In the model with labor frictions, the effect of exogenous shocks is considerably magnified (this is consistent with Hall's results). The TFP shock's volatility is only 66% relative to output (143% without frictions) and the monetary policy shock only 36% (93% without frictions). The surprising exception is the government expenses shock, in this case the model with labor frictions requires about twice the volatility in this shock in comparison to the model with no frictions, to generate the same response in output.

The introduction of labor frictions leads to decrease in straight time employment volatility (except in the case of the TFP shock) and a great increase in overtime employment volatility. Without frictions both variables have the same volatility (about the same as output). In the data overtime is indeed more volatile than straight time employment but the labor frictions model seems largely exceeds it. This occurs because with labor frictions firms can only adjust overtime employment in the short-run making this variable extremely volatile. This effect is particularly strong in the government expenses and monetary shock cases (for these shocks overtime is more than 9 times more volatile than output) than in the TFP case (the relative volatility of overtime to output is 3.2 which is fairly close to the data)[16]. In all of these shocks, the volatility of "net hiring" (denoted as h) is always considerably high (always several times more volatile than output) , which means the problem is not so much that there are no movements in people going in and out of the workforce but that there is really too much movement in overtime employment.

For the TFP case, straight time employment is more volatile for the model with frictions than for the model without frictions, whereas the opposite happens for the other shocks. This is very likely due to the reason that the government expenses shock and monetary shocks influence employment decisions through its effects on interest rates (it is better to work more and consume less in periods with high real interest rates), there are no effects in productivity. This may also be the reason why in these shocks overtime is much more volatile. The change in real interest rate may not be a sufficient motive for many agents to enter or leave the work force, leading to need to make large adjustments in overtime use.

Real wages volatility, for all shocks, in the labor frictions model is much smaller (about half) in

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[16]Hall's (96) model suffers from the reverse problem, in his case overtime employment is about 4 times less volatile than the data.

comparison to the model with no frictions (which always generates higher volatility of wages relative to output when the opposite happens in the data). This result is likely due to the introduction of convex labor adjustment costs. On the other hand, marginal costs are more volatile in the model with labor frictions, this is consistent with the data (see table 10) that strongly suggests that marginal costs when measured in overtime employment are considerably more volatile. This means also that the introduction of labor frictions changes which variables affect more the volatility of marginal costs (and therefore inflation), without frictions, wage movements play a relatively larger role.

Another large difference between the two models is the contemporaneous correlation of output with regards to the productivity shock. In the model without frictions several variables (employment/hours, inflation and marginal costs) are countercyclical. Since these variables are clearly procyclical in the data, this model is not compatible with a large role for TFP shocks in explaining business cycles[17]. The introduction of labor frictions allows TFP shocks to play a larger role observed cyclical movements in economic variables.

7.2   Impulse response functions

We can also see great differences in the IRFs between the models with and without labor adjustment costs (see figures 6-11). When adjustment costs are present N1 exhibits a "hump" shaped response to shocks. In the model with labor frictions, overtime work, total hours, marginal cost, inflation and output have larger reactions to shocks on impact. These reactions tend to be short lived because they are driven mostly by overtime employment. Firms cannot adjust straight time employment in the short run, so they must resort to overtime employment. Since overtime wages are higher, firms decrease their overtime use as quickly as possible.

Impulse response functions between these models differ dramatically in the case of a TFP

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[17]Gali (1999) has fueled the debate on the importance of technology shocks as a business cycle impulse. Gali uses a structural VAR that he identifies by assuming that technology shocks are the only source of long-run changes in labor productivity. He finds that in the short run, hours worked fall in response to a positive shock to technology.Gali's results have sparked an animated, ongoing debate. Christiano, Eichenbaum, and Vigfusson (2003) find that Gali's results are not robust to specifying

the VAR in terms of the level, as opposed to the first-difference, of hours worked. Chari, Kehoe and McGrattan (2004) show that Gali's findings can be the result of misspecification.

innovation. N1 falls in the model with no adjustment costs, leading also to decreases in marginal cost and inflation (figure 5). The opposite happens in the labor frictions model: N2 rises sharply on impact and N1 rises steadily, displaying a very persistent response. As a result hours increase in response to a TFP shock, this is unusual in sticky price models. Sticky price models have been associated to a negative labor input response to TFP, because the TFP increase allows firms to produce the same output with less labor input (since firms are constrained in adjusting price). But in the labor frictions model, the fraction of price constrained firms is much smaller than in the baseline New Keynesian models. More firms are able to take advantage of the positive productivity increase which leads to an increase in hours used. This model also displays stronger reactions of output, interest rate, consumption and real wages.

If the shock to the economy is an increase in government purchases (figure 6), marginal cost has an opposite pattern between the two models, with inflation rising instead of falling in the model with labor frictions. This occurs because the overtime work reaction is so strong on impact that it is able to drive inflation up despite falling wages. It is curious that this is the only shock that has stronger effect on economic variables in the model with no adjustment costs.

We can also observe significant differences when comparing the two model's impulse response function to a monetary policy shock (figure 7). The model without labor frictions displays very strong reactions on impact of N1, consumption, wages and the nominal interest rate. The labor frictions model on the other hand exhibits stronger reactions on impact of N2, marginal cost, inflation, hours and output variables (because these variables are driven mostly by overtime work which has strong reactions on impact to shocks in this model). Without frictions, we observe a strong and immediate response of N1 and consumption, whereas in the model with frictions these variables reactions only peak about 4 quarters after the change in monetary policy. Which is more according to what the data suggests (see Trigari (2005) estimates). In both models however, the peak response of inflation is immediate. This is in contradiction with most economists estimates: Bernanke, Laubach, Mishkin, and Posen (1999) describe a two-year lag between policy actions and their main effect on inflation as 'a common estimate'.

7.3 Okun's law

Another interesting observation that can be made from these simulations, is the relation between output and employment. In the no frictions model, we can observe that, except for the productivity shock, employment deviates more in response to shocks than output (this can easily be seen by looking at the standard deviation values in tables 17-19 or by a closer inspection of the impulse response functions). This seems to be at odds with the empirical evidence, regressions of Okun's law estimate a 3% decrease in output for every 1% increase in the unemployment rate (Prachowny 1993). Even the TFP shock is at odds with evidence, since employment and output are strongly positively correlated in the data and in the model with no labor frictions these variables are negatively correlated.

The impulse response functions and the moments of the model with labor frictions seem to be consistent with Okun's law, indicating that labor frictions in business cycle models are necessary in order to accurately describe the output and employment dynamics observed in the data. It also confirms that changes in hours from employed workers (in this case the number of workers in the overtime shift) as a strong motive why GDP may increase or decrease more rapidly than unemployment decreases or increases.

7.4 Monetary and fiscal policy

The observation from the impulse response functions of output and employment in the labor frictions model has important implications for both monetary and fiscal policy. We can observe that for these shocks, employment displays a much weaker response than output, while in the case of a TFP shock to the economy, employment increases about the same as output. The labor adjustment cost model's impulse response functions seem to indicate that fiscal policy in particular (its effect in employment is really very small), is not very effective in stimulating employment, output and total hours worked do increase but only due to very large changes in the number of overtime workers. Monetary policy shocks do seem to have quite a relevant effect in employment dynamics in the short-run but to a much smaller extent than in output, this indicates that care should be taken in the elaboration of the monetary policy goals, output or employment stabilization is not indifferent.

Observing the TFP responses we can observe that the "jobless growth" phenomenon in the labor frictions model seems to result from monetary and fiscal shocks. In contrast in the overtime

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model with no labor adjustment costs "jobless growth" is a result of technology innovations.

8   Conclusion

This paper describes a NKPC model with straight time and overtime shifts. The introduction of labor frictions allows the model to be consistent with both the micro evidence on the frequency of price adjustment and the parameter values required to explain the comovement between inflation and aggregate labor costs. This model implies that firm's marginal costs should be measured by overtime work costs. Empirical estimations of the NKPC with overtime cost measures do not yield coefficient estimates significantly different from those obtained using the labor share. Unlike the labor share, marginal costs measured in overtime are procyclical and seem to be Granger caused by inflation, as predicted by the NKPC model. The results shown here show some promise in measuring marginal costs in overtime work and its use should be the focus of future research.

The introduction of labor frictions significantly alters employment and inflation dynamics. In labor frictions model, inflation rises on impact in response to a TFP and government expenses shock (the opposite happens in the absence of labor frictions). In this model, hours rise in response to a positive TFP shock. Suggesting that a sticky price model that is consistent with the micro evidence on price stickiness may no longer be characterized by a negative response from labor to productivity shocks. In the case of a government expenses or monetary policy shock, most of the fluctuations in hours is due to changes in overtime work and not employment numbers. The model seems to generate too much volatility in overtime employment, particularly in the case of government expenses and monetary shocks.

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9 Appendix

9.1 Data

The employment and hours data series used in this paper are aggregate data in U.S. nonagricultural industries from the BLS's Current Population Survey. Total employment is denoted as N, N0 will denote the number of partial time workers (persons who worked 1 to 34 hours a week), N1 will denote the number of full time workers (persons who worked 35 hours and over a week), finally we denote overtime employment as N2 (number of persons who worked 41 hours and over a week). Data for N0 is only available for the period1976Q3-2006Q4; data for N is available for the period 1955Q2-2006Q4, N1 and N2 spans the period 1955Q1-2006Q4[18]. Data regarding employment numbers was converted to quarterly by averaging monthly observations and was subsequentially seasonally adjusted. Per capita variables were constructed by dividing by civilian noninstitutional population NSA from the BLS.

Data for average weekly full-time hours (excludes persons working less than 35 hours a week) and part time hours (average weekly hours by persons who worked 1 to 34 hours a week) are available from 1976Q3-2006Q1, this was converted to quarterly by assuming a month to be equal to 4.3 weeks and then summing the resulting monthly observations, these are non-seasonaly adjusted series. Regular hours was calculated by assuming a 40 hour workweek for full-time workers. I then constructed overtimehours by multiplying N1 by fulltimehours minus regularhours and dividing by N2. N0_hrs denotes total part time hours and was constructed by multiplying N0 by part time hours. N1_hrs denotes total regular hours and was constructed by multiplying N1 by regular hours. N2_hrs denotes total overtime hours and was constructed by multiplying N2 by overtime hours. N_hrs is the sum of N0_hrs, N1_hrs and N2_hrs. Average hours was constructed by dividing N_hrs by N.

I now describe the construction of the timeseries used in the NKPC regressions in chapter 5. The inflation measure is the log difference of the GDP deflator, wage inflation is the log difference of compensation per hour in the nonfarm business sector, commodity price inflation is the log difference of the producer price index (all commodities), the long-short interest rate spread was constructed as the log of the 10 year treasury rate minus the log of the 1 year treasury rate. I detail

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[18]I'm grateful to George Hall for sharing his data on full time and overtime employment from 1955 to 1992.

below the series just mentioned and others used in the paper:

GS1   1-Year Treasury Constant Maturity Rate; source: Board of Governors of the Federal Reserve system; 1953Q2-2007:Q1.

GS10   10-Year Treasury Constant Maturity Rate; source: Board of Governors of the Federal Reserve system; 1953Q2-2007:Q1.

PPIACO   Producer Price Index: All Commodities; source:BLS; 1921Q1-2007:Q1

CNP16OV   Civilian Noninstitutional Population; source:BLS; 1948Q1-2007:Q1

COMPNFB   Nonfarm Business Sector: Compensation Per Hour; source:BLS; 1947Q1-2007:Q1.

GDP   Gross Domestic Product; source:BEA; 1947Q1-2007:Q1.

Real GDP   Gross Domestic Product; source:BEA; 1947Q1-2007:Q1

GDPDEF   Gross Domestic Product: Implicit Price Deflator; source: BEA; 1947Q1-2007:Q1.

GEXPND   Government Current Expenditures; source: BEA; 1947Q1-2007:Q1.

PCEC   Personal Consumption Expenditures; source: BEA; 1947Q1-2007:Q1.

FEDFUNDS   Effective Federal Funds Rate; source: BEA; 1954M7-2007:M6.

GS1,GS10, PPIACO, CNP16OV, COMPFNB, GDP, Real GDP, GDPDEF, GEXPND, PCEC and the FEDFUNDS were downloaded from the St. Louis Fed website, the remaining series were downloaded from Economagic website. GS1,GS10, PPIACO, CNP16OV, COMPFNB and FED-FEUNDS were converted to quarterly by averaging the monthly observations.

9.2   Representative agent's utility function

Assume $\pi_{1,t}$ and $\pi_{1,t}$ are the probability of working just the straight time shift and the probability of working both shifts respectively. Hence $1 - \pi_{1,t} - \pi_{2,t}$ is the probability of being unemployed. An agent's expected single period utility, after normalizing the agent's time endowment to unity, is then:

$$\pi_{1,t}[\frac{1}{1-\sigma}C_t^{1-\sigma}+v\frac{1}{1-\chi}(1-h_1)^{1-\chi}]+\pi_{2,t}[\frac{1}{1-\sigma}C_t^{1-\sigma}+v\frac{1}{1-\chi}(1-h_1-h_2)^{1-\chi}]+(1-\pi_{1,t}-\pi_{2,t})[\frac{1}{1-\sigma}C_t^{1-\sigma}+v\frac{1}{1-\chi}(1)^{1-\chi}] \qquad (A1)$$

Define $N_{1,t}$ to be the share of agents who work the straight time shift (full time employment) and $N_{2,t}$ the share of agents who work both shifts(overtime employment). So $N_{1,t} = \pi_{1,t}+ \pi_{2,t}$ and

$N_{2,t} = \pi_{2,t}$, and one can write the representative agent's utility function as:

$$\max \sum_{t=0}^{\infty} \beta^t [\tfrac{1}{1-\sigma} C_t^{1-\sigma} - a_1(N_{1,t} - N_{2,t}) - a_2 N_{2,t} - a_0(1 - N_{1,t})] \qquad (A2)$$

Where $a_0 = -v\tfrac{1}{1-\chi}, a_1 = -v\tfrac{1}{1-\chi}(1-h_1)^{1-\chi}, a_2 = -v\tfrac{1}{1-\chi}(1-h_1-h_2)^{1-\chi}.$

9.3 Steady State

9.3.1 Overtime model with Labor frictions

In steady state, (13), (14) and (19) reduce to:

$$N = (h_1 N_1^{1-\alpha} + h_2 N_2^{1-\alpha})$$

$$H = \delta_{N1} N_1$$

$$\rho = 1/\beta - (1 - \delta_{N1})$$

From the production function it is simple to obtain Y:

$$Y = AN$$

And then obtain the steady state consumption from the resource constraint:

$$C = (1 - sg)Y - H = w_1 h_1 N_1 + w_2 h_2 N_2$$

where sg=G/Y.

Steady state values for w_1, w_2, v and χ are obtained by solving the system of equations:

$$w_2 = ((a_2 - a_1)C^\sigma)/h_2$$

$$w_1 = ((a_1 - a_0)C^\sigma)/h_1$$

$$MC = 1/\mu = \frac{w_2}{(1-\alpha)AN_2^{-\alpha}}$$

And from (19):

$$\rho_Y = (w_2 \tfrac{\alpha}{1-\alpha} N_2^{2\alpha-1} N \tfrac{h_1}{h_2} N_1^{-\alpha})/\rho$$

$$\rho_A = \rho_Y$$

$$\rho_{N1} = (\alpha w_2 h_1 N_2^\alpha N_1^{-\alpha} + \alpha w_2 \tfrac{\alpha}{1-\alpha} N_2^{2\alpha-1} \tfrac{h_1}{h_2} N_1^{1-2\alpha} h_1)/\rho$$

$$\rho_{W1} = (w_1 h_1)/\rho$$

$$\rho_{W2} = (w_2 h_1 N_2^\alpha N_1^{-\alpha})/\rho$$

Furthermore, it is useful to define:

$$B = \alpha N_2^{\alpha-1}$$

$$C = \tfrac{1}{1-\alpha} N \tfrac{1}{h_2}$$

$$D = \tfrac{h_1}{h_2} N_1^{1-\alpha}$$

9.3.2 Overtime model without Labor frictions

Y, N, w_1 and w_2 remain the same. The steady state consumption is now:

$$C = (1 - sg)Y$$

9.4 Log-Linear Expansions

From now on, I will use lower case letters or hats to denote variables in log deviation from the steady state. I start by log-linearizing the representative agent first order conditions, (4), (5) and (6):

$$c_t = E_t c_{t+1} - \tfrac{1}{\sigma}(i_t - E_t \pi_{t+1} + \log \beta) \qquad (A3)$$

$$\hat{w}_{2,t} = \sigma c_t \qquad (A4)$$

$$\hat{w}_{1,t} = \sigma c_t \qquad (A5)$$

The log-linearized aggregate production function, labor adjustment cost function and aggregate resource constraint are:

$$Y y_t = a_t + (1 - \alpha) h_1 N_1^{1-\alpha} n_{1,t} + (1 - \alpha) h_2 N_2^{1-\alpha} n_{2,t} \qquad (A6)$$

$$\delta_{N1} h_t = n_{1,t+1} - (1 - \delta_{N1}) n_{1,t} \qquad (A7)$$

$$Y y_t = C c_t + sgY g_t + H h_t \qquad (A8)$$

Log-linearizing (18), (19) and using (A3), results in:

$$n_{1,t+1}(i) = \tfrac{1}{1+\beta} n_{1,t}(i) + \tfrac{\beta}{1+\beta} E_t n_{1,t+2}(i) + \tfrac{1-\beta(1-\delta_{N1})}{(1+\beta)\epsilon_{\psi N1}} E_t \hat{\rho}_{i,t+1} - \tfrac{1}{\epsilon_{\psi N1}} E_t(i_t - E_t \pi_{t+1} + \log \beta) \quad (A9)$$

$$\hat{\rho}_{i,t+1} = -\hat{w}_{1,t+1} \rho_{W1} + \hat{w}_{2,t+1} \rho_{W2} + y_{i,t+1} \rho_Y - a_{t+1} \rho_A - n_{1,t+1}(i) \rho_{N1} \qquad (A10)$$

Averaging over all intermediate good firms, I obtain the following law of motion of aggregate total employment:

$$n_{1,t+1} = \tfrac{1}{1+\beta} n_{1,t} + E_t \tfrac{\beta}{1+\beta} n_{1,t+2} + \tfrac{1-\beta(1-\delta_{N1})}{(1+\beta)\epsilon_{\psi N1}} E_t \hat{\rho}_{t+1} - \tfrac{1}{\epsilon_{\psi N1}} E_t(i_t - E_t \pi_{t+1} + \log \beta) \quad (A11)$$

with:

$$\hat{\rho}_{t+1} = -\hat{w}_{1,t+1} \rho_{W1} + \hat{w}_{2,t+1} \rho_{W2} + y_{t+1} \rho_Y - a_{t+1} \rho_A - n_{1,t+1} \rho_{N1} \qquad (A12)$$

Log-linearization of the consumer demand and the optimal price conditions results in:

$$E_t \sum_{j=0}^{\infty} (\theta \beta)^j [p_{i,t+j} - mc_{i,t+j}] = 0 \qquad (A13)$$

$$y_{i,t} - y_t = -\epsilon p_{it} \qquad (A14)$$

The linearized individual firm and aggregate marginal costs conditions are:

$$mc_t = \hat{w}_{2,t} - (1 + BC)a_t - BDn_{1,t} + BCy_t \qquad (A15)$$

$$mc_{i,t} = mc_t - BDn_{1,t}(i) - \epsilon BCp_{it} \qquad (A16)$$

Under static indexing a firm that does not optimally reset its price for J periods:

$$E_t p_{i,t+J} = p_{i,t} - \sum_{j=1}^{J} E_t \pi_{t+j} \qquad (A17)$$

Substituting (A16) and A(17) in (A13) :

$$(1 + \epsilon BC)p_{i,t} = E_t \sum_{j=0}^{\infty} (\theta\beta)^j [(1 + \epsilon BC) \sum_{j=1}^{J} \pi_{t+j} + mc_{t+j} - BDn_{1,t+j}(i)] \qquad (A18)$$

9.5 Aggregate price dynamics

I start by using i's demand curve (A14) to express relative output as a function of the firm's relative price, in order to write (A9) as:

$$E_t[Q(L)n_{1,t+2}(i)] = \Xi E_t p_{i,t+1} \qquad (A19)$$

Where the lag polynomial is

$$Q(L) = \beta - [1 + \beta + (1 - \beta(1 - \delta_{N1}))\rho_{N1}\epsilon_{\psi N1}^{-1}]L + L^2 \qquad (A20)$$

and

$$\Xi = (1 - \beta(1 - \delta_{N1}))\epsilon\rho_y\epsilon_{\psi N1}^{-1}.$$

Following Woodford (2005), I posit (and later verify) that:

$$p_{i,t}^* = p_t^* - \psi_{N1}n_{1,t}(i) \qquad (A21)$$

$$n_{1,t+1}(i) = \nu_1 n_{1,t}(i) + \nu_2 p_{i,t} \qquad (A22)$$

Calvo price staggering allows us to express the price index as:

$$P_t = [\theta P_{t-1}^{1-\epsilon} + (1 - \theta)(P_t^*)^{1-\epsilon}]^{1/(1-\epsilon)} \qquad (A23)$$

Recall that under static indexing:

$$E_t p_{i,t+J} = p_{i,t} - \sum_{j=1}^{J} E_t \pi_{t+j}$$

The expectation when one integrates over all possible future states conditional upon the state of the world at date t:

$$E_t p_{i,t+1} = \theta[p_{i,t} - E_t \pi_{t+1}] + (1 - \theta)E_t p_{i,t+1}^* \qquad (A24)$$

Log-linearizing the price index, I obtain:

$\pi_t = \frac{(1-\theta)}{\theta} p_t^*$ $(A25)$

Using this and (A21) in (A24) yields:

$E_t p_{i,t+1} = \theta p_{i,t} - (1-\theta)\nu_1 \psi_{N1} n_{1,t+1}(i)$ $(A26)$

Together (A22) and (A26) form a system of 2 equations on two variables. In order to have convergent dynamics both eigenvalues of the matrix in this system must be inside the unit circle. Substituting (A22) and (A26) in (A19) it is possible to obtain, after some rearranging:

$[1 - \nu_1 \phi_{N1} + \beta\nu_1^2 - (1-\theta)\nu_1 \psi_{N1}(\beta\nu_2 - \Xi)]n_{1,t}(i)+$

$+[-\phi_{N1} + \beta\nu_1^2 + \beta\nu_1\theta - \Xi\theta\frac{\nu_1}{\nu_2} - (1-\theta)\nu_1\psi_{N1}(\beta\nu_2 - \Xi)]\frac{\nu_2}{\nu_1}p_{i,t} = 0$ $(A27)$

The coefficients on $n_{1,t}(i)$ and $p_{i,t}$ must be zero.

$[1 - \nu_1\phi_{N1} + \beta\nu_1^2 - (1-\theta)\nu_1\psi_{N1}(\beta\nu_2 - \Xi)] = 0$ $(A28)$

$[-\phi_{N1} + \beta\nu_1^2 + \beta\nu_1\theta - \Xi\theta\frac{\nu_1}{\nu_2} - (1-\theta)\nu_1\psi_{N1}(\beta\nu_2 - \Xi)] = 0$ $(A29)$

Equation (A22) implies that:

$$E_t \sum_{j=0}^{\infty}(\theta\beta)^j n_{1,t+j}(i) = (1-\theta\beta\nu_1)^{-1}n_{1,t}(i) + \nu_2\frac{\theta\beta}{(1-\theta\beta)(1-\theta\beta\nu_1)}[p_{i,t} - \sum_{j=1}^{\infty}(\theta\beta)^j\pi_{t+j}]$$ $(A30)$

Substitution of this in equation (A18):

$$\phi_{N1}p_{i,t} = (1-\theta\beta)E_t\sum_{j=0}^{\infty}(\theta\beta)^j mc_{t+j} + \phi_{N1}\sum_{j=1}^{\infty}(\theta\beta)^j\pi_{t+j} - BD\frac{(1-\theta\beta)}{(1-\theta\beta\nu_1)}n_{1,t}(i)$$ $(A31)$

Where

$\phi_{N1} = 1 + \epsilon BC - BD\nu_2\frac{\theta\beta}{(1-\theta\beta\nu_1)}$ $(A32)$

The solution to this equation is of the conjectured form (A21) if and only if (A31) satisfies:

$$\phi_{N1}p_t^* = (1-\theta\beta)E_t\sum_{j=0}^{\infty}(\theta\beta)^j mc_{t+j} + \phi_{N1}\sum_{j=1}^{\infty}(\theta\beta)^j\pi_{t+j}$$ $(A33)$

With

$\phi_{N1}\psi_{N1} = BD\frac{1-\theta\beta}{(1-\theta\beta\nu_1)}$ $(A34)$

One can now solve for the undetermined parameters ($\phi_{N1}, \psi_{N1}, \nu_1, \nu_2$) of the firm's optimal decision rules, using (A28),(A29),(A32) and (A34). Like in Woodford, this system can be reduced to a single equation for ν_1. Woodford (2005) shows that a non-explosive solution to the firm's decision problem exists in the case of large enough adjustment costs.

To obtain the NKPC equation I now quasi-difference (after dividing by ϕ_{N1}) equation (A33), to yield:

$$p_t^* = (1 - \theta\beta)\phi_{N1}^{-1}mc_t + \theta\beta E_t\pi_{t+1} + \theta\beta E_t p_{t+1}^* \qquad (A35)$$

Finally use (A25) to substitute out the optimal price variable and obtain the NKPC:

$$\pi_t = \beta E_t\pi_{t+1} + \gamma mc_t$$

The parameter γ in the NKPC is :

$\gamma = \frac{(1-\theta)(1-\theta\beta)}{\theta}\phi_{N1}^{-1}$

Whereas, in the standard NKPC model with homogeneous factors and a Cobb Douglas production function:

$$Y_{i,t} = A_t K_{i,t}^{\alpha} N_{i,t}^{1-\alpha} \qquad\qquad (A36)$$

γ is simply equal to $\frac{(1-\theta)(1-\theta\beta)}{\theta}$.

In a model with no capital and no labor frictions:

$$Y_{i,t} = A_t N_{i,t}^{1-\alpha} \qquad\qquad (A37)$$

γ then equals $\frac{(1-\theta)(1-\theta\beta)}{\theta}\frac{1-\alpha}{1-\alpha+\alpha\epsilon}$. Under the assumption of constant returns to scale ($\alpha = 0$) then there is no difference between this case and standard NKPC model with homogeneous factors.

9.6. Figures

Figure 1
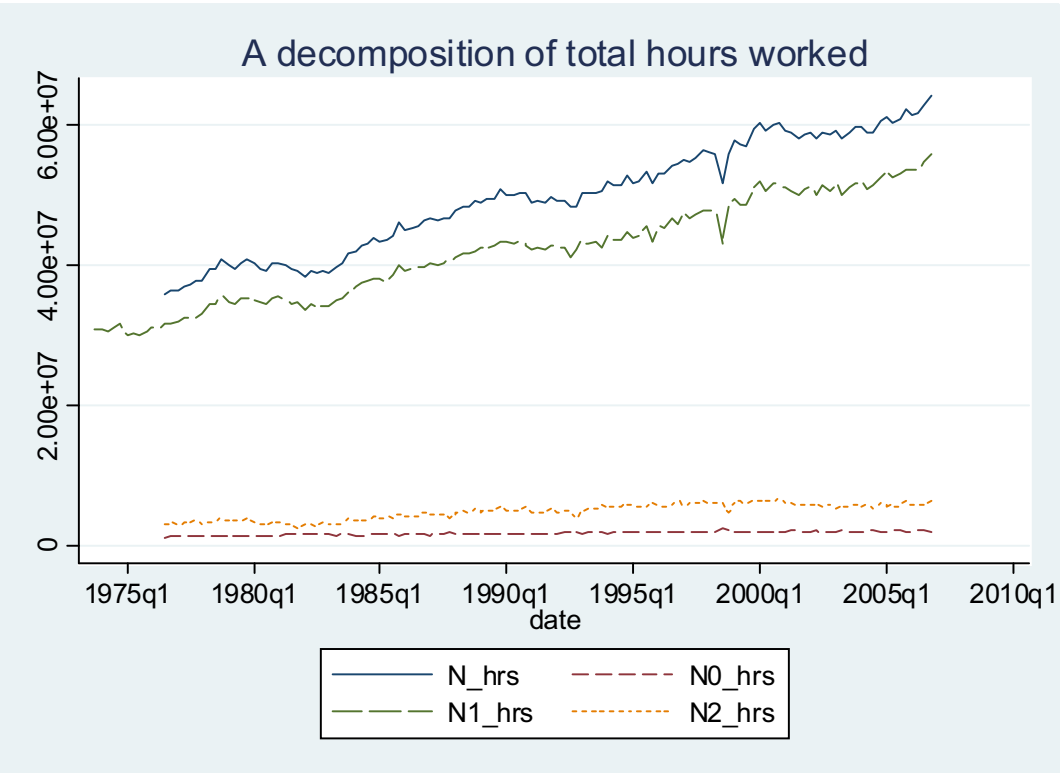
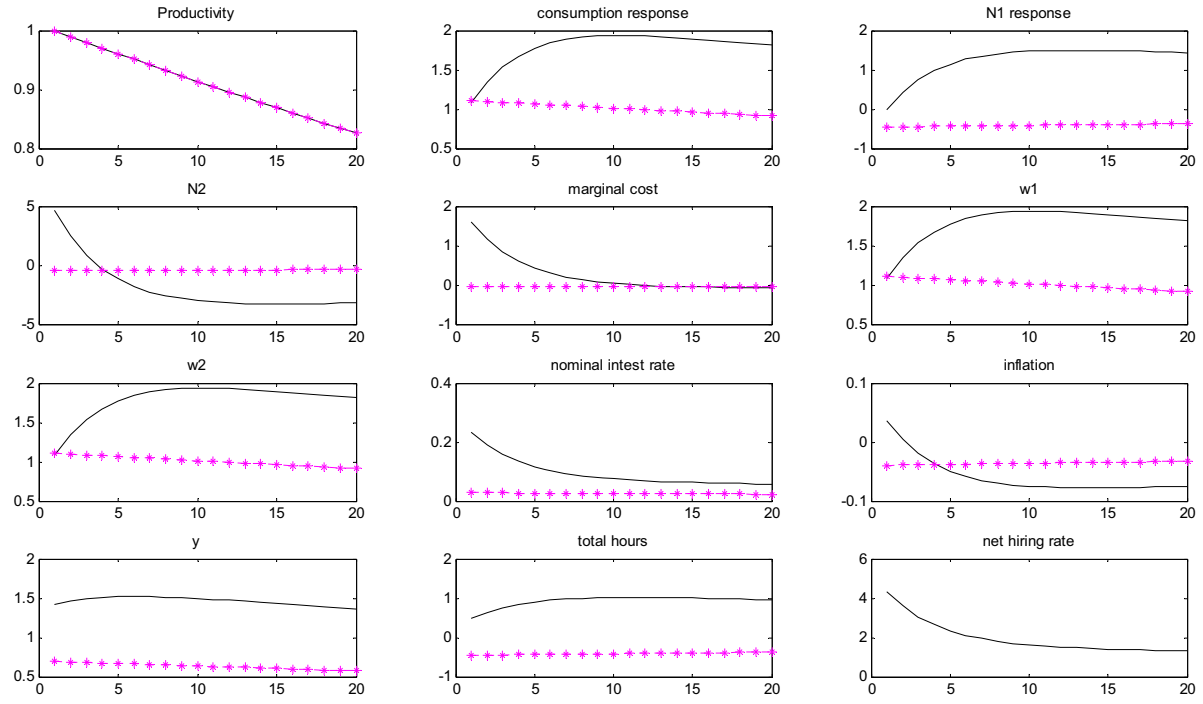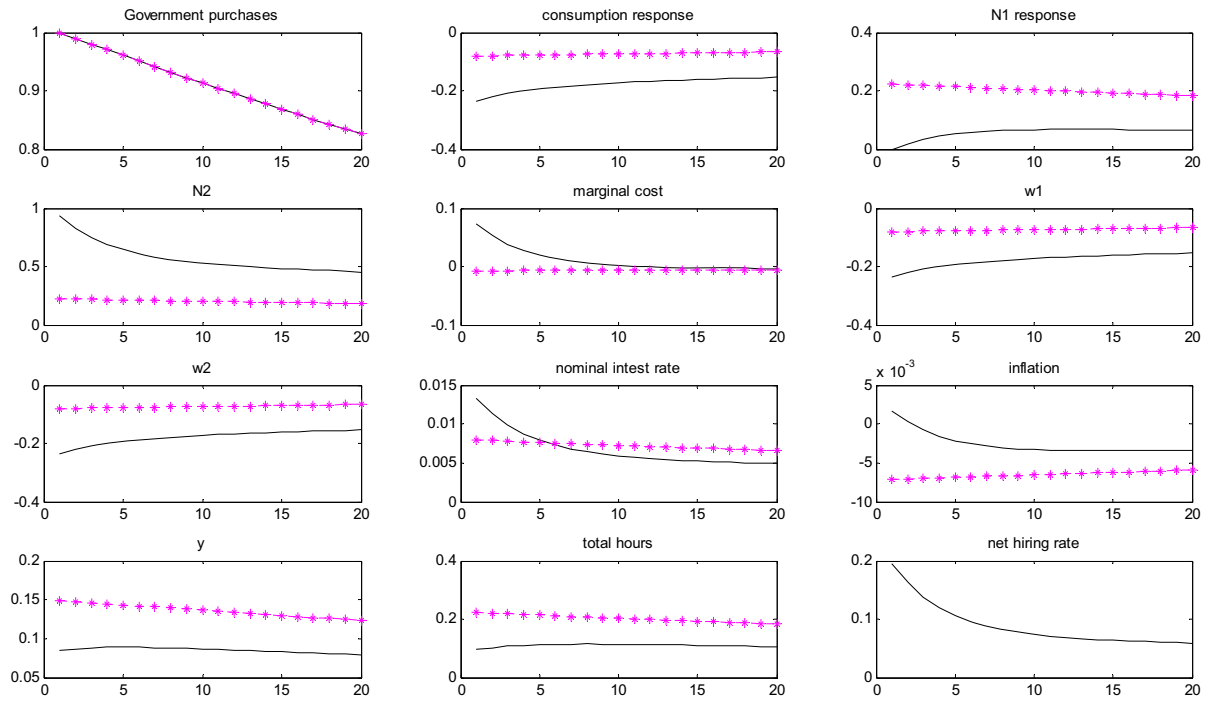Figure 2
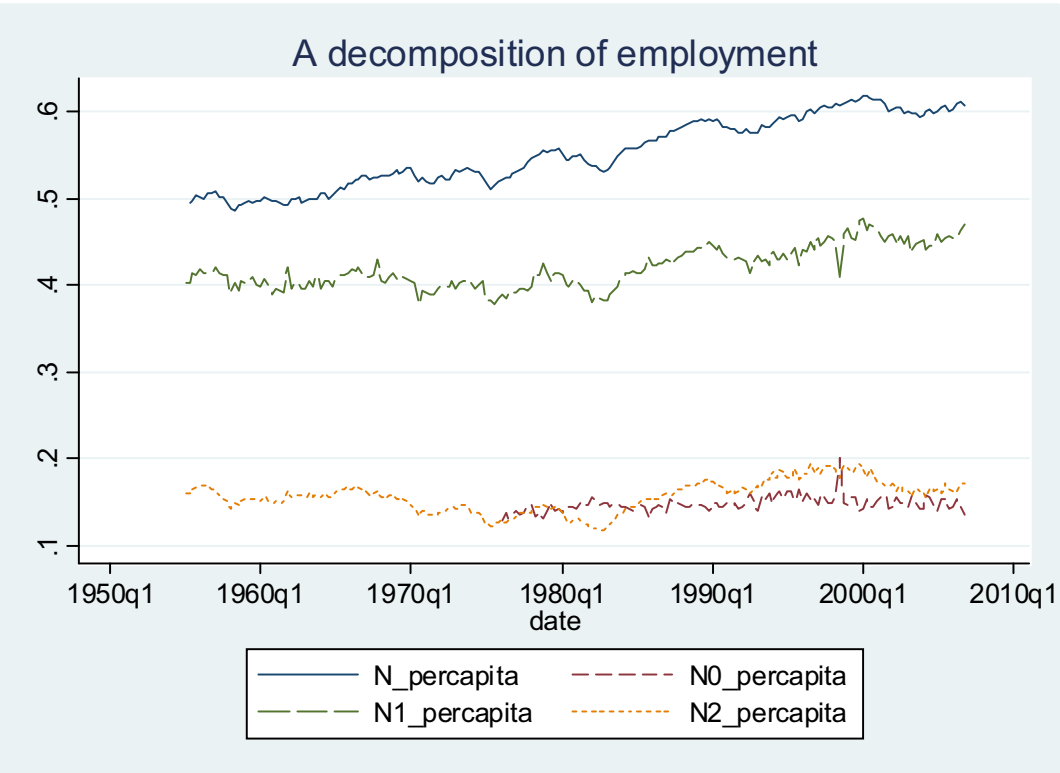
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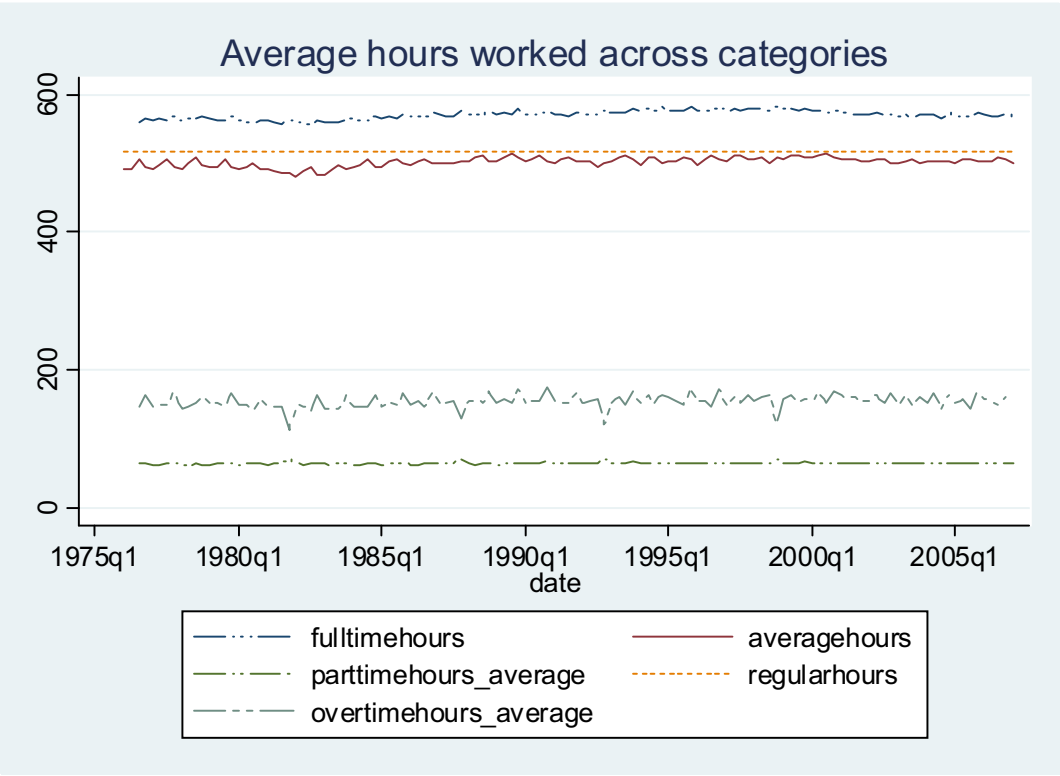
Figure 4
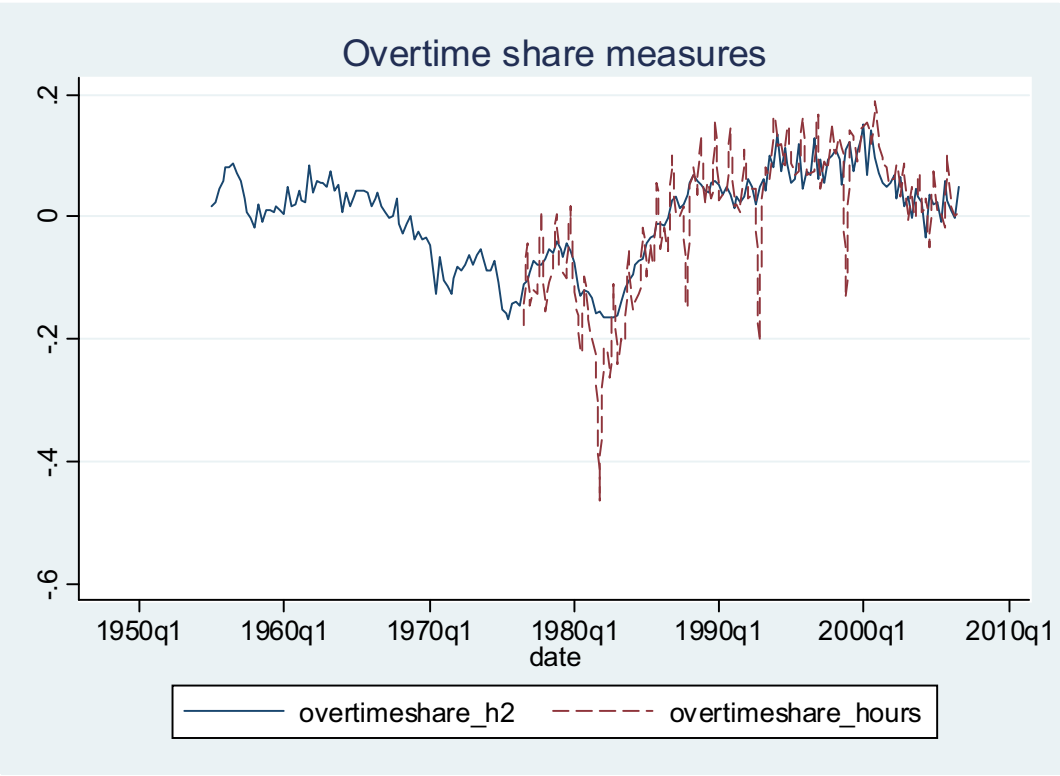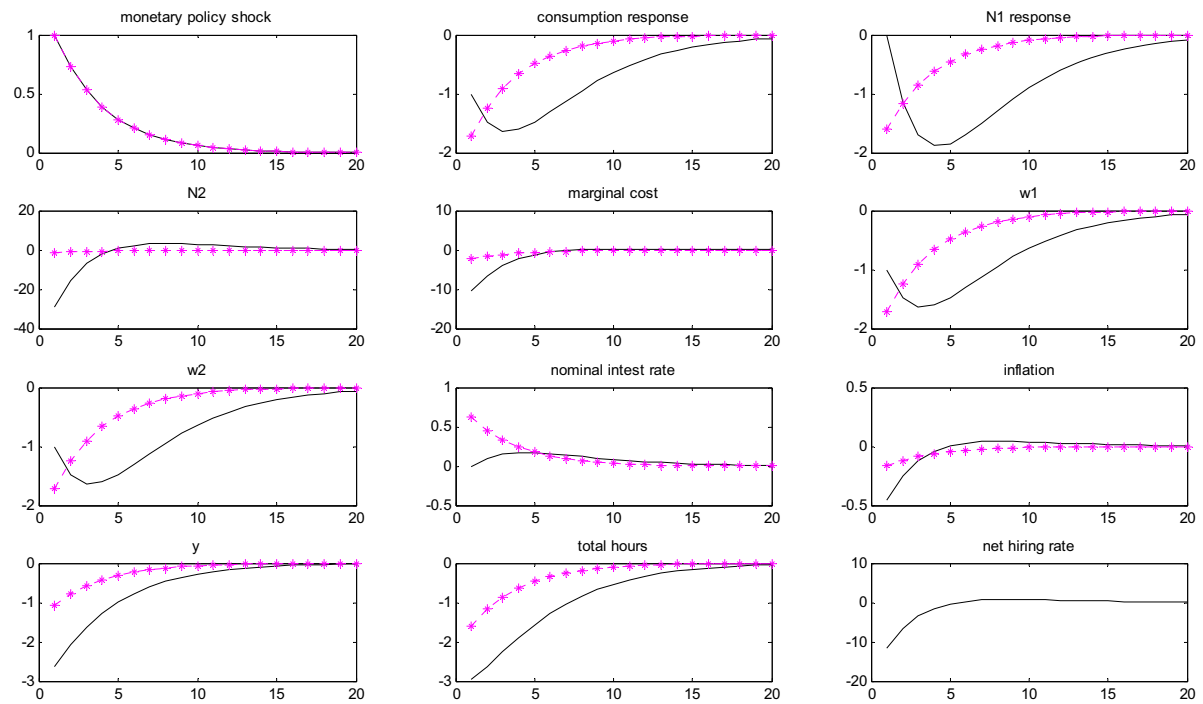
Figure 5:   TFP shock

Figures 6: Government expense shock

Key: —Model with labor frictions; ∗ − ∗ Model without labor Frictions

Figure 7: Monetary Policy shock

Key: —Model with labor frictions; ∗ − ∗ Model without labor Frictions

9.7. Tables

Table 1: Categories of worker types as percentage of civilian population		
Variable	Data range	Mean
N_percapita SA	1955Q2:2006Q4	0.551
N0_percapita SA	1976Q3:2006Q4	0.148
N1_percapita SA	1955Q1:2006Q4	0.419
N2_percapita SA	1955Q1:2006Q4	0.158

Data for U.S. nonagricultural industries:N denotes total employment, N0 denotes persons at work 1-34 hours, N1 denotes persons at work 35 hours and over, N2 denotes persons at work 41 hours and over. All variables are seasonally adjusted and converted to per capita terms using the civilian, noninstitutional population.

Table 2: Average quarterly hours per worker category		
Variable	Obs	Mean
average hours NSA, all workers	1976Q1:2006Q4	508.548
part time hours NSA	1976Q3:2006Q4	64.8991
full time hours NSA	1976Q3:2006Q4	570.616
regular hours NSA	1976Q3:2006Q4	516
overtime hours NSA	1976Q3:2006Q4	155.049

Data for full-time hours excludes persons working less than 35 hours a week. Part time hours are average hours of persons at work 1-34 hours a week. Regular hours was calculated by assuming a 40 hour weekly duration for the straight time shift. Overtime hours = (N1*(full time hours-regular hours))/N2. Quarterly values were obtained by assuming a month to be equal to 4.3 weeks and then summing the resulting monthly observations, these are non-seasonaly adjusted series.

Table 3: Variance decomposition		
	Covariances	
N_hrs	1	
N1_hrs	0.839	
N2_hrs	0.131	
N0_hrs	0.029	
	Variance	ratio
log_N0_hrs	0.021	1
log_N0	0.020	0.952
log_part time hours	0.0007	0.033
covariance term*	0.0006	0.057
log_N1_hrs	0.071	1
log_N1	0.071	1
log_regular hours	0	0
covariance term *	0	0
log_N2_hrs	0.061	1
log_N2	0.048	0.787
log_overtimehours	0.005	0.082
covariance term*	0.004	0.131

N_hrs denotes total hours worked in the nonagricultural industries.
N0_hrs denotes total part time hours worked in the nonagricultural industries.
N1_hrs denotes total regular hours worked in the nonagricultural industries.
N2_hrs denotes total overtime hours worked in the nonagricultural industries.
*in the covariance term the ratio is computed by multiplying the covariance of the number of workers with the average hours in the category by 2 and then dividing by the variance.

Table 4: U.S. Business cycle statistics		
	relative standard deviation	contemp. correlation with output
HP_log_C	0.61	0.88
HP_log_N	0.63	0.82
HP_log_N0	2.63	-0.03
HP_log_N1	1.23	0.60
HP_log_N2	2.23	0.73
HP_log_w	0.55	0.12
inflation	0.40	0.18
HP_log_y	1	1
FF	0.51	0.38
HP_log_N_hrs	0.99	0.88
HP_log_A	0.69	0.47
HP_log_G	1.63	0.15

y denotes real GDP per capita, G is government current expenditures per capita, C is personal consumption expenditures per capita, FF is the federal funds rate, w is compensation per hour in the nonfarm business sector divided by the GDP price deflator, the inflation measure was constructed using the GDP price deflator. A_N is a TFP measure (see note 12 in the paper for details). N, N0, N1 and N2 are the same series detailed in table 1. N_hrs denotes total hours worked per capita. All series are in logs and were detrended with an HP filter (with the exception of inflation and FF).

Table 5: OLS regressions (with constant) on HP detrended real GDP		
	Coef.	Std. Err.
HP_log_N	0.487	0.025
HP_log_N0	-0.322	0.578
HP_log_N1	0.793	0.071
HP_log_N2	1.879	0.099

Table 6: micro evidence on the frequency of price adjustment			
Sample	fr	implied T	implied θ
1. All Items			
All prices	0.293	3.413	0.121
Regular prices	0.233	4.292	0.301
2. Core Items			
All prices	0.26	3.846	0.220
Regular prices	0.207	4.831	0.379

The first colum is from Klenow and Kryvstov. and gives the mean fraction of changing monthly prices.
T is the implied mean number of months for which a price remains fixed.
The last column gives us the implied probability of a price being fixed for a quarter.

Table 7: Implication for price frequency of alternative assumptions about factor markets				
	implied values of θ			
gamma	Homo. Fact.	Firm-specific capital	DRS	labor frictions
0.05	0.804	0.615	0.619	0.328
0.04	0.823	0.646	0.651	0.354
0.03	0.845	0.731	0.689	0.402
0.02	0.872	0.724	0.738	0.468

Table 8: Implication for price frequency of the output share of the constrained factor	
	implied values of teta
	Firm-specific capital
α = 0.66	0.569
	labor frictions
t1=200; N1=0.20	0.634

Table 9: Implication for price frequency of alternative parameter choices	
	implied values of teta
δ_{N1}=0.03; $\varepsilon_{\psi N1}$=2	0.468
δ_{N1}=0.1; $\varepsilon_{\psi N1}$=3	0.470
δ_{N1}=0.03; $\varepsilon_{\psi N1}$=0.5	0.460

Table 10: Summary statistics of marginal cost measures		
	standard deviation	correlation with HP_log_y
laborshare	0.02	-0.11
overtimeshare_h2	0.08	0.25
overtimeshare_hrs	0.12	0.21

Table 11: GMM nonlinear regressions of NKPC			
	coeficient	standard errors	Prob. J
1. labor share (Gali&Gertler)			
beta	0.926	0.024	
teta	0.829	0.013	
gamma	0.047		
2.overtimeshare_h2			
beta	0.991	0.023	0.055
teta	0.875	0.040	
gamma	0.019		
3.overtimeshare_hrs			
beta	1.005	0.026	0.153
teta	0.883	0.041	
gamma	0.015		
4.overtimeshare_hrs (beta=1)			
beta	1		0.193
teta	0.885	0.040	
gamma	0.016		

Table 12: GMM linear regressions of NKPC			
	coeficient	standard errors	Prob. J
1. labor share (Gali&Gertler)			
beta	0.942	0.045	
gamma	0.023	0.012	
2.overtimeshare_h2			
beta	0.980	0.023	0.070
gamma	-0.005	0.011	
3.overtimeshare_hrs			
beta	1.003	0.025	0.193
gamma	-0.014	0.010	
4.overtimeshare_hrs (beta=1)			
beta	1		0.182
gamma	-0.014	0.010	

Table 13: OLS estimates of labor share on lagged inflation			
	coeficient	P-value	R2
pi_t-1	0.015	0.849	0.015
pi_t-2	-0.015	0.863	F-statistic
pi_t-3	0.015	0.868	0.477
pi_t-4	0.045	0.561	

Table 14: OLS estimates of overtimeshare_h2 on lagged inflation			
	coeficient	P-value	R2
pi_t-1	0.377	0.336	0.206
pi_t-2	0.027	0.951	F-statistic
pi_t-3	-0.387	0.377	0.000
pi_t-4	-0.782	0.047	

Table 15: OLS regressions of inflation on present value of marginal costs			
	coeficient	standard errors	Adj. R2
1. PV(labor share)			
gamma	0.014	0.011	0.002
2. PV(overtimeshare_h2)			
gamma	-0.017	0.001	0.741

Table 16: OLS regressions of changes in inflation on changes of present value of marg. costs			
	coefficient	standard errors	Adj. R2
1. ΔPV(labor share)			
gamma	0.015	0.013	0.001
2. ΔPV(overtimeshare_h2)			
gamma	0.015	0.002	0.17

Table 17: Business cycle statistics - TFP shock

	Model with labor frictions		Model without labor frictions	
	relative standard deviations	contemporaneous correlation with output	relative standard deviations	contemporaneous correlation with output
c	1.08	0.95	1.59	1
n1	0.78	0.65	0.65	-1
n2	3.20	0.17	0.65	-1
w1	1.08	0.95	1.59	1
inflation	0.05	-0,28	0.06	-1
y	1	1	1	1
h	2.35	0.87		
mc	0.87	0.64	0.06	-1
i	0.13	0.84	0.04	1
hrs	0.55	0.93	0.65	-1
a	0.66	1.00	1.43	1

Table 18: Business cycle statistics - G shock

	Model with labor frictions		Model without labor frictions	
	relative standard deviations	contemporaneous correlation with output	relative standard deviations	contemporaneous correlation with output
c	2.43	-0,98	0.54	-1
n1	0.60	0.63	1.49	1
n2	9.05	0.95	1.49	1
w1	2.43	-0,98	0.54	-1
inflation	0.04	-0,24	0.05	-1
y	1	1	1	1
h	1.80	0.88		
mc	0.67	0.66	0.05	-1
i	0.12	0.91	0.05	1
hrs	1.23	1.00	1.49	1
g	11.15	1.00	6.70	1

Table 19: Business cycle statistics - M shock

	Model with labor frictions		Model without labor frictions	
	relative standard deviations	contemporaneous correlation with output	relative standard deviations	contemporaneous correlation with output
c	0.80	0.80	1.59	1
n1	0.92	0.46	1.49	1
n2	9.77	0.85	1.49	1
w1	0.80	0.80	1.59	1
inflation	0.15	0.86	0.15	1
y	1	1	1	1
h	3.91	0.89		
mc	3.59	0.94	2.09	1
i	0.08	-0,41	0.58	-1
hrs	1.25	0.99	1.49	1
v	0.36	-0,99	0.93	-1