Monetary Policy and Unemployment

Jordi Galí *
CREI and Universitat Pompeu Fabra

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Abstract

Over the past few years a growing number of researchers have turned their attention towards the development and analysis of extensions of the New Keynesian framework that model unemployment explicitly. The present paper describes some of the essential ingredients and properties of those models, and their implications for monetary policy.

Keywords: nominal rigidities, labor market frictions, wage rigidities.

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*Correspondence: CREI, Ramon Trias Fargas 25, 08005 Barcelona (Spain). E-mail: jgali@crei.cat . This paper has been prepared for the Conference on "Key Development in Monetary Economics," to be held in Frankfurt, 29-30 October. Many of the insights contained in the present paper are based on earlier joint work with Olivier Blanchard. I also thank Jan Eeckhout and participants at the CREI Faculty Lunch for helpful comments at different stages of this project. Tomaz Cajner and Lien Laureys provided excellent research assistance. I acknowledge the financial support from the European Research Council, the Ministerio de Ciencia e Innovación, the Government of Catalonia and the Barcelona GSE Research Network.

1 Introduction

The existence of involuntary unemployment has long been recognized as one the main ills of modern industrialized economies. And the rise in unemployment that invariably accompanies all economic downturns is, arguably, one of the main reasons why cyclical fluctuations are generally viewed as undesirable and an often invoked justification for stabilization policies.

Despite the central role of unemployment in the policy debate, that variable has been–until recently–conspicuously absent from the new generation of models that have become the workhorse for the analysis of monetary policy, inflation and the business cycle, and which are generally referred to as New Keynesian.[1] That absence may be justified on the grounds that explaining unemployment and its variations has never been the focus of that literature, so there was no need to model that phenomenon explicitly..But this could be interpreted as suggesting that there is no independent role for unemployment–as distinguished, say, from measures of output or employment–as a determinant of inflation (or other macro variables) or as variable that central banks should be concerned about. In other words, it suggests that unemployment is not essential for understanding fluctuations in nominal and real variables, nor to determine the optimal design of monetary policy in light of those fluctuations.

Over the past few years, however, a growing number of researchers have

[1] The term "unemployment" cannot be found in the index of Walsh (2003) or Woodford (2003), two textbooks providing a modern treatment of monetary economics. Galí (2008) briefly mentions "unemployment" in the concluding chapter of his book, but only in reference to the recent extensions of the New Keynesian model discussed in the present paper.

turned their attention towards the development and analysis of extensions of the New Keynesian framework that model unemployment explicitly. The typical framework in this literature combines the nominal rigidities and consequent monetary non-neutralities of New Keynesian models with the real frictions in labor markets that are characteristic of the search and matching models in the Diamond-Mortensen-Pissarides tradition.[2] Table 1 provides a tentative list of recent contributions to that literature, classified according to (i) whether they adopt a positive or normative perspective, and (ii) whether they allow for some sort of wage rigidities or not. (A more detailed discussion of aspects of some of these contributions can be found throughout text, though it will receive a more extensive treatment in future versions of the paper).

The objective of the present paper is twofold. First, to describe some of the essential ingredients of a model that combines labor market frictions and nominal rigidities. And, secondly, to use such a model to address questions of interest pertaining to the interaction between labor market frictions and nominal rigidities. Two broad questions are emphasized in the analysis below: What is the role of labor market frictions in shaping the economy's response to shocks? And what are their implications for the design of monetary policy?

In order to address those questions, I develop an extension of the New Keynesian model that allows for labor market frictions and unemployment. The model is highly stylized, combining elements found in existing papers, but abstracting from ingredients that (in my view) are not essential given the purpose at hand. Relative to the relevant literature, the main novelty

[2]See Pissarides (2000) for a comprehensive exposition of the search and matching approach.

of the framework developed here, lies in the introduction of variable labor market participation. That feature is meant to overcome the surprising contrast between the importance given by the New Keynesian literature to the elasticity of labor supply (e.g. as a determinant of the persistence of the real effects of monetary policy shocks) and the assumption of a fully inelastic labor supply found almost invariably in the literature on labor market frictions and nominal rigidities.

Several lessons emerge from the analysis, which are summarized next in the form of bullet points.

- Quantitatively realistic labor market frictions are likely to have, by themselves, a limited effect on the economy's equilibrium dynamics. Instead, their main role is."to make room" for wage rigidities, with the latter leading to inefficient responses to shocks and significant tradeoffs for monetary policy.

- When combined with a realistic Taylor-type rule, the introduction of price rigidities in a model with labor market frictions has a limited impact on its equilibrium response to real shocks (though, of course, it makes monetary policy non-neutral).

- If the conditions that guarantee the efficiency of the steady state are assumed, the optimal policy under flexible Nash bargained wages is one of strict inflation targeting, which requires that the price level be stabilized at all times. When nominal wages are bargained over and readjusted infrequently, the optimal policy involves moderate deviations from price stability and can be approximated well by a simple interest rate rule that responds to price inflation with a coefficient of about 1.5.

- Deviations in the unemployment rate from its efficient level are generally a source of welfare losses above and beyond those generated by fluctuations in the output or employment gaps. An optimized simple interest rate rule calls for a systematic (though relatively weak) stabilizing policy response to inefficient fluctuations in unemployment.

The paper is organized as follows. Section 2 presents some evidence on the cyclical behavior of labor market variables and inflation, as well as a simple structural interpretation of their fluctuations. Section 3 develops a baseline model with labor market frictions and price rigidities. Section 3 discusses wage determination, in two alternative environments (flexible and sticky wages). Section 4 discusses the properties of a calibrated version of the model, focusing on the implied responses to monetary and technology shocks. Section 5 presents the welfare criterion associated with the model under the assumption of an efficient steady state, and discusses the responses to a technology shock under the optimal monetary policy and the optimal simple rule. Section 6 discusses possible model extensions, to be pursued in future work. Section 7 concludes. References and discussion of the relevant literature are interspersed throughout the paper, rather than lumped in a single section.

2 Evidence on the Cyclical Behavior of Labor Market Variables

This section summarizes the cyclical properties of employment, the labor force, the unemployment rate, price and wage inflation and the real wage in the postwar U.S. economy. GDP is taken to be the benchmark cyclical indicator. I use quarterly data corresponding to the sample period 1948Q1-2008Q4. Employment, the labor force, and GDP are measured as a fraction of the working age population and, together with the real wage, are expressed in natural logarithms. All variables are detrended using a band-pass filter that seeks to preserve fluctuations with a periodicity between 6 and 32 quarters.

The first panel of Table 2 reports two key unconditional second moments for the cyclical component of each variable: its standard deviation relative to GDP and its correlation with GDP. Many of the facts reported here are well know but are summarized here as a reminder. Thus, note that employment is substantially more volatile than the labor force, with unemployment lying somewhere in between. The real wage is also shown to be substantially less volatile than GDP. Turning to the correlation with GDP, we see that both employment and the labor force are procyclical, though the latter only moderately so (their respective correlations are 0.83 and 0.30). The unemployment rate is highly countercyclical, with a correlation with GDP close to -0.9. Price inflation and wage inflation are mildly procyclical, but the real wage is essentially acyclical.

In addition to the unconditional statistics just summarized, Table 2 also reports conditional statistics based on a decomposition of each variable into "technology-driven" and "demand-driven" components. The decomposition is based on a partially-identified VAR with five variables: (log) labor productivity, (log) employment, the unemployment rate, price inflation and the average price markup. The latter is computed as the difference between (log) labor productivity and the (log) real wage.[3] Following the strategy proposed in Galí (1999)) I identify technology shocks as the only source of the unit root in labor productivity. The structural VAR contains four additional shocks that are left unidentified, and referred to loosely as "demand" shocks. I define the "demand" component of each variable of interest as the sum of its components associated with each of those four shocks.

The second and third panels in Table 2 report some statistics of interest for the demand and technology components of a number of variables, computed after detrending the estimated components with a band-pass filter analogous to the one applied earlier to the raw data. Note that the conditional second moments associated with the demand-driven component are very similar to the unconditional second moments; this is not surprising once we become aware that non-technology shocks account for the bulk of the volatility of all variables (statistics not shown here). The only exception lies in the strong negative conditional correlation between the real wage and employment, which contrasts with its near zero unconditional correlation.

The conditional statistics associated with the technology-driven components are shown in the third panel of Table 2. Note that the labor force is now largely acyclical and the real wage mildly procyclical. Also, while the technology components of employment and the unemployment rate are

[3] The baseline results discussed below are based on a specification of the VAR with (log) employment in first differences and the unemployment rate detrended using a second order polynomial of time. The main findings are robust to an alternative specification with employment detrended in log-levels.

shown to be procyclical and countercyclical, as measured by the corresponding correlation with GDP, a look at the estimated dynamic responses of those variables to a technology shock reveal a more complex pattern. Figure 1 displays the estimated responses to a favorable technology shock, i.e. one which is shown to increase output and labor productivity permanently. Note that employment declines on impact in response to that shock, and only gradually reverts back to its initial level. Thus, output and employment move clearly in opposite directions (with the positive comovement uncovered in the third panel of Table 2 likely being a result of the detrending procedure).[4] The smaller decline in the labor force leads to a persistent increase in the unemployment.rate, which is only reverted after six quarters. Both the drop in employment and the simultaneous rise in the unemployment in response to a positive technology shock contrast with the predictions of standard real models of fluctuations, either of the RBC tradition (as emphasized in Galí (1999) or of the search and matching one (as stressed by Barnichon (2007)).

Next I explore whether a model that combines nominal rigidities and labor market frictions can account for some of the qualitative evidence just described.

[4] A similar result can be found in Galí (1999), Basu, Fernald and Kimball (2006), Francis and Ramey (2005), and Galí and Rabanal (2004), among others.

3 A Model with Nominal Rigidities and Labor Market Frictions

3.1 Households

I assume a large number of identical households. Each household is made up of a continuum of members represented by the unit interval. There is assumed to be full consumption risk sharing within each household. The household seeks to maximize the objective function

$$E_0 \sum_{t=0}^{\infty} \beta^t \, U(C_t, L_t) \tag{1}$$

where $\beta \in [0,1]$ is the discount factor, $C_t \equiv \left(\int_0^1 C_t(i)^{1-\frac{1}{\epsilon}} di \right)^{\frac{\epsilon}{\epsilon-1}}$ is an index of the quantities consumed of the different types of final goods by the household, and L_t is an index of the total effort or hours that household members allocate to labor market activities. More specifically, I define L_t as

$$L_t = N_t + \psi U_t \tag{2}$$

where N_t and U_t denote, respectively, the fraction of household members who are employed and unemployed (and looking for a job).[5] Parameter $\psi \in [0,1]$ represents the marginal disutility generated by an unemployed member relative to an employed one. Non-participants in the labor market generate no disutility to the household. Note that the labor force (or participation

[5] I focus on variations in labor input at the extensive margin, and abstract from possible variations over time in hours per worker (or effort per worker). Even though the latter display non trivial cyclical movements in the data, its introduction seems unnecessary to convey the basic points made below. See Trigari (2009) and Thomas (2008), aamong others, for examples of related models that allow for variation in (disutility-generating) hours per worker.

rate) is given by $N_t + U_t$. The following constraints must be satisfied for all t: $C_t(i) \geq 0$, all $i \in [0,1]$, $0 \leq N_t + U_t \leq 1$, $U_t \geq 0$ and $N_t \geq 0$.

The household's period utility is assumed to take the form

$$U(C_t, L_t) \equiv \log C_t - \frac{\chi}{1+\varphi} \; L_t^{1+\varphi}$$

and where the disutility implied by labor market activities can be interpreted as resulting from foregone leisure and/or consumption of home produced goods. If one sets $\psi = 0$ the resulting utility function becomes one commonly used in monetary models of the business cycle. On the other hand, if $\varphi = 0$ is assumed, we can interpret the term $\chi N_t + \chi\psi U_t$ as the integral of the disutilities of labor market activities of household members, with work and unemployment generating, respectively, individual disutilities ob χ and $\chi\psi$ (with no disutility generated by non-participation).[6] Note also that the chosen specification differs from the one generally used in the search and matching literature, where the marginal rate of substitution is assumed to be constant, thus implying a fully inelastic labor supply above a certain threshold wage. The specification here is consistent with a balanced growth path and involves a direct parametrization of the Frisch labor supply elasticity, which is given by $1/\phi$.[7]

Employment evolves over time according to

$$N_t = (1-\delta)N_{t-1} + x_t U_t^0 \tag{3}$$

where δ is a constant separation rate, x_t is the job finding rate, and U_t^0 is the

[6] See, e.g., Shimer (2008).

[7] Merz (1995) and Andolfatto (1996) were the first to adopt a the assumption of a representative "large" household with a conventional utility function in the context of a search model.

fraction of household members who are unemployed (and looking for a job) at the beginning of period t. Note that $U_t = (1 - x_t)U_t^0$.[8]

The household faces a sequence of budget constraints given by

$$\int_0^1 P_t(i)C_t(i)\ di + Q_t\ B_t \leq B_{t-1} + \int_0^1 W_t(j)N_t(j)\ dj + \Pi_t$$

where $P_t(i)$ is the price of good i, $W_t(j)$ is the nominal wage paid by firm j, B_t represents purchases of one-period bonds (at a price Q_t), and Π_t is a lump-sum component of income (which may include, among other items, dividends from ownership of firms or lump-sum taxes). The above sequence of period budget constraints is supplemented with a solvency condition which prevents the household from engaging in Ponzi schemes.

Optimal demand for each good takes the familiar form:

$$C_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\epsilon} C_t \tag{4}$$

where $P_t \equiv \left(\int_0^1 P_t(i)^{1-\epsilon}\ di\right)^{\frac{1}{1-\epsilon}}$ denotes the price index for final goods. Note also that (4) implies that total consumption expenditures can be written as $\int_0^1 P_t(i)C_t(i)\ di = P_t C_t$.

The intertemporal optimality condition is given by

$$Q_t = \beta\ E_t\left\{\frac{C_t}{C_{t+1}}\frac{P_t}{P_{t+1}}\right\} \tag{5}$$

[8]Note that (3) implies that current hires become productive in the same period. This is the timing assumed in Blanchard and Galí (2009) and consistent with the bulk of the business cycle literature, where employment is assumed o be a non-predetermined variable. In contrast, most search and matching models assume it takes one period for a new hire to become productive, thus making employment predetermined, and forcong it not to respond contemporaneously to shocks.

In the model with frictionless, perfectly competitive labor markets the household would determine how much labor to supply, taking as given the (single) market wage, and all the labor supplied would be employed (i.e. $L_t = N_t$ since there would be no unemployment). Under the assumed preferences, the intratemporal optimality condition $W_t/P_t = \chi C_t N_t^{\varphi}$ would hold, implicitly determining the quantity of labor supplied. Instead, and as discussed below, the present model assumes the wage is bargained between the worker and the firm, in order to split the surplus generated by the existence of labor market frictions. Employment is then the result of the aggregation of firms' hiring decisions, given the wage. In other words, employment is demand determined, with the households' participation decision influencing employment only indirectly, through the impact on wages.

3.2 Firms

As in much of the literature on nominal rigidities and labor market frictions, I assume a model with a two sector structure. Firms in the final goods sector do not use labor as an input, but are subject to nominal rigidities in the form of restrictions to the frequency of their price-setting decisions. On the other hand, firms in the intermediate goods sector are perfectly competitive and take prices as given, but are subject to labor market frictions and need to engage in wage bargaining with its workers. That modelling strategy gets around the difficulties associated with having price setting decisions and wage bargaining concentrated in the same firms.[9]

[9]See Thomas (2008b) for an analysis of a version of the model where price setters are subject to labor market frictions.

3.2.1 Final Goods

We assume a continuum of monopolistically competitive firms indexed by $i \in [0,1]$, each producing a differentiated final good. All firms have access to an identical technology

$$Y_t(i) = X_t(i)$$

where $X_t(i)$ is the quantity of the (single) intermediate good used by firm i as an input.

Under flexible prices each firm would set the price of its good optimally each period, subject to a demand schedule with constant price elasticity ϵ.[10] Profit maximization thus implies the familiar price-setting condition:

$$P_t(i) = \mathcal{M}_p(1-\tau)\ P_t^I$$

where P_t^I is the price of the intermediate good, $\mathcal{M}_p \equiv \frac{\epsilon}{\epsilon-1}$ is the optimal (gross) markup and τ is a subsidy on the purchases of intermediate goods. Since all firms choose the same price it follows that

$$P_t = \mathcal{M}_p(1-\tau)\ P_t^I$$

for all t.

Instead of flexible prices, I assume in much of what follows a price-setting environment à la Calvo (1983) with each firm being able to adjust its price each period with probability $1-\theta_p$ only. All firms adjusting their price in any given period choose the same price, denoted by P_t^*, since they face an

[10] As discussed below, this requires that the demand of final goods coming from intermediate goods firms (in order to pay for their hiring costs), has the same price elasticity as the demand originating in households.

identical problem. The (log-linearized) optimal price setting condition in this environment is given by[11]

$$p_t^* = \mu^p + (1 - \beta\theta_p) \sum_{k=0}^{\infty} (\beta\theta_p)^k \ (E_t\{p_{t+k}^I\} - \tau)$$

where lower case letters denote the logs of the original variables, $\mu^p \equiv \log \frac{\epsilon}{\epsilon - 1}$ is the desired markup (in logs), By combining the above price setting condition with the (log-linearized) law of motion for the aggregate price level

$$p_t = \theta_p \ p_{t-1} + (1 - \theta_p) \ p_t^*$$

one can derive the inflation equation

$$\pi_t^p = \beta \ E_t\{\pi_{t+1}^p\} - \lambda_p \ \widehat{\mu}_t^p \tag{6}$$

where $\pi_t^p \equiv p_t - p_{t-1}$ is price inflation, $\widehat{\mu}_t^p \equiv p_t - (p_t^I - \tau) - \mu^p$ denotes the deviation of the (log) average price markup from its steady state value, and $\lambda_p \equiv \frac{(1-\theta_p)(1-\beta\theta_p)}{\theta_p}$. Thus, the influence of labor market frictions on the dynamics of inflation will necessarily have to work through their impact on firms' markups.

3.2.2 Intermediate Goods

The intermediate good is produced by a continuum of identical, perfectly competitive firms, represented by the unit interval and indexed by $j \in [0, 1]$. All such firms have access to a production function

$$Y_t^I(j) = A_t \ N_t(j)^{1-\alpha}$$

[11] See, e.g. Galí (2008, chapter 3), for details of the derivation.

Variable A_t represents the state of technology, which is assumed to be common across firms and to vary exogenously over time. More precisely, I assume that $a_t \equiv \log A_t$ follows an $AR(1)$ process with autoregressive coefficient ρ_a and variance σ_a^2.

Employment at firm j evolves according to

$$N_t(j) = (1 - \delta)\ N_{t-1}(j) + H_t(j) \tag{7}$$

where $\delta \in (0, 1)$ is an exogenous separation rate, and $H_t(j)$ represents the measure of workers hired by firm j in period t. Note that new hires start working in the period they are hired. My timing assumption, which follows Blanchard and Galí (2009), deviates from that often found in the search and matching literature, but is consistent with most business cycle models, where employment is not a predetermined variable.

Labor Market Frictions. Following Blanchard and Galí (2009), I introduce labor market frictions in the form of a hiring cost, represented by G_t and defined in terms of final goods. That cost is assumed to be exogenous to each individual firm. Incurring the cost G_t guarantees that the firm can recruit a worker who will become productive in the same period.

Though G_t is taken as given by each individual firm, it is natural to think of it as depending on aggregate factors. One natural such determinant is the degree of labor market tightness, as measured by $x_t \equiv H_t/U_t^0$, i.e. the ratio of aggregate hires, $H_t \equiv \int_0^1 H_t(j)dj$, to the size of the unemployment pool at the beginning of the period, U_t^0. More specifically, I assume

$$\begin{aligned} G_t &= G(x_t) \\ &= \Gamma\ x_t^{\gamma} \end{aligned}$$

Note that the measure of labor market tightness x_t corresponds, from the viewpoint of the unemployed, to the job finding rate, already used in equation (3) above.[12]

Relation to the matching function approach. The above formulation is equivalent to having firms and workers match according to a function $M(V_t, U_t)$ where V_t represents the number of aggregate vacancies, and where a firm can post vacancies at a unit cost D. Under the assumption of homogeneity of degree one in the matching function, the fraction of posted vacancies that get filled is given by $M(V_t, U_t)/V_t \equiv q(V_t/U_t)$, where $q\prime < 0$. On the other hand, the job finding rate is given by $x_t = M(V_t, U_t)/U_t \equiv p(V_t/U_t)$ where $p\prime > 0$. It follows that a fraction $q(p^{-1}(x_t))$ of vacancies posted are filled out with the resulting cost per hire being given by $G_t = \Gamma/q(p^{-1}(x_t))$, which is increasing in x_t. In particular, under the assumption of a Cobb-Douglas matching function $M(V_t, U_t) = V_t^{\varsigma} U^{1-\varsigma}$ we have $G_t = \Gamma\ x_t^{\frac{1-\varsigma}{\varsigma}}$, which coincides with the above specification of the cost function.

In the presence of labor market frictions, wages (and, as a result, employment) may differ across firms, since they cannot be automatically arbitraged out by workers switching from low to high wage firms. I make this explicit by using the subindex j to refer to firm specific variables. Given a wage $W_t(j)$, the optimal hiring policy of firm j is described by the condition

$$MRPN_t(j) = \frac{W_t(j)}{P_t} + G_t - (1-\delta)\ E_t\left\{\Lambda_{t,t+1}\ G_{t+1}\right\} \tag{8}$$

[12] Instead, Blanchard and Galí (2009) assume a hiring cost of the form $A_t \Gamma x_t^{\gamma}$. Though at the possible cost of less realism, that formulation has the advantage of preserving the homogeneity of the efficiency conditions with respect to the technology shock A_t, leading to an constrained-efficient allocations with a constant employment, which is a convenient benchmark.

where $MRPN_t(j) \equiv (P_t^I/P_t)\ (1-\alpha)A_t N_t(j)^{-\alpha}$ is the marginal revenue product of labor (expressed in terms of final goods) and $\Lambda_{t,t+k} \equiv \beta^k(C_t/C_{t+k})$ is the k-period ahead (real) stochastic discount factor.[13] In words, each period the firm hires workers up to the point where the marginal revenue product of labor equals the cost of hiring a marginal worker. The latter, represented by the right hand side of (8), has three components: (i) the real wage $W_t(j)/P_t$, (ii) the hiring cost G_t, and (iii) the discounted savings in future hiring costs that result from having to hire $(1-\delta)$ fewer workers the following period. Equivalently, and solving (8) forward, we have:

$$G_t = E_t \left\{ \sum_{k=0}^{\infty} \Lambda_{t,t+k}(1-\delta)^k \left(MRPN_{t+k}(j) - \frac{W_{t+k}(j)}{P_{t+k}} \right) \right\}$$

i.e. the hiring cost must equate the (expected) surplus generated by the (marginal) employment relationship.

For future reference it is useful to define the "net" hiring cost as $B_t \equiv G_t - (1-\delta)E_t\{\Lambda_{t,t+1}\ G_{t+1}\}$. Thus, one can rewrite (8) more compactly as:

$$MRPN_t(j) = \frac{W_t(j)}{P_t} + B_t \tag{9}$$

The previous optimality condition can be used to derive an expression for the (log) average price markup in the final goods sector, which was shown above to be the driving force of inflation. Using $n_t \simeq \int_0^1 n_t(j)\ dj$ and $w_t \simeq \int_0^1 w_t(j)\ dj$ as approximate measures of (log) aggregate employment and the (log) average nominal wage around a symmetric steady state, log-linearization of (9) and subsequent integration over all firms yields the

[13] Note that intermediate good firms are perfectly competitive and thus take the price P_t^I as given.

following expression for the average markup in the final goods sector:[14]

$$\widehat{\mu}_t^p = (a_t - \alpha\ \widehat{n}_t) - [(1-\Phi)\ \widehat{\omega}_t + \Phi\ \widehat{b}_t] \tag{10}$$

where $\omega_t \equiv w_t - p_t$ is the average (log) real wage, and $\Phi \equiv \frac{B}{(W/P)+B}$. Also, note for future reference that

$$\widehat{b}_t = \frac{1}{1-\beta(1-\delta)}\ \widehat{g}_t - \frac{\beta(1-\delta)}{1-\beta(1-\delta)}\ (E_t\{\widehat{g}_{t+1}\} - \widehat{r}_t) \tag{11}$$

where r_t denotes the real return on a riskless one-period bond. [15]

Finally, note that (9) also implies

$$\alpha\ (n_t(j) - n_t) = -(1-\Phi)\ (\omega_t(j) - \omega_t) \tag{12}$$

i.e. the relative demand for labor by any given firm depends exclusively on its relative wage. Note that this is a consequence of the hiring cost being common to all firms and independent of each firm's hiring and employment levels.[16]

[14] Under the assumption that $\frac{P^I}{P}$, N, $\frac{W/P}{A}$ and $\frac{B}{A}$ have well defined steady states, the previous equation will also hold in log-levels (with an added constant term), and hence will be consistent with non-stationary technology.

[15] The price of a one-period riskless real bond is given by $\exp\{-r_t\} = E_t\{\Lambda_{t,t+1}\}$. Log-linearizing around a steady state we have

$$\widehat{r}_t \equiv r_t - \rho \simeq -E_t\{\widehat{\lambda}_{t,t+1}\}$$

where $\rho \equiv -\log\beta$ and $\lambda_{t,t+1} \equiv \log\Lambda_{t,t+1}$.

[16] The assumption of a decreasing returns technology is required in order for wage differentials across firm to be consistent with equilibrium, given the assumption of price taking behavior (otherwise only the firm with the lowest wage would not be priced out of the market). As an alternative, Thomas (2008) assumes a constant returns technology, but combines it with the assumption of firm-specific convex vacancy posting costs, in the (somewhat heterodox) form of management utility losses.

3.2.3 Labor Market Frictions and Inflation Dynamics

Empirical assessments of the price setting block of the New Keynesian model have often focused on inflation equation (6) and have made use of the fact that in the absence of labor market frictions the average price markup (or, equivalently, the real marginal cost, with the sign reversed) is given by

$$\begin{aligned}\widehat{\mu}_t^p &= (a_t - \alpha\ \widehat{n}_t) - \widehat{\omega}_t \\ &= -\widehat{s}_t^n\end{aligned}$$

where $s_t^n \equiv \omega_t - (y_t - n_t)$ is the (log) labor income share, which is readily available for most industrialized countries and can thus be used to construct a time series for the average markup can be subsequently used in empirical work.[17]

The analysis above implies that in the presence of labor market frictions

$$\begin{aligned}\widehat{\mu}_t^p &= (a_t - \alpha\ \widehat{n}_t) - [(1-\Phi)\ \widehat{\omega}_t + \Phi\ \widehat{b}_t] \\ &= -s_t^n - \Phi\ (\widehat{b}_t - \widehat{\omega}_t)\end{aligned}$$

where $\Phi \equiv \frac{B}{(W/P)+B}$. Thus the resulting empirical inflation equation may be written as

$$\pi_t^p = \beta\ E_t\{\pi_{t+1}^p\} + \lambda_p\ \left(s_t^n + \Phi\ (\widehat{b}_t - \widehat{\omega}_t)\right) \tag{13}$$

Given that

$$\widehat{b}_t = \frac{\gamma}{1-\beta(1-\delta)}\ \widehat{x}_t - \frac{\beta(1-\delta)}{1-\beta(1-\delta)}\ (\gamma E_t\{\widehat{x}_{t+1}\} - \widehat{r}_t)$$

[17] See Galí and Gertler (1999), Galí, Gertler and López-Salido (2001) and Sbordone (2002) for early applications of that approach.

it follows that in the presence of labor market frictions the measure of the average markup takes the form of a "corrected" labor income share, where the correction involves information on the job finding rate.

A recent paper by Krause, López-Salido and Lubik (2008) revisits the empirical evidence on inflation dynamics using an equation related to (13) and information about the job finding rate to contruct a modified markup series. They conclude that the impact of labor market frictions on inflation's driving variable is pretty limited. To some extent this is something one could anticipate for, as discussed below in the context of the model's calibration, $\frac{B}{W/P} = (0.045)(1 - \beta(1 - \delta)) \simeq 0.006$, implying too small a coefficient Φ to make a significant difference in the markup measure, at least in the absence of implausibly large fluctuations in net hiring costs relative to wages.

3.3 Monetary Policy

Under the model's baseline specification, monetary policy is assumed to be described by a simple Taylor-type interest rate rule represented by

$$i_t = \rho + \phi_\pi \ \pi_t^p + \phi_y \ y_t + v_t \tag{14}$$

where $i_t \equiv -\log Q_t$ is the yield on a one-period nominally riskless bond, $\rho \equiv -\log \beta$ is the household's discount rate, and v_t is an exogenous policy shifter, which is assumed to follow an $AR(1)$ process with autoregressive coefficient ρ_v and variance σ_v^2.

The previous rule, based on the specification proposed by Taylor (1993, 1999), is meant to provide a rough approximation to actual monetary policy in the U.S., especially over the past thirty years. In the normative analysis of Section 6, alternative specifications of the policy rule are considered.

4 Labor Market Frictions and Wage Determination

I consider two alternative assumptions regarding wage setting: flexible wages and sticky wages. Under the former, all wages are renegotiated and (potentially) adjusted every period. Under the latter only a (constant) fraction of firms can adjust their nominal wages in any given period. In both cases, the wage is determined according to a Nash bargaining protocol, with constant shares of the total surplus associated with each existing employment relation accruing to the worker (or his household) and the firm, respectively.

In contrast with the existing monetary models with labor market frictions, the framework below lies in its explicit (albeit stylized) modelling of the participation decision. This is possible through the introduction of a (utility) cost to labor market participation, which the household must trade-off against the probability and benefits resulting from becoming employed.[18]

Next I show, for each scenario how the surplus is split between households and firms as a function of the wage.

4.1 The Case of Flexible Wages

Under this scenario all firms negotiate every period with their workers over their individual compensation [19]The value accruing to the representative

[18]My approach here generalizes the one used by Shimer (2008) in the context of a real search and matching model.

[19]Early papers combining labor market frictions, price rigidities à la Calvo and fully flexible (Nash bargained) wages are Walsh (2005) and Trigari (2009). Trigari allows for variations in hours per worker, as well as in the number of workers. Both papers focus on the role of labor market frictions in accounting for the large and persistent response of output and the sluggish response of inflation to a monetary policy shock.

household from its marginal member employed at firm j, expressed in terms of final goods, is given by:

$$\mathcal{V}_t^N(j) = \frac{W_t(j)}{P_t} - MRS_t + E_t \left\{ \Lambda_{t,t+1} \ \left[(1-\delta) \ \mathcal{V}_{t+1}^N(j) + \delta \ \mathcal{V}_{t+1}^U \right] \right\}$$

where $MRS_t \equiv \chi C_t L_t^{\varphi}$ is the household's marginal rate of substitution between consumption and labor market effort,[20] and $\mathcal{V}_t^U$ is the value generated by an individual who is unemployed at the beginning of period t. The latter is given by

$$\mathcal{V}_t^U = x_t \int_0^1 \frac{H_t(z)}{H_t} \ \mathcal{V}_t^N(z) \ dz \ + (1-x_t) \ \left(-\psi MRS_t + E_t \left\{ \Lambda_{t,t+1} \ \mathcal{V}_{t+1}^U \right\} \right)$$

The value associated with non-participation is normalized to zero. Under the assumption of an interior allocation with positive non-participation, the household must be indifferent between sending an additional member to the labor market or not. Thus, it must be the case that $\mathcal{V}_t^U = 0$ for all t. The latter condition in turn implies:

$$\psi \ MRS_t = \frac{x_t}{1-x_t} \int_0^1 \frac{H_t(z)}{H_t} \ \mathcal{S}_t^H(z) \ dz \tag{15}$$

Also, and letting $\mathcal{S}_t^H(j) \equiv \mathcal{V}_t^N(j) - \mathcal{V}_t^U(j)$ denote the surplus accruing to the household from an established employment relation at firm j, we have:

$$\mathcal{S}_t^H(j) = \frac{W_t(j)}{P_t} - MRS_t + (1-\delta) \ E_t \left\{ \Lambda_{t,t+1} \ \mathcal{S}_{t+1}^H(j) \right\} \tag{16}$$

On the other hand, the surplus from an existing employment relation accruing to the typical firm is given by

[20] Equivalently, MRS_t is the marginal disutility of labor market effort, expressed in the terms of the final goods bundle.

$$\mathcal{S}_t^F(j) = MRPN_t(j) - \frac{W_t(j)}{P_t} + (1-\delta)\ E_t\left\{\Lambda_{t,t+1}\ \mathcal{S}_{t+1}^F(j)\right\} \tag{17}$$

Note that under the maintained assumption that the firm is maximizing profits, it follows from (8) and (**??**) that $\mathcal{S}_t^F(j) = G_t$ for all j. In words, the surplus that a profit maximizing firm gets from an existing employment relation must be equal to the hiring cost (which is also the cost of replacing a current worker by a new one, and thus what a firm saves from maintaining an existing relation).

The reservation wage for a worker employed at firm j is the minimum wage consistent with a non-negative surplus. It is given by

$$\Omega_t^H(j) = MRS_t - (1-\delta)\ E_t\left\{\Lambda_{t,t+1}\ \mathcal{S}_{t+1}^H(j)\right\}$$

The corresponding reservation wage for the firm, i.e. the wage consistent with a non-negative surplus for the firm is:

$$\Omega_t^F(j) = MRPN_t(j) + (1-\delta)\ E_t\left\{\Lambda_{t,t+1}\ \mathcal{S}_{t+1}^F(j)\right\}$$

The bargaining set at firm j in period t is defined by the range of wage levels consistent with a non-negative surplus for both the firm and the worker, and is thus given by the interval $\left[\Omega_t^H(j), \Omega_t^F(j)\right]$. Note that the size of the bargaining set is given by

$$\begin{aligned} \Omega_t^F(j) - \Omega_t^H(j) &= \mathcal{S}_t^F(j) + \mathcal{S}_t^H(j) \\ &\geq G_t \end{aligned}$$

In other words, the presence of hiring costs guarantees the existence of a non-trivial bargaining set and, as a consequence, room for bargaining between firms and workers. As emphasized by Hall (2005) any wage that lies within the bargaining set is consistent with a privately efficient employment relation. Much of the literature relies on the assumption of Nash bargaining between workers and firms in order to determine the prevailing wage. I stick to that assumption in what follows.

Any given firm and each of its employees determine the period t wage by solving the problem

$$\max_{W_t(j)} \mathcal{S}_t^H(j)^{1-\xi} \ \mathcal{S}_t^F(j)^{\xi}$$

subject to (16) and (17), and where $\xi \in (0,1)$ denotes the relative bargaining power of firms vis a vis workers.

The solution to that problem implies the following constant share rule:

$$\xi \ \mathcal{S}_t^H(j) = (1-\xi) \ \mathcal{S}_t^F(j)$$

The associated (Nash) wage is thus given by

$$\begin{aligned} \frac{W_t(j)}{P_t} &= \xi \ \Omega_t^H(j) + (1-\xi) \ \Omega_t^F(j) \\ &= \xi \ MRS_t + (1-\xi) \ MRPN_t(j) \end{aligned} \tag{18}$$

Using (9) to substitute for $MRPN_t(j)$ we confirm that the wage is common to all firms and, as a result, so will be employment, the hiring rate, and the marginal revenue product. Thus, we can henceforth omit the j index and write the Nash wage as

$$\frac{W_t}{P_t} = \xi \ MRS_t + (1-\xi) \ MRPN_t \tag{19}$$

which combined with (8) (evaluated at the symmetric equilibrium) implies

$$G_t - (1-\delta) \ E_t \{\Lambda_{t,t+1} \ G_{t+1}\} = \xi \ (MRPN_t - MRS_t) \tag{20}$$

Finally, note that under Nash bargaining the participation condition (15) can be rewritten as

$$\xi\psi \; MRS_t = (1-\xi) \, \frac{x_t}{1-x_t} \, G_t \tag{21}$$

4.2 The Case of Sticky Wages

I introduce wage rigidities in the form of staggered nominal wage setting. More especifically, I assume that the *nominal* wages paid by a given firm to its employees are renegotiated (and likely reset) with probability $1-\theta_w$ each period, independently of the time elapsed since the last adjustment at that firm.[21] The newly set wage is determined through Nash barganing between each individual worker and the firm. Once the nominal wage is set, it remains unchanged until a new opportunity for resetting the wage arises. As a result, in any given period the wage will generally deviate from the flexible Nash wage derived in the previous subsection. Yet, and to the extent that shocks are not too large, the wage will remain within the relevant bargaining set and will thus be privately efficient to maintain the corresponding employment relation. The introduction of labor market frictions thus provides a theoretical justification for the possibility of wage rigidities, as forcefully argued in Hall (2005).

Most importantly, I assume that workers hired between renegotiation periods are paid the *average* wage prevailing at the firm. Thus, the average wage will have an influence on the firm's hiring and employment levels. Yet,

[21] Earlier papers introducing staggered nominal wage setting in the context of a New Keynesian model with labor market frictions include Bodart et al. (2006), Gertler, Sala and Trigari (2008) and Thomas (2008). None of these papers, however, allows for variable participation.

I assume that the number of workers is large enough that neither the firm nor the worker barganining over the wage internalize the impact that such a choice will have on the average wage. In a symmetric equilibrium all workers will get the same wage, which ex-post will be equal to the average.[22]

It is important to stress that the previous assumption is not an innocuous one. If new hires could negotiate their wage freely at the time of being hired, the existence of long spells with unchanged nominal wages for incumbent workers would have no direct impact on the hiring decisions and, as a result, on output and employment, as emphasized by and Pissarides (2008). The empirical evidence on the relevance of wage stickiness for new hires remains controversial (see. e.g. Haefke et al. (2008), Gertler and Trigari (2009), and Galuscak et al. (2008), among others). In Section 6 I discuss a possible extension of the present model which allows for differential flexibility between incumbents and new hires, but in the remainder of the paper I stick to the above assumption.

An immediate consequence of the staggering assumption is that wages will generally differ across firms, and so will employment and output. That dispersion in the allocation of workers across otherwise identical firms, coupled with the assumption of decreasing returns, is inefficient from a social viewpoint.[23]

Next I derive the basic equations describing the surpluses accruing to

[22] This assumption simplifies the subsequent analysis considerably.

[23] The inefficiencies resulting from staggered nominal wage setting were already stressed in Erceg et al. (2000), in the context of a model without labor market frictions. Wage staggering in Thomas (2008) leads to an aggregate inefficiency as a result of the convexity of vacancy posting costs at the level of each firm. Here the inefficiency results from the presence of decreasing returns to labor.

households and firms from existing employment relations, as a preliminary step to the analysis of wage determination as the outcome of a Nash bargain.

Let $\mathcal{V}_{t+k|t}^{N}$ denote the value accruing to a household in period $t+k$ from a member who is employed at a firm that last reset its wage in period t. Under the assumption made above we have:

$$\mathcal{V}_{t+k|t}^{N} = \frac{W_t^*}{P_{t+k}} - MRS_{t+k} + E_{t+k}\left\{\Lambda_{t+k,t+k+1}\ \left[(1-\delta)(\theta_w \mathcal{V}_{t+k+1|t}^{N} + (1-\theta_w)\mathcal{V}_{t+k+1|t+k+1}^{N}) + \delta V_{t+k+1}^{U}\right]\right\}$$

for $k = 0, 1, 2, 3...$ where W_t^* denotes the nominal wage newly set in period t.[24]

On the other hand, the value accruing to a household in period t from a member who is unemployed (but part of the labor force) at the beginning of period t is given by:

$$\mathcal{V}_t^{U} = x_t \int_0^1 \left(\frac{H_t(z)}{H_t}\right)\ \mathcal{V}_t^{N}(z)\ dz + (1-x_t)\ \left(-\psi MRS_t + E_t\{\Lambda_{t,t+1} V_{t+1}^{U}\}\right)$$

Again, optimal participation implies $\mathcal{V}_t^{U} = 0$ for all t. As a result

$$\mathcal{S}_{t+k|t}^{H} = \frac{W_t^*}{P_{t+k}} - MRS_{t+k} + (1-\delta)\ E_{t+k}\left\{\Lambda_{t+k,t+k+1}\ (\theta_w \mathcal{S}_{t+k+1|t}^{H} + (1-\theta_w)\mathcal{S}_{t+k+1|t+k+1}^{H})\right\} \tag{22}$$

and

$$\psi\ MRS_t = \frac{x_t}{1-x_t}\int_0^1 \left(\frac{H_t(z)}{H_t}\right)\ \mathcal{S}_t^{H}(z)\ dz \tag{23}$$

[24] Note that even though newly set wages can in principle differ across workers and firms, ex-post all individual wages set in any given period will be identical. That justifies the omission of firm or worker indexes in W_t^*

Iterating (22) forward and evaluating the resulting expression at $k = 0$ we obtain the following expression for the household surplus from an employment relation at a firm whose wages are currently being reset:

$$\begin{aligned} \mathcal{S}^H_{t|t} &= E_t \left\{ \sum_{k=0}^{\infty} ((1-\delta)\theta_w)^k \Lambda_{t,t+k} \left(\frac{W_t^*}{P_{t+k}} - MRS_{t+k} \right) \right\} \\ &\quad + (1-\theta_w)(1-\delta)\ E_t \left\{ \sum_{k=0}^{\infty} ((1-\delta)\theta_w)^k \Lambda_{t,t+k+1}\ \mathcal{S}^H_{t+k+1|t+k+1} \right\} \end{aligned} \tag{24}$$

On the other hand, the period $t + k$ surplus accruing to a firm that last reset its wage in period t, resulting from a marginal employment relation, is given by

$$\mathcal{S}^F_{t+k|t} \equiv MRPN_{t+k|t} - \frac{W_t^*}{P_{t+k}} + (1-\delta)\ E_{t+k} \left\{ \Lambda_{t+k,t+k+1}\ (\theta_w \mathcal{S}^F_{t+k+1|t} + (1-\theta_w)\mathcal{S}^F_{t+k+1|t+k+1}) \right\} \tag{25}$$

for $k = 0, 1, 2, 3, ...,$ where $MRPN_{t+k|t} \equiv \frac{P^I_{t+k}}{P_{t+k}}(1-\alpha)A_{t+k}N^{-\alpha}_{t+k|t}$ is the marginal revenue product of labor for that firm, and $N_{t+k|t}$ its employment level. Combined with the optimal choice of employment by the firm at each point in time, as described by (8), it implies:

$$\mathcal{S}^F_{t+k|t} = G_{t+k}$$

for all t and k.

Iterating (25) forward and evaluating the resulting expression at at $k = 0$ we obtain

$$\begin{aligned} \mathcal{S}^F_{t|t} &= E_t \left\{ \sum_{k=0}^{\infty} ((1-\delta)\theta_w)^k \Lambda_{t,t+k} \left(MRPN_{t+k|t} - \frac{W_t^*}{P_{t+k}} \right) \right\} \\ &\quad + (1-\theta_w)(1-\delta)\ E_t \left\{ \sum_{k=0}^{\infty} ((1-\delta)\theta_w)^k \Lambda_{t,t+k+1}\ \mathcal{S}^F_{t+k+1|t+k+1} \right\} \end{aligned} \tag{26}$$

In the present environment, the Nash bargained wage at a firm that can reset nominal wages in period t is given by the solution to

$$\max_{W_t^*} \; (\mathcal{S}_{t|t}^H)^{1-\xi} \; (\mathcal{S}_{t|t}^F)^{\xi}$$

subject to (24) and (26). The implied sharing rule is given by

$$\xi \; \mathcal{S}_{t|t}^H = (1-\xi) \; \mathcal{S}_{t|t}^F \tag{27}$$

which combined with (24) and (26) requires that the nominal wage newly set in period t satisfy the condition:

$$E_t \left\{ \sum_{k=0}^{\infty} ((1-\delta)\theta_w)^k \Lambda_{t,t+k} \; \left(\frac{W_t^*}{P_{t+k}} - \Omega_{t+k|t}^{tar} \right) \right\} = 0 \tag{28}$$

where

$$\Omega_{t+k|t}^{tar} \equiv \xi \; MRS_{t+k} + (1-\xi) \; MRPN_{t+k|t} \tag{29}$$

can be interpreted as the k-period ahead *target* real wage. Note that the expression for the latter corresponds to that of the relevant Nash wage under *flexible wages*, as derived in the previous subsection (see equation (18)).

Log-linearizing the wage setting rule (28) around a zero inflation steady state we obtain:

$$w_t^* = (1-\beta(1-\delta)\theta_w) \; E_t \sum_{k=0}^{\infty} (\beta(1-\delta)\theta_w)^k \; E_t\{\omega_{t+k|t}^{tar} + p_{t+k}\} \tag{30}$$

where $\omega_{t+k|t}^{tar} \equiv \log \Omega_{t+k|t}^{tar}$. In words, the newly set wage corresponds to a weighted average of the current and expected future *target* nominal wages relevant to the firm that is currently resetting wages. The weights decline geometrically with the horizon, at a rate which is a function of the degree of wage stickiness and the separation rate, since both those factors determine the expected duration of the newly set wage.

Next I rewrite the above expression in terms of *average* target wages. Log-linearizing (29) around a symmetric steady state we have

$$\widehat{\omega}_{t+k|t}^{tar} = (1-\Upsilon)\ (\widehat{c}_{t+k} + \varphi \widehat{l}_{t+k}) + \Upsilon\ (-\widehat{\mu}_{t+k}^{p} + a_{t+k} - \alpha\ \widehat{n}_{t+k|t}) \tag{31}$$

where $\Upsilon \equiv \frac{(1-\xi)MRPN}{W/P}$. Let ω_t^{tar} denote the (log) *average* target wage, defined as the current target wage for a firm whose employment matches average employment. Formally,

$$\widehat{\omega}_t^{tar} = (1-\Upsilon)\ (\widehat{c}_t + \varphi \widehat{l}_t) + \Upsilon\ (-\widehat{\mu}_t^{p} + a_t - \alpha\ \widehat{n}_t) \tag{32}$$

Note that one can interpret $\widehat{\omega}_t^{tar}$ as the Nash bargained wage that would be observed in a flexible wage environment, but conditional on the levels of consumption and (average) marginal revenue product generated by the equilibrium allocation under sticky wages.

Combining (31) and (32) with (12)

$$\widehat{\omega}_{t+k|t}^{tar} = \widehat{\omega}_{t+k}^{tar} + \Upsilon(1-\Phi)\ (w_t^* - w_{t+k}) \tag{33}$$

Substituting (33) into (30), and after some algebraic manipulation we can derive the difference equation

$$w_t^* = \beta(1-\delta)\theta_w\ E_t\{w_{t+1}^*\} - \frac{1-\beta(1-\delta)\theta_w}{1-\Upsilon(1-\Phi)}\ (\widehat{\omega}_t - \widehat{\omega}_t^{tar}) + (1-\beta(1-\delta)\theta_w)\ w_t \tag{34}$$

The law of motion for the (log) average wage $w_t \equiv \int_0^1 w_t(j)\ dj$ is given by

$$w_t = \theta_w w_{t-1} + (1-\theta_w) w_t^* \tag{35}$$

Combining (34) and (35), one can derive the following wage inflation equation:

$$\pi_t^w = \beta(1-\delta)\ E_t\{\pi_{t+1}^w\} - \lambda_w\ (\widehat{\omega}_t - \widehat{\omega}_t^{tar}) \tag{36}$$

where $\lambda_w \equiv \frac{(1-\beta(1-\delta)\theta_w)(1-\theta_w)}{\theta_w\ (1-\Upsilon(1-\Phi))}$. Note that the driving variable behind fluctuations in wage inflation is the wage gap $\omega_t - \omega_t^{tar}$, defined as the deviation between the average wage and the average *target* wage.[25]

Finally, one can show that under Nash bargaining, the optimal participation condition (23) can be approximated around the zero inflation steady state as follows (see Appendix 4 for a proof).

$$\widehat{c}_t + \varphi\widehat{l}_t = \frac{1}{1-x}\ \widehat{x}_t + \widehat{g}_t - \Xi\ \pi_t^w$$

where $\Xi \equiv \frac{\xi(W/P)}{(1-\xi)G}\frac{\theta_w}{(1-\theta_w)(1-\beta(1-\delta)\theta_w)}$. Note that under flexible wages $\theta_w = 0$, implying $\Xi = 0$.

Sustainability of the fixed wage. Both the firm and the worker will find it efficient to maintain an existing employment relation as long as their respective surpluses are positive. Thus, for a worker and firm that last reset the wage in period t, this will be the case as long as the nominal wage W_t^* remains within the bargaining set bounded by the reservation wages of the firm and the worker. Formally, we require

$$W_t^* \in [\underline{W}_{t+k|t}, \overline{W}_{t+k|t}]$$

where

$$\underline{W}_{t+k|t} \equiv P_{t+k}\ \left(MRS_{t+k} - (1-\delta)\ E_{t+k}\left\{\Lambda_{t+k,t+k+1}\ (\theta_w \mathcal{S}^H_{t+k+1|t} + (1-\theta_w)\mathcal{S}^H_{t+k+1|t+k+1})\right\}\right)$$

[25] Thomas (2008) derives a similar representation for wage inflation, in the context of a slightly different model with efficient hours choice, convex vacancy posting costs, and constant returns.

and

$$\overline{W}_{t+k|t} \equiv P_{t+k} \ \left(MRPN_{t+k|t} + (1-\delta) \ E_{t+k} \left\{ \Lambda_{t+k,t+k+1} \ G_{t+k+1} \right\} \right)$$

4.2.1 Relation to the New Keynesian Wage Inflation Equation.

Equation (36) has a structure analogous to the wage inflation equation that arises in the New Keynesian model with staggered nominal wage setting, as originally developed by Erceg, Henderson and Levin (2000; EHL, henceforth). In the latter, each household is specialized in supplying a differentiated type of labor service, and sets the corresponding nominal wage unilaterally, taking as given the demand for its services (which is assumed to have a constant elasticity ϵ_w), and recognizing that the wage will be adjustable only with probability $1-\theta_w$ in each of the subsequent periods.

The wage inflation equation that results from combining the log-linearized optimal wage setting rule with a law of motion for the average wage analogous to (35) can be written as

$$\pi_t^w = \beta \ E_t\{\pi_{t+1}^w\} - \lambda_{ehl} \ (\widehat{\omega}_t - \widehat{mrs}_t) \tag{37}$$

where mrs_t is the (log) average marginal rate of substitution between consumption and hours, and λ_{ehl} is a coefficient that is inversely related to the degree of wage stickiness θ_w. In particular, under the specification of preferences used in the model above, and the absence of unemployment, we have $\widehat{mrs}_t = \widehat{c}_t + \varphi \widehat{n}_t$ and $\lambda_{ehl} \equiv (1-\beta\theta_w)(1-\theta_w)/(\theta_w(1+\epsilon_w\varphi))$.

Three main differences with respect to (36)) are worth pointing out. First, the "effective" discount factor is smaller in the model with frictions, since it incorporates the probability of termination of each relationship (and thus of the associated wage), whereas in the EHL model the wage applies to the same group of workers throughout its duration, not to a specific relation that may be subject to termination. Secondly, the implicit target wage in the EHL model is given by the average marginal rate of substitution (augmented with a constant desired wage markup), whereas in the model with frictions the target wage is also a function of the marginal revenue product of labor, since that variable also influences the total surplus to be split through the wage negotiation. Finally, the difference in the coefficient on the wage gap between the two formulations captures the different adjustments needed to express the wage inflation equation in terms of average variables: the average marginal rate of substitution in the EHL model, and the average marginal revenue product of labor in the present model. Note that under the special parameter configuration $\delta = 0$ and $\xi = 1$ the wage inflation equation of the present model matches exactly that of the EHL model.

5 Aggregate Demand and Output

Under the assumption that hiring costs take the form of a bundle of final goods given by the same CES function as the one defining the consumption index, the demand for each final good will be given by $Y_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\epsilon} (C_t+G_tH_t)$, where $H_t \equiv \int_0^1 H_t(j)\, dj$ denotes aggregate hires. Given the implied constancy of the price elasticity of demand, thus justifying the constant desired markup assumed above.

Letting aggregate output be given by $Y_t \equiv \left(\int_0^1 Y_t(i)^{1-\frac{1}{\epsilon}} di\right)^{\frac{\epsilon}{\epsilon-1}}$ it is easy to show that the aggregate goods market clearing condition is now

$$Y_t = C_t + G_t H_t \tag{38}$$

Aggregate demand thus has two components. The first component is consumption, which evolves according to the Euler equation (5). The second component is a consequence of the demand for final goods originating in firms' hiring activities.

Turning to the supply side, one can derive the following aggregate relation between final goods and intermediate input

$$\begin{aligned} X_t &\equiv \int_0^1 X_t(i)\ dj \\ &= Y_t \int_0^1 \left(\frac{P_t(i)}{P_t}\right)^{-\epsilon} di \end{aligned} \tag{39}$$

where the term $D_t^p \equiv \int_0^1 \left(\frac{P_t(i)}{P_t}\right)^{-\epsilon} di \geq 1$ captures the inefficiency resulting from dispersion in the quantities produced and consumed of final goods, which is itself a consequence of the price dispersion caused by staggered price setting.

On the other hand, the total supply of intermediate goods is given by

$$\begin{aligned} X_t &= \int_0^1 Y_t^I(j)\ dj \\ &= A_t N_t^{1-\alpha} \int_0^1 \left(\frac{N_t(j)}{N_t}\right)^{1-\alpha} dj \end{aligned} \tag{40}$$

where the term $D_t^w \equiv 1/\int_0^1 \left(\frac{N_t(j)}{N_t}\right)^{1-\alpha} dj \geq 1$ captures the inefficiency resulting from dispersion in the allocation of labor across firms due to the staggering of wages, combined with the assumption of decreasing returns ($\alpha > 0$).

As shown in Appendix 1, in a neighborhood of the zero inflation steady state we have $D_t^p \simeq 1$ and $D_t^w \simeq 1$ up to a first order approximation. Thus, combining (39) and (40) we obtain the approximate aggregate production relation:

$$Y_t = A_t N_t^{1-\alpha} \tag{41}$$

6 Equilibrium Dynamics: The Effects of Monetary Policy and Technology Shocks

This section presents the equilibrium responses of several variables of interest to the model's exogenous shocks–monetary policy and technology–and discusses how those responses are affected by nominal rigidities and labor market frictions. As a preliminary step I discuss the model's steady state, which is partly the basis for the calibration.

6.1 Steady State and Calibration

The model's steady state is independent of the degree of price and wage rigidities, and of the monetary policy rule. I assume a steady state with zero inflation and no secular growth. I normalize the level of technology to be $A = 1$. Notice that in the steady state there are no relative price distortions so $D^p = D^w = 1$ Thus, the goods market clearing condition, evaluated at the steady state, can be written as

$$N^{1-\alpha} = C + \delta N \; \Gamma x^{\gamma} \tag{42}$$

Evaluating (20) at the steady state we have

$$(1-\beta(1-\delta))\ \Gamma x^{\gamma} = \xi\left(\frac{1-\alpha}{\mathcal{M}_p(1-\tau)}N^{-\alpha} - \chi C L^{\varphi}\right) \tag{43}$$

Finally, the steady state participation condition requires

$$(1-x)\xi\psi\chi C L^{\varphi} = (1-\xi)\ \Gamma x^{1+\gamma} \tag{44}$$

The remaining steady state conditions include:

$$xU = (1-x)\delta N \tag{45}$$

$$L = N + U \tag{46}$$

In order to calibrate the model I adopt the following strategy. First, I pin down the steady state employment rate, participation rate and job finding rate using observed average values in the postwar U.S. economy. This leads to the choice of $N = 0.59$ and $L = 0.62$, which in turn imply $U = 0.03$. Note that the implied unemployment rate as a fraction of the labor force–the conventional definition–is close to five percent. $(0.03/0.62 \simeq 0.048)$. Following Blanchard and Galí (2009), I set the steady state value for the (quarterly) job finding rate x to 0.7.. The implied separation rate is thus $\delta = (x/1-x)U/N \simeq 0.12$. Following convention I set $\alpha = 1/3$ and $\beta = 0.99$. Parameter φ is the inverse of the labor supply elasticity, a more controversial parameter due to the conflict between micro and macro evidence. I set $\varphi = 5$ in the baseline calibration, but experiment with alternative values.

The baseline values for the parameters determining the degree of price and wage stickiness are set to imply average durations of one year in both cases, i.e. $\theta_p = 0.75$ and $\theta_w = 0.75$. This is consistent with microeconomic evidence on wage and price setting.[26]

Using the equivalence with the matching function approach and using estimates of the latter I set $\gamma = 1$. I also assume $\mathcal{M}_p(1-\tau) = 1$, one of the conditions for an efficient steady state. Following Hagedorn and Manovskii (2008) and Shimer (2009), who rely on the evidence reported in Silva and Toledo (2009), I take the average cost of hiring a worker to be 4.5% of the quarterly wage, i.e. $G = 0.045\ (W/P)$. Accordingly, the share of hiring costs in GDP is $\Theta = \delta NG/Y = (0.045)\ \delta\ S^n$, where S^n is the labor income share. Setting the latter to 2/3 we have $\Theta = 0.0014$, i.e. slightly above one-tenth of a percentage point of GDP. It follows that $\Gamma = G/x^\gamma = \Theta/(N^\alpha x^\gamma \delta) = 0.02$.

This leaves me with three free (though related) parameters, the firm's share in the Nash bargain (ξ), the weight of unemployment in the the disutility of market effort (ξ), and the parameter scaling the disutility of market effort (χ). Given the value for one of these parameters, I can determine the remaining two by combining (42), (44) and (43). Given the choice of $\gamma = 1$ above, perhaps a natural benchmark setting for ξ is 0.5, which is consistent with an efficient steady state. Yet, that configuration implies $\psi = 0.041$, a weight on unemployment which is arguable unrealistically small. As an alternative parameter configuration I choose $\xi = 0.05$, which is associated with $\psi = 0.82$, a more plausible value (and as discussed below, with significantly different implications). The implied settings for χ are 15.5 and 12.3, respectively.

[26] See, e.g. Nakamura and Steinsson (2008) for recent micro evidence on price rigidities, and Dickens et al (2007) and Druant et al. (2009) for related evidence on wages.

6.2 The Effects of Monetary Policy and Technology Shocks

Figure 2a displays the dynamic responses of six macro variables to an exogenous monetary policy shock under the assumption of $\xi = 0.5$, which corresponds to the case of an efficient steady state. More specifically, disturbance v_t in the interest rate is assumed to rise by 0.25 percentage points, and to die out gradually according to an AR(1) process with an autoregressive coefficient $\rho_v = 0.5$. Note that such an experiment would be associated with a one percentage point increase in the (annualized) interest rate, in the absence of an endogenous component in the rule.

Though the estimated VAR model discussed in section 2 did not seek to identify monetary shocks especifically, to the extent that those shocks and other demand shocks generate similar patterns among the variables considered, we can use the estimated conditional moments associated with demand shocks as a rough benchmark when evaluating the model's response to a monetary policy shock.

In response to that tightening of policy both output and employment declines, due to the contraction in consumption (not shown) resulting from the interest rate hike. Note also that the labor force increases by nearly 5 percent, driving up the unemployment rate by about 5 percentage points. In light of the evidence presented in section 2, both responses seem implausibly large and, in the case of the labor force, it appears to go in the wrong direction. Note also that price inflation is procyclical, in a way consistent with the evidence. The procyclical response of the real wage is, on the other hand, at odds with the estimated negative correlation with output conditional on demand shocks.

Figure 2b displays the corresponding responses to a technology shock. The latter takes the form of a 1 percent increase in a_t, which dies out gradually according to an AR(1) process with an autoregressive coefficient of 0.9. Note that, in a way consistent with the estimated impulse responses shown in Figure 1, output rises and inflation declines, as we would expect from a positive technology shock. Note also that the real wage rises gradually, as anticipated given the presence of nominal wage rigidities. Furthermore, and in contrast with the standard search and matching model, employment declines and unemployment increases in response to the same positive technology shock. As was the case with demand shocks, however, the rise in unemployment is largely driven by the increase in the labor force, which is far more volatile than employment and comoves negatively with the latter variable (in the data the conditional correlation between the labor force and employment is 0.85).

A possible reason for the unrealistically large fluctuations in the labor force and unemployment just described is the low value of parameter ψ (about 0.04) associated with the calibration underlying Figure 2. Such a low value penalizes little the fluctuations in those variables. Figures 3a and 3b show the model's implied responses to monetary and technology shocks under the alternative calibration, with $\psi = 0.82$ and $\xi = 0.05$. As the figures make clear, now the labor force experiences much smaller variations, and comoves positively with employment. The latter's more sizable movements are the dominant force behind the variations in unemployment, in a way consistent with the evidence. The response of the remaining variables is not qualitatively affected. Thus, the only variable whose response is at odds with the evidence in section 2 is the real wage, which responds procyclically to a monetary shock in the model, while displaying a negative correlation with output conditional on "demand" shocks in the data. That discrepancy could be due, however, to the presence of shocks other than technology shocks or monetary shocks (e.g. fiscal policy or labor supply shocks) that may be responsible for that negative correlation picked up by the partially identified VAR discussed in section 2.

6.3 The Role of Labor Market Frictions

In order to ascertain the role played by the presence of labor market frictions in shaping the economy's response to different shocks, I compare the model's implied responses to those shocks in the presence or not of such frictions. In both cases I maintain the assumption of flexible wages, since in the context of our framework wage stickiness cannot be justified in the absence of frictions.

Figures 4a and 4b display the economy's response to a monetary policy and a technology shock, respectively. Note that, in most cases the difference is quantitatively very small. Qualitatively, the only significant difference lies in the non-zero unemployment response to either shock in the presence of frictions, whereas in their absence a perfectly competitive labor market guarantees that there is no unemployment, implying that its response to shocks is flat at zero, as shown in the figure. The variations in unemployment generated by the introduction of frictions are, however, very small for both shocks. This result is reminiscent of the so-called Shimer puzzle, i.e. the small volatility of unemployment in response to technology shocks generated by a (real) search and matching framework with flexible wages (Shimer (2005)).

The finding of a small role of labor market frictions in the response to monetary policy shocks contrasts somewhat with the conclusions from the analysis in Trigari (2005) and Walsh (2005) in a related model, which points a significantly more sluggish response of inflation and a larger and more persistent response of output in the presence of those frictions. Some further inquiry into the reasons for the difference in results seems warranted and will be pursued in future revisions.

6.4 The Role of Price Stickiness

How does the introduction of sticky prices affect, qualitatively and quantitatively, the response of unemployment and other variables to aggregate shocks? In order to address this question I analyze the response to monetary and technology shocks of two versions of the model economy developed above, with the only difference among them is the presence or not of staggered price setting in the final goods sector. In both cases I maintain the assumption of full wage flexibility.

Figures 5a and 5b display the corresponding impulse response functions. First, and not surprisingly, we see that the introduction of price stickiness has a significant impact on the economy's response to a monetary policy shock (Figure 5a). Thus, under flexible prices no real variable is affected by the shock, and only inflation declines in response to the tightening of policy. In contrast, once a realistic degree of price stickiness is allowed for, the model implies a decline in output, employment and the labor force, with a rise in the unemployment rate (after a tiny one period decline). Inflation and the real wage also decline, as expected.

The impact of price stickiness on the response to a positive technology shock (Figure 5b) appears to be much more limited. In particular, the effect on the size of the output response–more muted under sticky prices–is hardly discernable. The difference is sufficient, however, to account for a sign reversal in the response of employment, from positive to negative, though quantitatively the size of the employment adjustment is very small in both cases. Combined with a small influence (in the same direction) on the response of the labor force, the impact of price stickiness on the response of unemployment to the technology shock is almost negligible. The only sizable impact of price stickiness appears to be on the response of the real wage, which declines considerably as a result of the large rise in the markup of final goods firms that results from their failure to lower prices to match the decline in the price of intermediate goods. This is reflected in a muted rise in the marginal revenue product of intermediate goods firms and, as a result, on the wage.

6.5 The Role of Wage Stickiness

Finally, I turn to an examination of the role played by wage stickiness in shaping the responses of the economy with labor market frictions to monetary and technology shocks. Figures 6a and 6b display the implied responses to both shocks under two alternative calibrations of the economy with labor market frictions: with and without wage stickiness. In both cases prices are assumed to be sticky.

As Figure 6a makes clear, the presence of sticky wages strengthens substantially the effects of a monetary policy shock on economic activity. In particular, the decline in output and employment is roughly twice as large as in the case of sticky prices only. Since the response of the labor force is hardly affected, the resulting increase in unemployment is also much larger. In addition, and not surprisingly, we see how the average real wage shows a much smoother response in the presence of staggered contracts, leading to less downward pressure on marginal costs and, as a result, a smaller decline in inflation.

The impact of wage stickiness on the responses to a technology shock is also substantial, as shown in Figure 6b. In particular, the negative response of employment is now larger, and that of the labor force (slightly) smaller. This is sufficient for the response of the unemployment rate to switch its sign, and ot rise in response to a positive technology shock. That implication contrasts with the prediction of real models with labor market frictions (e.g. Shimer (2005)), but is consistent with the evidence presented in Section 2.

Note also that the introduction of sticky wages dampens the response of the real wage even further in the short run, driving closer to the near-zero short run response uncovered by the empirical evidence in Section 2.

As discussed above, the presence of labor market frictions, by itself, does not appear to have much impact on the economy's response to shocks. The indirect impact is, however, more subtantial to the extent that it makes it possible to sustain sticky wages in equilibrium.

Having looked at some of the positive predictions of the model under alternative sets of assumptions, I turn next to its normative implications.

7 Labor Market Frictions, Nominal Rigidities and Monetary Policy Design

I start this section by describing the constrained-efficient allocation, and then turn my attention to the optimal design of monetary policy in the presence of labor market frictions and nominal rigidities.

7.1 The Social Planner's Problem

The social planner maximizes the representative household's utility

$$E_0 \sum_{t=0}^{\infty} \beta^t \left(\log C_t - \frac{\chi}{1+\varphi} L_t^{1+\varphi} \right)$$

subject to the resource constraint $C_t + \Gamma x_t^{\gamma} \; H_t = A_t N_t^{1-\alpha}$ and the definitions $L_t = N_t + \psi U_t$, $H_t = N_t - (1-\delta) N_{t-1}$, and $x_t = H_t(1-x_t)/U_t$.

In contrast with firms and households, the social planner internalizes the impact of its hiring and participation decisions on labor market tightness x_t. The optimality conditions characterizing the resulting constrained-efficient allocation are given by

$$\chi C_t L_t^{\varphi} = (1-\alpha) N^{-\alpha} - (1+\gamma) \left(G_t - (1-\delta) E_t \{ \Lambda_{t,t+1} G_{t+1} \} \right) \tag{47}$$

and

$$(1-x_t)\psi \chi C_t L_t^{\varphi} = \gamma x_t G_t \tag{48}$$

where $MPN_t \equiv (1-\alpha) A_t N_t^{-\alpha}$ is the marginal product of labor.

7.1.1 The Efficient Steady State

Evaluated at the steady state, the previous two efficiency conditions take the form:

$$(1+\gamma)(1-\beta(1-\delta))\ \Gamma x^{\gamma} = (1-\alpha)N^{-\alpha} - \chi C L^{\varphi} \tag{49}$$

$$(1-x)\psi\chi C L^{\varphi} = \gamma\Gamma x^{1+\gamma} \tag{50}$$

By comparing (49)-(50) with the corresponding steady state conditions of the decentralized economy (43)-(44), it is easy to see that the latter's steady state will be efficient whenever

$$\mathcal{M}_p(1-\tau) \tag{51}$$

and

$$\xi(1+\gamma) = 1 \tag{52}$$

In words, condition (51) requires that the subsidy on the purchases of intermediate goods should exactly offset the positive desired markup resulting from firms' market power. Condition (52) is a version of the Hosios condition similar to the one derived in Blanchard and Galí (2009). It involves an inverse relation between firms' relative bargaining power ξ and the elasticity of hiring costs relative to the labor market tightness variable, γ. That inverse relation captures the negative externality (in the form of larger hiring costs) caused by firms' hiring decisions, and the positive externality resulting from higher participation (in the form of reduced hiring costs). If the strength of these externalities were to increase (through a larger γ), it would be necessary to reduce the relative barganing power of firms (and increase that of workers) in order to induce fewer hires and more participation, in order to restore efficiency.

7.2 Optimal Monetary Policy

Throughout this section I maintain the assumption of a constrained-efficient steady state, i.e. conditions (51) and (52) are assumed to hold. Like before, I consider the two scenarios of flexible and sticky wages in turn.

7.2.1 The Case of Flexible Wages

Under flexible Nash bargained wages, it is easy to check that the optimal monetary policy involves strict inflation targeting, i.e. full stabilization of the price level.

To see this, note from (6) that under that policy the markup of final goods firms will remain constant and equal to the desired level, i.e. $P_t/P_t^I = \mathcal{M}_p(1-\tau)$ for all t. Combined with assumption (51), it follows that $MRPN_t = (1-\alpha)N_t^{-\alpha}$. Thus, and imposing (52), one can easily check that equilibrium conditions (20) and (21) mach exactly efficiency conditions (47) and (48).

Intuitively, under assumptions (51) and (52) the allocation associated with the equilibrium when both prices and (Nash bargained) wages are flexible is constrained-efficient. A monetary policy that succeeds in fully stabilizing the price level replicates that allocation, and it is thus optimal. That policy can be implemented with the assumed interest rate rule by choosing an arbitrarily large coefficient ϕ_π. This is thus an environment characterized by what Blanchard and Galí (2007) refer to as "the divine coincidence."

The previous finding hinges on the efficiency of the flexible price equilibrium allocation, guaranteed by assumptions (51)-(52). Faia (2009) analyzes the optimal policy in a related model with flexible wages, while relaxing the assumption of efficiency of the flexible price allocation. She shows that in that case it is optimal for the central bank to deviate from a policy of strict inflation targeting, though the size of the deviations for her calibrated model is quantitatively small.

7.2.2 The Case of Sticky Wages

As is well know from the analysis of Erceg et al. (2001) and others, when both prices and wages are sticky it will generally be impossible for the central bank to replicate the constrained-efficient equilibrium allocation, which under assumptions (51)-(52) corresponds to the equilibrium allocation in the absence of nominal rigidities (he natural allocation, for short), as discussed above. The intuition behind that result is straightforward: in response to real shocks the real wage will generally adjust in the equilibrium with flexible prices and wages, and that adjustment will be necessary to support the resulting (constrained-efficient) allocation. Any adjustment of the real wage requires some movements in price inflation or wage inflation (or both). But in the presence of sticky prices and wages such variations will occur only in response to deviations of average price markups and/or average real wages from their natural counterparts (see equations (6) and (36)).

In order to determine the optimal policy in that context I start by deriving a second order approximation to the representative household's utility losses caused by deviations from the constrained efficient allocation due to the presence of nominal rigidities. In so doing I restrict myself to the case of small fluctuations around an efficient steady state. As derived in Appendix 4, the loss function takes the following form (expressed in terms of the consumption-equivalent loss, as a fraction of GDP):

$$\mathbb{L} \equiv \frac{1}{2} E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{\epsilon}{\lambda_p} (\pi_t^p)^2 + \frac{(1-\Phi)^2(1-\alpha)}{\alpha \lambda_w^*} (\pi_t^w)^2 + \frac{(1+\varphi)(1-\Omega)N}{(1-\alpha)L} \left(\widetilde{y}_t + \frac{(1-\alpha)\psi U}{N} \widetilde{u}_t \right)^2 \right] \tag{53}$$

where $\widetilde{y}_t \equiv y_t - y_t^n$ and $\widetilde{u}_t \equiv u_t - u_t^n$ are the output and unemployment gaos, respectively, $\lambda_w^* \equiv (1-\theta_w)(1-\beta\theta_w)/\theta_w$ is inversely related to the degree of wage rigidities θ_w, and $1 - \Omega \equiv \frac{MRS}{MPN} = 1 - \frac{B(1+\gamma)}{MPN}$ is the steady state gap between the marginal rate of substitution and the marginal product of labor resulting from the existence of labor market frictions.

Note that in the absence of labor market frictions and with flexible wages $\lambda_w^* \to \infty$, $\Omega = 0$, $U = 0$ and $N/L = 1$, so the previous loss function collapses to the familiar one from the basic New Keynesian model.

The presence of labor market frictions has two implications for the welfare criterion. First, to the extent that they are accompanied by staggered nominal wage setting, fluctuations in wage inflation will generate welfare losses due to the implies dispersion in wages and the resulting losses from an inefficient allocation of labor across firms, a result also familiar from the monopoly union model of Erceg et al. (2000). Note that here the size of the welfare losses resulting from any given departure from wage stability depends on $1 - \Phi$ (which measures the sensitivity of employment allocations to changes in relative wages), and decreasing in the degree of diminishing returns to labor α, since the latter determines the extent of aggregate output losses that result from the dispersion of employment across firms.

Secondly, the welfare criterion above points to a specific role for unemployment gap fluctuations as a source of welfare losses, beyond that associated with variations in the output gap (or the employment gap, which is proportional to the latter). That role is related to the fact that unemployment is a component of effective market effort, and that fluctuations in the latter (relative to its efficient benchmark) generate disutility. The importance of unemployment fluctuations is thus increasing in ψ and U, which determine the weight of unemployment in the total disutility from market effort.

The equilibrium allocation under the optimal monetary policy can be determined by minimizing (53) subject to the log-linearized equilibrium conditions listed in Appendix 2 (excluding the Taylor rule). Figure 7.displays the equilibrium responses of a number of variables to a technology shock under the optimal policy, together with the corresponding responses under the conventional Taylor rule (the latter is meant to approximate "actual" policy). The simulation is based on a calibration with stickiness in both prices and wages. Note that the optimal response implies some deviation from price stability. In particular it requires a temporary decline in inflation, which makes it possible for the real wage to adjust upward with a smaller upward adjustment of nominal wages.[27] It also allows for a stronger accommodation of the increase in productivity, as reflected in the larger positive response of output. In accordance, employment is allowed to rise, and unemployment to decline. Note also that the optimal policy is associated with a smaller decline in inflation than the Taylor rule. Despite the greater price stability, the cumulative response of the real wage is stronger under the optimal policy, which requires positive wage inflation (not shown) in contrast with the wage deflation associated with the equilibrium under the Taylor rule.

[27] See Thomas (2008) for a related result in the context of a similar model.

Is there a simple interest rate rule that the central bank could follow that would improve on the assumed Taylor rule? In order to answer that question I compute the optimal rule among the class of interest rate rules of the form:

$$i_t = \rho + \phi_p \ \pi_t^p + \phi_y \ y_t + \phi_w \ \pi_t^w + \phi_u \ u_t$$

where I have added wage inflation and the unemployment rate as arguments, relative to the conventional Taylor rule. The coefficients that minimize the households welfare loss, determined by iterating over all possible configurations, are $\phi_p = 1.51$, $\phi_y = -0.10$, $\phi_w = 0.01$, and $\phi_u = -0.025$. Figure 8 summarizes the dynamic response of the economy under that optimal simple rule, and compares it to the corresponding responses under the fully optimal policy. As the figure makes clear the differences between the two are practically negligible. Note that relative to the standard Taylor rule, the optimized simple rule calls for further accommodation of supply-driven output variation and also puts some weight on stabilization of unemployment. Interestingly, the optimal coefficient on price inflation is very close to 1.5, the value often assumed in standard calibrations of the Taylor rule (following Taylor (1994)). Perhaps more surprisingly, the weight on wage inflation is close to zero. This is in contrast with the findings in Erceg et al. (2000), where stabilization of wage inflation emerges as a highly desirable policy from a welfare viewpoint.[28] On the other hand, the desirability of a systematic policy response to unemployment fluctuations is in line with the findings on optimal simple rules in Blanchard and Galí (2009) and Faia (2009).

[28]The structure of the present model and the associated inefficiencies resulting from wage dispersion lead to a coefficient on wage volatility in the loss function that is about one-third the size of the coefficient on price inflation. That ranking is reversed for standard calibrations of the Erceg et al (2000) model.

Given the relatively small values of the coefficients on variables other than price inflation in the optimized interest rate rule, a rule of the form $i_t = \rho + 1.5\ \pi_t^p$ leads to technology shock responses that are similar to those generated by the optimized one (responses not shown). That rule can be interpreted as capturing the notion of flexible inflation targeting, whereby central banks seek to attain a pre-specified inflation target only gradually ("in the medium term," using the language of the ECB), as opposed to the "strict inflation targeting" that is optimal in environments in which price stickiness is the only nominal distortion.

8 Possible Extensions

A number of extensions may be worth pursuing (or not). I briefly list some of them.

Real wage rigidities. As emphasized by Blanchard and Galí (2007, 2009) the presence of real wage rigidities may have implications for the optimal design of monetary policy that are likely to differ from the ones generated by a model with nominal wage rigidities only (like the one emphasized here). Among other things, in the presence of real wage rigidities, the policymaker cannot use price inflation to facilitate the adjustment of real wages. A simple way to introduce real wage rigidities would be to allow for (possibly partial) wage indexation to contemporaneous wage inflation between wage renegotiations. Formally, one can assume:

$$W_{t+k||t} = W_{t+k-1|t}\ (P_{t+k}/P_{t+k-1})^{\varsigma}$$

for $k = 1, 2, 3, ...$and $W_{t|t} = W_t^*$, and where $W_{t+k||t}$ is the nominal wage in period $t+k$ for an employment relationship whose wage was last renegotiated in period t. Note that parameter $\zeta \in [0, 1]$ measures the degree of indexation.

Greater wage flexibility for new hires. A number of authors (Haefke et al. (2007), Pissarides (2008), Carneiro et al. (2008),...) have argued that while the wages of incumbent workers display some clear rigidities, the latter may not have allocative consequences (to the extent they remain within the bargaining set) since the wage that determines hiring decision is the wage of new hires, which is likely to be more flexible, according to some evidence Even though that evidence remains controversial and has been disputed in some quarters (see. e.g. Gertler and Trigari (2009), Galuscak et al. (2008)), it may be of interest to see how such differential flexibility can be introduced in the model, and to explore its positive and normative implications.

Following Bodart et al (2006) one can assume that new hires at a firm are paid either the average wage (with probability $1 - \eta$) or a freely negotiated wage (with probability η). Parameter η is an index of the degree of relative wage flexibility for new hires. One can then quantify the extent to which the responses to shocks and the optimal policy vary with η.

Smaller wealth effects. The analysis above has relied on a specification of utility with wealth effects of labor supply that are likely to be implausible large. That could explain the unusual unrealistic behavior of the labor force under some of the calibrations discussed above. One way to get around that problem is to assume a version of the preferences proposed by Jaimovich and Rebelo (2008):

$$U(C_t, L_t) \equiv \frac{1}{1-\sigma}\left(C_t - \frac{\chi}{1+\varphi}\ L_t^{1+\varphi} Z_t\right)^{1-\sigma}$$

where

$$Z_t = Z_{t-1}^{1-\upsilon}\ C_t^{\upsilon}$$

and $\upsilon \in [0,1]$.In that case the marginal rate of substitution between consumption and market effort is given (in logs) by

$$mrs_t = z_t + \varphi l_t$$

where $z_t = \upsilon c_t + (1-\upsilon) z_{t-1}$. Thus, changes in consumption will have a limited effect on the supply for market effort if υ is small.

Other demand shocks. The analysis of optimal monetary policy above assumes the economy faces only a technology shock (naturally, the monetary policy shock is turned off for the purposes of that exercise). How the policy implications may vary once a shock other than technology is introduced.seems worthy of investigation. In particular, it may be the case that in that scenario the optimal policy will attach a greater weight to output stabilization.[29]

9 Conclusions

[incomplete]

Over the past few years a growing number of researchers have turned their attention towards the development and analysis of extensions of the New Keynesian framework that model unemployment explicitly. The present

[29] Sveen and Weinke (2008) make a forceful case for the importance of demand shocks in accounting for labor market dynamics.

paper has described some of the essential ingredients and properties of those models, and their implications for monetary policy. One novelty of the model developed is its allowance for variable participation.

The analysis of a calibrated version of the model developes suggests that labor market frictions are unlikely, by themselves or through their interaction with sticky prices, to have dramatic consequences for the equilibrium response to shocks in an economy with nominal rigidities and a monetary policy described by a simple Taylor type rule. In that respect, perhaps the most important contribution of those frictions lies in their ability to reconcile the presence of nominal wage rigidities with privately efficient employment relations. The presence of those nominal wage rigidities has, on the other hand, important consequences for the economy 's response to shocks as well as for the optimal design of monetary policy.

Appendix 1: Proof of Lemma

From the definition of the price index:

$$\begin{aligned}
1 &= \int_0^1 \left(\frac{P_t(i)}{P_t}\right)^{1-\epsilon} di \\
&= \int_0^1 \exp\{(1-\epsilon)(p_t(i)-p_t)\} \ di \\
&\simeq 1 + (1-\epsilon)\int_0^1 (p_t(i)-p_t) \ di + \frac{(1-\epsilon)^2}{2}\int_0^1 (p_t(i)-p_t)^2 \ di
\end{aligned}$$

where the approximation results from a second-order Taylor expansion around the zero inflation steady state. Thus, and up to second order, we have

$$p_t \simeq E_i\{p_t(i)\} + \frac{(1-\epsilon)}{2}\int_0^1 (p_t(i)-p_t)^2 \ di$$

where $E_i\{p_t(i)\} \equiv \int_0^1 p_t(i) \ di$ is the cross-sectional mean of (log) prices.

In addition,

$$\begin{aligned}
\int_0^1 \left(\frac{P_t(i)}{P_t}\right)^{-\epsilon} di &= \int_0^1 \exp\left\{-\epsilon \ (p_t(i)-p_t)\right\} \ di \\
&\simeq 1 - \epsilon\int_0^1 (p_t(i)-p_t) \ di + \frac{\epsilon^2}{2}\int_0^1 (p_t(i)-p_t)^2 \ di \\
&\simeq 1 + \frac{\epsilon}{2}\int_0^1 (p_t(i)-p_t)^2 \ di \\
&\simeq 1 + \frac{\epsilon}{2} \ var_i\{p_t(i)\} \geq 1
\end{aligned}$$

where the last equality follows from the observation that, up to second order,

$$\begin{aligned}
\int_0^1 (p_t(i)-p_t)^2 \ di &\simeq \int_0^1 (p_t(i)-E_i\{p_t(i)\})^2 \ di \\
&\equiv var_i\{p_t(i)\}
\end{aligned}$$

Finally, using the definition of d_t^p we obtain

$$d_t^p \simeq \frac{\epsilon}{2} \; var_i\{p_t(i)\}$$

On the other hand,

$$\begin{aligned}
\int_0^1 \left(\frac{N_t(j)}{N_t}\right)^{1-\alpha} dj &= \int_0^1 \exp\left\{(1-\alpha)\;(n_t(j)-n_t)\right\}\; dj \\
&\simeq 1+(1-\alpha)\int_0^1 (n_t(j)-n_t)\; dj + \frac{(1-\alpha)^2}{2}\int_0^1 (n_t(j)-n_t)^2\; dj \\
&\simeq 1-\frac{\alpha(1-\alpha)}{2}\int_0^1 (n_t(j)-n_t)^2\; dj
\end{aligned}$$

where the third equality follows from the fact that $\int_0^1 (n_t(j)-n_t)\; dj \simeq -\frac{1}{2}\int_0^1 (n_t(j)-n_t)^2\; dj$ (using a second order approximation of the identity $1 \equiv \int_0^1 \frac{N_t(j)}{N_t}\; dj$).

Log-linearizing the optimal hiring condition (8) around a symmetric equilibrium we have

$$n_t(j) - n_t \simeq -\frac{1-\Phi}{\alpha}\; (w_t(j)-w_t)$$

Thus

$$\int_0^1 \left(\frac{N_t(j)}{N_t}\right)^{1-\alpha} dj \simeq 1 - \frac{(1-\Phi)^2(1-\alpha)}{2\alpha}\int_0^1 (w_t(j)-w_t)^2\; dj$$

implying

$$d_t^w \equiv -\log \int_0^1 \left(\frac{N_t(j)}{N_t}\right)^{1-\alpha} \simeq \frac{(1-\Phi)^2(1-\alpha)}{2\alpha}\; var_j\{w_t(j)\}$$

Appendix 2: Log-linearized Equilibrium Conditions

- Technology and Resource Constraints

Goods market clearing (38)

$$\widehat{y}_t = (1-\Theta)\ \widehat{c}_t + \Theta\ (\widehat{g}_t + \widehat{h}_t)$$

where $\Theta \equiv \frac{\delta N G}{Y}$.

Aggregate production function

$$\widehat{y}_t = a_t + (1-\alpha)\ \widehat{n}_t$$

Aggregate hiring and employment

$$\delta\ \widehat{h}_t = \widehat{n}_t - (1-\delta)\ \widehat{n}_{t-1}$$

Hiring cost function

$$\widehat{g}_t = \gamma\ \widehat{x}_t$$

Job finding rate

$$\widehat{x}_t = \widehat{h}_t - \widehat{u}_t^o$$

Effective Market Hours

$$\widehat{l}_t = \left(\frac{N}{L}\right)\ \widehat{n}_t + \left(\frac{\psi U}{L}\right)\ \widehat{u}_t$$

Labor force

$$\widehat{f}_t = \left(\frac{N}{F}\right)\ \widehat{n}_t + \left(\frac{U}{F}\right)\ \widehat{u}_t$$

Unemployment:

$$\widehat{u}_t = \widehat{u}_t^o - \frac{x}{1-x}\ \widehat{x}_t$$

Unemployment rate

$$\widehat{ur}_t = \widehat{f}_t - \widehat{n}_t$$

- Decentralized Economy: Other Equilibrium Conditions

Euler equation ()

$$\widehat{c}_t = E_t\{\widehat{c}_{t+1}\} - \widehat{r}_t$$

Fisherian equation

$$\widehat{r}_t = \widehat{i}_t - E_t\{\pi_{t+1}\}$$

Inflation equation ()

$$\pi_t = \beta \ E_t\{\pi_{t+1}\} - \lambda_p \ \widehat{\mu}_t^p$$

Optimal hiring condition (),

$$\widehat{\mu}_t^p = (a_t - \alpha \ \widehat{n}_t) - [(1-\Phi) \ \widehat{\omega}_t + \Phi \ \widehat{b}_t]$$

$$\widehat{b}_t = \frac{1}{1-\beta(1-\delta)} \ \widehat{g}_t - \frac{\beta(1-\delta)}{1-\beta(1-\delta)} \ (E_t\{\widehat{g}_{t+1}\} - \widehat{r}_t)$$

Optimal participation condition () (see Appendix 2 for derivation)

$$\widehat{c}_t + \varphi \widehat{l}_t = \frac{1}{1-x} \ \widehat{x}_t + \widehat{g}_t - \Xi \ \pi_t^w$$

where $\Xi \equiv \frac{\xi(W/P)}{(1-\xi)G} \frac{\theta_w}{(1-\theta_w)(1-\beta(1-\delta)\theta_w)}$ (note $\Xi = 0$ under flexible wages)

Interest rate rule

$$\widehat{i}_t = \phi_\pi \pi_t + \phi_y \widehat{y}_t + v_t$$

- *Wage Setting Block*: *Flexible Wages*

Nash wage equation (19)

$$\widehat{\omega}_t = (1 - \Upsilon)\ (\widehat{c}_t + \varphi \widehat{l_t}) + \Upsilon\ (-\widehat{\mu}_t^p + a_t - \alpha\ \widehat{n}_t)$$

where $\Upsilon \equiv \frac{(1-\xi)MRPN}{W/P}$

- *Wage Setting Block*: *Sticky Wages*

$$\widehat{\omega}_t = \widehat{\omega}_{t-1} + \pi_t^w - \pi_t^p$$

$$\pi_t^w = \beta(1 - \delta)\ E_t\{\pi_{t+1}^w\} - \lambda_w\ (\widehat{\omega}_t - \widehat{\omega}_t^{tar})$$

$$\widehat{\omega}_t^{tar} = (1 - \Upsilon)\ (\widehat{c}_t + \varphi \widehat{l_t}) + \Upsilon\ (-\widehat{\mu}_t^p + a_t - \alpha\ \widehat{n}_t)$$

- Social Planner's Problem: Efficiency Conditions

$$a_t - \alpha\ \widehat{n}_t = (1 - \Omega)\ (\widehat{c}_t + \varphi \widehat{l_t}) + \Omega\ \widehat{b}_t$$

$$\widehat{c}_t + \varphi \widehat{l}_t = \frac{1}{1 - x}\ \widehat{x}_t + \widehat{g}_t$$

where $\Omega \equiv \frac{(1+\gamma)B}{MPN}$.

Appendix 3: Linearization of Participation Condition

Lemma. Define $Q_t \equiv \int_0^1 \left(\frac{H_t(z)}{H_t}\right) \ \mathcal{S}_t^H(z) \ dz$. Then, around a zero inflation deterministic steady state we have

$$\widehat{q}_t \simeq \widehat{g}_t - \Xi \ \pi_t^w$$

where $\Xi \equiv \frac{\xi(W/P)}{(1-\xi)G} \frac{\theta_w}{(1-\theta_w)(1-\beta(1-\delta)\theta_w)}$.

Proof of Lemma:

$$\begin{aligned} Q_t &\simeq \int_0^1 \mathcal{S}_t^H(z) \ dz \\ &= (1-\theta_w) \sum_{q=0}^{\infty} \theta_w^q \ \mathcal{S}_{t|t-q}^H \\ &= (1-\theta_w) \sum_{q=0}^{\infty} \theta_w^q \ (\mathcal{S}_{t|t}^H + \mathcal{S}_{t|t-q}^H - \mathcal{S}_{t|t}^H) \end{aligned}$$

where the first equality holds up to a first order approximation in a neighborhood of a symmetric steady state.

Using the Nash bargaining condition (27) we have:

$$\xi \ Q_t = (1-\xi) \ G_t + \xi(1-\theta_w) \sum_{q=0}^{\infty} \theta_w^q \ (\mathcal{S}_{t|t-q}^H - \mathcal{S}_{t|t}^H)$$

Note that

$$\begin{aligned} \mathcal{S}_{t|t-q}^H - \mathcal{S}_{t|t}^H &= E_t \left\{ \sum_{k=0}^{\infty} ((1-\delta)\theta_w)^k \Lambda_{t,t+k} \ \left(\frac{W_{t-q}^*}{P_{t+k}} - \frac{W_t^*}{P_{t+k}} \right) \right\} \\ &= \left(\frac{W_{t-q}^* - W_t^*}{P_t} \right) \ E_t \left\{ \sum_{k=0}^{\infty} ((1-\delta)\theta_w)^k \Lambda_{t,t+k} \ \left(\frac{P_t}{P_{t+k}} \right) \right\} \end{aligned}$$

Using the law of motion for the aggregate wage,

$$
\begin{aligned}
(1-\theta_w)\sum_{q=0}^{\infty}\theta_w^q \ (\mathcal{S}_{t|t-q}^H - \mathcal{S}_{t|t}^H) &= \left(\frac{W_t - W_t^*}{P_t}\right) \ E_t\left\{\sum_{k=0}^{\infty}((1-\delta)\theta_w)^k \Lambda_{t,t+k} \ \left(\frac{P_t}{P_{t+k}}\right)\right\} \\
&\simeq -\pi_t^w \ \left(\frac{\theta_w}{1-\theta_w}\right)\frac{W_{t-1}}{P_t} \ E_t\left\{\sum_{k=0}^{\infty}((1-\delta)\theta_w)^k \Lambda_{t,t+k} \ \left(\frac{P_t}{P_{t+k}}\right)\right\} \\
&\simeq -\pi_t^w \ \left(\frac{\theta_w}{(1-\theta_w)(1-\beta(1-\delta)\theta_w)}\right)\left(\frac{W}{P}\right)
\end{aligned}
$$

where the latter approximation holds in a neighborhod of the zero inflation steady state. It follows that

$$
\xi \ Q_t \simeq (1-\xi) \ G_t - \xi \ \left(\frac{\theta_w}{(1-\theta_w)(1-\beta(1-\delta)\theta_w)}\right)\left(\frac{W}{P}\right) \ \pi_t^w
$$

or, equivalently, in (log) deviations from steady state values:

$$
\widehat{q}_t \simeq \widehat{g}_t - \Xi \ \pi_t^w
$$

where $\Xi \equiv \frac{\xi(W/P)}{(1-\xi)G}\frac{\theta_w}{(1-\theta_w)(1-\beta(1-\delta)\theta_w)}$.

Appendix 4: Derivation of Loss Function

Combining a second order expansion of the utility of the representative household and the resource constraint around the constrained-efficient allocation yields

$$E_0 \sum_{t=0}^{\infty} \beta^t \ \widetilde{U}_t \simeq - \ E_0 \sum_{t=0}^{\infty} \beta^t \ \left(\frac{1}{1-\Theta}(d_t^p + d_t^w) + \frac{1}{2}(1+\varphi)\chi L^{1+\varphi} \ \widetilde{l}_t^2 \right)$$

As shown in appendix 1 $d_t^p \simeq \frac{\epsilon}{2} \ var_i(p_t(i))$.and $d_t^w \simeq \frac{(1-\Phi)^2(1-\alpha)}{2\alpha} \ var_j\{w_t(j)\}$. I make use of the following property of the Calvo price and wage setting environment:

Lemma:

$$\sum_{t=0}^{\infty} \beta^t \ var_i\{p_t(i)\} = \frac{\theta_p}{(1-\theta_p)(1-\beta\theta_p)} \sum_{t=0}^{\infty} \beta^t \ (\pi_t^p)^2$$

$$\sum_{t=0}^{\infty} \beta^t \ var_j\{w_t(j)\} = \frac{\theta_w}{(1-\theta_w)(1-\beta\theta_w)} \sum_{t=0}^{\infty} \beta^t \ (\pi_t^w)^2$$

Proof: Woodford (2003, chapter 6).

Combining the previous results and letting $\mathbb{L} \equiv -E_0 \sum_{t=0}^{\infty} \beta^t \ \widetilde{U}_t(C/Y)$ denote the utility losses expressed as a share of steady state GDP we can write

$$\mathbb{L} \equiv \frac{1}{2} \ E_0 \sum_{t=0}^{\infty} \beta^t \ \left[\frac{\epsilon}{\lambda_p} \ (\pi_t^p)^2 + \frac{(1-\Phi)^2(1-\alpha)}{\alpha\lambda_w^*} \ (\pi_t^w)^2 + (1+\varphi)(\chi C L^{1+\varphi}/Y) \ \widetilde{l}_t^2 \right]$$

where $\lambda_w^* \equiv (1-\theta_w)(1-\beta\theta_w)/\theta_w$.

Next note that, up to first order,

$$\widetilde{l}_t = \left(\frac{N}{L(1-\alpha)}\right)\widetilde{y}_t + \left(\frac{\psi U}{L}\right)\widetilde{u}_t$$
$$= \left(\frac{N}{L(1-\alpha)}\right)\left(\widetilde{y}_t + \frac{(1-\alpha)\psi U}{N}\widetilde{u}_t\right)$$

Thus we have:

$$\mathbb{L} \equiv \frac{1}{2}\, E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{\epsilon}{\lambda_p}\,(\pi_t^p)^2 + \frac{(1-\Phi)^2(1-\alpha)}{\alpha\lambda_w^*}\,(\pi_t^w)^2 + \frac{(1+\varphi)(1-\Omega)N}{(1-\alpha)L}\,\left(\widetilde{y}_t + \frac{(1-\alpha)\psi U}{N}\widetilde{u}_t\right)^2\right]$$

where $1 - \Omega \equiv \frac{MRS}{MPN} = 1 - \frac{B(1+\gamma)}{MPN}$ is the steady state gap between the marginal rate of substitution and the marginal product of labor resulting from the existence of labor market frictions.

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Table 1: Nominal Rigidities and Labor Market Frictions

	Positive	Normative
Flexible Wages	Chéron-Langot (2000) Walsh (2005) Trigari (2009) Andrés-Doménech-Ferri (2006)	
Sticky Wages	Trigari (2006) Christoffel-Linzert (2005) Gertler-Sala-Trigari (2008)	Blanchard-Galí (2009) Thomas (2008) Faia (2008, 2009)

Table 2. Cyclical Properties

	Unconditional		*Demand*		*Technology*	
	$\frac{\sigma(x)}{\sigma(y)}$	$\rho(x,y)$	$\frac{\sigma(x)}{\sigma(y)}$	$\rho(x,y)$	$\frac{\sigma(x)}{\sigma(y)}$	$\rho(x,y)$
Employment	0,60	0.83	0.59	0.92	0.90	0.51
Labor force	0.20	0.30	0.20	0.31	0.39	0.02
Unemployment rate	0.49	−0.90	0.50	−0.93	0.62	−0.76
Real Wage	0.44	0.07	0.32	−0.78	0.27	0.27
Price Inflation	0.19	0.27	0.18	0.37	0.27	0.60

Figure 1. Estimated Effects of Technology Shocks

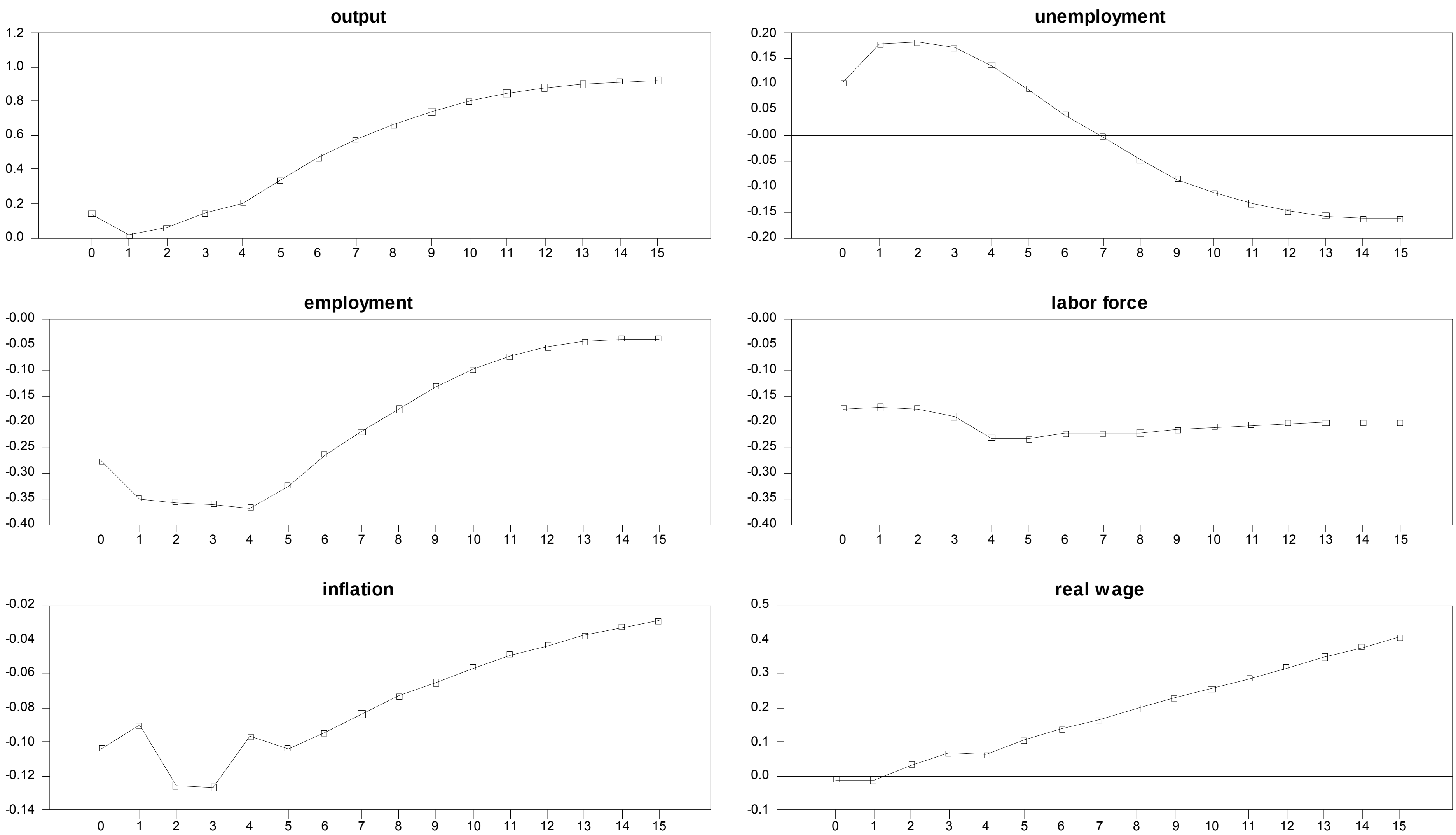

Figure 2a. The Effects of Monetary Policy Shocks: Sticky Wages (ξ=0.5)

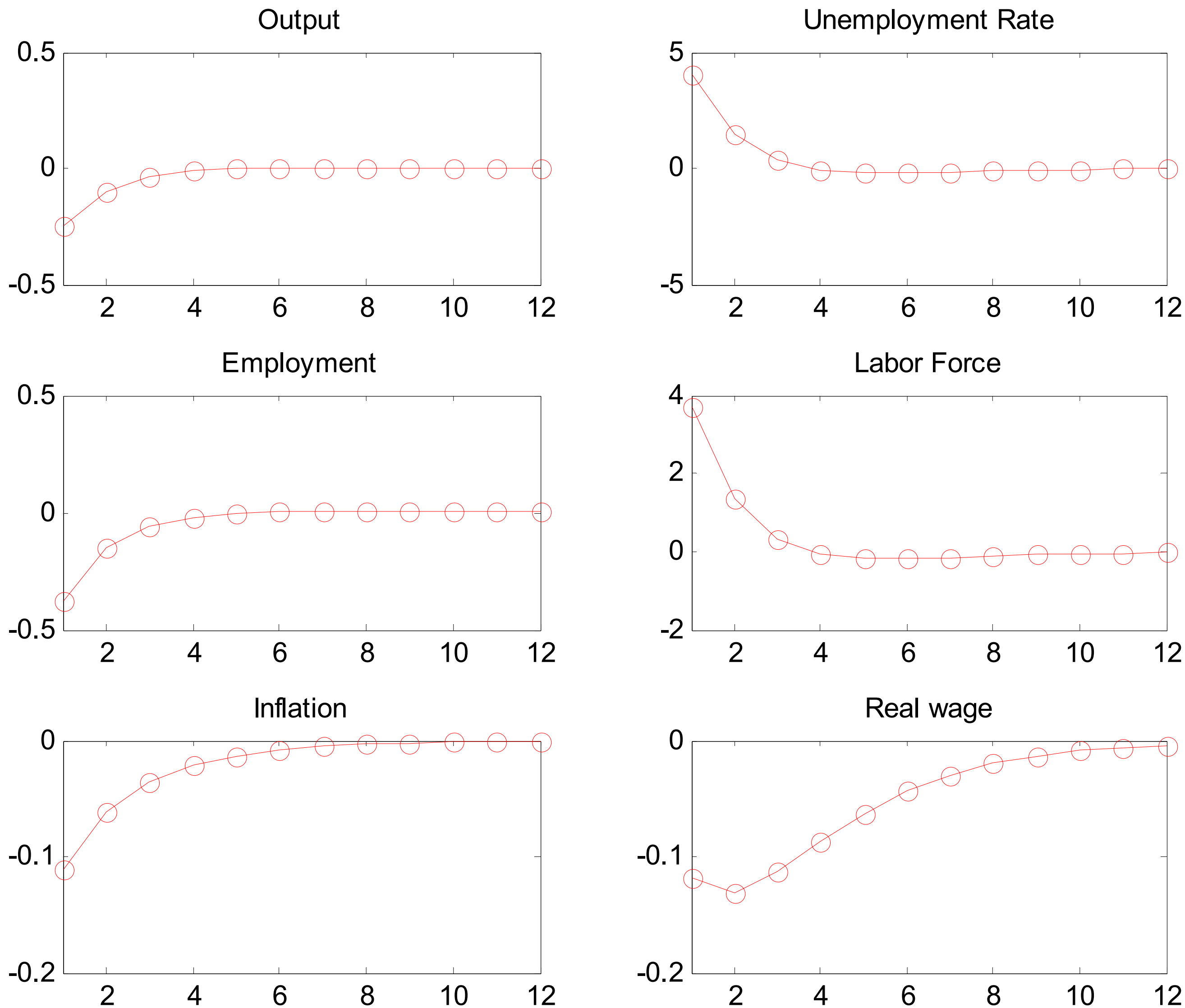

Figure 2b. The Effects of Technology Shocks: Sticky Wages (ξ=0.5)

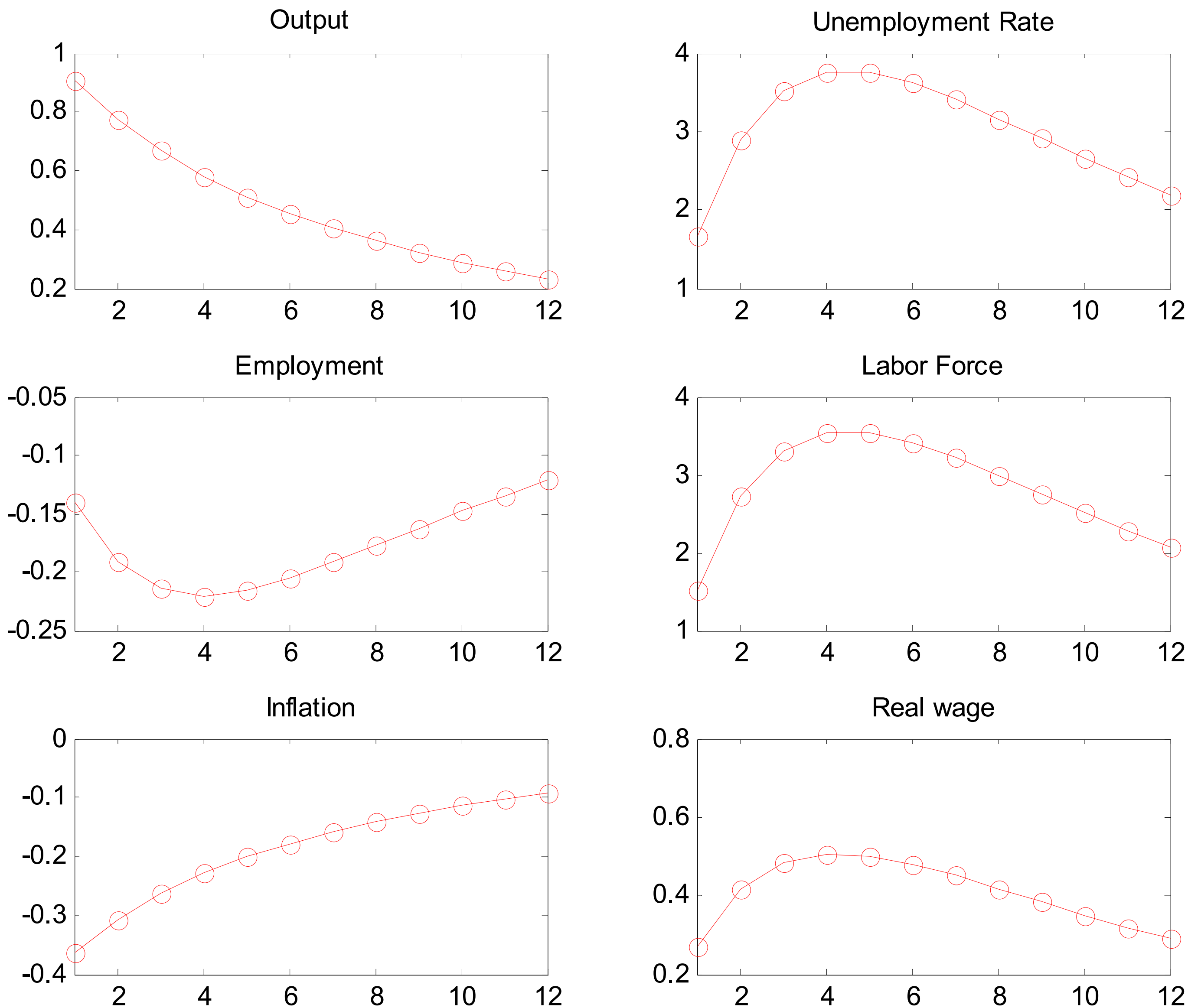

Figure 3a. The Effects of Monetary Policy Shocks: Sticky Wages (ξ=0.05)

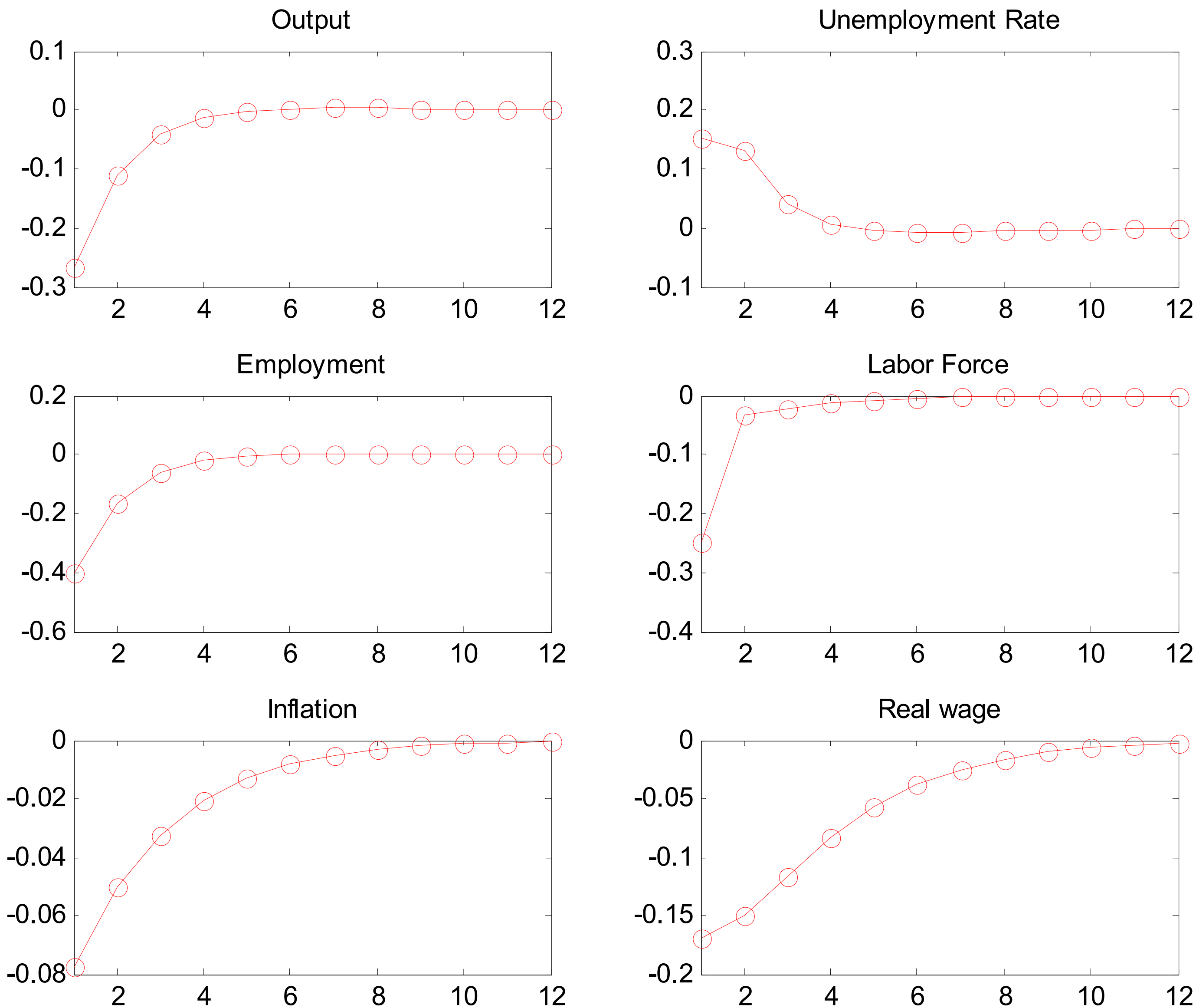

Figure 3b. The Effects of Technology Shocks: Sticky Wages (ξ=0.05)

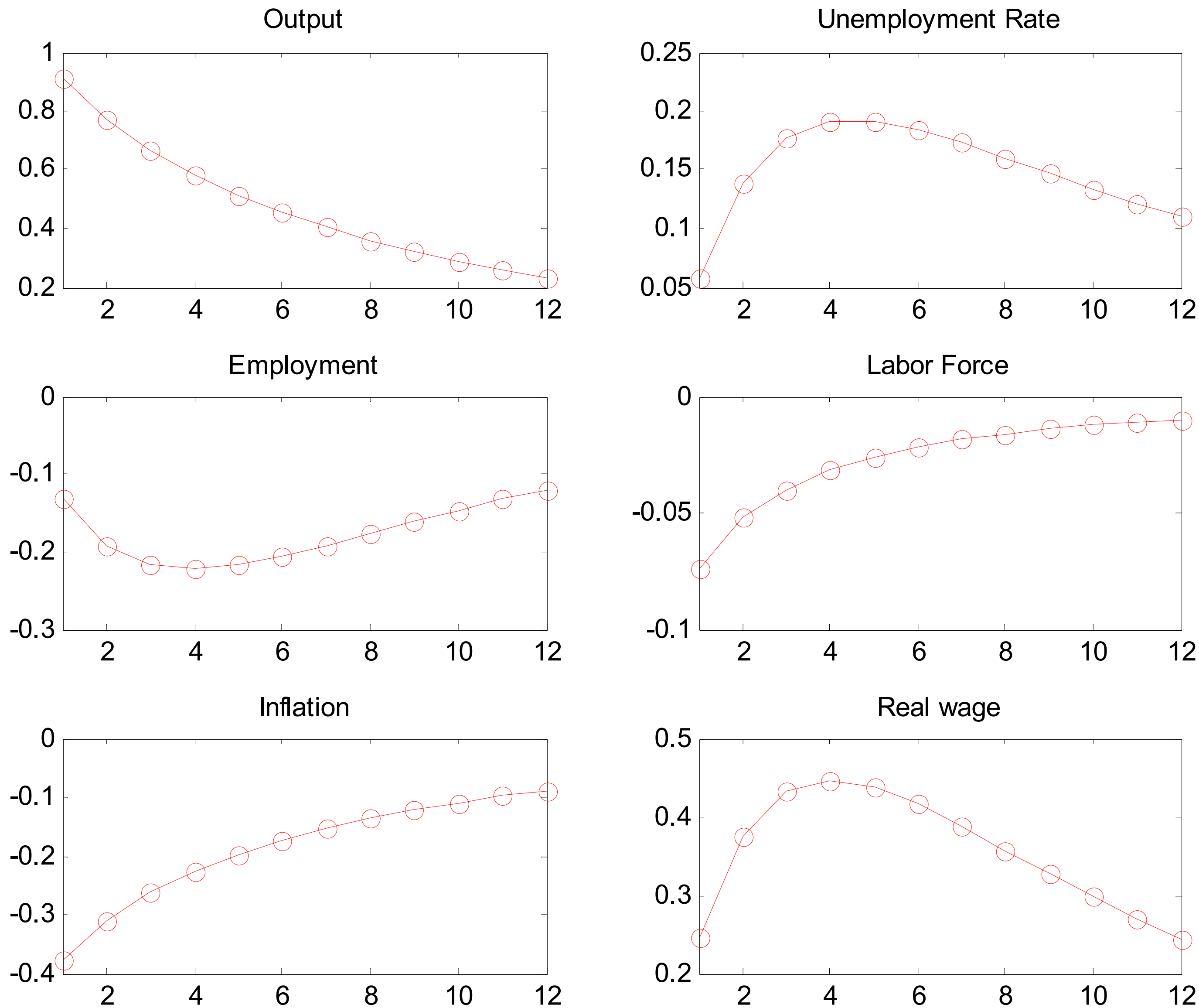

Figure 4a. The Role of Labor Market Frictions

Flexible Wages, Monetary Policy Shock

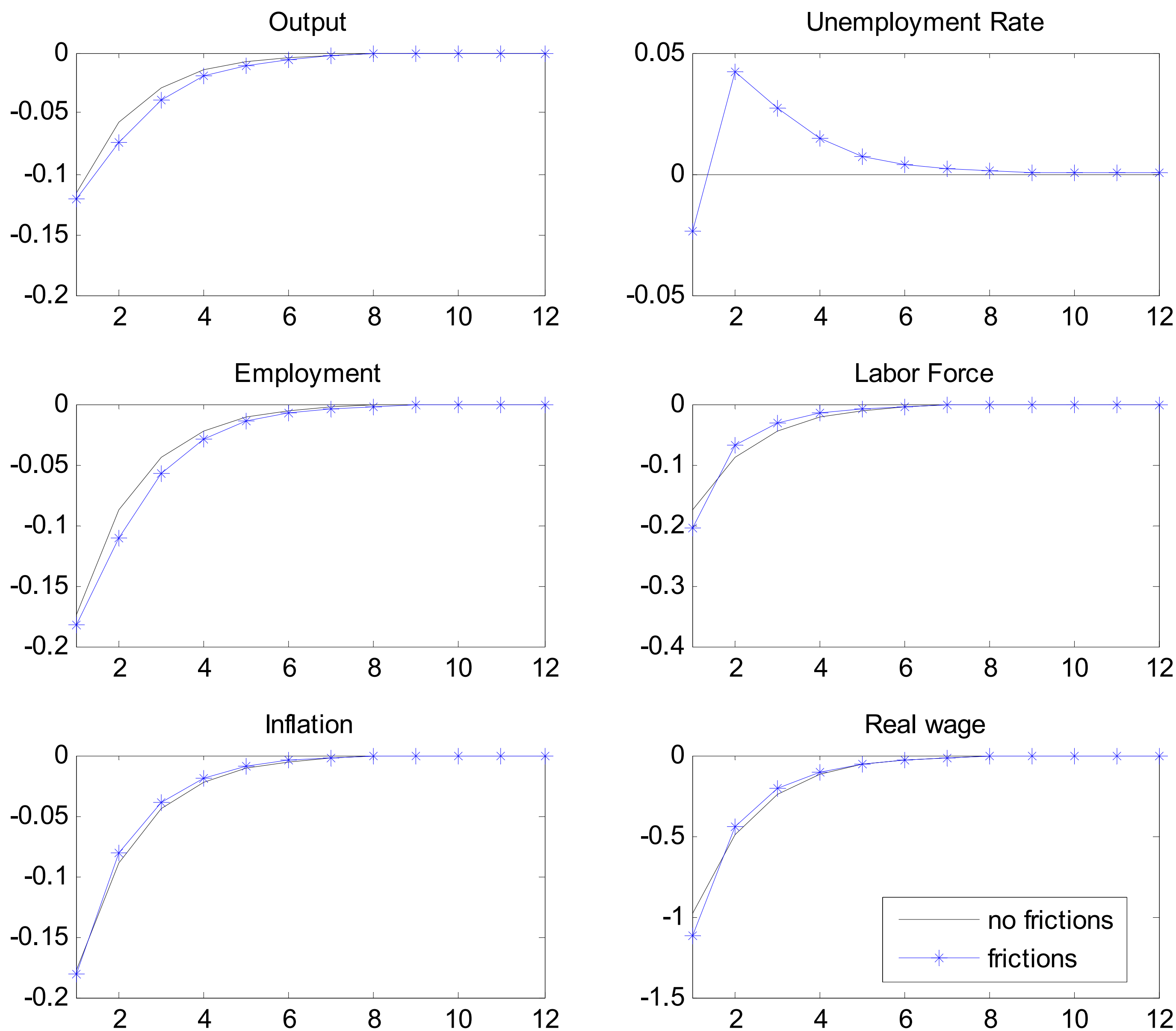

Figure 4b. The Role of Labor Market Frictions

Flexible Wages, Technology Shock

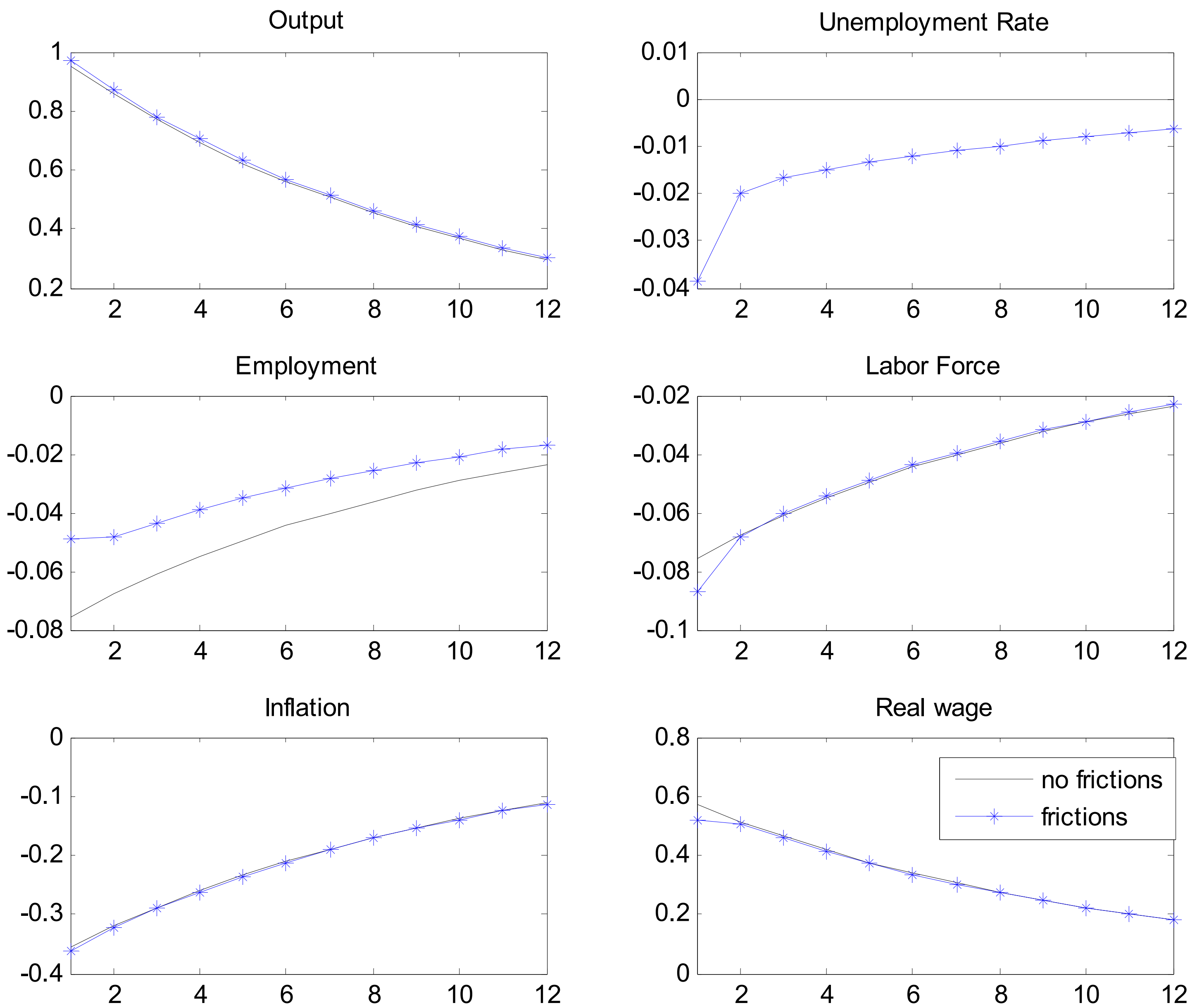

Figure 5a. The Role of Price Stickiness

Flexible Wages, Monetary Policy Shock

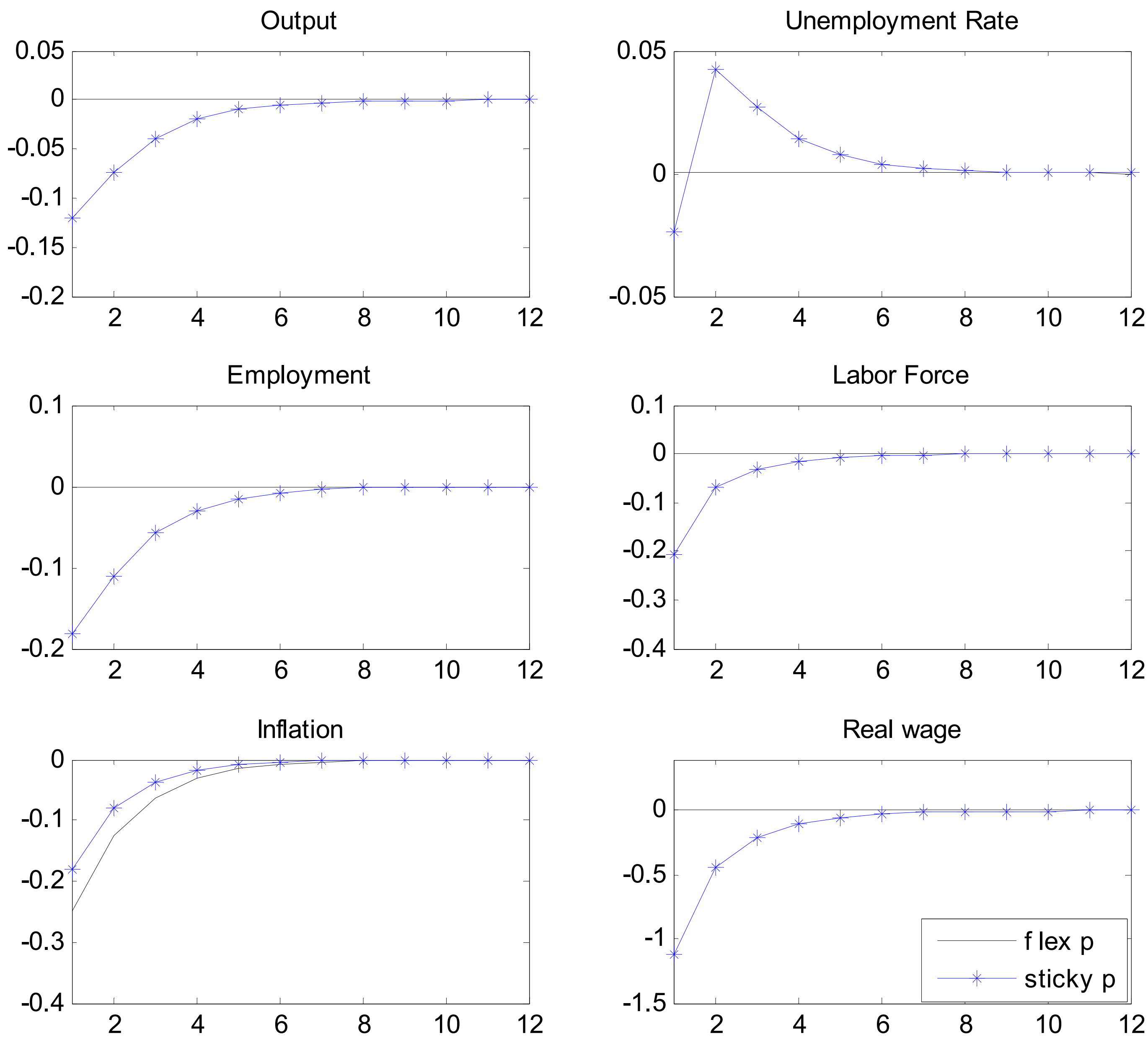

Figure 5b. The Role of Price Stickiness

Flexible Wages, Technology Shock

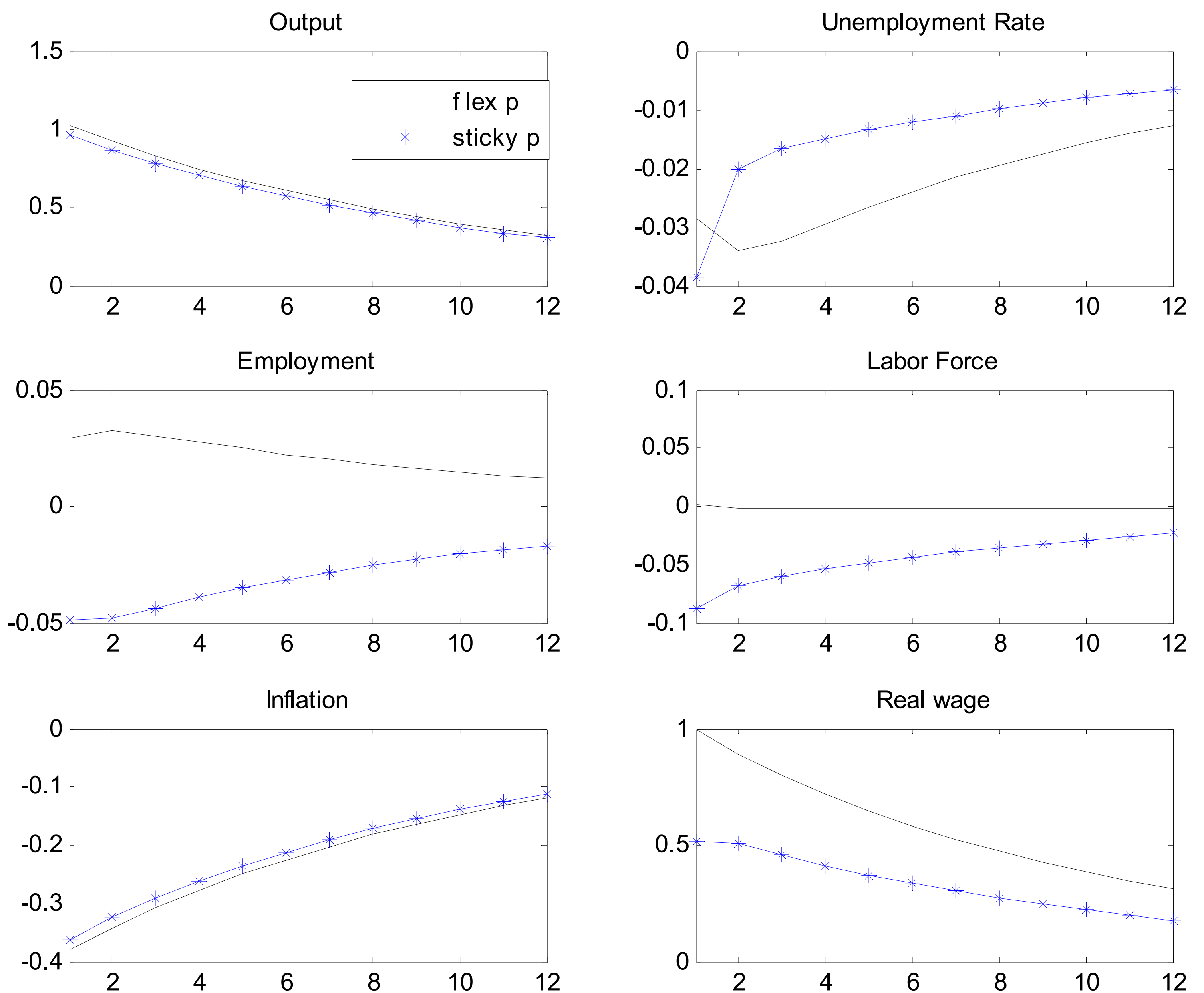

Figure 6a. The Role of Wage Stickiness

Sticky Prices, Monetary Policy Shock

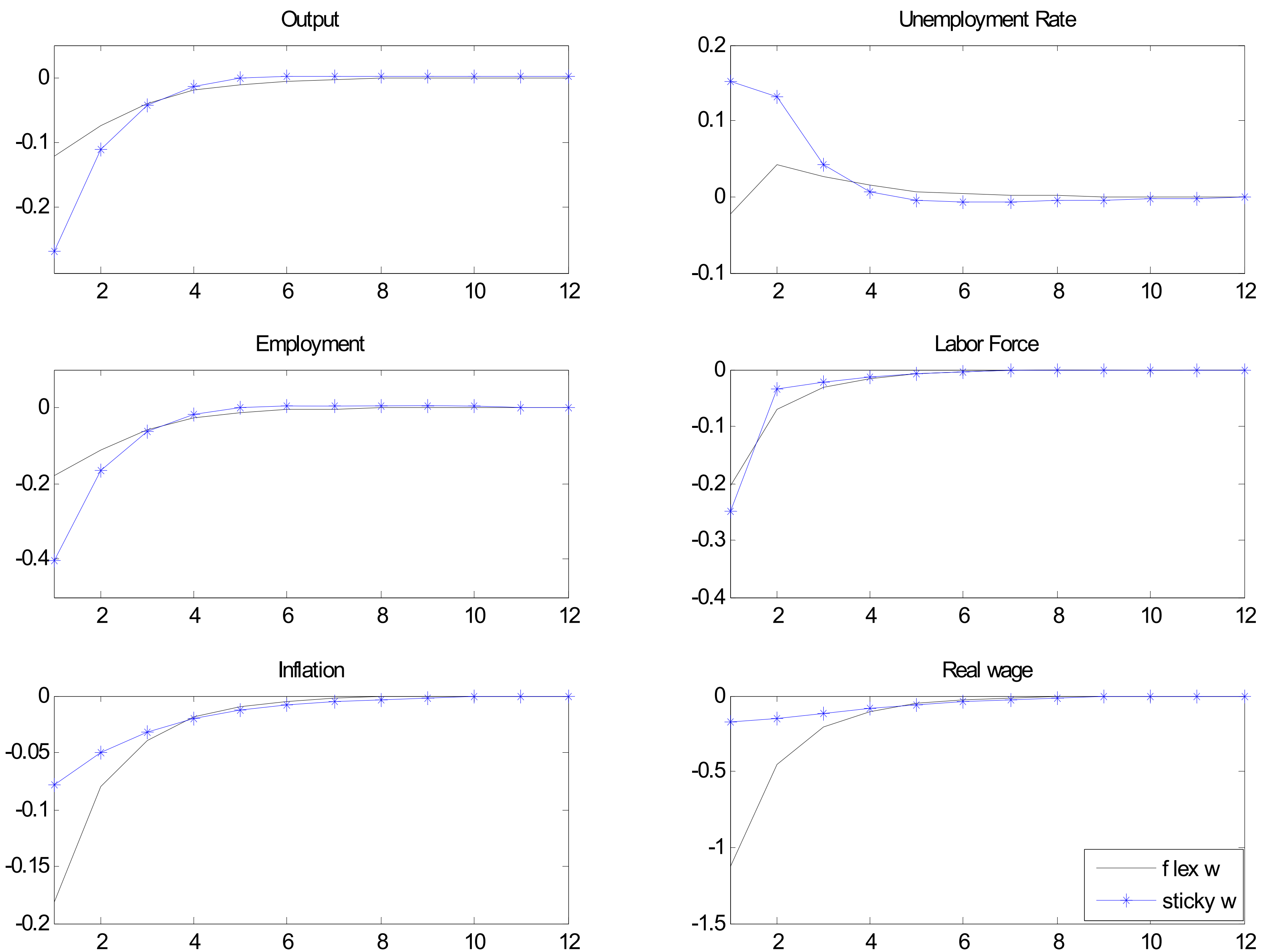

Figure 6b. The Role of Wage Stickiness

Sticky Prices, Technology Shock

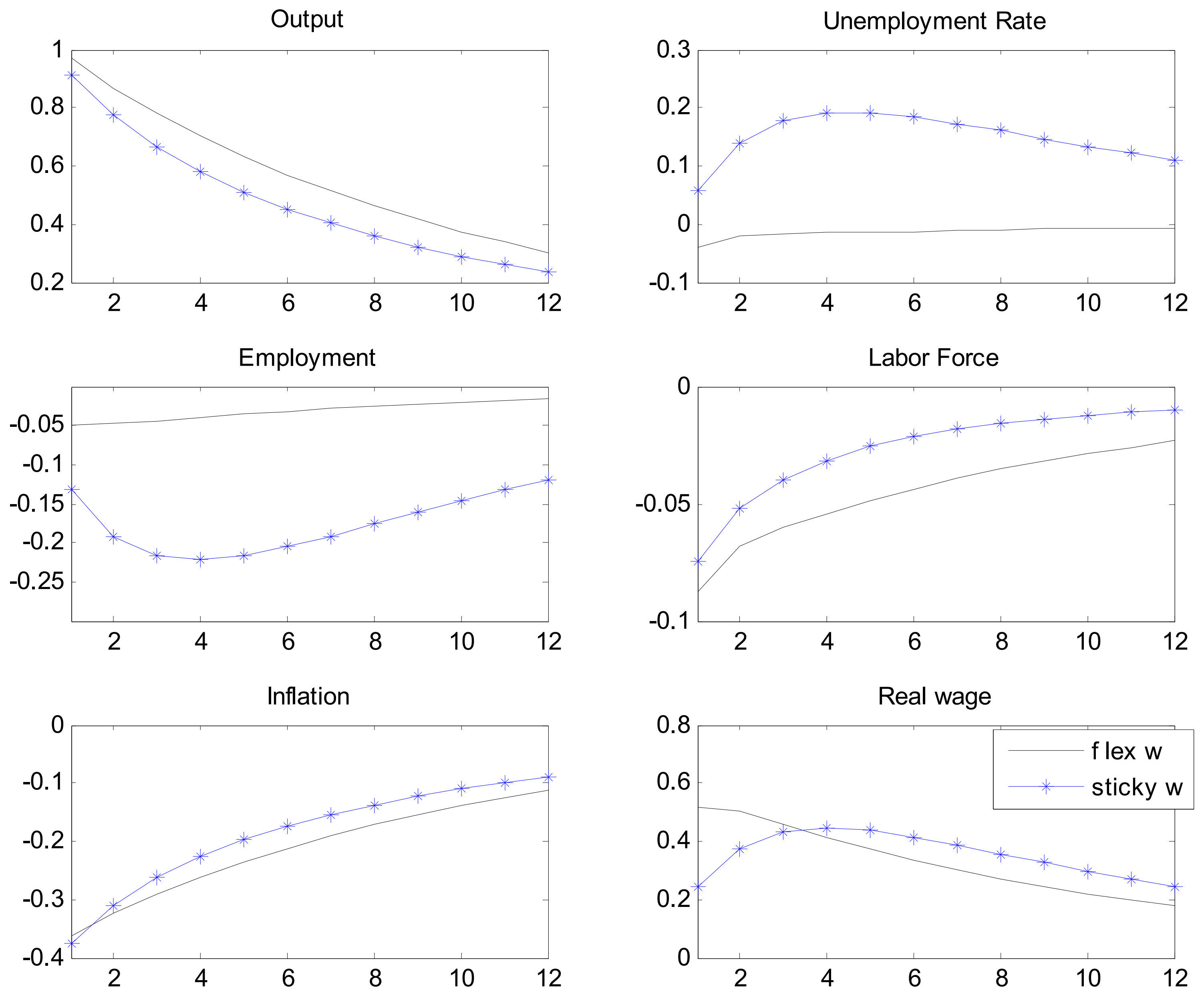

Figure 7. Monetary Policy Design: Optimal vs. Taylor

Sticky Prices and Wages, Technology Shock

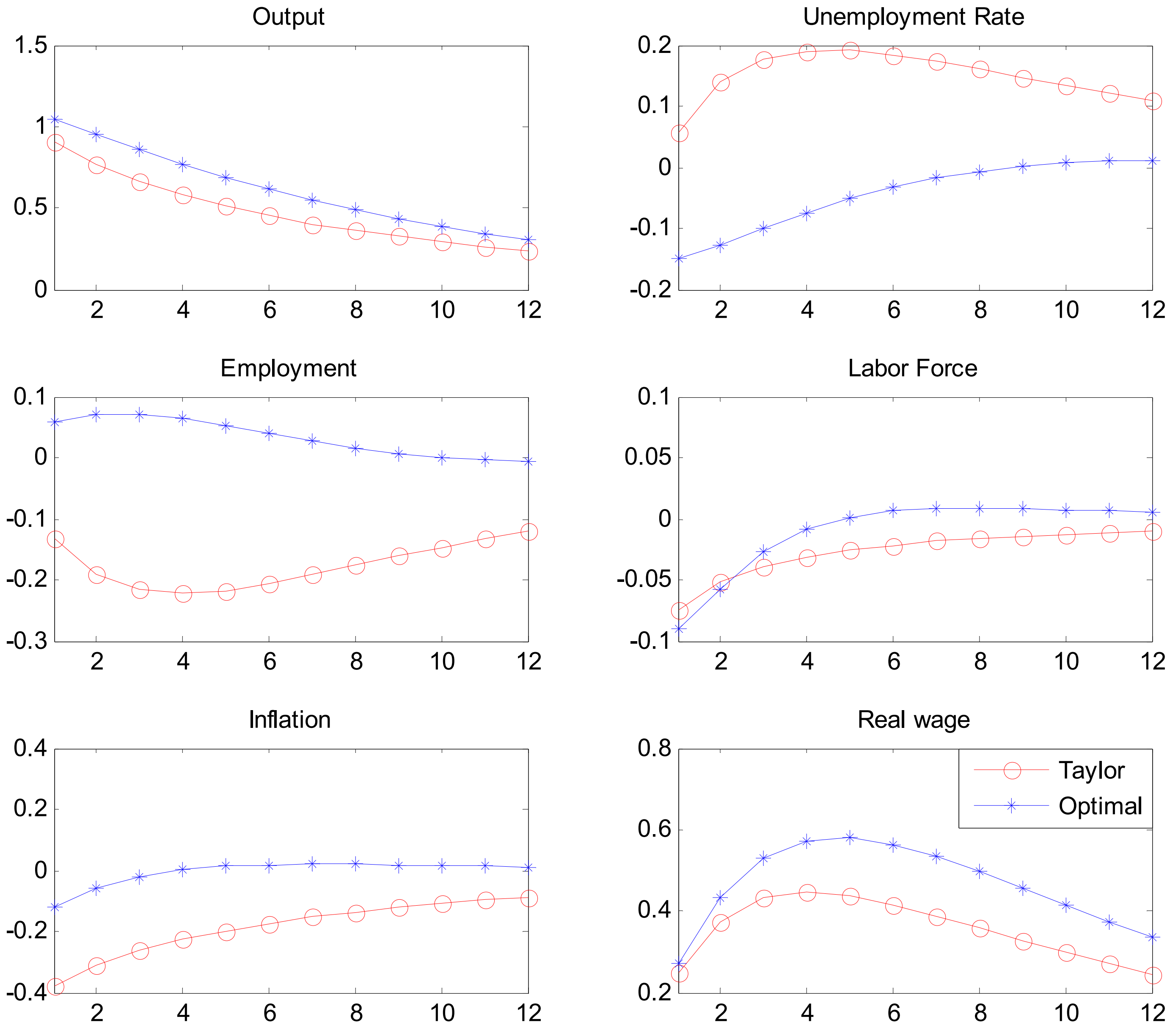

Figure 8. Monetary Policy Design: Optimal vs. Optimal Simple

Sticky Prices and Wages, Technology Shock