Unemployment in an Estimated New Keynesian Model*

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Abstract

We develop a reformulated version of the Smets-Wouters (2007) framework that embeds the theory of unemployment proposed in Galí (2011a,b). We estimate the resulting model using postwar U.S. data, while treating the unemployment rate as an additional observable variable. Our approach overcomes the lack of identification of wage markup and labor supply shocks highlighted by Chari, Kehoe and McGrattan (2008) in their criticism of New Keynesian models, and allows us to estimate a "correct" measure of the output gap. In addition, the estimated model can be used to analyze the sources of unemployment fluctuations.

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1 Introduction

Over the past decade an increasing number of central banks and other policy institutions have developed and estimated medium-scale New Keynesian DSGE models.[1] The combination of a good empirical fit with a sound, micro founded structure makes these models particularly suitable for forecasting and policy analysis. However, as highlighted by Gali and Gerter (2009) and others, one of the shortcomings of these models is that there is the lack of a reference to unemployment. This is unfortunate because unemployment is an important indicator of resource utilisation in the macro economy. Recently, a number of papers have started to address this shortcoming by embedding in the basic New Keynesian model various theories of unemployment based on the presence of labor market frictions (e.g. Blanchard and Galí (2007), Christoffel et al (2007), Gertler, Sala and Trigari (2008), Christiano, Trabandt and Walentin (2009), and de Walque et al (2008)).

The present paper takes a different approach. Following Gali (2011a, 2011b), it reformulates the Smets and Wouters (2007; henceforth, SW) model to allow for involuntary unemployment, while preserving the convenience of the representative household paradigm. Unemployment in the model results from market power in labor markets, reflected in positive wage markups. Variations in unemployment over time are associated with changes in wage markups, either exogenous or resulting from nominal wage rigidities.

The proposed reformulation allows us to overcome an identification problem pointed out by Chari, Kehoe and McGrattan (2008) (CKM) as an illus-

[1] See, for example, Smets et al. (2010) for a short description of the two aggregate euro area models used at the ECB. Two of the DSGE models used at the Federal Reserve are described in Edge et al. (2007) and Erceg et al. (2006).

tration of the immaturity of New Keynesian models. Their observation is motivated by the SW finding that wage markup shocks account for almost 50 percent of the variations in real GDP at horizons of more than 10 years. However, without an explicit measure of unemployment (or, alternatively, labour supply), these wage markup shocks cannot be distinguished from preference shocks that shift the marginal disutility of labour. The policy implications of these two sources of output fluctuations are, however, very different. Variations in wage markup shocks are inefficient and a welfare-maximising government should be interested in stabilising output fluctuations driven by such shocks (at least partly). In contrast, if output and employment fluctuations are mostly driven by preference shocks shifting the labor supply schedule, then the optimal policy would be to accommodate such changes. Put it differently, the relative importance of those two shocks will influence the extent to which fluctuations in output during a given historical episode should or should not be interpreted as reflecting movements in the welfare relevant output gap (i.e. the distance between the actual and efficient levels of output). By including unemployment as an observable variable, this identification problem can be overcome, and "correct" measures of the output gap can be constructed, as we show in Section 4.

When we estimate the reformulated SW model using unemployment as an observable variable, we find a much diminished role for wage markup shocks as a source of output and employment fluctuations, even though those shocks preserve a large role as drivers of inflation. Our estimates lead us to classify the multiple shocks in the model in three categories (which we label "demand", "supply", and "labor market" shocks), on the basis of their implied joint comovement among employment, the labor force, unemployment, inflation and the real wage, as captured by their associated impulse response functions (IRFs). In addition, we show how the implied measure of the welfare-relevant output gap is to a large extent the mirror image of the unemployment rate, and resembles conventional measures of the cyclical component of log GDP, based on statistical detrending methods. At times there are, however; significant differences depending on the source of the business cycle fluctuations.

Our estimates of the reformulated SW model allow us to address a number of additional questions of interest which could not be dealt with using the model's original formulation. Thus, in section 5 we assess quantitatively the relative importance of different shocks as sources of unemployment fluctuations and their role during specific historical episodes, including the recent recession. Also, our approach allows us to uncover a measure of the natural rate of unemployment (i.e. the flexible wage counterfactual) and to study its comovement with actual unemployment. That comovement is shown to be particularly strong at low frequencies, as expected, but the gap between the two caused by wage rigidities is estimated to be large and persistent. We also revisit the evidence on the joint behavior of inflation and unemployment under the lens of our estimated model. This allows us to give a structural interpretation to empirical Phillips curves, both for wage and price inflation. In section 6 we discuss the robustness of our findings to the use of alternative sample period and data. Section 7 concludes.

In addition to reformulating the wage Phillips curve in terms of unemployment, our model shows a number of small differences with that in SW

(2007). First, and regarding the data on which the estimation is based, we use employment rather than hours worked, and redefine the wage as the wage per worker rather than the wage per hour. We do so since the model focuses on variations in labor at the extensive margin, in a way consistent with the conventional definition of unemployment. Given that most of the variation in hours worked over the business cycle is due to changes in employment rather than hours per employee, this change does not have major consequences in itself. We also combine two alternative wage measures in the estimation, compensation and earnings, and model their discrepancy explicitly. Second, we generalise the utility function in a way that allows us to parameterise the wealth effect on labour supply, as shown in Jaimovich and Rebelo (2009). This generalisation yields a better fit of the joint behavior of employment and the labor force, as we discuss in detail. Third, for simplicity, we revert to a Dixit-Stiglitz aggregator in the labor market rather than the Kimball aggregator used in SW (2007).

The rest of the paper is structured as follows. Section 2 describes the modified Smets-Wouters model. Next, Section 3 presents the data and estimation. Section 4 contains the discussion of the CKM critique. Section 5 analyses different aspects of unemployment fluctuations which the reformulation of the SW model makes possible. Section 6 presents some robustness exercises and, finally, Section 7 concludes and points to possible extensions.

2 Introducing Unemployment in the Smets-Wouters Model

2.1 Staggered Wage Setting and Wage Inflation Dynamics

This section introduces a variant of the wage setting block of the SW model, which is itself an extension of that in Erceg, Henderson and Levin (2000; henceforth, EHL). The variant presented here, based on Galí (2011a, 2011b), assumes that labor is indivisible, with all variations in hired labor input taking place at the extensive margin. That feature gives rise to a notion of unemployment consistent with its empirical counterpart.

The model assumes a (large) representative household with a continuum of members represented by the unit square and indexed by a pair $(i, j) \in [0, 1] \times [0, 1]$. The first dimension, indexed by $i \in [0, 1]$, represents the type of labor service in which a household member is specialized. The second dimension, indexed by $j \in [0, 1]$, determines his disutility from work. The latter is given by $\chi_t \Theta_t j^{\varphi}$ if he is employed, zero otherwise, where $\varphi \geq 0$, $\chi_t > 0$ is an exogenous preference shifter (referred to below as a "labor supply" shock) and Θ_t is an endogenous preference shifter, taken as given by each individual household and defined below.

Individual utility is assumed to be given by:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left(\log \widetilde{C}_t(i, j) - 1_t(i, j) \chi_t \Theta_t j^{\varphi} \right)$$

where $\widetilde{C}_t(i, j) \equiv C_t(i, j) - h\overline{C}_{t-1}$, with $h \in [0, 1]$.and with $\overline{C}_{t-1}$ denoting (lagged) aggregate consumption (taken as given by each household), and where $1_t(i, j)$ is an indicator function taking a value equal to one if individual (i,j) is employed in period t, and zero otherwise. Thus, as in SW and related monetary DSGE models, we allow for (external) habits in consumption, indexed by h.

As in Merz (1995), full risk sharing of consumption among household members is assumed, implying $C_t(i,j) = C_t$ for all $(i,j) \in [0,1] \times [0,1]$ and t. Thus, we can write the household utility (i.e., the integral of its members' utilities) as:

$$\begin{aligned} E_0 \sum_{t=0}^{\infty} \beta^t U_t(C_t, \{N_t(i)\}) &\equiv E_0 \sum_{t=0}^{\infty} \beta^t \left(\log \widetilde{C}_t - \chi_t \Theta_t \int_0^1 \int_0^{N_t(i)} j^{\varphi} dj di \right) \\ &= E_0 \sum_{t=0}^{\infty} \beta^t \left(\log \widetilde{C}_t - \chi_t \Theta_t \int_0^1 \frac{N_t(i)^{1+\varphi}}{1+\varphi} di \right) \end{aligned}$$

where $N_t(i) \in [0,1]$ denote the employment rate in period t among workers specialized in type i labor and $\widetilde{C}_t \equiv C_t - h\overline{C}_{t-1}$. We define the endogenous preference shifter Θ_t as follows:

$$\Theta_t \equiv \frac{Z_t}{\overline{C}_t - h\overline{C}_{t-1}}$$

where Z_t evolves over time according to the difference equation

$$Z_t = Z_{t-1}^{1-\upsilon} (\overline{C}_t - h\overline{C}_{t-1})^{\upsilon}$$

and can thus be interpreted as a "smooth" trend for (quasi-differenced) aggregate consumption. Thus, when the latter is above trend (i.e. during aggregate consumption booms), the disutility from work goes down.

The previous specification generalizes the preferences assumed in SW by allowing for an exogenous labor supply shock, χ_t, and by introducing an endogenous shifter, Z_t, whose main role is to reconcile the existence of a balanced growth path with an arbitrarily small *short-term* wealth effect. The latter's importance is determined by the size of parameter $\upsilon \in [0,1]$. As discussed below, that feature is needed in order to match the cyclical behavior of the labor force. That modification is related to, but not identical, to that proposed by Jaimovich and Rebelo (2009) with a similar objective.[2]

Note that under the previous preferences, the relevant marginal rate of substitution between consumption and employment for type i workers in period t is given (in a symmetric equilibrium where $\overline{C}_t = C_t$) by

$$\begin{aligned} MRS_t(i) &\equiv -\frac{U_{n(i),t}}{U_{c,t}} \\ &= \chi_t Z_t N_t(i)^{\varphi} \end{aligned}$$

Equivalently, letting $\xi_t \equiv \log \chi_t$ and using lower case letters to denote the natural logarithms of the original variables, we can write:

$$mrs_t(i) = z_t + \varphi n_t(i) + \xi_t$$

As in EHL, and following the formalism of Calvo (1983), workers supplying a labor service of a given type (or a union representing them) get to reset their (nominal) wage with probability $1-\theta_w$ each period. That probability is independent of the time elapsed since they last reset their wage, in addition to being independent across labor types. Thus, a fraction of workers θ_w do not reoptimize their wage in any given period, making that parameter

[2] In particular, and leaving aside the presence of habits, our specification assumes that the period utility is separable in consumption and employment. This facilitates aggregation of individual utilities into the household utility, and simplifies the analysis by implying equalization of consumption across individuals as a result of risk sharing within each household.

a natural index of nominal wage rigidities. All those who reoptimize their wage choose an identical wage, denoted by W_t^*, since they face an identical problem. Following SW, we allow for partial wage indexation between reoptimization periods, by making the nominal wage adjust mechanically in proportion to past price inflation. Formally, and letting $W_{t+k|t}$ denote the nominal wage in period $t+k$ for workers who last reoptimized their wage in period t, we assume

$$W_{t+k|t} = W_{t+k-1|t}\ \Pi^x (\Pi_{t-1}^p)^{\gamma_w} (\Pi^p)^{1-\gamma_w}$$

for $k = 1, 2, 3, ...$and $W_{t,t} = W_t^*$, and where $\Pi_t^p \equiv P_t/P_{t-1}$ denotes the (gross) rate of price inflation, Π^p is its corresponding steady state value, Π^x is the steady state (gross) growth rate of productivity, and $\gamma_w \in [0,1]$ measures the degree of wage indexation to past inflation.

When reoptimizing their wage in period t, workers choose a wage W_t^* in order to maximize household utility (as opposed to their individual utility), subject to the usual sequence of household flow budget constraints, as well as a sequence of isoelastic demand schedules of the form $N_{t+k|t} = (W_{t+k|t}/W_{t+k})^{-\epsilon_{w,t}} N_{t+k}$, where $N_{t+k|t}$ denotes period $t+k$ employment among workers whose wage was last reoptimized in period t, and where $\epsilon_{w,t}$ is the period t wage elasticity of the relevant labor demand schedule.[3] The first order condition associated with that problem can be written as:

$$\sum_{k=0}^{\infty} (\beta\theta_w)^k E_t \left\{ \left(\frac{N_{t+k|t}}{C_{t+k}} \right) \left(\frac{W_{t+k|t}^*}{P_{t+k}} - \mathcal{M}_{w,t}^n MRS_{t+k|t} \right) \right\} = 0 \qquad (1)$$

where, in a symmetric equilibrium, $MRS_{t+k|t} \equiv \chi_t Z_t N_{t+k|t}^{\varphi}$ is the relevant

[3] Details of the derivation of the optimal wage setting condition can be found in EHL (2000).

marginal rate of substitution between consumption and employment in period $t+k$, and $\mathcal{M}_{w,t}^{n} \equiv \frac{\epsilon_{w,t}}{\epsilon_{w,t}-1}$ is the natural (or desired) wage markup in period t, i.e. the one that would obtain under flexible wages.

Under the above assumptions, we can rewrite the aggregate wage index $W_t \equiv \left(\int_0^1 W_t(i)^{1-\epsilon_{w,t}} di\right)^{\frac{1}{1-\epsilon_{w,t}}}$ as follows:

$$W_t \equiv \left[\theta_w (W_{t-1}\Pi^x (\Pi_{t-1}^p)^{\gamma_w} (\Pi^p)^{1-\gamma_w})^{1-\epsilon_{w,t}} + (1-\theta_w)(W_t^*)^{1-\epsilon_{w,t}}\right]^{\frac{1}{1-\epsilon_{w,t}}} \quad (2)$$

Log-linearizing (1) and (2) around a perfect foresight steady state and combining the resulting expressions, allows us to derive (after some algebra) the following equation for wage inflation $\pi_t^w \equiv w_t - w_{t-1}$:

$$\pi_t^w = \alpha_w + \gamma_w \pi_{t-1}^p + \beta E_t\{\pi_{t+1}^w - \gamma_w \pi_t^p\} - \lambda_w(\mu_{w,t} - \mu_{w,t}^n) \quad (3)$$

where $\alpha_w \equiv (1-\beta)((1-\gamma)\pi^p + \pi^x)$, $\lambda_w \equiv \frac{(1-\beta\theta_w)(1-\theta_w)}{\theta_w(1+\epsilon_w\varphi)}$, $\mu_{w,t}^n \equiv \log \mathcal{M}_{w,t}^n$ is the (log) natural wage markup, and

$$\mu_{w,t} \equiv (w_t - p_t) - mrs_t \quad (4)$$

is the (log) average wage markup, with $mrs_t \equiv z_t + \varphi n_t + \xi_t$ denoting the (log) average marginal rate of substitution. As equation (3) makes clear, variations in wage inflation above and beyond those resulting from indexation to past price inflation are driven by deviations of average wage markup from its natural level, because those deviations generate pressure on workers currently setting wages to adjust those wages in one direction or another.

2.2 Introducing Unemployment

Consider an individual specialized in type i labor and with disutility of work $\chi_t Z_t j^{\varphi}$. *Using household welfare as a criterion*, and *taking as given* current labor market conditions (as summarized by the prevailing wage for his labor type), that individual will find it optimal to participate in the labor market in period t if and only if

$$\left(\frac{1}{\widetilde{C}_t}\right)\left(\frac{W_t(i)}{P_t}\right) \geq \chi_t \Theta_t \; j^{\varphi}$$

Evaluating the previous condition at the symmetric equilibrium, and letting the marginal supplier of type i labor be denoted by $L_t(i)$, we have:

$$\frac{W_t(i)}{P_t} = \chi_t Z_t L_t(i)^{\varphi}$$

Taking logs and integrating over i we obtain

$$w_t - p_t = z_t + \varphi l_t + \xi_t \tag{5}$$

where $l_t \equiv \int_0^1 l_t(i)\, di$ can be interpreted as the model's implied (log) aggregate participation rate (or labor force).

Following Galí (2011a, 2011b), we define the unemployment rate u_t as:

$$u_t \equiv l_t - n_t \tag{6}$$

Combining (4) with (5) and (6), the following simple linear relation between the average wage markup and the unemployment rate can be derived

$$\mu_{w,t} = \varphi u_t \tag{7}$$

which is also graphically illustrated in Figure 1.

Finally, combining (3) and (7) we obtain an equation relating wage inflation to price inflation, the unemployment rate and the wage markup.

$$\pi_t^w = \alpha_w + \gamma_w \pi_{t-1}^p + \beta E_t\{\pi_{t+1}^w - \gamma_w \pi_t^p\} - \lambda_w \varphi u_t + \lambda_w \mu_{w,t}^n \tag{8}$$

Note that in contrast with the representation of the wage equation found in SW and related papers, the error term in (8) captures exclusively shocks to the wage markup, and *not* preference shocks (even though the latter have been allowed for in the model above). That feature, made possible by reformulating the wage equation in terms of the (observable) unemployment rate, allows us to overcome the identification problem raised by CKM in their critique of New Keynesian models. We turn to this issue below, when we discuss our empirical findings.

Finally, note that we can define the *natural* rate of unemployment, u_t^n, as the unemployment rate that would prevail in the absence of nominal wage rigidities. Under our assumptions, that natural rate will vary exogenously in proportion to the natural wage markup, and can be determined using the simple relation:

$$\mu_{w,t}^n = \varphi u_t^n \tag{9}$$

The remaining equations describing the log-linearized equilibrium conditions of the model are presented in the appendix. Those equations are identical to a particular case of those found in SW (2007), corresponding to logarithmic consumption utility. In addition to the wage markup and labor supply shocks discussed above, the model includes six additional shocks: a neutral, factor-augmenting productivity shock, a price markup shock; a risk premium shock, an exogenous spending shock, an investment-specific technology shock and a monetary policy shock:

3 Data and Estimation

3.1 Data

We estimate our model on US data for the sample period 1966Q1-2007Q4 using Bayesian full-system estimation techniques as in SW (2007). We end our estimation period in 2007Q4 to prevent our estimates from being distorted due to the likely non-linearities induced by the zero lower bound on the federal funds rate and possible downward nominal wage rigidities during the most recent recession.[4] In Section 5 below we nevertheless use the estimated model to interpret the behaviour of unemployment in the recent recession, i.e. beyond the estimated period. Section 7 on robustness discusses the impact of estimating our model over an extended sample period ending in 2010Q4.

Five of the seven data series used by SW (2007) are also used here: GDP, consumption, investment, GDP deflator inflation, and the federal funds rate, with the first three expressed in per capita terms and log differenced. As the SW model is reformulated in terms of employment (given our interest in explaining unemployment), we use per capita employment rather than hours worked. The main results are not affected if we use hours instead, as discussed in Section 7. In addition, we experiment with two wage concepts. The first one is total compensation per employee obtained from the BLS Productivity and Costs Statistics.[5] The second one is "average weekly earnings" from the Current Employment Statistics. Finally, we add the unemployment rate as

[4]For some discussion on how downward nominal wage rigidity may the estimates of the New Keynesian wage Phillips curve, see Gali (2011a).

[5]Note that SW (2007) used compensation per hour instead, in a way consistent with their model specification.

an additional observable variable. In the following section, we systematically compare the model estimated with and without the latter variable as an observable variable.

The properties of both wage series are quite different.[6] This is illustrated in Figure 2, which plots their quarterly nominal growth rates. First, average wage inflation based on compensation per employee is significantly higher than that based on earnings per employee (1.24 versus 1.02). Given average price inflation, the compensation series is more compatible with a balanced growth path in which real wages grow at the same rate as real output, consumption and investment. Second, the compensation series is much more volatile than the earnings series, especially over the past two decades. The standard deviation of wage inflation based on compensation is 0.70, compared to 0.56 for the earnings-based series. Finally, the correlation between both wage inflation measures is surprisingly low at *0.60*.

For our baseline estimation, we use both wage series as imperfect measures of the model-based wage concept. This is done by adding measurement error to both measurement equations and allowing for a separate, smaller trend in the earnings series.[7] In the section on robustness, we briefly discuss the estimation results when only using the wage compensation series. In the rest of the paper, we focus on the model with both wage concepts and measurement error.

[6] See Abraham, Spletzer and Stewart (1999) and Mehran and Tracy (2001) for a discussion about the sources of some of those difference.

[7] Justiniano, Primiceri and Tambalotti (2010) have argued that estimated wage markup shocks can be partly interpreted as resulting from measurement error in the underlying wage series. Accordingly, they allow for measurement error in wages but consider one compensation series in their estimation.

3.2 Estimation Results

Table 1 compares the estimated structural parameters of the model obtained with and without unemployment being used as an observable variable. As discussed above, adding unemployment allows us to separately identify wage markup and labour supply shocks. In addition, it allows us to exploit the model's prediction of proportionality between the unemployment rate and the wage markup (see equation (7)), in order to identify and estimate the elasticity of substitution between different labor types, which in turn determines the steady-state wage markup. In the model without unemployment this parameter is not identified; instead, we calibrate it to be very similar to the mean of the estimate in the model with observable unemployment.

Overall, most of the estimated structural parameters are very similar in the two models.[8] Focusing on the parameters that are important for the labour market, a number of findings are worth emphasizing.[9] First, the estimated labour supply elasticity is quite similar whether one uses unemployment or not as an observable variable: the inverse of the Frisch elasticity increases slightly from 3.3 to 4.0 as one includes unemployment. In the latter case, the steady state wage markup is identified and estimated to be slightly below 20 percent, which is consistent with an average unemployment rate of about 5 percent.

Turning to some of the other parameters that enter the wage Phillips

[8] A robust feature of the model with observed unemployment is that the labour preference shock and the productivity shock are positively correlated. Allowing for such a correlation further improves the fit of the model, but does not affect the estimation results discussed below.

[9] Unless otherwise noted, we will consistently refer to the mode of the posterior probability distribution when discussing estimates. Table 1 also reports the mean and 5 and 95 percentiles of the posterior distribution.

curve, the estimated degree of wage indexation is relatively small (around 0.15) and robust across the two models. The estimated Calvo probability of unchanged wages falls somewhat from 0.61 to 0.47, suggesting relatively flexible wages with average contract durations of 2 quarters. Overall, the introduction of unemployment as an observable variable leads to a somewhat steeper wage Phillips curve.

Third, the parameter, ν, governing the short-run wealth effects on labour supply, changes quite dramatically from 0.73 to 0.02. Roughly speaking this amounts to a change from preferences à la King, Plosser and Rebelo (1988; henceforth, KPR), characterized by strong short-run wealth effects, to a specification closer to that in Greenwood, Hercowitz and Huffman (1988). In the latter case, wealth effects are close to zero in the short run. As discussed below, this helps ensure that not only employment, but also the labour force moves procyclically in response to most shocks.[10]

Finally, it is worth pointing out that the monetary policy reaction coefficient to the output gap (defined as the deviation relative to the constant markup output), doubles from 0.07 to 0.15. As discussed below, this is mainly due to the lower volatility of the output gap once unemployment is used to identify wage markup shocks.

3.3 Impulse Responses

Figures 3 to 5 show the estimated impulse responses of output, inflation, the real wage, the interest rate, employment, the labour force, the unemployment

[10] Jaimovich and Rebelo (2009) have argued that small short-run wealth effects on labour supply are necessary to generate a positive response of output to favorable news about future productivity.

rate, and the output gap to the eight structural shocks. Figure 3 focuses on the four "demand" shocks, which include the investment-specific technology shock, the risk premium shock, the exogenous spending shock and the monetary policy shock. We use the label "demand" to refer to those shocks because, with the exception of unemployment, all depicted variables (and, in particular, output and inflation) comove positively. It is particularly noteworthy that employment and the labour force comove positively in response to all those shocks. Note, however, that the size of the labour force response is typically much smaller than that of employment, so that unemployment fluctuations are mostly driven by changes in employment. This is consistent with the empirical VAR evidence as shown in Christiano et al. (2010).

Figure 4 reports the dynamic responses to the labour supply and markup shocks, which we group under the heading of "labor market" shocks. These shocks generate a negative comovement of inflation and the real wage with output. An adverse wage markup shock has a sizeable positive impact on price inflation and unemployment and a negative one on output, employment and the output gap, thus generating a clear trade-off for policy makers. In contrast, the effects of an exogenous adverse labor supply shock has effects of the same sign on output, employment and inflation, but instead it leads to a temporary drop in unemployment rate and an increase in the output gap, so that no significant policy trade-off arises. It is this different effect on unemployment and the output gap associated the two labour market shocks that makes their separate identification so important, as further discussed below.

Figure 5 displays the estimated model's implied impulse responses to a positive neutral technology shocks and a (negative) price markup shock. We refer to those shocks as "supply" shocks, their distinctive feature being that they generate simultaneously a procyclical real wage response and a countercyclical response of inflation. It is worth noting, that, in line with much of the recent empirical evidence, a positive technology shocks lead to a short-run decline in employment (e.g. Galí (1999)) and a rise in the unemployment rate (e.g. Barnichon (2010)), in contrast with the predictions of conventially calibrated real business cycle or search and matching models. Secondly, and in a way analogous to wage markup shocks, we see that price markup shocks also create a policy trade-off between stabilising inflation and the output gap. This is not the case for technology shocks, since they drive both these variables in the same direction.

Before turning to several interesting questions that can be addressed with our estimated model, we wish to emphasize the importance of departing from conventional KPR preferences in order to match certain aspects of the data. Note that under standard KPR preferences the labor supply equation (5) can be written as

$$w_t - p_t = c_t + \varphi l_t + \xi_t$$

where habit formation is omitted to simplify the argument. As emphasized by Christiano et al. (2010) the previous equation is at odds with their empirical estimates of the effects of monetary policy shocks, which show a countercyclical response of $w_t - p_t - c_t$ coexisting with a procyclical response of the labor force l_t. Instead, under the assumed preferences, a procyclical response of the labor force is consistent with the model as long as the short run wealth effect is sufficiently weak, implying a small adjustment of z_t and hence a procyclical response of $w_t - p_t - z_t$. This is illustrated in Figure 6 which compares the impulse responses of employment, the labor force and the unemployment rate to a monetary policy shock under (i) our baseline estimated model and (ii) an otherwise identical model with KPR preferences (corresponding to $\nu = 1$). Note that in the latter case, and in contrast with the evidence, the labor force indeed falls significantly following an easing of monetary policy, amplifying the response of the unemployment rate and becoming the main driver of the latter.

4 Wage Markup vs. Labour Supply Shocks: Addressing the CKM Critique

In this section we address one of the CKM criticisms pointing to an implausibly large variance of wage markups shocks and a large contribution of the latter to output and employment fluctuations, as often implied by estimated DSGE models (e.g. SW, 2007). As forcefully argued by CKM, that central role allocated to wage markups shocks cannot be of much use to policymakers since the SW model is not able to distinguish between wage markup and labor supply shocks. They are effectively "lumped together" as a residual in the wage equation, even though–as discussed above–they have very different policy implications.

As discussed above, that problem of incomplete identification is in principle overcome by our reformulation of the SW model using the unemployment rate as an observable variable.[11] In particular, the estimated parameters of

[11] Justiniano, Primiceri and Tambalotti (2010) seek to overcome that problem by assuming a different stochastic structure for both driving forces: purely transitory in the case of markup shocks, and potentially persistent (as allowed for by an AR(1) process) for

the ARMA(1,1) process for the exogenous wage markup reported in Table 1 imply that the standard deviation drops from *23* to *12* percent once unemployment is included as an observable. Based on equation (7) and the estimated inverse labour supply elasticity, this implies a standard deviation of the natural unemployment rate of the order of 3%. This estimate is relatively high, but not unreasonable.

How important are wage markup shocks in driving output and employment fluctuations in the reformulated model? Table 2 presents the variance decomposition of the forecast errors of the eight observable variables at the 10 quarter and 10 year horizons. The first entry in each cell gives the percent contribution of each shock to fluctuations in each variable in the model with unemployment as an observable, whereas the second entry given the corresponding share in the model without unemployment. CKM argue that the contribution of the wage markup shocks to output and employment fluctuations (about 50 and 80 percent at the 10 year horizon) was too high to be plausible. Distinguishing labour supply shocks from wage markup shocks by introducing unemployment helps address this issue. From Table 2 it is clear that the contribution of the wage markup shocks to output (employment) fluctuations at the 10 year horizon drops from 45 (77) percent to 17 (39) percent in the model with unemployment. Furthermore, in the latter labor supply shocks (which are now separately identified) account for about 17, 40 and 89 percent of fluctuations in output, employment and the labor force respectively.

the labor supply shock. Their assumption of a white noise wage markup shock is at odds with our estimated process for that shock, which displays an important low frequency component.

As discussed by CKM, the identification of wage markup and labor supply shocks has implications for monetary policy, since those two shocks have very different effects on the efficient level of output and thus on the welfare-relevant output gap. Figure 7 plots the welfare relevant output gap, i.e. the gap between actual output and the level of output that would prevail with constant mark-ups and flexible prices and wages, as implied by the estimated models with and without unemployment (Note that, under the assumptions of the model, the output gap thus defined will differ from the gap from the efficient level of output by an additive constant). Figure 7 shows that the separate identification of labour supply shocks allowed by our reformulation has a substantial impact on the estimated output gap, which now looks considerably more stationary.

Figure 8 shows that this estimate of the output gap is to a large extent the mirror image of the unemployment rate. The correlation between the two is -0.95. This finding suggests that variations in wage markups, whether exogenous or induced by wage rigidities, are a key factor underlying inefficient output fluctuations.[12] That finding is consistent with the evidence in Galí, Gertler and López-Salido (2007).[13]

Finally, Figure 9 emphasizes that the model-based output gap resembles conventional measures of the cyclical component of log GDP, based

[12]See also the analysis in Galí (2011b) in the context of a much simpler model. A similar qualitative finding is uncovered in Sala, Soderstrom, and Trigari (2010), though their approach is subject to the CKM critique.

[13]It would also appear to be consistent with the evidence on the so-called "labor wedge" (e.g. Chari, Kehoe and McGrattan (2007), Shimer (2010)). Note, however, that the concept of "labor wedge" often used in the literature is proportional to the gap between the marginal rate of substitution and the marginal product of labor (as opposed to the wage). As a result (and despite its name) it captures variations in goods makets distortions, like price markups, in addition to labor market ones.

on a variety of statistical detrending methods (HP filter, band-pass filter, quadratic detrending, CBO measure).[14] There are, however, periods such as the 2005-2006 boom period with substantial deviations from the conventional measures.

5 Understanding Unemployment Fluctuations

In the present section we use our estimated model to analyze different aspects of unemployment fluctuations, which the reformulation of the SW model makes possible.

First, we can assess the role of wage rigidities as a factor underlying observed unemployment fluctuations by comparing the observed unemployment rate to its estimated *natural* counterpart, where the latter is defined as the unemployment rate that would be observed in the absence of nominal wage rigidities, as determined by equation (9). Figure 10 shows the time series for both variables, together with the gap between the two. The figure makes clear that the natural rate of unemployment accounts for a large fraction of the low-frequency movements in the observed unemployment rate. Yet, it is clear that the natural rate cannot account for the bulk of unemployment fluctuations at business cycle frequencies, which are captured by the unemployment gap.

The variance decomposition reported in Table 1 shows that about 50 percent of unemployment fluctuations at the 10-quarter horizon is due to "demand " shocks, mostly risk premium shocks. The other half is mostly due

[14] Justiniano, Primiceri and Tambalotti (2010) obtain a qualitatively similar finding, using an approach that does not exploit the connection between unemployment and wage markups, assuming instead a particular stochastic structure for the latter (white noise).

to wage mark-up shocks. In the longer run (10-year horizon), the contribution of demand shocks drops to 17 percent and wage markup shocks become the dominant driving force. Interestingly, those wage markup shocks also explain a dominant share of the fluctuations in price and wage inflation at all horizons. In contrast, labor supply and other supply shocks have only a limited impact on unemployment. The labor force instead is mostly driven by labor supply shocks, in line with the limited impact most other shocks have on the labor force.

The importance of demand and wage markup shocks in driving unemployment can be also be illustrated by means of the historical decomposition depicted in Figure 11. The secular rise of unemployment and inflation in the 1970s and early 1980s is mostly driven by cost-push factors coming from increasing wage markups. This is reversed in the mid 1980s. On the other hand, most of the unemployment fluctuations qt the business-cycle frequency are seen to be driven by demand shocks. This is particularly the case since the early 1990s. Both the 2001 and 2007-2008 recessions are driven by negative demand shocks. Figure 12 zooms in on the most recent recession, displaying the contribution of each individual shock to the rise of unemployment over this period. We see that about three quarters of the 5 percentage point increase in the unemployment rate is due to demand factors with adverse risk premium shocks playing a large role at the start of the crisis, thus capturing the tightening of financial conditions. As of 2009 our estimates identify an "effective" tightening of monetary policy, due to the attainment of the zero lower bound on the federal funds rate, and which is shown to contribute about 1 to 2 percentage points to the rise in the unemployment rate. Finally, it is also worth noting that our estimates suggest a significant contribution of wage markup shocks to the rise in the unemployment rate. As conjectured by Gali (2011a), this may be due to downward nominal wage rigidities, which may have prevented the average real wage from adjusting as much as it would be warranted by the decline in inflation and the rise in unemployment.

Finally, we can use the estimated model to interpret the observed comovements between the unemployment rate and measures of wage and price inflation. With that objective, Figure 13 displays the joint variation in wage inflation and the unemployment rate conditional on each shock, as well as their unconditional joint variation (bottom-right diagram). The evidence makes clear that whatever Phillips curve-like negative comovement between wage inflation and unemployment can be found in the data it is largely the result of the four demand shocks. By contrast, wage markup shocks generate what looks like a positive lower frequency comovement in both variables, and are largely reponsible for the lack of a clean Phillips curve-like pattern in the observed data. Supply shocks, on the other hand, lead to a near-zero comovement. Note that this is still consistent with wage inflation equation (3), for their implied responses of unemployment are non-monotonic (see Figure 5), thus leaving wage inflation largely unchanged as a result.

Figure 14 displays analogous evidence for unemployment and price inflation. As in the case of wage inflation, the four demand shocks generate a clear negative comovement between price inflation and the unemployment rate, while wage markup shocks underlie a low frequency positive comovement. Contrary to traditional textbook analyses, productivity shocks are also shown to generate a negative comovement between price inflation and the unemployment rate. On the other hand, price markup shocks produce a nearly vertical Phillips curve, since their impact on the unemployment rate is tiny, while their effect on price inflation is substantial.

6 Robustness

In this section we briefly summarize the findings based on a number of alternative specifications. First, we use hours worked rather than employment as our measure of labour input. While the benchmark model is written in terms of employment, the actual labour input that enters the production function should be total hours worked. Using employment will therefore distort the estimated productivity process. When we use hours, we leave the unemployment rate unchanged, thus making the implicit assumption that those who are unemployed want to work the same number of hours as those who are employed.[15] In that alternative specification we also use wage per hour. When we leave the model unchanged but use hours worked rather than employment as our measure of labour input, the main results emphasized above are not affected. The full set of results is available on request. Two differences are worth mentioning. First, as expected the contribution of productivity shocks to output fluctuations becomes less important. Second, the degree of wage rigidity is estimated to be higher (0.60) and as a result the slope of the Phillips curve becomes less steep.

Second, we estimated the model using only the compensation series as a wage measure. Again, the main results are unchanged. The main impact of

[15] In order to address these issues, ideally we need to explicitly include the intensive margin, i.e. hours worked per employee, in the model and re-estimate it accordingly. That extension is part of our currently ongoing research.

the higher volatility in the compensation series is to increase the estimate of the inverse Frisch elasticity of the labour supply to 5.6 when unemployment is added. With higher observed volatility of wages, the response of labour supply to real wages is estimated to be less. This has an additional impact on some of the other parameters, such as the degree of habit formation.

Thirdly, we have also estimated the model under KPR preferences and an alternative set of Jaimovich-Rebelo preferences where the Z_t factor evolves in line with aggregate productivity instead of aggregate consumption. The model with KPR preferences leads to a significant deterioration of the empirical fit by about 15 points. As discussed above, in this case the labor force moves countercyclically in response to monetary policy and other demand shocks. However, the modified JR model leads to a significantly improved empirical fit by about 28 points. Moreover, the parameter υ rises back to 0.9 (from 0.02 in the baseline model) suggesting that in response to productivity shocks the data prefer stronger short-run wealth effects on labor supply. We still have to think harder about the interpretation of these results.

Finally, we have also re-estimated our model using data up to 2010Q4, thus ignoring the potential problems raised above. The main difference with the benchmark results is that the estimated wage stickiness rises and the overall persistence in the economy as captured by the persistence of the shocks rises.

7 Conclusion

In this paper we have developed a reformulated version of the Smets-Wouters (2007) framework that embeds the theory of unemployment proposed in Galí

(2011a,b). We estimate the resulting model using postwar U.S. data, while treating the unemployment rate as an additional observable variable. This helps overcome the lack of identification of wage markup and labor supply shocks highlighted by Chari, Kehoe and McGrattan (2008) in their criticism of New Keynesian models..In turn, our approach allows us to estimate a "correct" measure of the output gap. In addition, the estimated model can be used to analyze the sources of unemployment fluctuations.

A number of key results emerge from our analysis. First, we show that wage markup shocks play a smaller role in driving output and employment fluctuations than previously thought. Secondly, fluctuations in our estimated output gap are shown to be the near mirror image of those experienced by the unemployment rate, and to be well approximated by conventional measures of the cyclical component of GDP. Thirdly, demand shocks are the main driver of unemployment fluctuations at business cycle frequencies, but wage markup shocks are shown to be more important at lower frequencies. Finally, our estimates point to an adverse risk-premium shock as the key force behind the initial rise in unemployment during the Great Recession. The important role uncovered for monetary policy and wage markup shocks at a later stage can be interpreted as capturing the likely amplifying role played by the zero lower bound on the nominal rate and the possible presence of downward wage rigidities.

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APPENDIX

In this appendix, we summarize the remaining log-linear equations of the model. For a more detailed presentation, we refer to the discussion in SW.

- Consumption Euler equation:

$$\widehat{c}_t = c_1 E_t\left[\widehat{c}_{t+1}\right] + (1-c_1)\widehat{c}_{t-1} - c_2(\widehat{R}_t - E_t[\widehat{\pi}_{t+1}] - \widehat{\varepsilon}^b_t)$$

with $c_1 = 1/(1+h)$, $c_2 = c_1(1-h)$ where h is the external habit parameter. $\widehat{\varepsilon}^b_t$ is the exogenous AR(1) risk premium process.

- Investment Euler equation:

$$\widehat{i}_t = i_1\widehat{i}_{t-1} + (1-i_1)\widehat{i}_{t+1} + i_2\widehat{Q}^k_t + \widehat{\varepsilon}^q_t$$

with $\mathrm{i}_1 = 1/(1+\beta)$, $i_2 = i_1/\Psi$ where β is the discount factor, and Ψ is the elasticity of the capital adjustment cost function. $\widehat{\varepsilon}^q_t$ is the exogenous AR(1) process for the investment specific technology.

- Value of the capital stock:

$$\widehat{Q}^k_t = -(\widehat{R}_t - E_t[\widehat{\pi}_{t+1}] - \widehat{\varepsilon}^b_t) + q_1 E_t[r^k_{t+1}] + (1-q_1)E_t[Q^k_{t+1}]$$

with $q_1 = r^k_*/(r^k_* + (1-\delta))$ where r^k_* is the steady state rental rate to capital, and δ the depreciation rate.

- Aggregate demand equals aggregate supply:

$$\begin{aligned}\widehat{y}_t &= \frac{c_*}{y_*}\widehat{c}_t + \frac{i_*}{y_*}\widehat{i}_t + \widehat{\varepsilon}^g_t + \frac{r^k_* k_*}{y_*}\widehat{u}_t \\ &= \mathcal{M}_p\left(\alpha\widehat{k}_t + (1-\alpha)\widehat{L}_t + \widehat{\varepsilon}^a_t\right)\end{aligned}$$

with $\mathcal{M}_p$ reflecting the fixed costs in production which corresponds to the price markup in steady state. $\widehat{\varepsilon}^g_t$, $\widehat{\varepsilon}^a_t$ are the AR(1) processes representing exogenous demand components and the TFP process.

- Price-setting under the Calvo model with indexation:

$$\widehat{\pi}_t - \gamma_p \widehat{\pi}_{t-1} = \pi_1 \left(E_t \left[\widehat{\pi}_{t+1} \right] - \gamma_p \widehat{\pi}_t \right) - \pi_2 \widehat{\mu}_t^p + \widehat{\varepsilon}_t^p$$

with $\pi_1 = \beta$, $\pi_2 = (1-\xi_p\beta)(1-\xi_p)/[\xi_p(1+(\mathcal{M}_p-1)\varepsilon_p)]$, with θ_p and γ_p respectively the probability and indexation of the Calvo model, and ε_p the curvature of the aggregator function. The price markup $\widehat{\mu}_t^p$ is equal to the inverse of the real marginal $\widehat{mc}_t = (1-\alpha)\ \widehat{w}_t + \alpha\ \widehat{r}_t^k - \widehat{A}_t$.

- Capital accumulation equation:

$$\widehat{\overline{k}}_t = \kappa_1\ \widehat{\overline{k}}_{t-1} + (1-\kappa_1)\widehat{i}_t + \kappa_2 \widehat{\varepsilon}_t^q$$

with $\kappa_1 = 1 - (i_*/\overline{k}_*)$, $\kappa_2 = (i_*/\overline{k}_*)(1+\beta)\Psi$. Capital services used in production is defined as: $\widehat{k}_t = \widehat{u}_t + \widehat{\overline{k}}_{t-1}$

- Optimal capital utilisation condition:

$$\widehat{u}_t = (1-\psi)/\psi \widehat{r}_t^k$$

with ψ is the elasticity of the capital utilisation cost function.

- Optimal capital/labor input condition:

$$\widehat{k}_t = \widehat{w}_t - \widehat{r}_t^k + \widehat{L}_t$$

- Monetary policy rule:

$$\widehat{R}_t = \rho_R \widehat{R}_{t-1} + (1-\rho_R)(r_\pi \widehat{\pi}_t + r_y(\widehat{ygap}_t) + r_{\Delta y}\Delta(\widehat{ygap}_t) + \widehat{\varepsilon}_t^r$$

with $ygap_t = \widehat{y}_t$ - $\widehat{y}_t^{flex}$, the difference between actual output and the output in the flexible price and wage economy in absence of distorting price and wage markup shocks.

The following parameters are not identified by the estimation procedure and therefore calibrated: $\delta = 0.025$, $\varepsilon_p = 10$.

Table 1: Posterior Estimates for the model with and without unemployment as observed variable - Complete list of parameters

	prior distribution			posterior distribution							
				With UR				Without-UR			
	type	mean	st.dev	mode	mean	5%	95%	mode	mean	5%	95%
st.dev. of the innovations[1]											
σ_a	U	2.5	1.44	0.41	0.42	0.37	0.46	0.42	0.42	0.37	0.46
σ_b	U	2.5	1.44	1.73	1.60	0.56	2.50	0.73	0.91	0.35	1.66
σ_g	U	2.5	1.44	0.47	0.48	0.43	0.52	0.47	0.48	0.43	0.52
σ_q	U	2.5	1.44	0.42	0.42	0.34	0.49	0.38	0.38	0.30	0.46
σ_r	U	2.5	1.44	0.21	0.22	0.19	0.24	0.23	0.23	0.21	0.26
σ_p	U	2.5	1.44	0.05	0.11	0.03	0.18	0.06	0.32	0.02	0.73
σ_w	U	2.5	1.44	0.04	0.06	0.01	0.13	0.07	0.10	0.03	0.20
σ_{ls}	U	2.5	1.44	1.07	1.17	0.89	1.45	-	-	-	-
σ_{wC}	U	2.5	1.44	0.45	0.46	0.41	0.50	0.45	0.45	0.40	0.50
σ_{wE}	U	2.5	1.44	0.34	0.36	0.32	0.41	0.33	0.34	0.29	0.39
persistence of the exogenous processes: ρ = AR(1), μ = MA(1)											
ρ_a	B	0.5	0.2	0.98	0.98	0.97	0.99	0.98	0.97	0.96	0.99
ρ_b	B	0.5	0.2	0.36	0.42	0.19	0.67	0.66	0.64	0.39	0.86
ρ_g	B	0.5	0.2	0.97	0.97	0.96	0.99	0.98	0.98	0.96	0.99
ρ_q	B	0.5	0.2	0.72	0.75	0.62	0.88	0.75	0.74	0.62	0.86
ρ_r	B	0.5	0.2	0.09	0.10	0.02	0.17	0.09	0.11	0.02	0.19
ρ_p	B	0.5	0.2	0.76	0.43	0.07	0.79	0.84	0.64	0.23	0.93
ρ_w	B	0.5	0.2	0.99	0.98	0.97	1.00	0.99	0.99	0.99	1.00
μ_p	B	0.5	0.2	0.59	0.57	0.24	0.96	0.68	0.73	0.46	0.97
μ_w	B	0.5	0.2	0.67	0.63	0.35	0.91	0.66	0.65	0.38	0.91
a_g[2]	N	0.5	0.25	0.69	0.69	0.55	0.83	0.71	0.70	0.56	0.85
structural parameters											
Ψ	N	4.0	1.0	4.09	3.96	2.34	5.58	3.33	3.77	2.32	5.20
h	B	0.7	0.10	0.78	0.75	0.65	0.85	0.66	0.68	0.57	0.81
φ	N	2.0	1.0	3.99	4.35	3.37	5.32	3.32	3.46	2.27	4.66
υ	B	0.5	0.2	0.02	0.02	0.01	0.04	0.73	0.70	0.50	0.92
θ_p	B	0.5	0.15	0.58	0.62	0.53	0.71	0.60	0.71	0.56	0.84
θ_w	B	0.5	0.15	0.47	0.55	0.44	0.66	0.61	0.66	0.56	0.76
γ_p	B	0.5	0.15	0.26	0.49	0.20	0.78	0.26	0.46	0.16	0.82
γ_w	B	0.5	0.15	0.16	0.18	0.07	0.29	0.17	0.20	0.08	0.31
ψ	B	0.5	0.15	0.57	0.56	0.36	0.75	0.41	0.42	0.24	0.60
$\mathcal{M}_p$	N	1.25	0.12	1.74	1.74	1.61	1.88	1.71	1.73	1.59	1.86
ρ_R	B	0.75	0.10	0.85	0.86	0.82	0.89	0.83	0.84	0.79	0.89
r_π	N	1.5	0.25	1.91	1.89	1.62	2.16	2.03	1.96	1.65	2.26
r_y	N	0.12	0.05	0.15	0.16	0.11	0.22	0.07	0.07	0.04	0.10
$r_{\Delta y}$	N	0.12	0.05	0.24	0.25	0.20	0.30	0.27	0.28	0.22	0.33
$\overline{\pi}$	G	0.62	0.1	0.62	0.66	0.49	0.83	0.79	0.80	0.61	0.99
$100(\beta^{-1}-1)$	G	0.25	0.1	0.31	0.31	0.17	0.43	0.21	0.22	0.11	0.33
$\bar{l}$	N	0.0	2.0	-1.65	-1.52	-3.83	0.77	3.56	3.37	1.46	5.29
τ	N	0.4	0.1	0.34	0.34	0.30	0.37	0.40	0.39	0.36	0.43
τ_{wE}	N	0.2	0.1	0.07	0.08	0.03	0.12	0.11	0.10	0.05	0.15
$\mathcal{M}_w$	N	1.25	0.25	1.18	1.22	1.15	1.29	1.25[3]	1.25[3]	-	-
α	N	0.3	0.05	0.17	0.17	0.14	0.20	0.16	0.16	0.13	0.19

[1] The IG-distribution is defined by the degree of freedom. [2] The effect of TFP innovations on exogenous demand. [3] The steady state wage mark-up is not identified if the unemployment rate is not observed.

Table 2: Variance Decomposition

Variance Decomposition	output	inflation	real wage	employment	labor force	unemployment
10 quarter horizon						
Demand Shocks						
Risk premium	6 / 14	2 / 8	3 / 6	16 /25	0 / 15	20 / 25
Exogenous demand	3 / 5	1 / 0	1 / 0	7 / 10	1 / 9	8 / 1
Investment spec. techn.	9 / 7	3 / 2	8 / 2	12 / 9	2 / 3	10 / 2
Monetary policy	5 / 7	8 / 8	6 / 4	11 / 12	0 / 4	11 / 10
Supply Shocks						
Productivity	59 / 46	6 / 4	40 /32	5 / 2	3 / 4	4 / 1
Price mark-up	2 / 6	27 / 33	30 / 45	3 / 6	5 / 3	0 / 1
Labor Market shocks						
Wage mark-up	6 / 15	53 / 46	12 / 11	18 / 35	3 / 61	41 / 61
Labor supply	11 / -	0 / -	1 / -	29 / -	86 / -	5 / -
40 quarter horizon						
Demand Shocks						
Risk premium	2 / 5	1 / 6	1 / 3	6 / 8	0 / 6	7 / 7
Exogenous demand	1 / 2	1 / 0	1 / 0	3 / 5	1 / 8	3 / 0
Investment spec. techn.	5 / 3	2 / 1	6 / 3	4 / 3	1 / 2	3 / 0
Monetary policy	2 / 3	5 / 7	3 / 3	4 / 4	0 / 2	4 / 3
Supply Shocks						
Productivity	56 / 39	4 / 3	71 / 59	3 / 1	2 / 1	1 / 0
Price mark-up	1 / 2	18 / 26	13 / 26	1 / 2	2 / 1	0 / 0
Labor Market shocks						
Wage mark-up	17 / 45	67 / 57	5 / 6	39 / 77	5 / 81	80 / 89
Labor supply	17 / -	0 / -	0 / -	40 / -	89 / -	2 / -

Figure 1. The Wage Markup and the Unemployment Rate

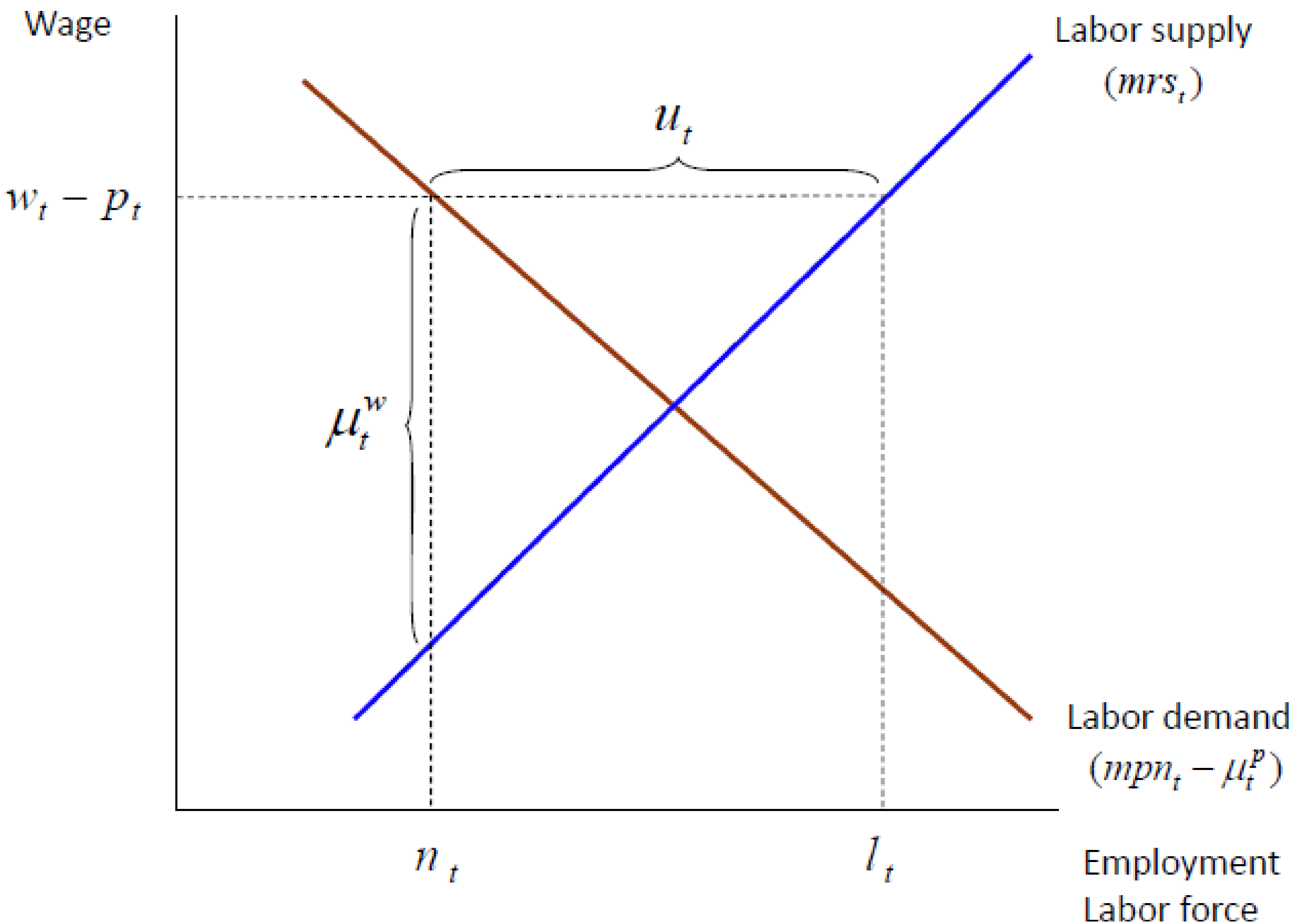

Figure 2. Two Wage Inflation Measures

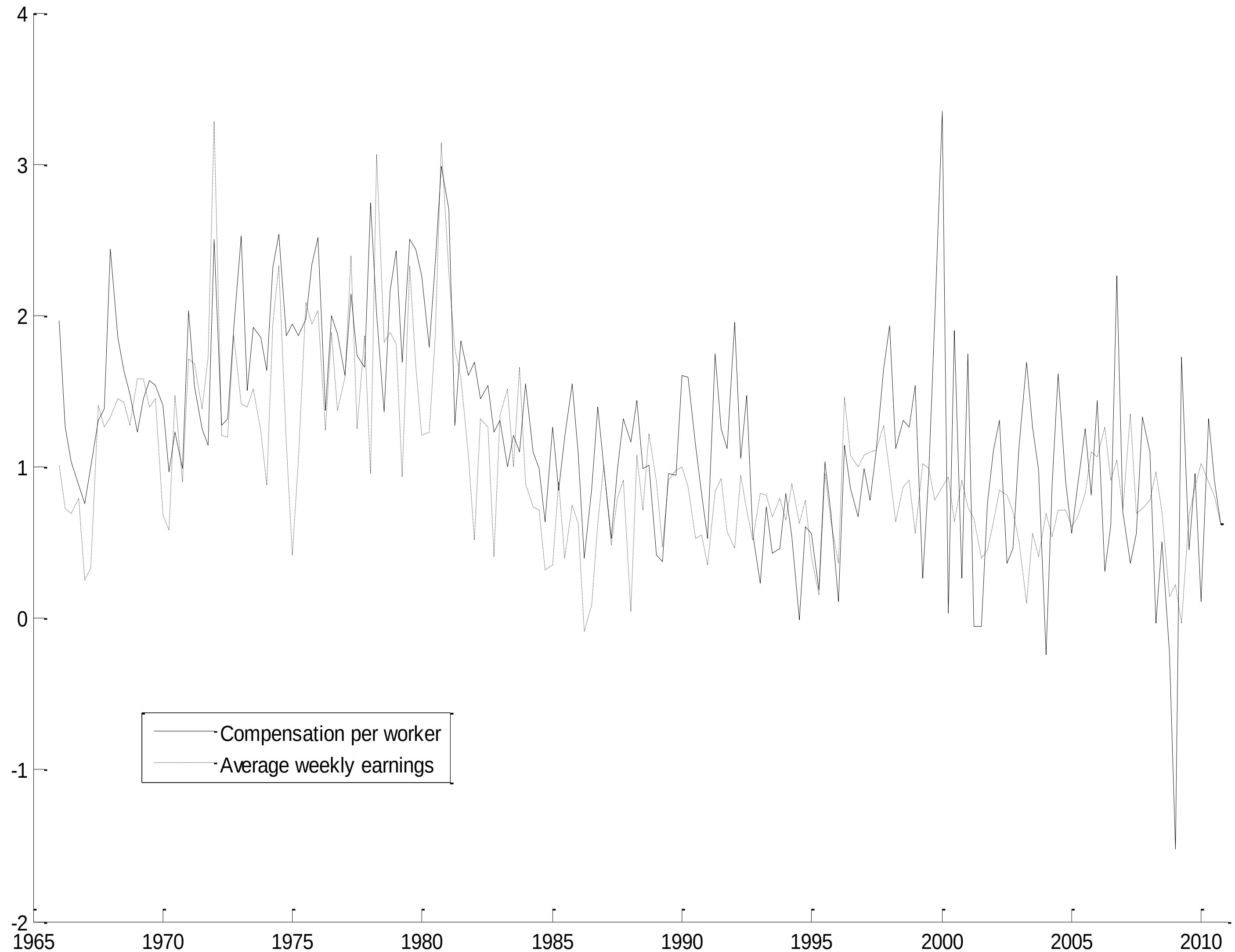

Figure 3. Dynamic Responses to Demand Shocks

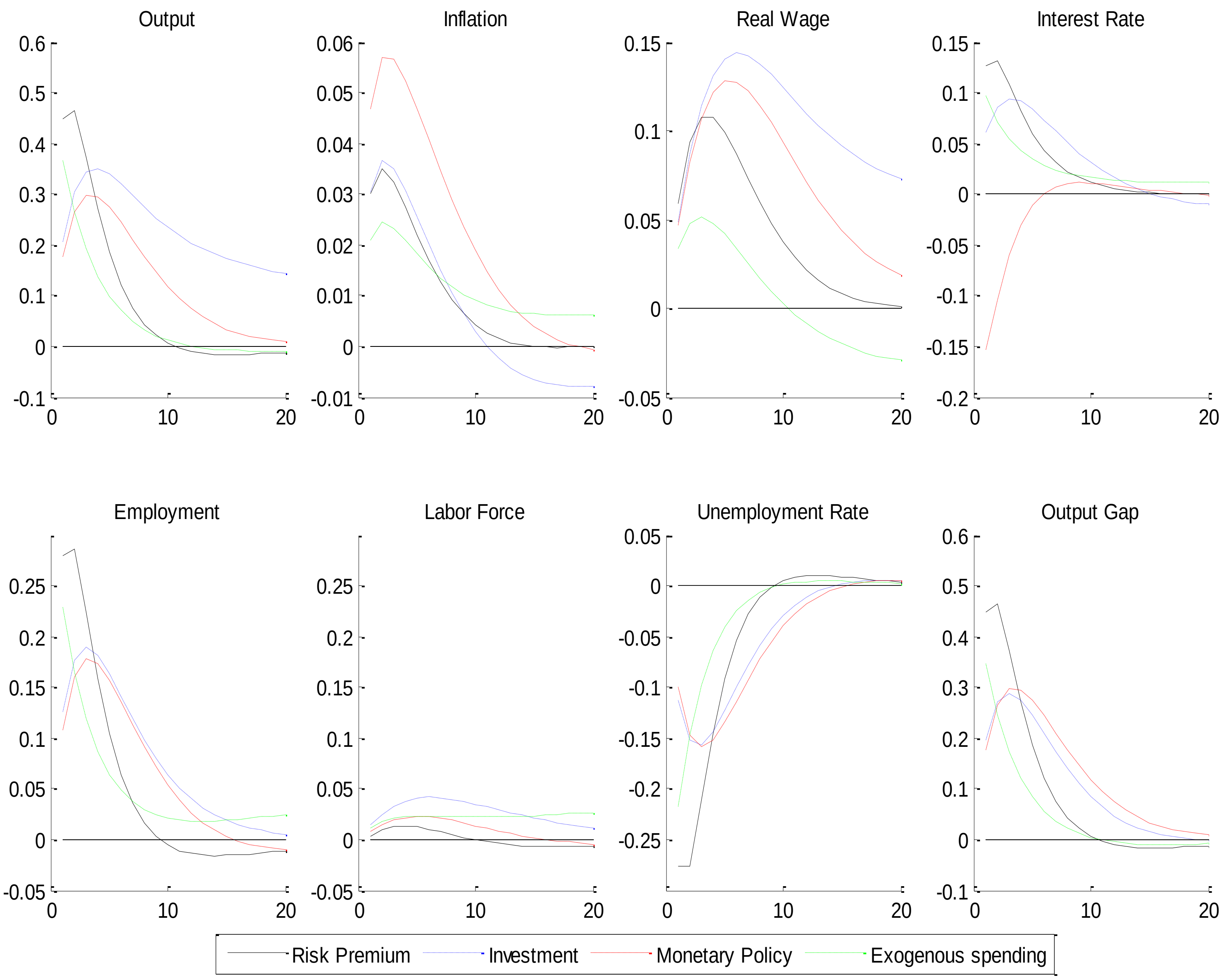

Figure 4. Dynamic Responses to Labor Market Shocks

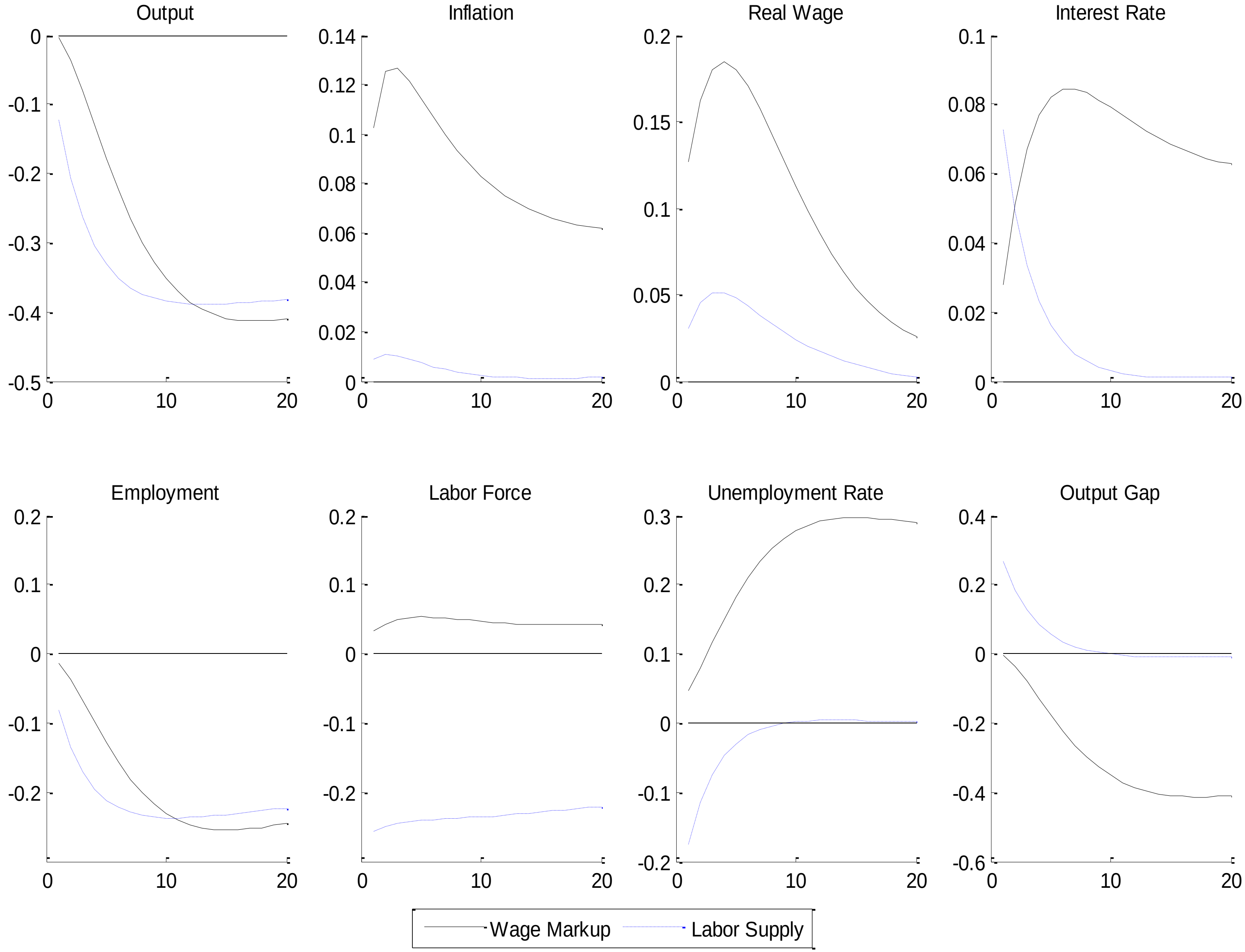

Figure 5. Dynamic Responses to Supply Shocks

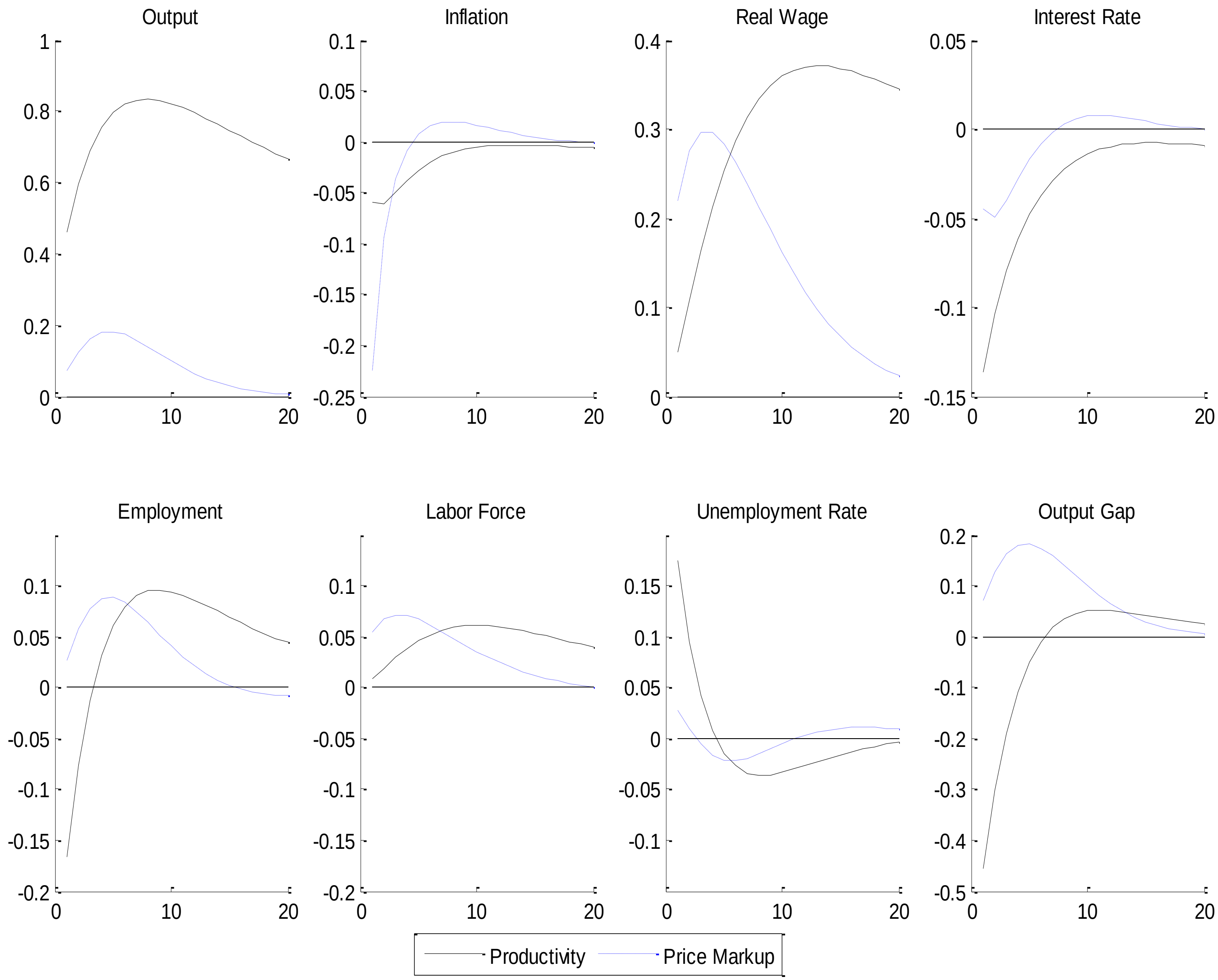

Figure 6. Monetary Policy Shocks and the Role of Wealth Effects

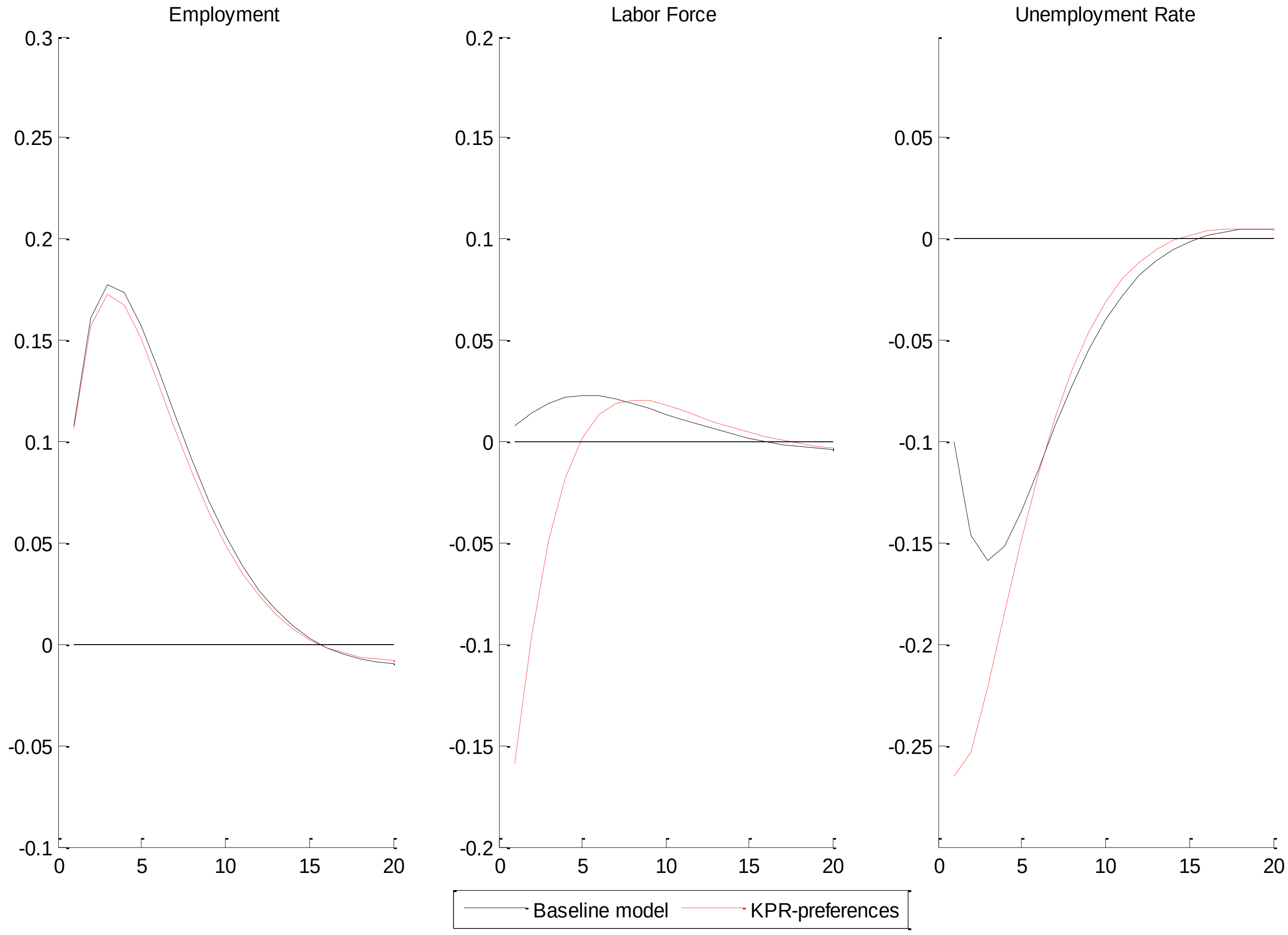

Figure 7. Two Measures of the Output Gap

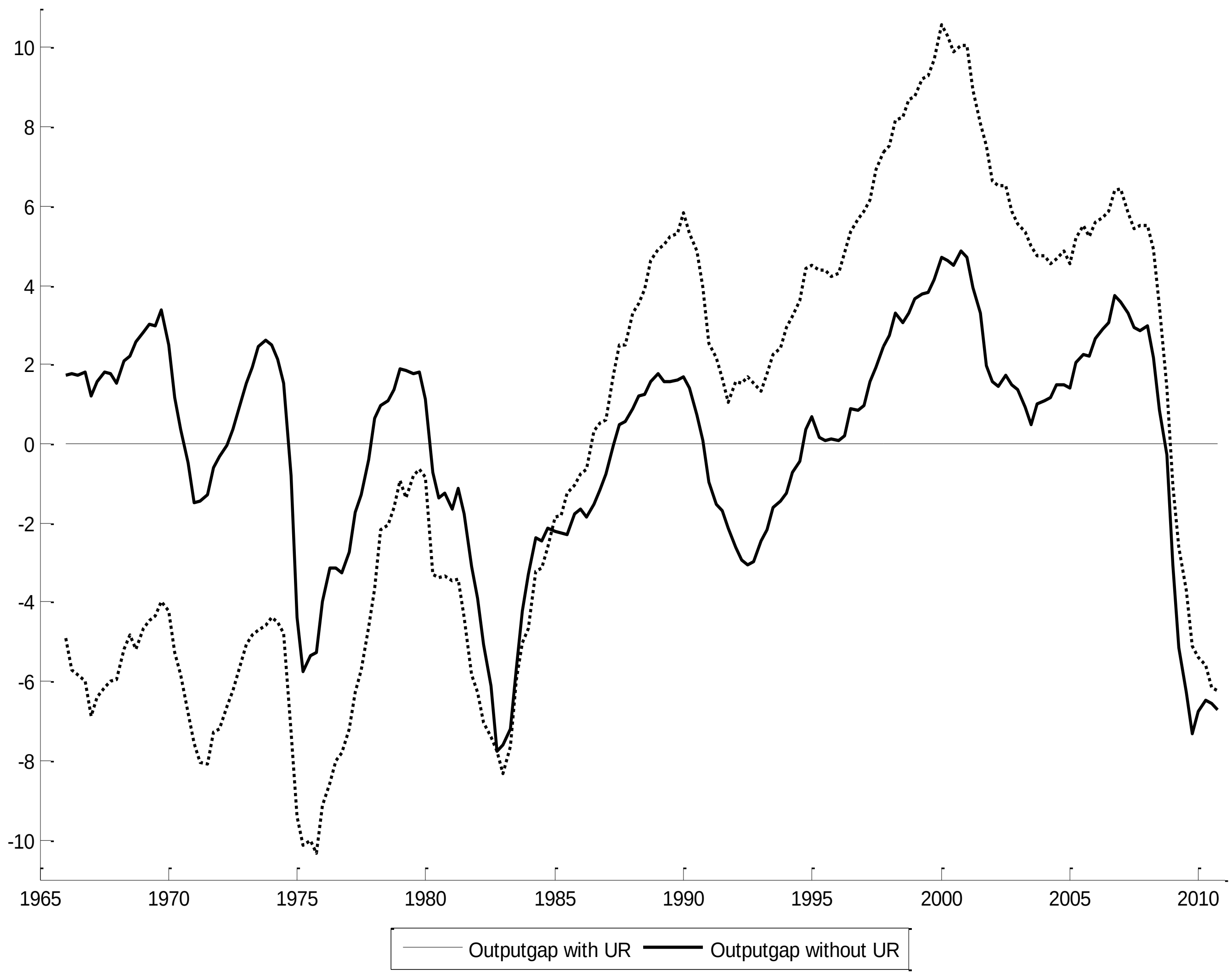

Figure 8. The Output Gap and the Unemployment Rate

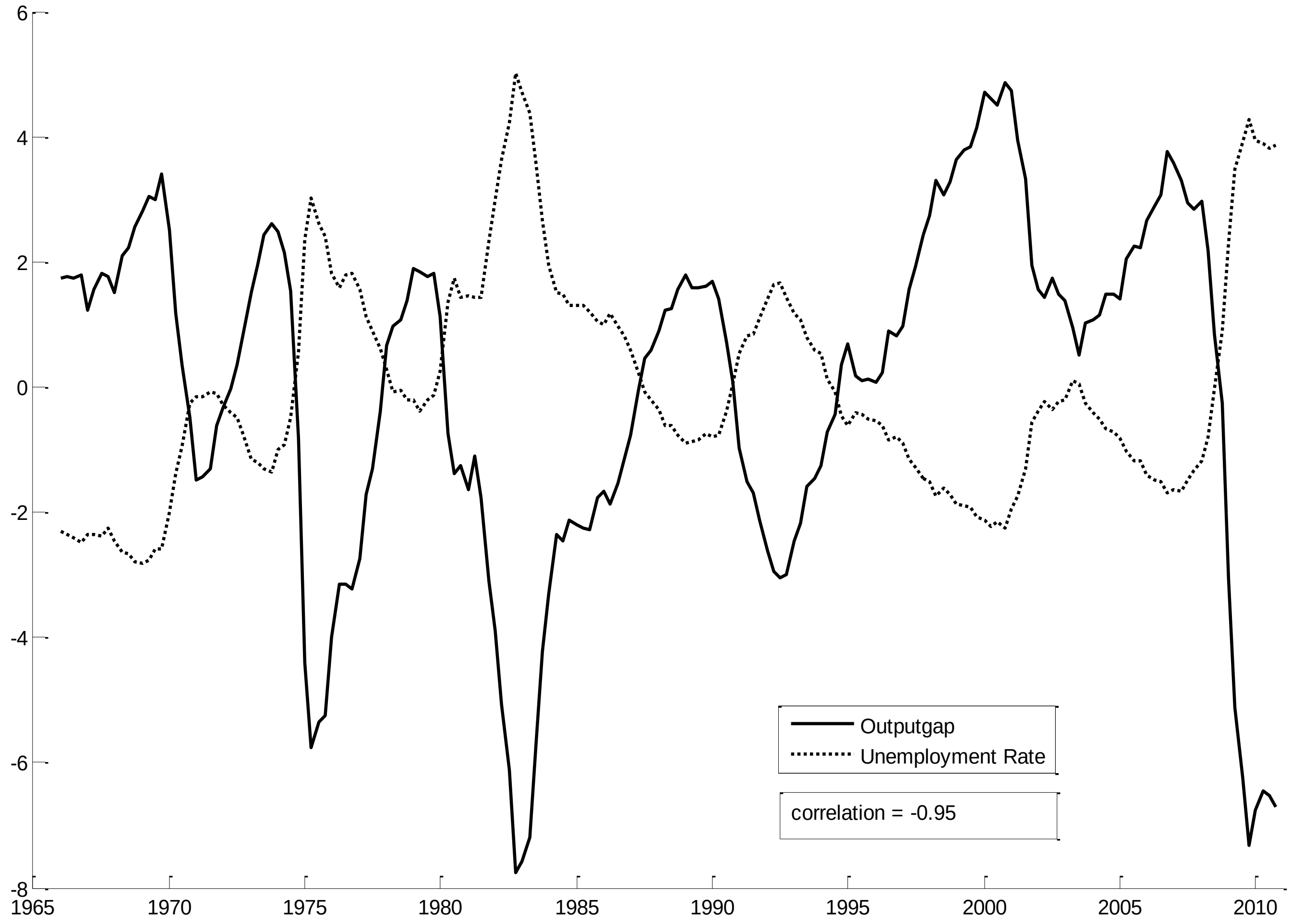

Figure 9. The Output Gap vs. Detrended GDP

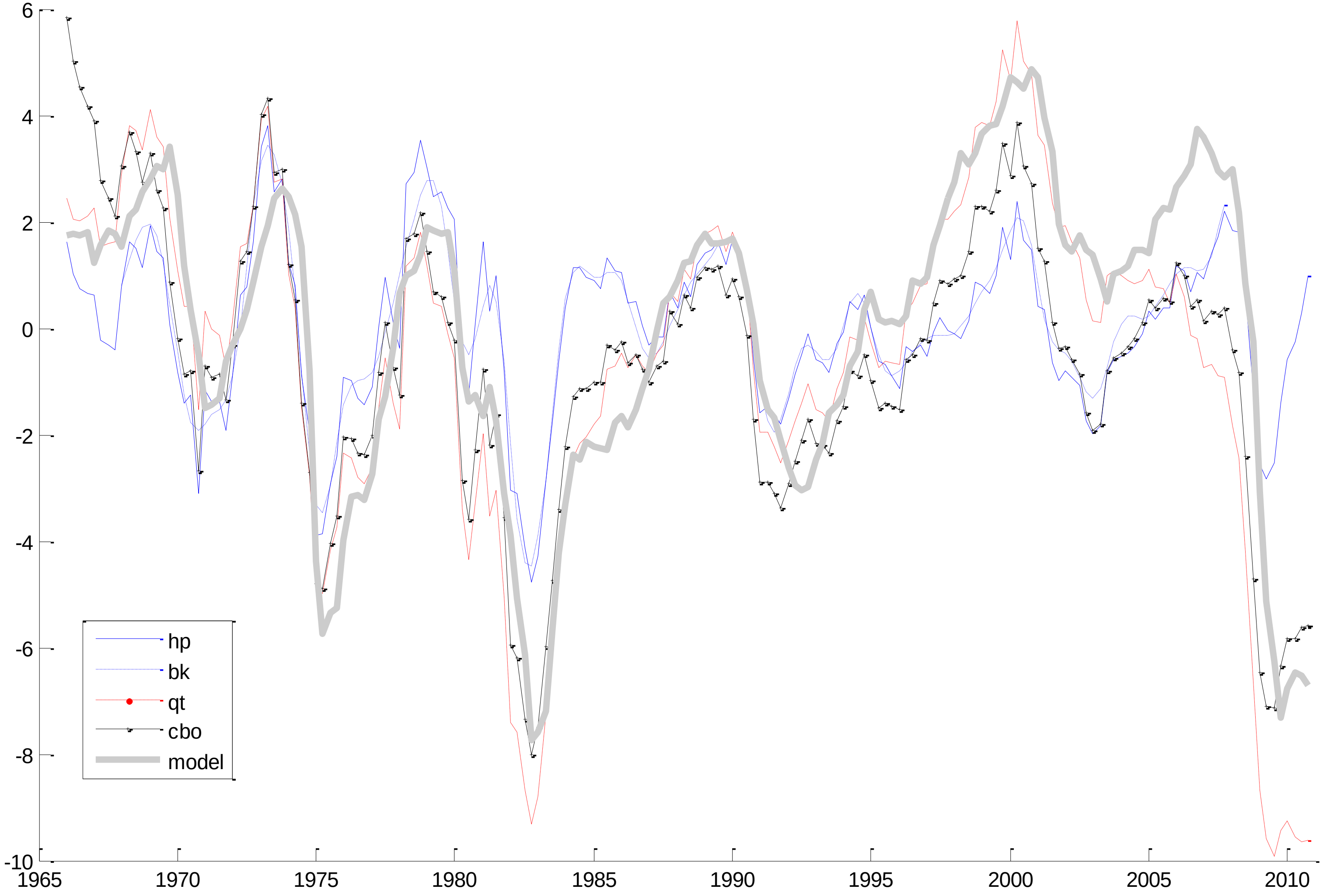

Figure 10. The Natural Rate of Unemployment

Figure 11. Sources of Unemployment Rate Fluctuations

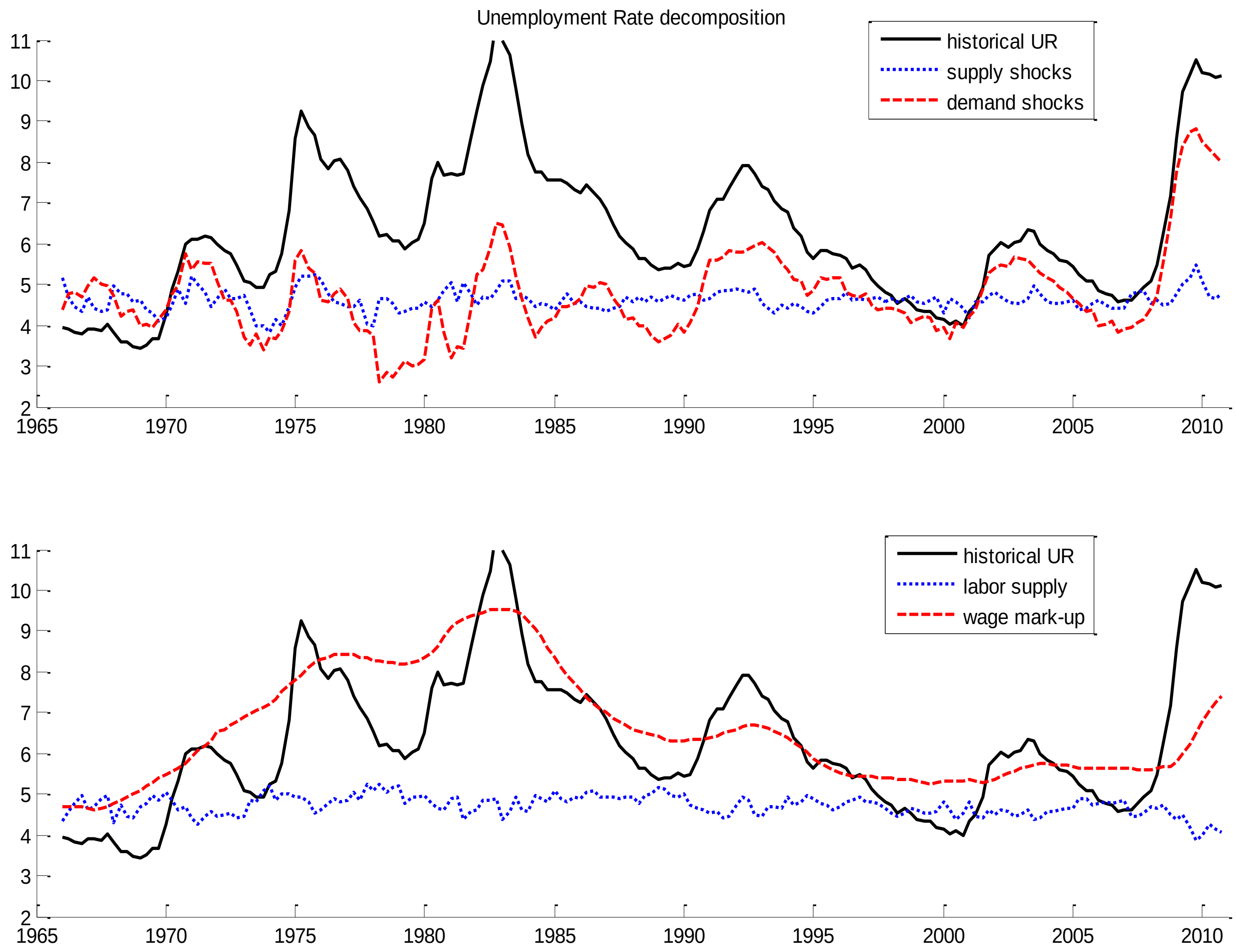

Figure 12. Unemployment during the Great Recession

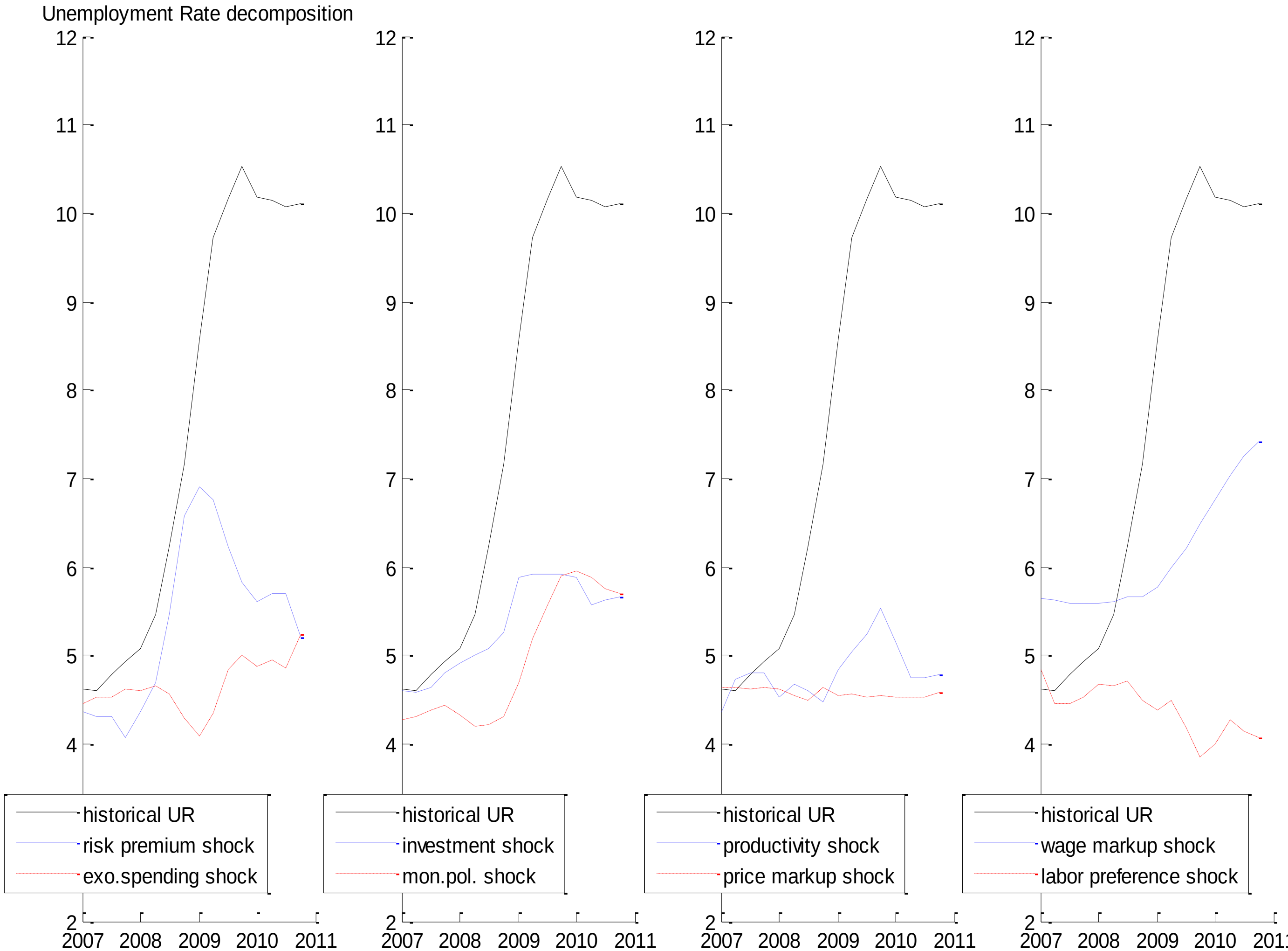

Figure 13. Unemployment and Wage Inflation

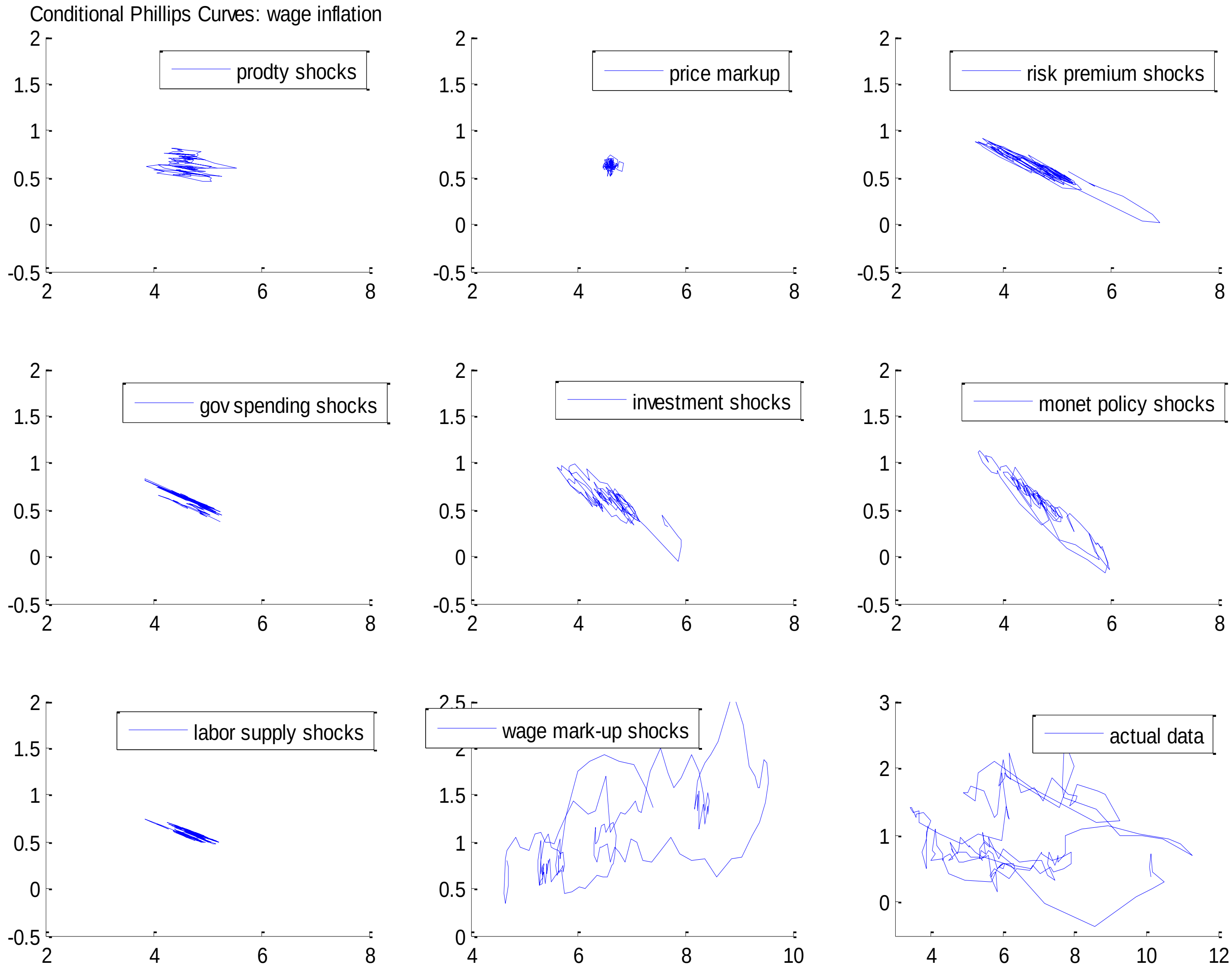

Figure 14. Unemployment and Price Inflation