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MONETARY POLICY, INFLATION AND UNEMPLOYMENT IN DEFENSE OF THE FEDERAL RESERVE

Nicolas Groshenny
Reserve Bank of New Zealand and CAMA

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Monetary Policy, Inflation and Unemployment
In Defense of the Federal Reserve

Nicolas Groshenny*
Reserve Bank of New Zealand and CAMA

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Abstract

To what extent did deviations from the Taylor rule between 2002 and 2006 help to promote price stability and maximum sustainable employment? To address that question, this paper estimates a New Keynesian model with unemployment and performs a counterfactual experiment where monetary policy strictly follows a Taylor rule over the period 2002:Q1 - 2006:Q4. The paper finds that such a policy would have generated a sizeable increase in unemployment and resulted in an undesirably low rate of inflation. Around mid-2004, when the counterfactual deviates the most from the actual series, the model indicates that the probability of an unemployment rate greater than 8 percent would have been as high as 80 percent, while the probability of an inflation rate above 1 percent would have been close to zero.

Keywords: DSGE models, inflation, unemployment, Taylor rules

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*Address: Economics Department, Reserve Bank of New Zealand, 2 The Terrace, PO Box 2498, Wellington, New Zealand. *email address:* nicolas.groshenny@rbnz.govt.nz. The views expressed in this paper are mine and do not necessarily reflect the views of the Reserve Bank of New Zealand. I am especially grateful to Ulf Söderström for very helpful comments. I would like to thank Fabio Canova, Iris Claus, Rebecca Craigie, Manu De Veirman, Francesco Furlanetto, Bill Gavin, Pedro Gomis, Alfred Guender, Leni Hunter, Peter Ireland, Punnoose Jacob, Günes Kamber, Özer Karagedikli, Jonathan Kearns, Leo Krippner, Kirdan Lees, Thomas Lubik, Anella Munro, Bruce Preston, Pierre-Daniel Sarte, Christie Smith, Chris Waller and Raf Wouters for very useful feedback. I am grateful to seminar and conference participants at SWIM 2010, AMW 2010, SED Montreal 2010, WMD Sydney 2010, ACQM Adelaide 2010, the University of Canterbury and Victoria University of Wellington.

"During the period from 2003 to 2006 the federal funds rate was well below what experience during the previous two decades of good economic macroeconomic performance would have predicted. Policy rule guidelines showed this clearly. What would have happened if an alternative path for the federal funds rate were followed? The classic methodology for investigating such questions is a counterfactual scenario." John B. Taylor, September 2007.

"The aggressive monetary policy response in 2002 and 2003 was motivated by two principal factors. First, the recovery remained quite weak and jobless. Real gross domestic product rose at an average pace insufficient to halt continued increases in the unemployment rate. Second, the FOMC's policy response also reflected concerns about a possible unwelcome decline in inflation. Taking note of the painful experience of Japan, policymakers worried that the United States might sink into deflation." Ben Bernanke, January 3, 2010.

1 Introduction

According to its official mandate, the Federal Reserve sets the federal funds rate in order to achieve a dual goal of price stability and maximum sustainable employment. Recently, a debate has emerged regarding the justification of the Federal Reserve's conduct of monetary policy after 2001. In particular, Taylor (2007) argues that the Federal Reserve kept the federal funds rate too low for too long in the aftermath of the 2001 recession. In contrast, Bernanke (2010) argues that the stance of monetary policy post-2001 was appropriate to reduce the risks of deflation and high unemployment.[1]

This paper asks whether the deviations from the Taylor rule undertaken by the Federal Reserve over the period 2002-2006 were helpful in promoting "price stability" and "maximum sustainable employment" as dictated by its mandate. To answer this question one needs a structural macroeconomic model that describes how monetary policy – in particular the federal funds rate – affects inflation and unemployment. This paper therefore estimates a New Keynesian model with unemployment on post-1984 U.S. data. The estimated model is used to back out the shocks that have hit the U.S. economy and to perform a counterfactual experiment where the deviations from the estimated Taylor-type rule, i.e. the "monetary policy shocks", are turned off over the period 2002:Q1 - 2006:Q4.

The results suggest that the deviations from the estimated rule contributed materially to enhancing macroeconomic stability during the first half of the last decade. In particular, between 2002 and 2006, the non-systematic component of monetary policy significantly reduced the risk of deflation and high unemployment, especially in 2004:Q2. Hence, this paper provides some quantitative

[1] Other papers addressing Taylor's (2007) critique are Kohn (2007), Svensson (2010) and Dokko, Doyle, Kiley, Kim, Sherlund, Sim and den Heuvel (2009).

evidence that validates Bernanke's (2010) testimony.

The paper proceeds as follows: Section 2 briefly describes the model and the econometric strategy. Section 3 examines the effects of the Federal Reserve's deviations from the prescriptions of an estimated Taylor rule on inflation and unemployment post-2001. Section 4 assesses the robustness of the paper's main result by conducting some sensitivity analysis with respect to: (i) the specification of the Taylor-type rule; (ii) the set of shocks embedded in the macroeconometric model; and (iii) the period of the counterfactual scenario. Section 5 concludes.

2 Model and econometric strategy

2.1 Model

The model combines the current workhorse for monetary policy analysis, the New Keynesian model, with the search and matching model of the labour market developed by Diamond, Mortensen and Pissarides.[2] Merging the nominal rigidities of the New Keynesian model (which give monetary policy some leverage on real variables) with search and matching frictions (that give rise to equilibrium unemployment) allows us to study the joint behavior of inflation, unemployment and the federal funds rate.

The purpose of the paper is to provide a quantitative evaluation of Bernanke's claim that the stance of monetary policy was appropriate to prevent deflation and high unemployment. In order to provide this quantitative evaluation, the model incorporates the standard features introduced by Christiano, Eichenbaum and Evans (2005) to help fit the model to postwar U.S. macro data. Moreover, as in the benchmark quantitative macroeconometric model of Smets and Wouters (2007), fluctuations are driven by seven exogenous stochastic disturbances: a shock to the growth rate of total factor productivity (TFP), an investment-specific technology shock, a risk-premium shock, a price-markup shock, a wage-markup shock, a government spending shock and a monetary policy shock.[3] Gertler, Sala and Trigari (2008) have shown that such a model fits the macro data as accurately as the Smets and Wouters (2007) model.

The model economy consists of a representative household, a continuum of intermediate goods-producing firms, a representative finished goods-producing firm, and monetary and fiscal authorities which set monetary and fiscal policy respectively.[4]

The representative household The representative household is a large family that consists of a continuum of individuals of measure one. Family members are either working or searching for a job.[5] Each period, family members

[2] See Pissarides (2000) for a textbook treatment of the search and matching model.

[3] Each shock follows an $AR(1)$ process. Appendix 5 reports some of the impulse responses.

[4] Appendix 1 offers a complete description of the model.

[5] The model abstracts from the labor force participation decision.

self-insure their consumption path against unemployment risk by pooling their income and let the head of the family optimally choose per capita consumption. The household owns capital and chooses the capital utilization rate which transforms physical capital into effective capital services used for production. Adjusting the utilization rate of capital away from its steady-state value is costly. The household rents the effective capital stock K_t to the intermediate-goods-producing firms at rate r_t^K.

Each period, N_t family members are employed by the intermediate goods-producing firms. $N_t \in (0,1)$ denotes aggregate employment. Each employee works a fixed amount of hours and earns the nominal wage W_t. The remaining $(1-N_t)$ family members actively search for jobs and receive unemployment benefits $(1-N_t)\, b_t$, financed through lump-sum taxes. $U_t \equiv 1-N_t$ denotes aggregate unemployment.

During period t, the representative household receives total nominal factor payments $r_t^K K_t + W_t N_t + (1-N_t)\, b_t$. In addition, the household also receives profits from the monopolistically competitive intermediate goods-producing firms. Each period the family uses these resources to purchase finished goods, for both consumption and investment purposes at price P_t. As in Christiano et al. (2005), the household faces adjustment costs in investment. An investment-specific technology shock affects the efficiency with which consumption goods are transformed into capital.

As in Smets and Wouters (2007), a risk-premium shock drives a wedge between the short-term nominal interest rate r_t controlled by the central bank and the return on assets held by the representative family. Introducing this disturbance is a short-cut to capture unmodelled fluctuations in the degree of financial frictions. These frictions generate an external finance premium. The risk-premium shock works as an aggregate demand shock and generates a positive comovement between consumption and investment. The family's utility function exhibits internal habit formation in consumption, so consumption responds gradually to shocks.

The representative intermediate goods-producing firm Intermediate goods substitute imperfectly for one another in the production function of the representative finished goods-producing firm. Hence, each intermediate goods-producing firm $i \in (0,1)$, sells its output in a monopolistically competitive market, setting the price of its own product $P_t(i)$. Each firm faces adjustment costs when setting its nominal price. These costs are measured in terms of the finished good and given by

$$\frac{\phi_P}{2}\left[\frac{P_t(i)}{\pi_{t-1}^{\varsigma}\pi^{1-\varsigma}P_{t-1}(i)} - 1\right]^2 Y_t, \tag{1}$$

where $\pi_t = P_t/P_{t-1}$ denotes the rate of inflation in period t. $\pi > 1$ denotes the steady-state rate of inflation and coincides with the central bank's target. The parameter $0 \leq \varsigma \leq 1$ governs the importance of backward-looking behavior in

price setting.

We focus on a symmetric equilibrium where all intermediate goods-producing firms behave in an identical fashion so that we can consider a representative intermediate goods-producing firm. This firm enters in period t with a stock of N_{t-1} employees. Before production starts, ρN_{t-1} old jobs are destroyed. The rate of job destruction ρ is constant. The workers who have lost their job start searching immediately and can possibly still be hired in period t. The law of motion of aggregate employment is

$$N_t = (1-\rho)\, N_{t-1} + m_t, \tag{2}$$

where m_t denotes the flow of matches, i.e. the new employees. Newly hired workers are immediately productive. Hence, the firm can adjust its output instantaneously through variations in the workforce. However, the firm faces convex hiring costs. This feature helps the model fit the persistence of unemployment that we observe in the data.

The matching process is described by the following aggregate "matching function"

$$m_t = \zeta S_t^{\sigma} V_t^{1-\sigma}, \tag{3}$$

where ζ is a scale parameter that captures the efficiency of the matching technology, S_t and V_t denote the pool of job seekers and the aggregate flow of vacancies respectively. The pool of job seekers S_t, is given by

$$S_t = 1 - (1-\rho)\, N_{t-1}. \tag{4}$$

Each period, the nominal wage W_t is determined through Nash bargaining between the representative intermediate goods-producing firm and each worker separately. The worker's bargaining power evolves exogenously according to an $AR(1)$ process. This is the so-called wage-markup shock. Finally, the firm also faces quadratic wage-adjustment costs.

The firm combines labour and capital to produce the intermediate good using Cobb-Douglas technology with constant returns to scale. The growth rate of TFP follows an AR(1) process.

The representative finished goods-producing firm The representative finished goods-producing firm bundles all the intermediate goods to produce Y_t units of the finished good. A shock affects the elasticity of substitution across differentiated inputs. This disturbance thus generates exogenous stochastic fluctuations in the market power of the intermediate goods suppliers and, in turn, in their desired markup of price over marginal cost. This shock is therefore labelled the price-markup shock (or the cost-push shock).

Fiscal policy The government budget is balanced every period. Public spending is an exogenous time-varying fraction of GDP and follows an AR(1)

process.

Monetary policy The central bank adjusts the short-term nominal gross interest rate by following a Taylor-type rule

$$\ln\left(\frac{r_t}{r}\right) = \rho_r \ln\left(\frac{r_{t-1}}{r}\right) + (1-\rho_r)\left[\rho_\pi \ln\left(\frac{\pi_t}{\pi}\right) + \rho_y \ln\left(\frac{Y_t/Y_{t-1}}{z}\right)\right] + \ln \epsilon_{mpt}. \quad (5)$$

r_t denotes the federal funds rate. π_t denotes inflation measured by the quarterly growth rate of the GDP deflator.[6] Output, denoted by Y_t, is measured by real GDP per-capita. z is the steady-state growth rate of output. Variables without a time subscript (r, π and z) are steady-state values. The degree of interest-rate smoothing ρ_r and the reaction coefficients ρ_π, ρ_y are all positive. The interest-rate rule prescribes that the federal funds rate be raised whenever inflation is above target or output growth is above steady state z. Importantly, such a rule is fully consistent with Taylor's (2007) main recommendation for the conduct of monetary policy:

> *"What are the monetary policy implications of this review? First, stay with the systematic, predictable, principles-based policy that has worked well for most of the Great Moderation period. That is, adjust the short term interest rate according to macroeconomic developments in inflation and real GDP and be wary of adjustments based on other factors."*

The residual in the Taylor rule is called the monetary policy shock. This random component accounts for the deviations between the actual path of the federal funds rate and the path prescribed by the interest-rate rule. Hence, the monetary policy shock reflects the information that is used by the central bank to set the interest rate but not considered by the simple rule. In accordance with the common belief that the deviations from the Taylor rule have sometimes been persistent, especially after 2001, this disturbance is assumed to follow an $AR(1)$ process

$$\ln \epsilon_{mpt} = \rho_{mp} \ln \epsilon_{mpt-1} + \varepsilon_{mpt}, \quad (6)$$

where $0 \leq \rho_{mp} < 1$ and $\varepsilon_{mpt} \sim i.i.d.N\left(0, \sigma^2_{mp}\right)$.

Model solution Real output, consumption, investment, capital and wages share the common stochastic trend induced by the unit root process for neutral technological progress. In the absence of shocks, the economy converges to a steady-state growth path in which all stationary variables are constant. I first rewrite the model in terms of stationary variables, and then log-linearize the transformed economy around its deterministic steady state. The approximate model can then be solved using standard methods.

[6] Taylor (1993) measures inflation using the GDP deflator.

2.2 Econometric strategy

Calibrated parameters Because of identification issues, I calibrate nine parameters prior to estimation. Table 1 reports the calibration. The quarterly depreciation rate δ is set equal to 0.025. The capital share of output α is calibrated at 0.33. The elasticity of substitution between intermediate goods θ is set equal to 6, impliying a steady-state markup of 20 percent as in Rotemberg and Woodford (1995). The vacancy-filling rate q is set equal to 0.70. This is just a normalization as q is not identified. The steady-state government spending/output ratio G/Y is set equal to 0.20. Finally, the steady-state values of the unemployment rate U, the rate of inflation π, the nominal interest rate r, and the growth rate of output z, are set equal to their respective sample averages over the period 1985:Q1 - 2001:Q4. Table 2 reports the parameters whose values are derived from the steady-state conditions. Appendix 4 describes the data set in detail.

Bayesian estimation I estimate the remaining 28 parameters using Bayesian techniques. The estimation uses quarterly U.S. data on seven key macro variables. The model thus includes as many shocks as observables.[7] The estimation period is 1985:Q1 - 2001:Q4. Hence, the sample starts after the Volcker's disinflation and excludes the period over which Taylor (2007) criticizes the Federal Reserve's conduct of monetary policy, i.e. from 2002 to 2006. The seven observable variables are: the growth rate of real output per capita, the growth rate of real consumption per capita, the growth rate of real investment per capita, the growth rate of real wages, the inflation rate, the short-term nominal interest rate and the unemployment rate.[8]

Prior distributions are standard. I use the Random-Walk Metropolis-Hasting algorithm to generate 500,000 draws from the posterior distribution. The algorithm is tuned to achieve an acceptance ratio between 20 and 30 percent. I discard the first 250,000 draws. I then select every tenth draw in order to reduce the serial correlation of the chain. The results presented in the paper are based on 1,500 draws from the posterior distribution. Tables 3 and 4 summarize the priors and the posteriors.

Estimates of the Taylor rule coefficients and monetary policy shocks Of particular interest for the purpose of this paper are the estimates of the Taylor-type rule's coefficients. This simple interest-rate rule is meant to accurately approximate the behavior of the Federal Reserve over the period 1985:Q1 - 2001:Q4

[7] Prior to estimation, I normalize two disturbances, the price-markup shock $\widehat{\theta}_t$ and the wage-markup shock $\widehat{\eta}_t$, so that they enter with a unit coefficient in the model's equations. Such procedure facilitates the identification of the shocks' standard deviations. See appendix 3 for details.

[8] In the model, labor adjusts exclusively along the extensive margin. Data on employment or unemployment seem therefore better suited than data on total hours to estimate the model. Moreover, in the U.S., the bulk of fluctuations in total hours stems from variations in the extensive margin. See Gertler et al. (2008).

which is used to estimate the model. The Taylor rule's coefficients are well identified and consistent with a broad literature. The posterior medians of the degree of interest rate smoothing, the response-coefficient to the deviations of inflation from target, and the response-coefficient to output growth are 0.74, 2.09 and 0.30 respectively. The posterior medians of the autocorrelation and standard deviation of the monetary policy shock are 0.33 and 0.001 respectively.

Once I have estimated the model over the period 1985:Q1 - 2001:Q4, I use it together with data up to 2009:Q4 on the seven observables to back out the time series of the shocks that have hit the U.S. economy between 1985:Q1 and 2009:Q4.[9] Figure 1 plots the monetary policy shocks, as well as the actual federal funds rate and the prescriptions from the estimated Taylor-type rule. In line with Taylor (2007), we see that a string of large expansionary monetary policy shocks occured between 2001 and 2006. The presence of interest-rate smoothing in the estimated Taylor-type rule allows the monetary policy shocks to cumulate over time, resulting in large discrepancies between the actual federal funds rate and the rule's prescriptions.

Figure 15 illustrates how the non-systematic component of monetary policy affects the economy by plotting the impulse responses of inflation (quarter-on-quarter, annualized), unemployment and the policy rate (annualized) to a one-standard-deviation monetary policy shock. Impulse responses are expressed in percentage points. Focusing on the solid lines (which refer to the baseline model) in figure 15, we see that such a shock causes on impact a 25 basis points increase in the federal funds rate, which raises unemployment immediately by 30 basis points and reduces inflation by roughly 40 basis points. Inflation, unemployment and the interest rate are all back to steady state within approximately two years. Figure 2 shows the variance of output growth conditional on each of the seven structural disturbances and decomposed frequency by frequency. It illustrates the fact that, over the estimation period, monetary policy shocks were not an important source of business cycle fluctuations.

3 Deviations from the Taylor rule between 2002 and 2006 and the Federal Reserve's mandate

Taylor (2007) criticizes the Federal Reserve for departing from its usual way of conducting monetary policy after 2001. In particular, Taylor (2007) argues that monetary policy was too loose between 2002 and 2006. On the other hand, Bernanke (2010) defends the monetary policy decisions made by the Federal Reserve during that period on the grounds that the risks of deflation and high unemployment were threatening the U.S. economy at that time. In this section, I address the following question: What would have happen to inflation and unemployment if the Federal Reserve had strictly followed the prescriptions of a

[9] The state-space representation of the estimated log-linearized DSGE model allows me to apply the Kalman smoother on data up to 2009:Q4 on the seven observables to estimate the model's unobserved variables (e.g. shocks) at each point in time.

Taylor-type rule over the period 2002:Q1-2006:Q4?

3.1 The effects of monetary policy shocks on inflation and unemployment from 2002 to 2006

I can now perform a counterfactual experiment where the estimated deviations from the Taylor rule are set equal to zero over the period 2002:Q1-2006:Q4. The sample period used to estimate the model ends in 2001:Q4. This ensures that the estimation is robust to a potential change in the Taylor rule's parameter governing the response of the policy rate to the inflation gap occuring around 2002-2003, as Taylor (2007) suggests. Figure 3 illustrates the implementation of the counterfactual scenario. Black lines represent actual data while green lines depict the counterfactual experiment. The pink shaded area corresponds to the period over which the monetary policy disturbances are turned off, from 2002:Q1 to 2006:Q4. Figure 4 offers a zoom into the period of the experiment and adds the 90 percent posterior intervals around the counterfactual paths of inflation and unemployment. We see that a strict implementation of the estimated Taylor rule prescriptions would have caused a large and significant drop in inflation, with a trough in 2004:Q1. From 2004 to 2005, counterfactual inflation would have been on average 150 basis points lower than historical inflation. The unemployment rate would have increased substantially until 2004:Q2 and would have been rougly 150 basis above its historical path for three years.

Figures 5 and 6 show the evolution over time of the posterior densities of counterfactual inflation and unemployment. In 2003:Q4 and 2004:Q1 the upper bound of the inflation distribution would have been less than 1 percent with probability one. Meanwhile, the probability of unemployment greater than 8 percent in 2004:Q2 would have been 92.6 percent. These results suggest that the deviations from the Taylor rule between 2002 and 2006 did help reducing the risk of deflation and high unemployment materially. This counterfactual evidence is consistent with the justification of the Federal Reserve's conduct of monetary policy between 2002 and 2006 advocated by Bernanke (2010). This result is also reminiscent of Greenspan's (2003) view that monetary policy is about the management of risks: Deviating from the Taylor rule's prescription enabled the Federal Reserve to take some insurance against the risks of deflation and high unemployment.

3.2 Which shocks caused the Federal Reserve to deviate from its usual way of setting the policy rate?

Figure 7 shows the historical decompositions of inflation and unemployment focusing on the period 2000:Q1 to 2009:Q4. We see that adverse risk-premium shocks (i.e. shocks increasing the spread between the effective interest rate faced by households and firms and the policy rate) were the dominant source of downward pressure on inflation between 2002 and 2005. This finding is in line with

Bernanke's (2010) account of the particularly uncertain macroeconomic environment at that time.

> *"The U.S. economy suffered a moderate recession between March and November 2001, largely traceable to the ending of the dot-com boom and the resulting sharp decline in stock prices. Geopolitical uncertainties associated with the terrorist attacks of September 11, 2001, and the invasion of Iraq in March 2003, as well as a series of corporate scandals in 2002, further clouded the economic situation in the early part of the decade."*

Similarly, Kohn (2007) stresses the importance of risk-premium shocks around 2003.

> *"Accounting scandals caused economic agents to lose confidence in published financial statements and in bond ratings. The result was higher uncertainty about the financial health of firms, and credit spreads widened substantially. Risk spreads on corporate bonds were elevated in this period."*

Figure 7 clearly shows the expansionary influence of monetary policy shocks from 2002 to 2006, pushing inflation up and unemployment down. The unusually large and persistent deviations from the Taylor rule over that period successfully offset the effects of the adverse risk-premium shocks.

Looking at the more recent period, the model attributes a sizeable portion of the rise in unemployment to wage-markup shocks (i.e. shocks to workers' bargaining power). These disturbances reflect the presence of downward wage rigidity: given the extreme slack in the labour market, the equilibrium level of wages is much lower than the actual level. The model accounts for this discrepancy through wage-markup shocks.

3.3 Did the Fed stabilize unemployment around the natural rate?

Figure 4 provides evidence that the discretionary component of the Federal Reserve's monetary policy was successful in reducing the risk of high unemployment between 2002 and 2006. However, the Federal Reserve's mandate underlines the aim of promoting maximum sustainable employment. It is therefore crucial to estimate the natural rate of unemployment and the unemployment gap to evaluate the Federal Reserve's monetary policy. To estimate the extent to which the deviations from the Taylor rule have contributed to stabilize unemployment around the natural level, I use the DSGE model to back out the path of the unobserved natural rate of unemployment.[10] Following Sala, Söderström and Trigari (2008),

[10] I use the state-space representation of the estimated DSGE model to apply the Kalman smoother on data on the seven key macro variables up to 2009:Q4 to back out the path of the unobserved natural rate of unemployment.

the natural rate of unemployment is defined as the unemployment rate under flexible prices and wages in the absence of price-markup and bargaining-power shocks (also referred to as wage-markup shocks).[11] Figure 8 compares the actual rate of unemployment with the natural rate. The natural rate is smoother and characterized by a much smaller variance. These estimates of the natural rate are in line with those obtained by Sala et al. (2008) and Gertler et al. (2008).

I construct the unemployment gap as the log-deviation of the actual unemployment rate from the natural rate. Similarly, the model-consistent output gap is the log-deviation of actual output from natural output. Figure 9 plots the output gap and the unemployment gap. These two variables are almost perfectly negatively correlated. The unemployment gap increases in each recession (marked by dark shaded areas), the turning points being located right before the recessions. Hence, the model-based unemployment gap provides a useful indicator of the business cycle. Finally, I simulate the counterfactual paths of the output gap and unemployment gap when monetary policy shocks are turned off between 2002:Q1 and 2006:Q4. In figure 10, we see that without the deviations from the Taylor rule, the unemployment gap and the output gap would have been significantly different from their unconditional estimates from 2003 to 2005. More precisely, the unemployment gap would have been largely positive instead of being close to zero. Figure 11 also illustrates the fact that stabilizing the unemployment gap is not equivalent to stabilizing the output gap. In particular, we see that the unconditional estimate of the output gap remained positive throughout the period while the unemployment gap turned positive for a brief period of time around 2003. Again, given the formulation of the Federal Reserve's mandate, this difference matters when it comes to evaluating monetary policy.

4 Sensitivity analysis

This section checks the robustness of the results to: (i) a change in the specification of the interest-rate rule and (ii) a change in the set of shocks hitting the model economy. I estimate the modified models using the same data and priors as for the baseline model. Tables 5 and 6 report the posterior distributions while table 7 compares the log marginal likelihood of the three alternative specifications. We see that the three models fit the data equally well. I then repeat the counterfactual experiment, simulating the path of inflation and unemployment in the absence of monetary policy shocks between 2002:Q1-2006:Q4. Finally I turn off monetary policy shocks over the whole sample period.

Case 1: Taylor rule responding to the output gap (instead of output growth) In the baseline model specification (henceforth referred to as Case 0),

[11] Price-markups shocks are inefficient because they generate variations in the degree of distortion due to monopolistic competition. Bargaining power shocks are inefficient because they induce dynamic deviations from the Hosios condition as they affect the magnitude of the congestion externalities. See Sala et al. (2008) and Sala, Söderström and Trigari (2010).

the measure of real activity in the Taylor rule was output growth. Because output growth is observable, such a specification is often encountered in the literature. However, the original rule proposed by Taylor (1993) was responding to a different measure of real activity which is not directly observable, namely the output gap. A systematic response to output growth instead of the output gap entails different recommendations for the appropriate level of the policy rate, especially during the early stages of a recovery when output growth is relatively fast while the output gap is still negative. Figure 11 illustrates this point. It is therefore interesting to investigate how the results from the baseline model are affected when the Taylor rule responds to the output gap instead of output growth. Figure 12 shows that the magnitude of the drop in counterfactual inflation when the Taylor rule responds to the output gap is somewhat subdued in comparison to Case 0. However, the counterfactual path of unemployment still exhibits a peak significantly above 7 percent in 2004:Q2.

Case 2: Intertemporal preference shocks instead of risk-premium shocks Another interesting dimension along which to assess the robustness of the main result from the baseline model is the set of shocks hitting the economy. Chari, Kehoe and McGrattan (2009) argue that risk-premium shocks may not be truly structural disturbances.[12] I therefore re-estimate a variant of the baseline model where the risk-premium shocks are replaced with more conventional intertemporal preference shocks, i.e. shocks to the household's discount factor.[13] These disturbances induce variations in the patience of the household, and therefore, in its willingness to postpone consumption over time to take advantage of temporarily attractive real interest rates. Appendix 5 compares the impulse responses of the risk-premium shock with the ones of a discount-factor shock. Figure 13 shows that the main result from the baseline specification is robust to this change.

Turning off monetary policy shocks over the whole sample period Column 1 of figure 14 shows the estimated Taylor rule's residuals in the three models. We see that large discrepancies between the effective federal funds rate and the prescriptions from the estimated Taylor rules have occured in several episodes, especially at the onset of recessions. Hence, turning off monetary policy shocks only over the sub-period 2002:Q1-2006:Q4 is somewhat arbitrary as this short period excludes large expansionary shocks in 2001 for example. Figure 14 shows the counterfactual paths of inflation and unemployment in the three models when the deviations from the estimated Taylor rules are set equal to zero over the whole sample period, from 1985:Q1 to 2009:Q4.

Without monetary policy shocks, the magnitude of fluctuations in both inflation and unemployment increases substantially. These results suggest that the discretionary component of the Federal Reserve's monetary policy over the last

[12] See also De Graeve, Emiris and Wouters (2009) for a discussion of risk-premium shocks.

[13] See Primiceri, Schaumburg and Tambalotti (2006).

decade contributed materially to improving macroeconomic stability. Moreover, once we turn off the large expansionary monetary shocks that occured in 2001, the lower bound of the 90 percent posterior interval of counterfactual inflation approaches to 0 very closely around mid-2002, suggesting a heightened risk of deflation at that time.

5 Concluding remarks

This paper contributes to the ongoing debate regarding the justification of the Federal Reserve's actions in the last decade by investigating what would have been the consequences for inflation and unemployment of strictly following the prescriptions from a Taylor-type rule between 2002 and 2006. To do so, the paper estimates an empirical DSGE model with nominal rigidities and labor market frictions and performs a counterfactual experiment where the estimated deviations from the Taylor rule are set equal to zero from 2002 to 2006.

The paper finds that such a policy would have generated a sizeable increase in unemployment and resulted in an undesirably low rate of inflation. Around mid-2004, when the counterfactual deviates the most from the actual series, the model indicates that the probability of an unemployment rate greater than 8 percent would have been as high as 80 percent, while the probability of an inflation rate above 1 percent would have been close to zero. This quantitative evidence suggests that the expansionary stance of monetary policy in the first half of the decade was appropriate and consistent with the Federal Reserve's dual mandate. These results thereby validate Bernanke's (2010) testimony.

These findings also remind us that simple rules have limitations. In 2003-2004, the Taylor rule was ignoring both the proximity of the zero lower bound and the costs associated with the risk of sliding into a Japanese-style liquidity trap. For these reasons, and in accordance with its official mandate, the Federal Reserve decided to deviate from the Taylor rule in order to reduce the risks of a deflationary spiral and high unemployment.[14] As Kohn (2007) points out: *"It's not that simple to use simple rules!"*

Finally, it should be emphasized that this paper focuses on the period up to the end of 2006, and does not seek to provide a structural analysis of the 2007-09 financial crisis.[15] The introduction into the model of a housing sector and financial frictions, along the lines of Iacoviello and Neri (2010), would improve the congruence of the model to the recent experience. Such an extension would allow us to estimate the "sacrifice ratio", i.e. the size of the increase in unemployment required to reduce house prices by a given amount, and thereby to understand the extent to which the federal funds rate is a blunt instrument to pop house price bubbles.[16] We leave these tasks for future research.

[14] Greenspan (2003) elaborates on the importance of risk management in the conduct of monetary policy.

[15] Ireland (2010) provides a structural analysis of the Great Recession using the standard New Keynesian model.

[16] Del Negro and Otrok (2007) offer some empirical evidence on the effects of monetary policy

Appendix 1: Complete description of the model

The economy consists of a representative household, a representative finished goods-producing firm, a continuum of intermediate goods-producing firms indexed by $i \in [0,1]$, and a central bank and a government that set monetary and fiscal policy respectively. Firms adjust labour exclusively through job creation and face convex hiring costs. The model follows the model in Gertler et al. (2008) quite closely except for a few deviations. First, GST features a preference shock to the representative household's discount factor. Instead, my model features a risk-premium shock as in Smets and Wouters (2007). Second, GST use sticky prices à la Calvo while I opt for quadratic price adjustment costs à la Rotemberg. Third, I introduce nominal wage stickiness as in Arsenau and Chugh (2008) by assuming that firms bear the costs of adjusting nominal wages.

The representative household There is a continuum of identical households of mass one. Each household is a large family, made up of a continuum of individuals of measure one. Family members are either working or searching for a job.[17] Following Merz (1995), I assume that family members pool their income before allowing the head of the family to optimally choose per capita consumption.

The representative family enters each period $t = 0, 1, 2, ...$, with B_{t-1} bonds and $\overline{K}_{t-1}$ units of physical capital. At the beginning of each period, bonds mature, providing B_{t-1} units of money. The representative family uses some of this money to purchase B_t new bonds at nominal cost B_t/r_t, where r_t denotes the gross nominal interest rate between period t and $t+1$.

The representative household owns capital and chooses the capital utilization rate, u_t, which transforms physical capital into effective capital according to

$$K_t = u_t \overline{K}_{t-1}. \tag{7}$$

The household rents $K_t(i)$ units of effective capital to intermediate-goods-producing firm $i \in [0,1]$ at the nominal rate r_t^K. The household's choice of $K_t(i)$ must satisfy

$$K_t = \int_0^1 K_t(i)\, di. \tag{8}$$

The cost of capital utilization is $a(u_t)$ per unit of physical capital. I assume the following functional form for the function $a(.)$,

$$a(u_t) = \phi_{u1}(u_t - 1) + \frac{\phi_{u2}}{2}(u_t - 1)^2, \tag{9}$$

and that $u_t = 1$ in steady state.

on house prices in the U.S. states using a factor model.

[17] The model abstracts from the labour force participation decision.

Each period, $N_t(i)$ family members are employed at intermediate goods-producing firm $i \in [0,1]$. Each worker employed at firm i works a fixed amount of hours and earns the nominal wage $W_t(i)$. N_t denotes aggregate employment in period t and is given by

$$N_t = \int_0^1 N_t(i)\, di. \tag{10}$$

The remaining $(1 - N_t)$ family members are unemployed and each receives nominal unemployment benefits b_t, financed through lump-sum taxes.

During period t, the representative household receives total nominal factor payments $r_t^K K_t + W_t N_t + (1 - N_t) b_t$. In addition, the household also receives nominal profits $D_t(i)$ from each firm $i \in [0,1]$, for a total of

$$D_t = \int_0^1 D_t(i)\, di. \tag{11}$$

In each period $t = 0, 1, 2, ...$,the family uses these resources to purchase finished goods, for both consumption and investment purposes, from the representative finished goods-producing firm at the nominal price P_t. The law of motion of physical capital is

$$\overline{K}_t \leq (1 - \delta)\, \overline{K}_{t-1} + \mu_t \left[1 - S\left(\frac{I_t}{I_{t-1}}\right)\right] I_t, \tag{12}$$

where δ denotes the depreciation rate. The function S captures the presence of adjustment costs in investment, as in Christiano et al. (2005). I assume the following quadratic functional form for the function $S(.)$,

$$S\left(\frac{I_t}{I_{t-1}}\right) = \frac{\phi_I}{2}\left(\frac{I_t}{I_{t-1}} - g_I\right)^2, \tag{13}$$

where g_I is the steady-state growth rate of investment. Hence, along the balanced growth path, $S(g_I) = S'(g_I) = 0$ and $S''(g_I) = \phi_I > 0$. μ_t is an investment-specific technology shock affecting the efficiency with which consumption goods are transformed into capital. The investment-specific shock follows the exogenous stationary autoregressive process

$$\ln(\mu_t) = \rho_\mu \ln\left(\mu_{t-1}\right) + \varepsilon_{\mu t}, \tag{14}$$

where $\varepsilon_{\mu t}$ is $i.i.d.N\left(0, \sigma_\mu^2\right)$.

The family's budget constraint is given by

$$\begin{aligned} P_t C_t + P_t I_t + \frac{B_t}{\epsilon_{bt} r_t} \quad \leq \quad & B_{t-1} + W_t N_t + (1 - N_t)\, b_t + r_t^K u_t \overline{K}_{t-1} \\ & - P_t a(u_t)\, \overline{K}_{t-1} - T_t + D_t \end{aligned} \tag{15}$$

for all $t = 0, 1, 2, ...$ Let Λ_t denote the Lagrange multiplier on the family's budget constraint (15).

As in Smets and Wouters (2007), the shock ϵ_{bt} drives a wedge between the central bank's instrument rate r_t and the return on assets held by the representative family. As noted by De Graeve et al. (2009), this disturbance works as an aggregate demand shock and generates a positive comovement between consumption and investment. The risk-premium shock ϵ_{bt} follows the autoregressive process

$$\ln \epsilon_{bt} = \rho_b \ln \epsilon_{bt-1} + \varepsilon_{bt}, \tag{16}$$

where $0 < \rho_b < 1$, and ε_{bt} is $i.i.d.N\left(0, \sigma_b^2\right)$.

The family's lifetime utility is described by

$$E_t \sum_{s=0}^{\infty} \beta^s \ln \left(C_{t+s} - hC_{t+s-1}\right) \tag{17}$$

where $0 < \beta < 1$. When $h > 0$, the model allows for habit formation in consumption and consumption responds gradually to shocks.

The head of the family chooses C_t, B_t, u_t, I_t, and $\overline{K}_t$ for each $t = 0, 1, 2, ...$ to maximize the expected lifetime utility (17) subject to the constraints (12) and (15).

The representative intermediate goods-producing firm Each intermediate goods-producing firm $i \in [0, 1]$ enters in period t with a stock of $N_{t-1}(i)$ employees carried from the previous period. At the beginning of period t, before production starts, $\rho N_{t-1}(i)$ olds jobs are destroyed, where ρ is the job destruction rate.[18] The pool of workers ρN_{t-1} who have lost their job at the beginning of period t start searching immediately and can possibly be hired in period t. $N_t(i)$ denotes the pool of employees taking part to production at firm i in period t. The law of motion of the stock of productive workers at firm (i) is

$$N_t(i) = (1 - \rho) N_{t-1}(i) + m_t(i). \tag{18}$$

$m_t(i)$ denotes the flow of new employees hired by firm i in period t, and is given by

$$m_t(i) = q_t V_t(i), \tag{19}$$

where $V_t(i)$ denotes vacancies posted by firm i in period t and q_t is the aggregate probability of filling a vacancy in period t. Workers hired in period t take part to period t production. Employment is therefore an *instantaneous* margin. However, each period some vacancies and job seekers remain unmatched. As a consequence,

[18] The rate of match dissolution is exogenous. This is consistent with Hall (2005) and Shimer's (2005) finding that recent business cycle fluctuations in the U.S. labor market mostly come from the job creation margin.

a firm-worker pair enjoys a joint surplus that motivates the existence of a long-run relationship between the two parties.

Aggregate employment $N_t = \int_0^1 N_t(i)\,di$ evolves over time according to

$$N_t = (1-\rho)\,N_{t-1} + m_t, \tag{20}$$

where $m_t = \int_0^1 m_t(i)\,di$ denotes aggregate matches in period t. Similarly, the aggregate vacancies is equal to $V_t = \int_0^1 V_t(i)\,di$. The pool of job seekers in period t, denoted by S_t, is given by

$$S_t = 1 - (1-\rho)\,N_{t-1}. \tag{21}$$

The matching process is described by the following aggregate CRS function

$$m_t = \zeta S_t^{\sigma} V_t^{1-\sigma}, \tag{22}$$

where ζ is a scale parameter that captures the efficiency of the matching technology. The probability q_t to fill a vacancy in period t is given by

$$q_t = \frac{m_t}{V_t}. \tag{23}$$

The probability, s_t, for a job seeker to find a job is

$$s_t = \frac{m_t}{S_t}. \tag{24}$$

Finally aggregate unemployment is defined by

$$U_t \equiv 1 - N_t. \tag{25}$$

During each period $t = 0, 1, 2, ...,$ the representative intermediate goods-producing firm combines $N_t(i)$ homogeneous employees with $K_t(i)$ units of efficient capital to produce $Y_t(i)$ units of intermediate good i according to the constant-returns-to-scale technology described by

$$Y_t(i) = A_t^{1-\alpha} K_t(i)^{\alpha} N_t(i)^{1-\alpha}. \tag{26}$$

A_t is an aggregate labor-augmenting technology shock whose growth rate, $z_t \equiv A_t/A_{t-1}$, follows the exogenous stationary stochastic process

$$\ln(z_t) = (1-\rho_z)\ln(z) + \rho_z \ln(z_{t-1}) + \varepsilon_{zt}, \tag{27}$$

where $z > 1$ denotes the steady-state growth rate of the economy and ε_{zt} is $i.i.d.N(0, \sigma_z^2)$.

Following Yashiv (2006), intermediate goods-producing firms face convex hir-

ing costs, measured in terms of the finished good and given by

$$\frac{\phi_N}{2}\left[\frac{q_t V_t(i)}{N_t(i)}\right]^2 Y_t, \tag{28}$$

where ϕ_N governs the magnitude of these costs.

Intermediate goods substitute imperfectly for one another in the production function of the representative finished goods-producing firm. Hence, each intermediate goods-producing firm $i \in [0,1]$ sells its output $Y_t(i)$ in a monopolistically competitive market, setting $P_t(i)$, the price of its own product, with the commitment of satisfying the demand for good i at that price. Firms take the nominal wage as given when maximizing the discounted value of expected future profits.

Each intermediate goods-producing firm faces costs of adjusting its nominal price between periods, measured in terms of the finished good and given by

$$\frac{\phi_P}{2}\left[\frac{P_t(i)}{\pi_{t-1}^{\varsigma}\pi^{1-\varsigma}P_{t-1}(i)} - 1\right]^2 Y_t. \tag{29}$$

ϕ_P governs the magnitude of the price adjustment cost. $\pi_t = \frac{P_t}{P_{t-1}}$ denotes the gross rate of inflation in period t. $\pi > 1$ denotes the steady-state gross rate of inflation and coincides with the central bank's target. The parameter $0 \leq \varsigma \leq 1$ governs the importance of backward-looking behavior in price setting.[19]

Each intermediate goods-producing firm faces quadratic wage-adjustment costs which are proportional to the size of its workforce and measured in terms of the finished good

$$\frac{\phi_W}{2}\left(\frac{W_t(i)}{z\pi_{t-1}^{\varrho}\pi^{1-\varrho}W_{t-1}(i)} - 1\right)^2 N_t(i)\, Y_t, \tag{30}$$

where ϕ_W governs the magnitude of the wage adjustment cost. The parameter $0 \leq \varrho \leq 1$ governs the importance of backward-looking behavior in wage setting.

Adjustment costs on the hiring rate, price and wage changes make the intermediate goods-producing firm's problem dynamic. It chooses $K_t(i)$, $N_t(i)$, $V_t(i)$ and $Y_t(i)$ and $P_t(i)$ for all $t = 0, 1, 2, ...$to maximize its total market value, given by

$$E_t \sum_{s=0}^{\infty} \beta^s \Lambda_{t+s}\left[\frac{D_{t+s}(i)}{P_{t+s}}\right] \tag{31}$$

where $\beta^t \Lambda_t / P_t$ measures the marginal utility to the representative household of

[19] See Ireland (2007).

an additional dollar of profits during period t and where

$$\begin{aligned} D_t(i) &= P_t(i) Y_t(i) - W_t(i) N_t(i) - r_t^K K_t(i) - \frac{\phi_N}{2} \left(\frac{q_t V_t(i)}{N_t(i)} \right)^2 P_t Y_t \\ &\quad - \frac{\phi_P}{2} \left(\frac{P_t(i)}{\pi_{t-1}^{\varsigma} \pi^{1-\varsigma} P_{t-1}(i)} - 1 \right)^2 P_t Y_t \\ &\quad - \frac{\phi_W}{2} \left(\frac{W_t(i)}{z \pi_{t-1}^{\varrho} \pi^{1-\varrho} W_{t-1}(i)} - 1 \right)^2 N_t(i) P_t Y_t, \end{aligned} \tag{32}$$

subject to the constraints

$$Y_t(i) = \left[\frac{P_t(i)}{P_t} \right]^{-\theta_t} Y_t, \tag{33}$$

$$Y_t(i) \leq K_t(i)^{\alpha} \left[A_t N_t(i) \right]^{1-\alpha}, \tag{34}$$

$$N_t(i) = \chi N_{t-1}(i) + q_t V_t(i), \tag{35}$$

where $\chi \equiv 1 - \rho$ is the job survival rate. Let $\Xi_t(i)$ and $\Psi_t(i)$ denote the Lagrange multipliers on constraints (33) and (35) respectively. The multiplier $\Psi_t(i)$ measures the value to firm i, expressed in utils, of an additional job in period t. The multiplier $\Xi_t(i)$ measures the value to firm i, expressed in utils, of an additional unit of output. Finally, let $\xi_t(i) \equiv \Xi_t(i)/\Lambda_t$ denote firm i's real marginal cost in period t.

The representative finished goods-producing firm During each period $t = 0, 1, 2, ...$, the representative finished goods-producing firm uses $Y_t(i)$ units of each intermediate good $i \in [0, 1]$, purchased at the nominal price $P_t(i)$, to manufacture Y_t units of the finished good according to the constant-returns-to-scale technology described by

$$\left[\int_0^1 Y_t(i)^{(\theta_t - 1)/\theta_t} \, di \right]^{\theta_t/(\theta_t - 1)} \geq Y_t, \tag{36}$$

where θ_t translates into a random shock to the price markup over marginal cost. This markup shock follows the autoregressive process

$$\ln(\theta_t) = (1 - \rho_\theta) \ln(\theta) + \rho_\theta \ln(\theta_{t-1}) + \varepsilon_{\theta t}, \tag{37}$$

where $0 < \rho_\theta < 1$, $\theta > 1$, and $\varepsilon_{\theta t}$ is $i.i.d.N(0, \sigma_\theta^2)$.

Intermediate good i sells at the nominal price $P_t(i)$, while the finished good sells at the nominal price P_t. Given these prices, the finished goods-producing firm chooses Y_t and $Y_t(i)$ for all $i \in [0, 1]$ to maximize its profits

$$P_t Y_t - \int_0^1 P_t(i) Y_t(i) \, di, \tag{38}$$

subject to the constraint (12) for each $t = 0, 1, 2, ...$ The first-order conditions for this problem are (12) with equality and

$$Y_t(i) = \left[\frac{P_t(i)}{P_t}\right]^{-\theta_t} Y_t \tag{39}$$

for all $i \in [0, 1]$ and $t = 0, 1, 2, ...$

Competition in the market for the finished good drives the finished goods-producing firm's profits to zero in equilibrium. This zero-profit condition determines P_t as

$$P_t = \left[\int_0^1 P_t(i)^{1-\theta_t} di\right]^{1/(1-\theta_t)} \tag{40}$$

for all $t = 0, 1, 2, ...$

Wage setting Unemployment benefits b_t are proportional to the value of the nominal wage along the balanced growth path, $W_{ss,t}$,

$$b_t = \tau W_{ss,t}, \tag{41}$$

where τ is the replacement ratio. The fact that hiring costs and unemployment benefits both share the common stochastic trend ensures that the unemployment rate is stationary.

Jobs and workers at a given intermediate goods-producing firm are homogeneous. $W_t(i)$ denotes the nominal wage paid for any job at firm i in period t. Each period t, the representative intermediate goods-producing firm bargains with each of its employees separately over $W_t(i)$. The nominal wage is determined through bilateral Nash bargaining,

$$W_t(i) = \arg\max \left[S_t(i)^{\eta_t} J_t(i)^{1-\eta_t}\right]. \tag{42}$$

$S_t(i)$ denotes the surplus of the representative worker at firm i while $J_t(i)$ is the surplus of firm i. Both $S_t(i)$ and $J_t(i)$ are expressed in real terms. η_t denotes the worker's bargaining power which evolves exogenously according to

$$\ln \eta_t = \left(1 - \rho_\eta\right) \ln \eta + \rho_\eta \ln \eta_{t-1} + \varepsilon_{\eta t}, \tag{43}$$

where $0 < \eta < 1$ and $\varepsilon_{\eta t}$ is $i.i.d.N\left(0, \sigma_\eta^2\right)$.

The worker's surplus in terms of final consumption goods is given by

$$S_t(i) = \frac{W_t(i)}{P_t} - \frac{b_t}{P_t} + \beta E_t\left[\chi\left(1 - s_{t+1}\right)\right]\left(\frac{\Lambda_{t+1}}{\Lambda_t}\right) S_{t+1}(i). \tag{44}$$

The surplus of firm i expressed in real terms is given by

$$\begin{aligned} J_t(i) &= \xi_t(i)(1-\alpha)\frac{Y_t(i)}{N_t(i)} - \frac{W_t(i)}{P_t} + \frac{\phi_N Y_t x_t(i)^2}{N_t(i)} \\ &\quad -\frac{\phi_W}{2}\left(\frac{W_t(i)}{z\pi_{t-1}^{\varrho}\pi^{1-\varrho}W_{t-1}(i)} - 1\right)^2 Y_t + \beta\chi E_t\left[\frac{\Lambda_{t+1}}{\Lambda_t}J_{t+1}(i)\right]. \end{aligned} \tag{45}$$

Nash bargaining requires that the equilibrium nominal wage $W_t(i)$ satisfies the following first-order condition

$$\eta_t J_t(i)\frac{\partial S_t(i)}{\partial W_t(i)} = -(1-\eta_t)S_t(i)\frac{\partial J_t(i)}{\partial W_t(i)}, \tag{46}$$

where

$$\frac{\partial S_t(i)}{\partial W_t(i)} = \frac{1}{P_t}, \tag{47}$$

$$-\frac{\partial J_t(i)}{\partial W_t(i)} = \left\{ \begin{array}{c} \frac{1}{P_t} + \phi_W Y_t\left(\frac{1}{z\pi_{t-1}^{\varrho}\pi^{1-\varrho}W_{t-1}(i)}\right)\left(\frac{W_t(i)}{z\pi_{t-1}^{\varrho}\pi^{1-\varrho}W_{t-1}(i)} - 1\right) \\ -\beta\chi\phi_W E_t\left[\frac{\Lambda_{t+1}Y_{t+1}}{\Lambda_t W_t(i)}\left(\frac{W_{t+1}(i)}{z\pi_{t-1}^{\varrho}\pi^{1-\varrho}W_{t-1}(i)}\right)\left(\frac{W_{t+1}(i)}{z\pi_{t-1}^{\varrho}\pi^{1-\varrho}W_{t-1}(i)} - 1\right)\right] \end{array} \right\} \tag{48}$$

When $\phi_W = 0$, adjusting nominal wages is costless for the firm. In that case, the effects of a marginal increase in the nominal wage on the worker's surplus and on the firm's surplus have the same magnitude (with opposite signs):

$$\text{if } \phi_W = 0, \text{ then } \frac{\partial S_t(i)}{\partial W_t(i)} = -\frac{\partial J_t(i)}{\partial W_t(i)} = \frac{1}{P_t}. \tag{49}$$

In the absence of nominal wage-adjustment costs, Nash bargaining over the nominal wage implies the usual first-order condition

$$S_t(i) = \left(\frac{\eta_t}{1-\eta_t}\right)J_t(i). \tag{50}$$

Thus, as pointed out by Arsenau and Chugh (2008), Nash bargaining over the nominal wage when there are no nominal wage adjustment costs is equivalent to Nash bargaining over the real wage. The presence of nominal wage-adjustment costs (borne by the firm) affects the *effective* bargaining powers of the firm and the worker respectively. In the presence of nominal wage adjustment costs, the first-order condition from Nash bargaining is given by

$$\begin{aligned} S_t(i) &= \frac{\eta_t}{(1-\eta_t)}\frac{\left[\partial S_t(i)/\partial W_t(i)\right]}{\left[-\partial J_t(i)/\partial W_t(i)\right]}J_t(i), \\ S_t(i) &= \mathfrak{Q}_{it}J_t(i), \end{aligned} \tag{51}$$

where we have introduced the notation

$$\mathrm{I\!\Omega}_{it} \equiv \frac{\left(\frac{\eta_t}{1-\eta_t}\right)\left(\frac{\partial S_t(i)}{\partial W_t(i)}\right)}{\left(-\frac{\partial J_t(i)}{\partial W_t(i)}\right)}.$$

Finally, the equation governing the dynamics of the real wage at firm i is given by

$$\begin{aligned}\frac{W_t(i)}{P_t} &= \left(\frac{\mathrm{I\!\Omega}_{it}}{1+\mathrm{I\!\Omega}_{it}}\right)\left[\begin{array}{c}\xi_t(i)(1-\alpha)\frac{Y_t(i)}{N_t(i)}+\frac{\phi_N Y_t x_t(i)^2}{N_t(i)}\\ -\frac{\phi_W}{2}\left(\frac{W_t(i)}{z\pi_{t-1}^{\varrho}\pi^{1-\varrho}W_{t-1}(i)}-1\right)^2 Y_t\\ +\beta\chi E_t\left(\frac{\Lambda_{t+1}}{\Lambda_t}\right)\left(\frac{\phi_N Y_{t+1}x_{t+1}(i)}{N_{t+1}(i)}\right)\end{array}\right] \\ &+\frac{1}{(1+\mathrm{I\!\Omega}_{it})}\left[\frac{b_t}{P_t}-\beta\chi E_t\mathrm{I\!\Omega}_{it+1}(1-s_{t+1})\left(\frac{\Lambda_{t+1}}{\Lambda_t}\right)\left(\frac{\phi_N Y_{t+1}x_{t+1}(i)}{N_{t+1}(i)}\right)\right].\end{aligned} \tag{52}$$

Monetary and fiscal authorities The central bank adjusts the short-term nominal gross interest rate r_t by following a Taylor-type rule

$$\ln\left(\frac{r_t}{r}\right) = \rho_r\ln\left(\frac{r_{t-1}}{r}\right)+(1-\rho_r)\left[\rho_\pi\ln\left(\frac{\pi_t}{\pi}\right)+\rho_y\ln\left(\frac{Y_t/Y_{t-1}}{z}\right)\right]+\ln\epsilon_{mpt}, \tag{53}$$

$$\ln\epsilon_{mpt} = \rho_{mp}\ln\epsilon_{mpt-1}+\varepsilon_{mpt}. \tag{54}$$

where $\pi_t = P_t/P_{t-1}$. The monetary policy shock ϵ_{mpt} follows an AR(1) process with $0 \leq \rho_{mp} < 1$ and $\varepsilon_{mpt} \sim i.i.d.N\left(0,\sigma_{mp}^2\right)$. The degree of interest-rate smoothing ρ_r and the reaction coefficients ρ_π, ρ_y are all positive.

The government budget constraint is of the form

$$P_tG_t+(1-N_t)b_t = \left(\frac{B_t}{r_t^B}-B_{t-1}\right)+T_t, \tag{55}$$

where T_t denotes total nominal lump-sum transfers. Public spending is an exogenous time-varying fraction of GDP

$$G_t = \left(1-\frac{1}{\epsilon_{gt}}\right)Y_t, \tag{56}$$

where ϵ_{gt} evolves according to

$$\ln\epsilon_{gt} = \left(1-\rho_g\right)\ln\epsilon_g+\rho_g\ln\epsilon_{gt-1}+\varepsilon_{gt}, \tag{57}$$

with $\varepsilon_{gt} \sim i.i.d.N\left(0,\sigma_g^2\right)$.

Symmetric equilibrium In a symmetric equilibrium, all intermediate goods-producing firms make identical decisions, so that $Y_t(i) = Y_t$, $P_t(i) = P_t$, $N_t(i) = N_t$, $V_t(i) = V_t$, $K_t(i) = K_t$ for all $i \in [0,1]$ and $t = 0,1,2,.....$ Moreover, workers are homogeneous and all workers at a given firm i receive the same nominal wage

$W_t(i)$, so that $W_t(i) = W_t$ for all $i \in [0,1]$ and $t = 0, 1, 2, ...$ The aggregate resource constraint is obtained by aggregating the household budget constraint over all intermediate sectors $i \in [0,1]$,

$$\left[\begin{array}{c} \frac{1}{\epsilon_{gt}} - \frac{\phi_N}{2} x_t^2 - \frac{\phi_P}{2} \left(\frac{\pi_t}{\pi_{t-1}^{\varsigma} \pi^{1-\varsigma}} - 1 \right)^2 \\ -\frac{\phi_W}{2} \left(\frac{W_t}{z \pi_{t-1}^{\varrho} \pi^{1-\varrho} W_{t-1}} - 1 \right)^2 N_t \end{array} \right] Y_t = C_t + I_t + a(u_t) \overline{K}_{t-1}. \tag{58}$$

Model solution Real output, consumption, investment, capital and wages share the stochastic trend induced by the unit root process for neutral technological progress. In the absence of shocks, the economy converges to a steady-state growth path in which all stationary variables are constant. I first rewrite the model in terms of stationary variables, and then loglinearize the transformed economy around its deterministic steady state. The approximate model can then be solved using standard methods.

Appendix 2: The log-linearized model

1. y_t

$$\left(\frac{1}{\epsilon_g}-\frac{\phi_N}{2}x^2\right)\widehat{y}_t=\frac{c}{y}\widehat{c}_t+\frac{i}{y}\widehat{i}_t+\left(\phi_{u1}\frac{k}{y}\right)\widehat{u}_t+\left(\phi_N x^2\right)\widehat{x}_t+\frac{1}{\epsilon_g}\widehat{\epsilon}_{gt}$$

2. k_t

$$\widehat{z}_t+\widehat{k}_t=\widehat{u}_t+\widehat{\overline{k}}_{t-1}$$

3. $\overline{k}_t$

$$z\widehat{\overline{k}}_t=(1-\delta)\left(\widehat{\overline{k}}_{t-1}-\widehat{z}_t\right)+(z-1+\delta)\left(\widehat{\mu}_t+\widehat{i}_t\right)$$

4. λ_t

$$\widehat{\lambda}_t=\widehat{\epsilon}_{bt}+\widehat{r}_t^B+\widehat{\lambda}_{t+1}-\widehat{\pi}_{t+1}-\widehat{z}_{t+1}$$

5. c_t

$$\begin{aligned}\widehat{\lambda}_t &= \frac{\beta hz}{(z-\beta h)(z-h)}\widehat{c}_{t+1}-\frac{z^2+\beta h^2}{(z-\beta h)(z-h)}\widehat{c}_t+\frac{hz}{(z-\beta h)(z-h)}\widehat{c}_{t-1}\\ &\quad+\frac{\beta hz}{(z-\beta h)(z-h)}\widehat{z}_{t+1}-\frac{hz}{(z-\beta h)(z-h)}\widehat{z}_t\end{aligned}$$

6. $\widetilde{r}_t^K$

$$\widehat{\widetilde{r}}_t^K=\left(\frac{\phi_{u2}}{\phi_{u1}}\right)\widehat{u}_t$$

7. i_t

$$\widehat{\upsilon}_t=\left(\phi_I z^2\right)\left(\widehat{i}_t-\widehat{i}_{t-1}+\widehat{z}_t\right)-\widehat{\mu}_t-\left(\beta\phi_I z^2\right)\left(\widehat{i}_{t+1}-\widehat{i}_t+\widehat{z}_{t+1}\right)$$

8. υ_t

$$\widehat{\upsilon}_t=\widehat{\lambda}_{t+1}-\widehat{\lambda}_t-\widehat{z}_{t+1}+\left[(1-\delta)\beta z^{-1}\right]\widehat{\upsilon}_{t+1}+\left(\beta z^{-1}\widetilde{r}^K\right)\widehat{\widetilde{r}}_{t+1}^K$$

9. u_t

$$\widehat{y}_t=\alpha\widehat{k}_t+(1-\alpha)\widehat{N}_t$$

10. ξ_t

$$\widehat{\widetilde{r}}_t^K = \widehat{\xi}_t + \widehat{y}_t - \widehat{k}_t$$

11. N_t

$$\widehat{N}_t = \chi \widehat{N}_{t-1} + x\left(\widehat{q}_t + \widehat{V}_t\right)$$

12. S_t

$$\widehat{S}_t = -\left(\frac{\chi N}{S}\right)\widehat{N}_{t-1}$$

13. U_t

$$\widehat{U}_t = -\frac{N}{U}\widehat{N}_t$$

14. q_t

$$\widehat{q}_t = -\sigma\left(\widehat{V}_t - \widehat{S}_t\right)$$

15. s_t

$$\widehat{s}_t = (1-\sigma)\left(\widehat{V}_t - \widehat{S}_t\right)$$

16. V_t

$$\widehat{x}_t \equiv \widehat{q}_t + \widehat{V}_t - \widehat{N}_t$$

17. x_t

$$\begin{aligned}\widehat{x}_t &= \left[\frac{(1-\alpha)\,\xi}{\phi_N x\,(1-2x)}\right]\widehat{\xi}_t - \left[\frac{1}{\phi_N x\,(1-2x)}\frac{\widetilde{w}N}{y}\right]\left(\widehat{\widetilde{w}}_t + \widehat{N}_t - \widehat{y}_t\right) \\ &\quad + \left[\frac{\beta\chi}{1-2x}\right]\left(\widehat{\lambda}_{t+1} - \widehat{\lambda}_t + \widehat{N}_t - \widehat{N}_{t+1} + \widehat{y}_{t+1} - \widehat{y}_t + \widehat{x}_{t+1}\right)\end{aligned}$$

18. π_t

$$\widehat{\pi}_t = \left(\frac{\varsigma}{1+\beta\varsigma}\right)\widehat{\pi}_{t-1} + \left(\frac{\beta}{1+\beta\varsigma}\right)\widehat{\pi}_{t+1} + \left(\frac{1}{1+\beta\varsigma}\right)\left(\frac{\theta-1}{\phi_P}\right)\widehat{\xi}_t - \left(\frac{1}{1+\beta\varsigma}\right)\left(\frac{1}{\phi_P}\right)\widehat{\theta}_t$$

19. $\widetilde{\mathbf{b}}_t = \widetilde{\mathbf{b}} = \tau \widetilde{w}$

$$\widehat{\widetilde{\mathbf{b}}}_t = 0$$

20. $\widetilde{w}_t$

$$\begin{aligned}\left(\frac{1}{\eta}\frac{\widetilde{w}N}{y}\right)\widehat{\widetilde{w}}_t &= \left[(1-\alpha)\,\xi\right]\widehat{\xi}_t + \left[(1-\alpha)\,\xi + \phi_N x^2\right]\left(\widehat{y}_t - \widehat{N}_t\right) + \left(2\phi_N x^2\right)\widehat{x}_t \\ &\quad - \left[\frac{\widetilde{w}N}{y} - (1-\alpha)\,\xi - \phi_N x^2 - \beta\chi\phi_N x\right]\widehat{\Omega}_t \\ &\quad + (\beta\chi\phi_N x)\left[s\left(\widehat{\lambda}_{t+1} - \widehat{\lambda}_t + \widehat{y}_{t+1} - \widehat{N}_{t+1} + \widehat{x}_{t+1} + \widehat{s}_{t+1}\right) - (1-s)\,\widehat{\Omega}_{t+1}\right]\end{aligned}$$

21. Ω_t

$$\widehat{\Omega}_t = \left(\frac{1}{1-\eta}\right)\widehat{\eta}_t + \phi_W\left(\frac{y}{\widetilde{w}}\right)\left[\begin{array}{c}\beta\chi\left(\widehat{z}_{t+1} + \widehat{\pi}_{t+1} + \widehat{\widetilde{w}}_{t+1} - \widehat{\widetilde{w}}_t - \varrho\widehat{\pi}_t\right) \\ -\left(\widehat{z}_t + \widehat{\pi}_t + \widehat{\widetilde{w}}_t - \widehat{\widetilde{w}}_{t-1} - \varrho\widehat{\pi}_{t-1}\right)\end{array}\right]$$

22. r_t

$$\widehat{r}_t = \rho_r\widehat{r}_{t-1} + (1-\rho_r)\left[\rho_\pi\widehat{\pi}_t + \rho_y\left(\widehat{y}_t - \widehat{y}_{t-1} + \widehat{z}_t\right)\right] + \widehat{\epsilon}_{mpt}$$

23. $g_t = G_t/A_t$

$$\widehat{g}_t = \widehat{y}_t + \left(\frac{y}{g} - 1\right)\widehat{\epsilon}_{gt}$$

24. $gy_t = Y_t/Y_{t-1}$

$$\widehat{gy}_t = \widehat{y}_t - \widehat{y}_{t-1} + \widehat{z}_t$$

25. $gc_t = C_t/C_{t-1}$

$$\widehat{gc}_t = \widehat{c}_t - \widehat{c}_{t-1} + \widehat{z}_t$$

26. $gi_t = I_t/I_{t-1}$

$$\widehat{gi}_t = \widehat{i}_t - \widehat{i}_{t-1} + \widehat{z}_t$$

27. $gw_t = \widetilde{W}_t/\widetilde{W}_{t-1}$

$$\widehat{gw}_t = \widehat{\widetilde{w}}_t - \widehat{\widetilde{w}}_{t-1} + \widehat{z}_t$$

28. μ_t

$$\widehat{\mu}_t = \rho_\mu \widehat{\mu}_{t-1} + \varepsilon_{\mu t}$$

29. ϵ_{bt}

$$\widehat{\epsilon}_{bt} = \rho_b \widehat{\epsilon}_{bt-1} + \varepsilon_{bt}$$

30. z_t

$$\widehat{z}_t = \rho_z \widehat{z}_{t-1} + \varepsilon_{zt}$$

31. θ_t

$$\widehat{\theta}_t = \rho_\theta \widehat{\theta}_{t-1} + \varepsilon_{\theta t}$$

32. η_t

$$\widehat{\eta}_t = \rho_\eta \widehat{\eta}_{t-1} + \varepsilon_{\eta t}$$

33. ϵ_{gt}

$$\widehat{\epsilon}_{gt} = \rho_g \widehat{\epsilon}_{gt-1} + \varepsilon_{gt}$$

34. ϵ_{rt}

$$\widehat{\epsilon}_{mpt} = \rho_{mp} \widehat{\epsilon}_{mpt-1} + \varepsilon_{mpt}$$

Appendix 3: Rescaling two shocks prior to estimation

Two disturbances are normalized prior to estimation: the price-markup shock $\widehat{\theta}_t$ and the wage-markup shock $\widehat{\eta}_t$. The two rescaled disturbances which enter into the estimated model are

$$\begin{aligned}
\widehat{\theta}_t^* &= \left[\frac{1}{(1+\beta\varsigma)\,\phi_P}\right]\widehat{\theta}_t, \\
\widehat{\theta}_t^* &= \rho_{\theta^*}\widehat{\theta}_{t-1}^* - \varepsilon_{\theta^* t}, \\
\rho_{\theta^*} &= \rho_\theta, \\
\varepsilon_{\theta^* t} &\sim i.i.d.N\left(0, \sigma_{\theta^*}^2\right), \\
\sigma_{\theta^*} &= \left[\frac{1}{(1+\beta\varsigma)\,\phi_P}\right]\sigma_\theta,
\end{aligned}$$

$$\begin{aligned}
\widehat{\eta}_t^* &= \left(\frac{1}{1-\eta}\right)\widehat{\eta}_t, \\
\widehat{\eta}_t^* &= \rho_{\eta^*}\widehat{\eta}_{t-1}^* + \varepsilon_{\eta^* t}, \\
\rho_{\eta^*} &= \rho_\eta, \\
\varepsilon_{\eta^* t} &\sim i.i.d.N\left(0, \sigma_{\eta^*}^2\right), \\
\sigma_{\eta^*} &= \left(\frac{1}{1-\eta}\right)\sigma_\eta.
\end{aligned}$$

The two rescaled disturbances enter with a unit coefficient in the following two equations respectively:

1. π_t

$$0 = \widehat{\pi}_t - \left(\frac{\varsigma}{1+\beta\varsigma}\right)\widehat{\pi}_{t-1} - \left(\frac{\beta}{1+\beta\varsigma}\right)\widehat{\pi}_{t+1} - \left(\frac{1}{1+\beta\varsigma}\right)\left(\frac{\theta-1}{\phi_P}\right)\widehat{\xi}_t + \widehat{\theta}_t^*,$$

2. $\Im_t$

$$\begin{aligned}
0 &= \widehat{\Im}_t - \widehat{\eta}_t^* - \left(\beta\chi\phi_W\frac{y}{\widetilde{w}}\right)\widehat{z}_{t+1} - \left(\beta\chi\phi_W\frac{y}{\widetilde{w}}\right)\widehat{\pi}_{t+1} \\
&\quad - \left(\beta\chi\phi_W\frac{y}{\widetilde{w}}\right)\widehat{\widetilde{w}}_{t+1} + \left[\left(\phi_W\frac{y}{\widetilde{w}}\right)(1+\beta\chi)\right]\widehat{\widetilde{w}}_t \\
&\quad + \left[\left(\phi_W\frac{y}{\widetilde{w}}\right)(1+\beta\chi\varrho)\right]\widehat{\pi}_t + \left(\phi_W\frac{y}{\widetilde{w}}\right)\widehat{z}_t \\
&\quad - \left(\phi_W\frac{y}{\widetilde{w}}\right)\widehat{\widetilde{w}}_{t-1} - \left(\phi_W\frac{y}{\widetilde{w}}\right)\varrho\widehat{\pi}_{t-1}.
\end{aligned}$$

Appendix 4: Description of the database

All series are downloaded from the FREDII database maintained by the Federal Reserve Bank of St Louis. I measure nominal consumption using data on nominal personal consumption expenditures of nondurables and services. Nominal investment corresponds to the sum of personal consumption expenditures of durables and gross private domestic investment. Nominal output is measured by nominal GDP. Per capita real GDP, consumption and investment are obtained by dividing the nominal series by the GDP deflator and population. Real wages corresponds to nominal compensation per hour in the non-farm business sector, divided by the GDP deflator. Consistently with the model, I measure population by the labor force which is the sum of official unemployment and official employment. The unemployment rate is official unemployment divided by the labor force. Inflation is the first difference of the log of the GDP deflator. The nominal interest rate is measured by the effective federal funds rate.

Appendix 5: Impulse response functions

Figures 15-18 report the impulse responses of the unemployment rate, the inflation rate (quarter-on-quarter, annualized) and the federal funds rate (annualized) to the seven shocks embedded in the macroeconomic model: (1) the monetary policy shock, (2) the shock to the growth rate of TFP; (3) the investment-specific technology shock, (4) the government-spending shock, (5) the price-markup shock, (6) the wage-markup shock and (7) the risk-premium shock (or the preference shock in the sensitivity analysis (Case 2)). Each shock follows an $AR(1)$ process. Impulse responses are expressed in percentage points. The magnitude of each shock is set equal to its estimated standard deviation. Each period is a quarter.

The appendix compares the impulse responses across three different model specifications: "Case 0" corresponds to the baseline specification which features risk-premium shocks and where the measure of real activity in the Taylor rule is given by quarter-on-quarter output growth; "Case 1" denotes the first alternative specification where the measure of real activity in the Taylor rule is given by the output gap (instead of output growth). "Case 2" stands for the second alternative specification where risk-premium shocks have been replaced by intertemporal preference shocks (i.e. discount-factor shocks) and where the Taylor rule is the same as in the baseline model.

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Table 1: Calibrated parameters

Capital depreciation rate	δ	0.0250
Capital share	α	0.33
Elasticity of substitution between goods	θ	6.00
Probability to fill a vacancy within a quarter	q	0.7000
Government spending/output ratio	g/y	0.2000
Unemployment rate	U	0.0574
Quarterly growth rate	z	1.0044
Quarterly inflation rate	π	1.0061
Quarterly nominal interest rate	r	1.0144

Table 2: Parameters derived from steady-state conditions

Employment adjustment cost	ϕ_N	$\phi_N = \frac{2\times\left(\frac{\phi_N}{2}x^2\right)}{x^2}$
Discount factor	β	$\beta = \frac{z\pi}{r^B}$
Job survival rate	χ	$\chi = 1-\rho$
Employment rate	N	$N = 1-U$
Hiring rate	x	$x = \rho$
Mean of exogenous spending shock	ϵ_g	$\epsilon_g = \frac{1}{1-g/y}$
Real marginal cost	ξ	$\xi = \frac{\theta-1}{\theta}$
Quarterly net real rental rate of capital	$\widetilde{r}^K$	$\widetilde{r}^K = \frac{z}{\beta} - 1 + \delta$
Capital utilization cost first parameter	ϕ_{u1}	$\phi_{u1} = \widetilde{r}^K$
Capital/output ratio	k/y	$\frac{k}{y} = \frac{\alpha\xi}{\widetilde{r}^K}$
Investment/capital ratio	i/k	$\frac{i}{k} = z - 1 + \delta$
Investment/output ratio	i/y	$\frac{i}{y} = \frac{i}{k}\frac{k}{y}$
Consumption/output ratio	c/y	$\frac{c}{y} = \frac{1}{\epsilon_g} - \frac{\phi_N}{2}x^2 - \frac{i}{y}$
Vacancies	V	$V = N\frac{x}{q}$
Pool of job seekers	S	$S = 1-\chi N$
Matching function efficiency	ζ	$\zeta = q\left(\frac{V}{S}\right)^{\sigma}$
Job finding rate	s	$s = \zeta\left(\frac{V}{S}\right)^{1-\sigma}$
Employees' share of output	$\widetilde{w}n/y$	$\frac{\widetilde{w}N}{y} = \xi(1-\alpha) - (1-x-\beta\chi)\phi_N x$
Bargaining power	η	$\eta = \frac{1-\tau}{\vartheta-\tau}$ where $\vartheta \equiv \frac{\left[\xi(1-\alpha)+\phi_N x^2+\beta\chi\phi_N xs\right]}{\frac{\widetilde{w}N}{y}}$
Effective bargaining power	$\mathfrak{Y}$	$\mathfrak{Y} = \frac{\eta}{1-\eta}$

Table 3: Priors and posteriors of structural parameters for baseline model (Case 0)

		Prior	Posterior distributions			
		distribution	Median	Std dev	5%	95%
Job destruct. rate	ρ	Normal (0.08,0.01)	0.09	0.01	0.07	0.10
Replacement rate	10τ	IGamma (3,0.5)	2.79	0.49	2.22	3.81
Hiring cost/output	$1000\frac{\phi_N}{2}x^2$	Normal (5,0.5)	4.46	0.47	3.70	5.27
Habit in consump.	h	Beta (0.6,0.1)	0.45	0.06	0.35	0.55
Elasticity of match.	σ	Beta (0.5,0.05)	0.49	0.04	0.42	0.57
Invest. adj. cost	ϕ_I	Normal (5,0.5)	4.60	0.51	3.71	5.40
Capital ut. cost	ϕ_{u2}	Normal (0.5,0.1)	0.57	0.08	0.44	0.70
Price adjust. cost	ϕ_P	IGamma (55,10)	48.9	6.96	40.1	62.9
Wage adjust. cost	ϕ_W	IGamma (20,8)	28.6	4.74	22.2	36.3
Price indexation	ς	Beta (0.5,0.2)	0.39	0.12	0.21	0.62
Wage indexation	ϱ	Beta (0.5,0.2)	0.75	0.15	0.43	0.92
Interest smoothing	ρ_r	Beta (0.7,0.15)	0.74	0.03	0.68	0.79
Resp. to inflation	ρ_π	Normal (1.75,0.2)	2.09	0.14	1.86	2.34
Resp. to growth	ρ_y	Normal (0.25,0.1)	0.30	0.08	0.19	0.46

Table 4: Priors and posteriors of shock parameters for baseline model (Case 0)

		Prior	Posterior distributions			
		distribution	Median	Std dev	5%	95%
Technology growth	ρ_z	Beta (0.35,0.15)	0.20	0.07	0.09	0.32
	$100\sigma_z$	IGamma (0.1,2)	0.84	0.07	0.73	0.95
Monetary policy	ρ_{mp}	Beta (0.5,0.2)	0.32	0.07	0.21	0.44
	$100\sigma_{mp}$	IGamma (0.1,2)	0.12	0.01	0.10	0.14
Investment	ρ_μ	Beta (0.5,0.2)	0.79	0.05	0.70	0.87
	$100\sigma_\mu$	IGamma (0.1,2)	4.66	0.67	3.75	5.92
Risk-premium	ρ_b	Beta (0.5,0.2)	0.92	0.04	0.85	0.97
	$100\sigma_b$	IGamma (0.1,2)	0.14	0.03	0.10	0.21
Price markup	ρ_θ	Beta (0.5,0.2)	0.83	0.07	0.69	0.92
	$100\sigma_\theta$	IGamma (0.1,2)	0.09	0.01	0.07	0.10
Bargaining power	ρ_η	Beta (0.5,0.2)	0.30	0.08	0.17	0.43
	$100\sigma_\eta$	IGamma (0.1,2)	42.6	4.62	38.1	53.3
Government spending	ρ_g	Beta (0.7,0.2)	0.97	0.01	0.94	0.99
	$100\sigma_g$	IGamma (0.1,2)	0.35	0.03	0.31	0.40

Table 5: Priors and posteriors of structural parameters for alternative models

		Prior distributions	Posterior distributions			
			Case 1*		Case 2**	
			Median	Std dev	Median	Std dev
Job destruct. rate	ρ	Normal (0.08,0.01)	0.09	0.01	0.09	0.01
Replacement rate	10τ	IGamma (3,0.5)	2.74	0.41	2.73	0.42
Hiring cost/output	$1000\frac{\phi_N}{2}x^2$	Normal (5,0.5)	4.47	0.52	4.36	0.47
Habit in consump.	h	Beta (0.6,0.1)	0.43	0.07	0.49	0.07
Elasticity of match.	σ	Beta (0.5,0.05)	0.49	0.05	0.50	0.04
Invest. adj. cost	ϕ_I	Normal (5,0.5)	4.73	0.50	4.52	0.47
Capital ut. cost	ϕ_{u2}	Normal (0.5,0.1)	0.55	0.09	0.56	0.09
Price adjust. cost	ϕ_P	IGamma (55,10)	54.9	10.6	52.9	8.09
Wage adjust. cost	ϕ_W	IGamma (20,8)	19.2	3.9	26.7	4.31
Price indexation	ς	Beta (0.5,0.2)	0.47	0.15	0.35	0.13
Wage indexation	ϱ	Beta (0.5,0.2)	0.63	0.18	0.71	0.16
Interest smoothing	ρ_r	Beta (0.7,0.15)	0.76	0.04	0.75	0.04
Resp. to inflation	ρ_π	Normal (1.75,0.2)	2.02	0.14	2.08	0.15
Resp. to gap*/growth**	ρ_y	Normal (0.25,0.1)	0.27	0.08	0.29	0.07

*Case 1: Model with risk-premium shocks and a Taylor rule responding to the output gap.

**Case 2: Model with preference shocks and a Taylor rule responding to output growth.

Table 6: Priors and posteriors of shock parameters for alternative models

		Prior distribution	Posterior distributions			
			Case 1*		Case 2**	
			Median	Std dev	Median	Std dev
Technology growth	ρ_z	Beta (0.35,0.15)	0.24	0.07	0.17	0.07
	$100\sigma_z$	IGamma (0.1,2)	0.85	0.07	0.82	0.07
Monetary policy	ρ_{mp}	Beta (0.5,0.2)	0.31	0.09	0.37	0.09
	$100\sigma_{mp}$	IGamma (0.1,2)	0.12	0.01	0.12	0.01
Investment	ρ_μ	Beta (0.5,0.2)	0.73	0.06	0.68	0.07
	$100\sigma_\mu$	IGamma (0.1,2)	5.11	0.81	4.67	0.67
Risk-prem.*/Pref.**	ρ_b	Beta (0.5,0.2)	0.87	0.07	0.91	0.05
	$100\sigma_b$	IGamma (0.1,2)	0.18	0.08	3.00	0.52
Price markup	ρ_θ	Beta (0.5,0.2)	0.81	0.07	0.81	0.07
	$100\sigma_\theta$	IGamma (0.1,2)	0.08	0.01	0.09	0.01
Bargaining power	ρ_η	Beta (0.5,0.2)	0.32	0.09	0.31	0.08
	$100\sigma_\eta$	IGamma (0.1,2)	29.3	5.19	36.9	5.30
Government spending	ρ_g	Beta (0.7,0.2)	0.96	0.02	0.96	0.01
	$100\sigma_g$	IGamma (0.1,2)	0.35	0.03	0.35	0.03

*Case 1: Model with risk-premium shocks and a Taylor rule responding to the output gap.

**Case 2: Model with preference shocks and a Taylor rule responding to output growth.

Table 7: Log marginal likelihood

Case 0	Case 1	Case 2
−544.5	−544.3	−545.6

Case 0: Model with risk-premium shocks and a Taylor rule responding to output growth.

Case 1: Model with risk-premium shocks and a Taylor rule responding to the output gap.

Case 2: Model with preference shocks and a Taylor rule responding to output growth.

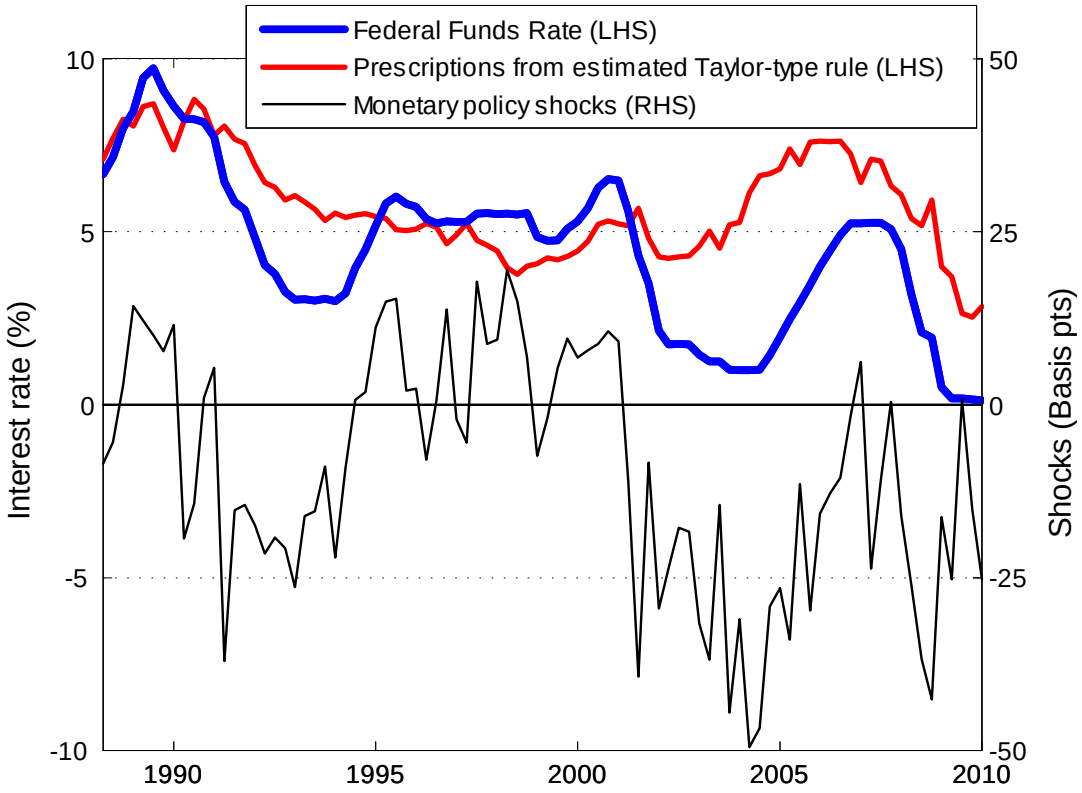

Figure 1: LHS: The effective federal funds rate versus the prescriptions from the estimated Taylor-type rule. The estimation period is 1985:Q1 - 2001:Q4. The rule reponds to inflation and output growth and features some interest-rate smoothing. RHS: Smoothed estimates of the monetary policy shocks, which are assumed to follow an AR(1) process.

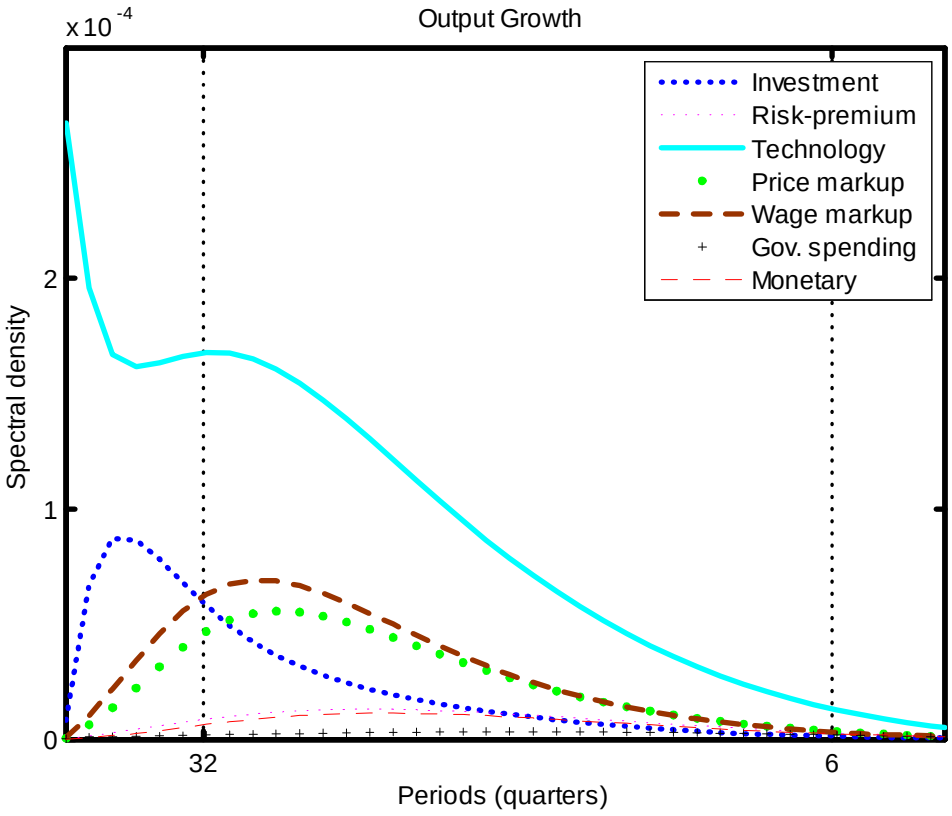

Figure 2: Sources of fluctuations in output growth at various frequencies. The conditional spectral densities are the frequency-domain decomposition of the variance of output growth conditional on each shock. Business cycles frequencies correspond to the cycles whose period ranges from 6 to 32 quarters.

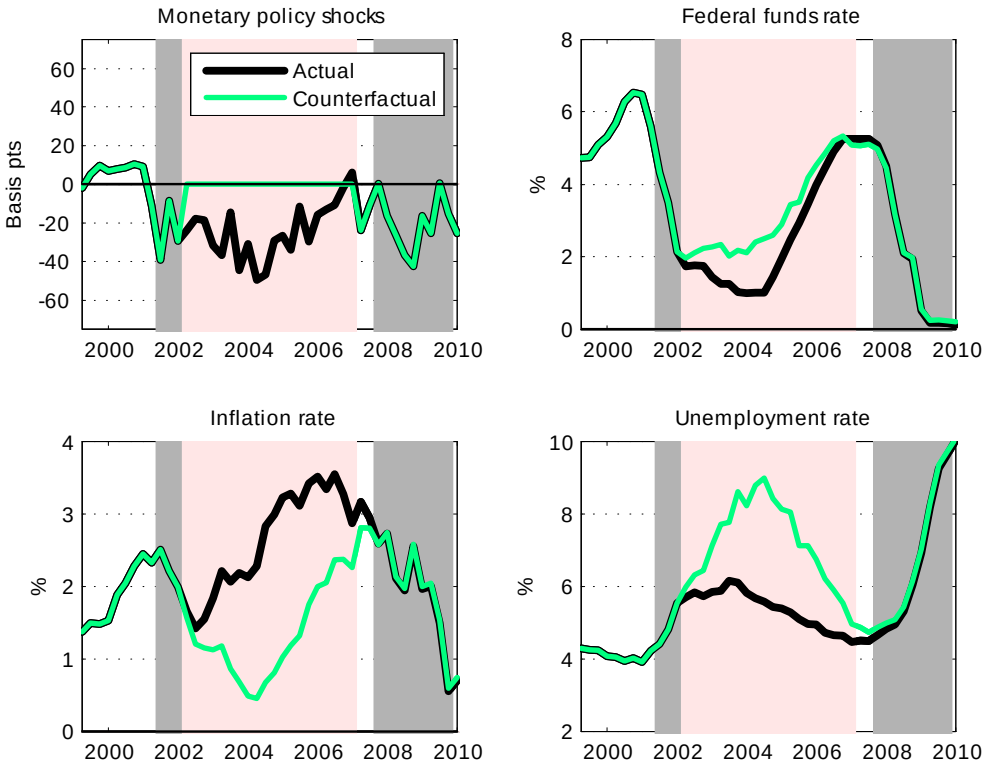

Figure 3: The counterfactual endogenous paths (green) of inflation, unemployment and the federal funds rate are generated by turning off the estimated monetary policy shocks over the period 2002:Q1 to 2006:Q4 indicated by the pink shaded area. Dark shaded areas mark the NBER recessions. Inflation is measured by the year-on-year rate of change in the GDP deflator.

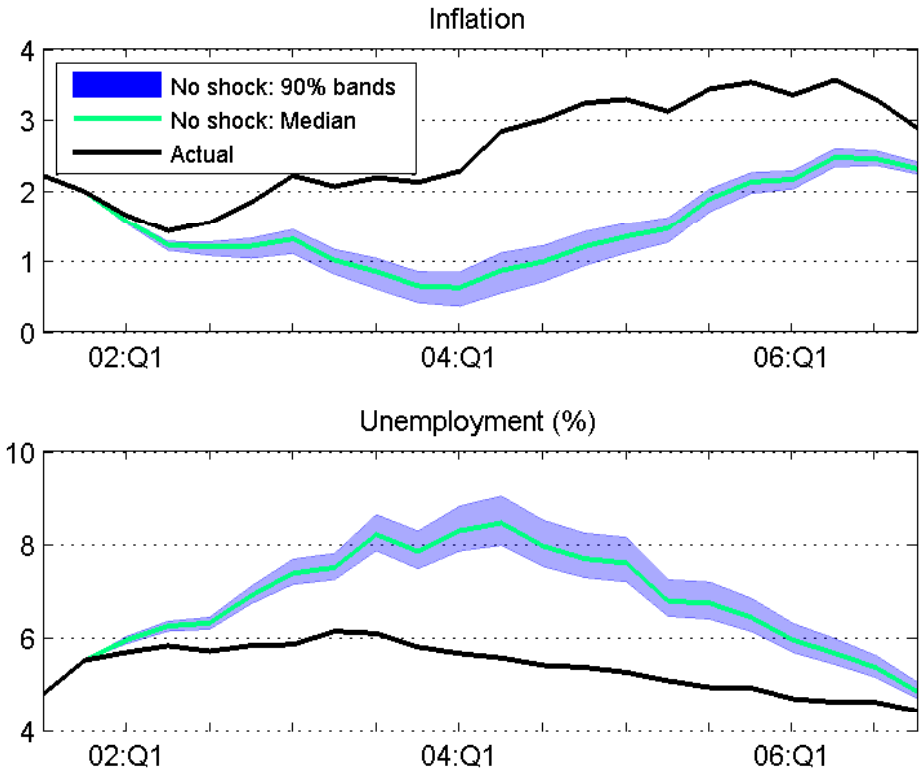

Figure 4: Counterfactual paths of inflation and unemployment with estimated monetary policy shocks turned off over the period 2002:Q1-2006:Q4. The black solid lines represent the actual data. The shaded area represent the 90% posterior probability intervals of the counterfactual data. The green lines depict the posterior medians of the counterfactual data. Inflation is measured by the year-on-year growth rate of the GDP deflator, expressed in percent.

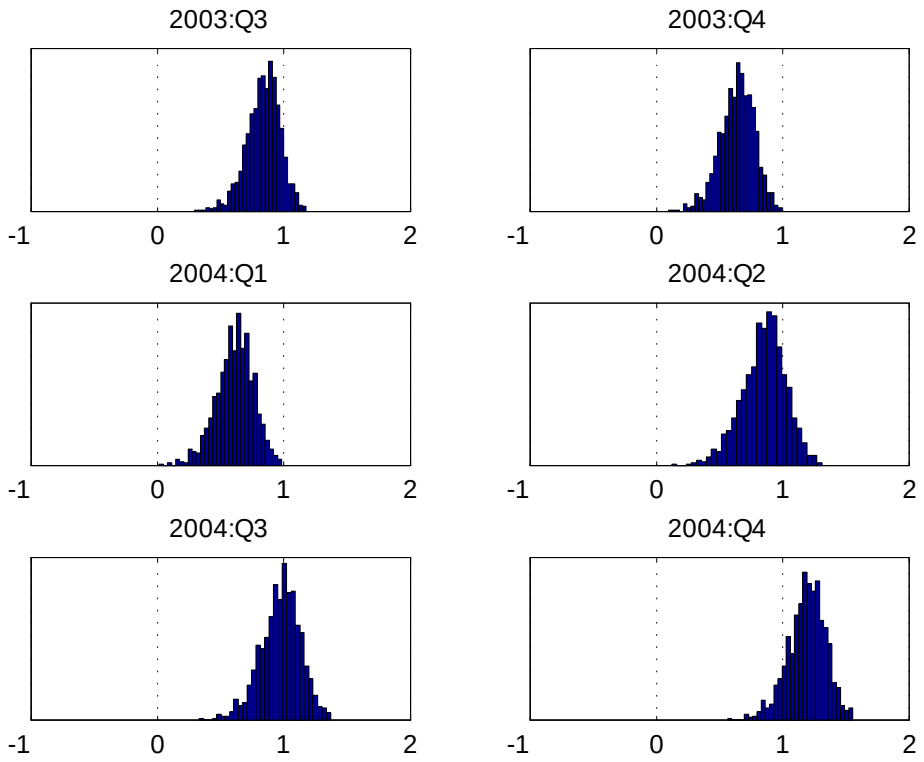

Figure 5: Posterior densities of counterfactual inflation when monetary policy shocks are turned off over the period 2002:Q1-2006:Q4. Inflation is measured by the year-on-year growth rate of the GDP deflator, expressed in percent.

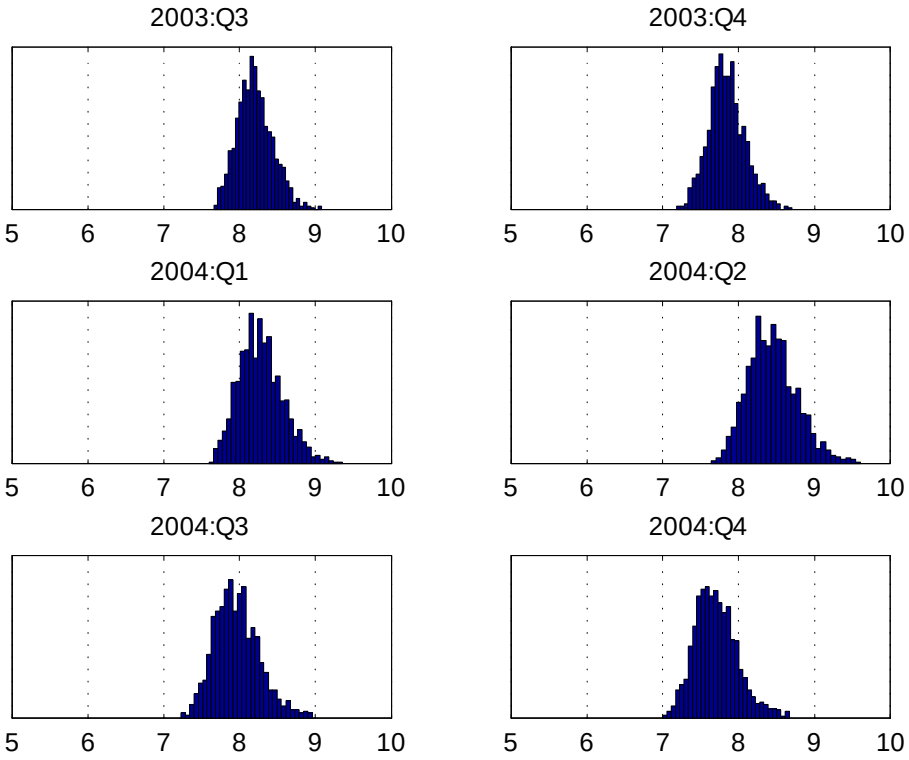

Figure 6: Posterior densities of counterfactual unemployment when monetary policy shocks are turned off over the period 2002:Q1-2006:Q4. The unemployment rate is expressed in percent.

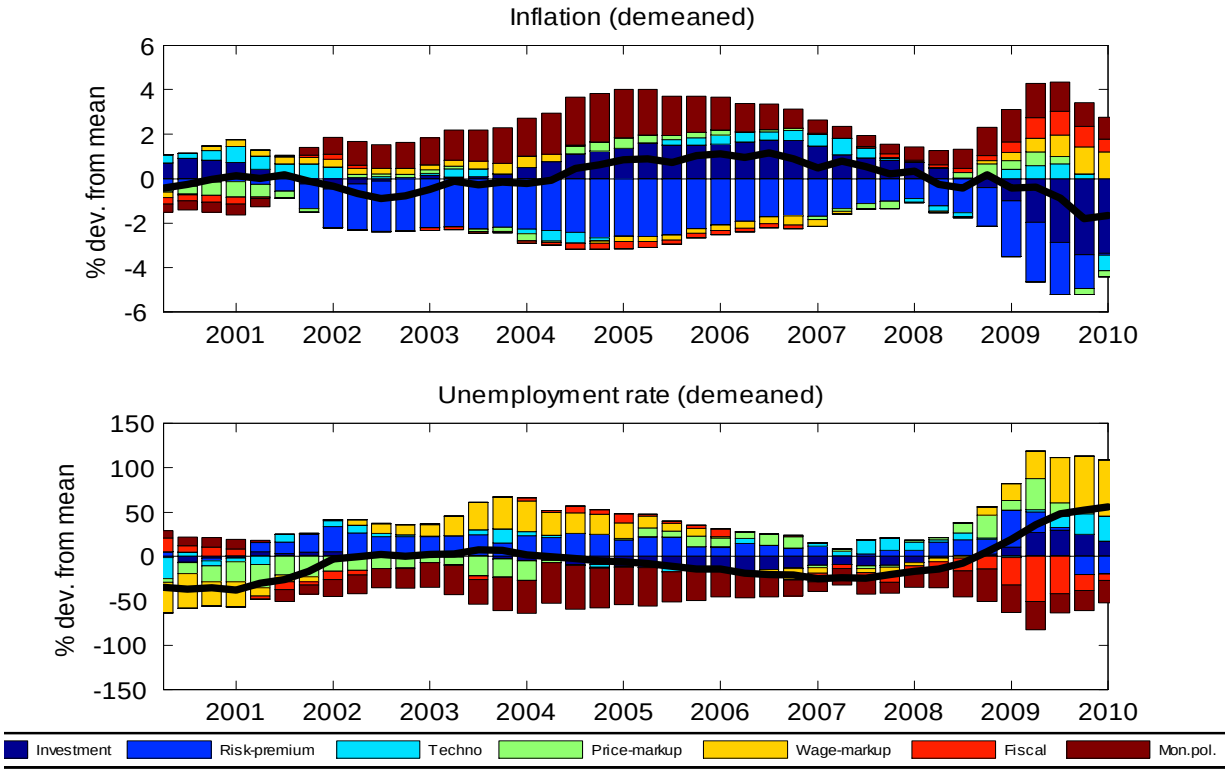

Figure 7: Historical decompositions of inflation (top panel) and unemployment (bottom panel). Each colour corresponds to one of the seven shocks hitting the model economy. The black solid line represent the actual data (demeaned). Inflation is measured by the year-on-year growth rate of the GDP deflator.

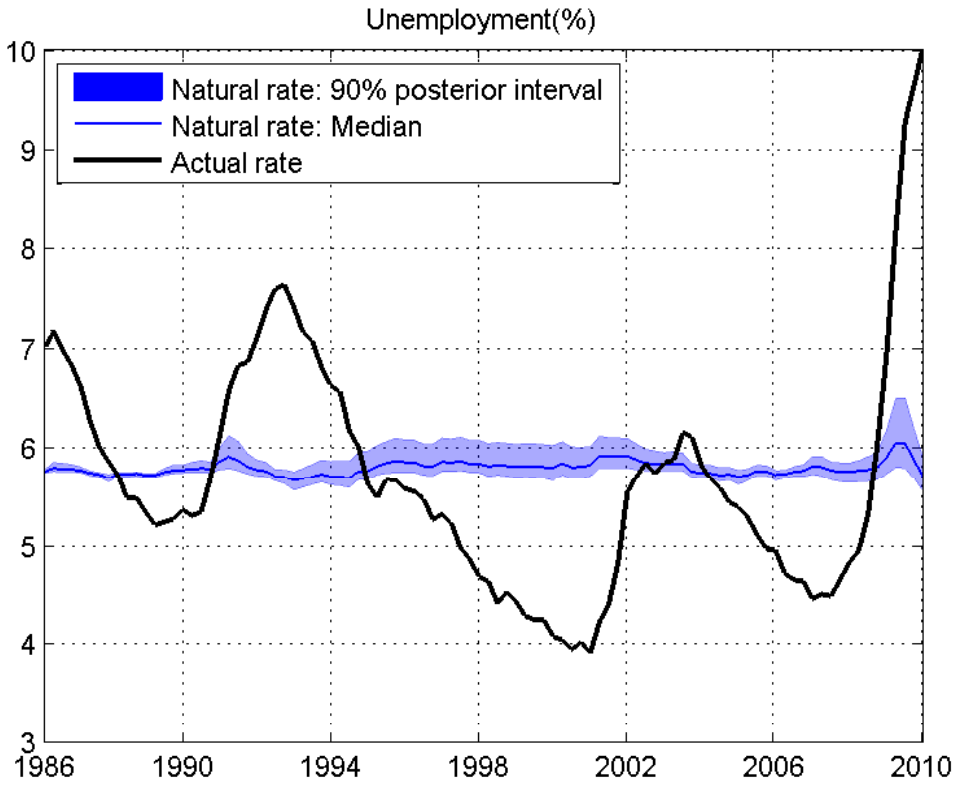

Figure 8: Actual and natural rate of unemployment. The shaded area represents the 90% posterior probability interval around the natural rate. The natural rate is defined as the rate of unemployment that would occur in the absence of nominal rigidities and markup shocks.

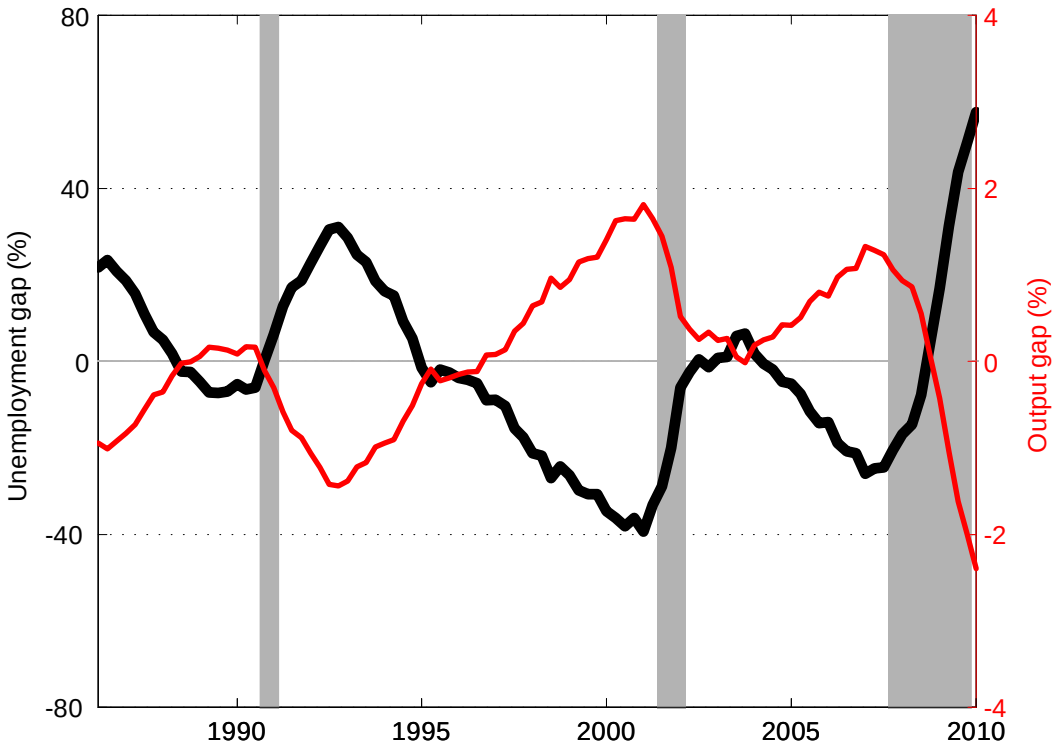

Figure 9: Output and unemployment gaps. The thick black line represents the unemployment gap (left scale). The thin red line represents the output gap (right scale). Vertical bars mark the NBER recessions. The output and unemployment gaps are defined as the percent deviations of actual output and unemployment from their respective natural values. Natural values of output and unemployment were obtained by turning off both nominal rigidities and markup shocks.

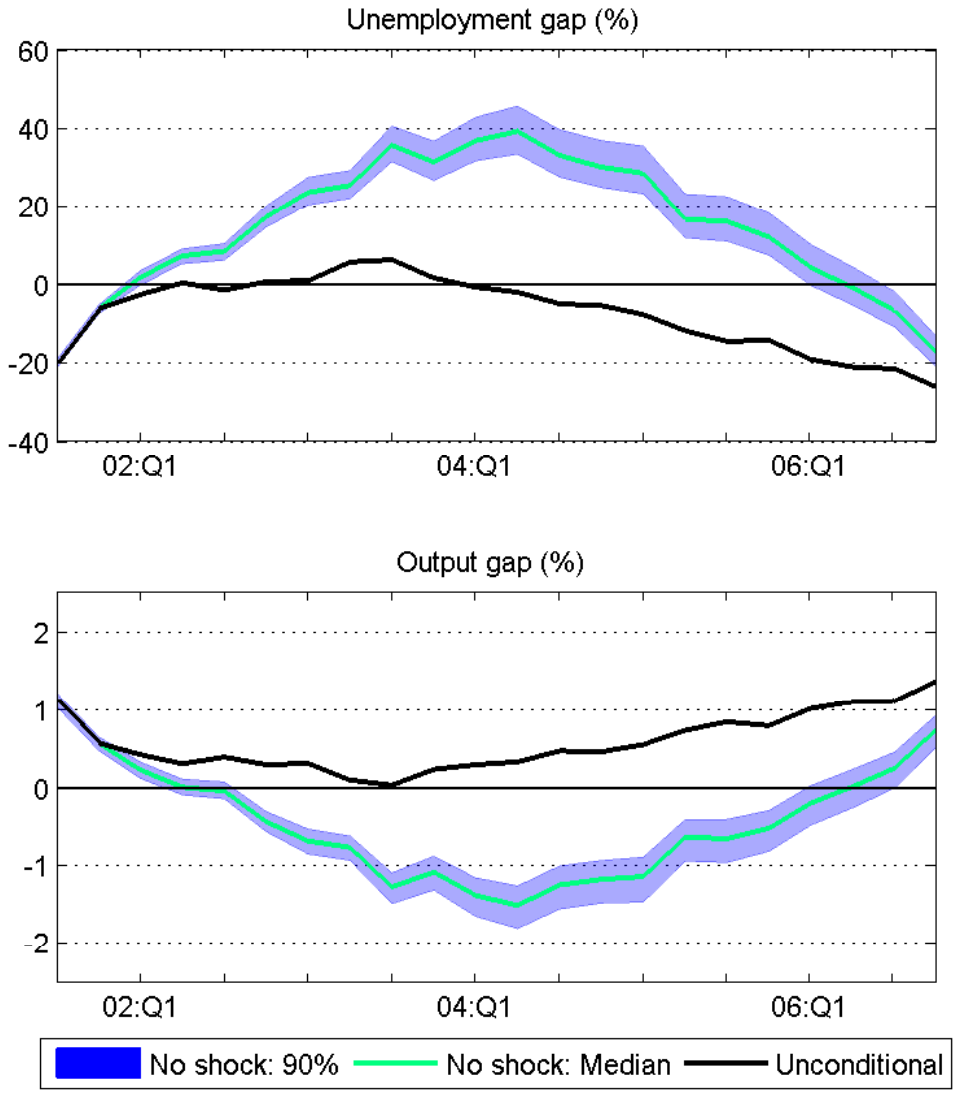

Figure 10: Unemployment and output gaps with and without monetary policy shocks. In each panel, the black line represents the posterior median of the unconditional gap; the shaded area represents the 90% posterior interval of the gap when monetary policy shocks are turned off over the period 2002:Q1-2006:Q4. The green line represents the posterior median.

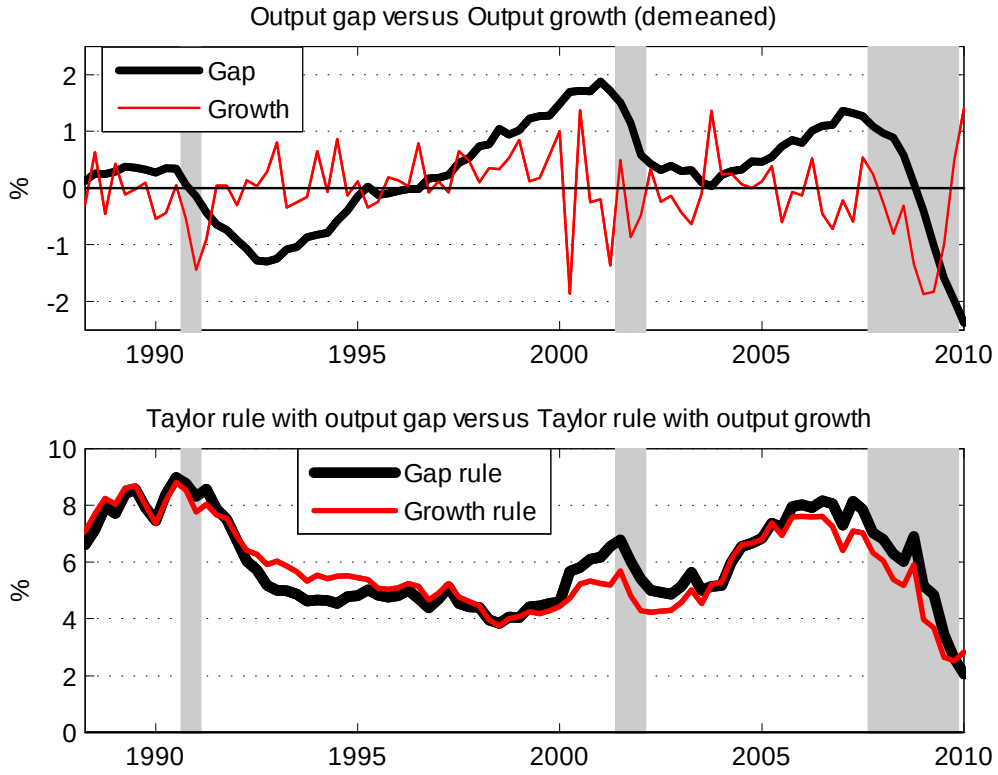

Figure 11: Top panel: Output gap versus output growth. The thick line depicts the smoothed estimates of the model-consistent output gap. The thin line represents the quarter-on-quarter growth rate of real GDP per capita, demeaned. Bottom panel: Prescriptions from two alternative estimated Taylor rules. The thick line represents the presriptions from the estimated rule that responds to the output gap. The thin line depicts the prescriptions from the estimated rule that responds to output growth. Both rules responds to inflation (measured by the demeaned, quarter-on quarter growth rate of the GDP deflator) and feature some interest rate smoothing.

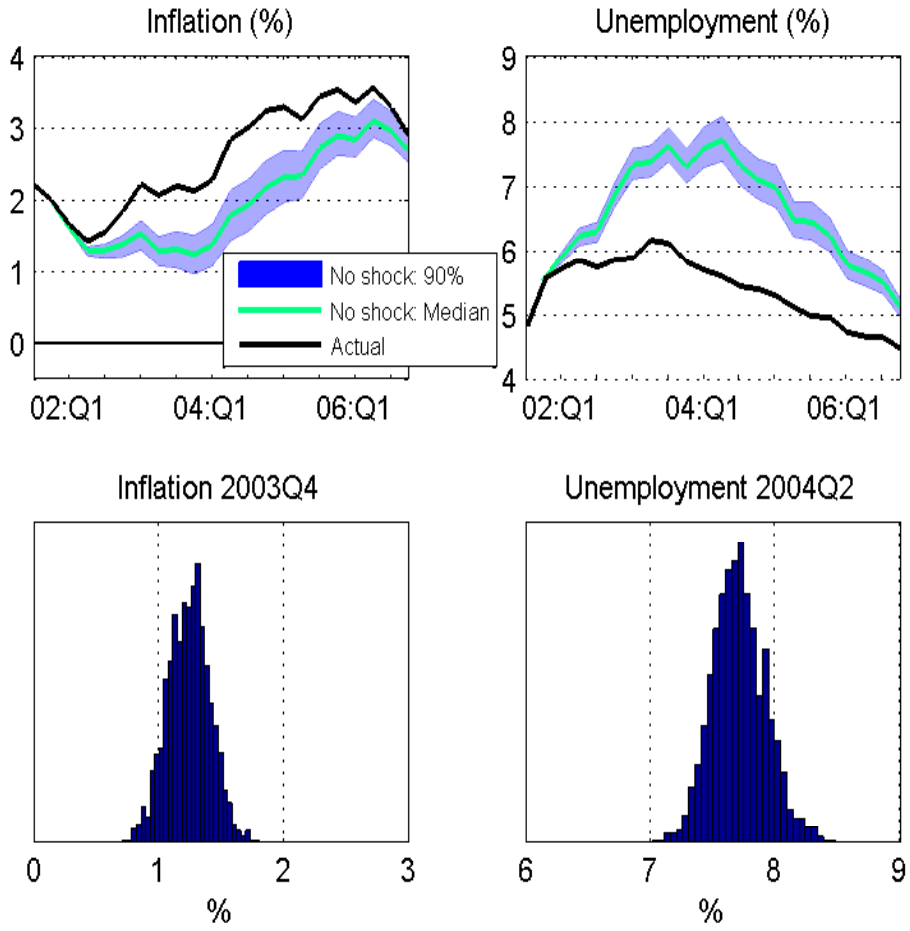

Figure 12: Sensitivity analysis: Model where the Taylor rule responds to the output gap. Top panels: Shaded areas correspond to the 90% posterior intervals of inflation and unemployment when monetary policy shocks have been turned off over the period 2002:Q1-2006:Q4. Bottom panels: Posterior densities of counterfactual variables in worst quarters.

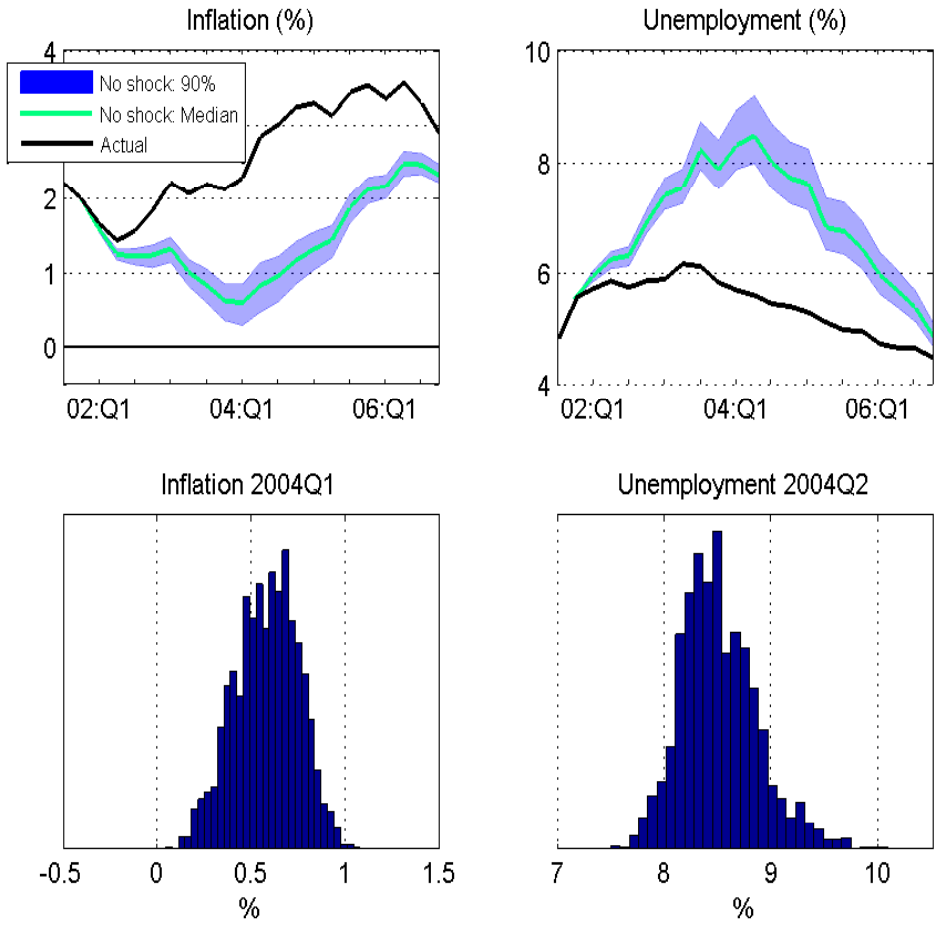

Figure 13: Sensitivity analysis: Model where risk-premium shocks have been replaced with intertemporal preference shocks. Top panels: Shaded areas correspond to the 90% posterior intervals of inflation and unemployment when monetary policy shocks have been turned off over the period 2002:Q1-2006:Q4. Bottom panels: Posterior densities of counterfactual variables in worst quarters.

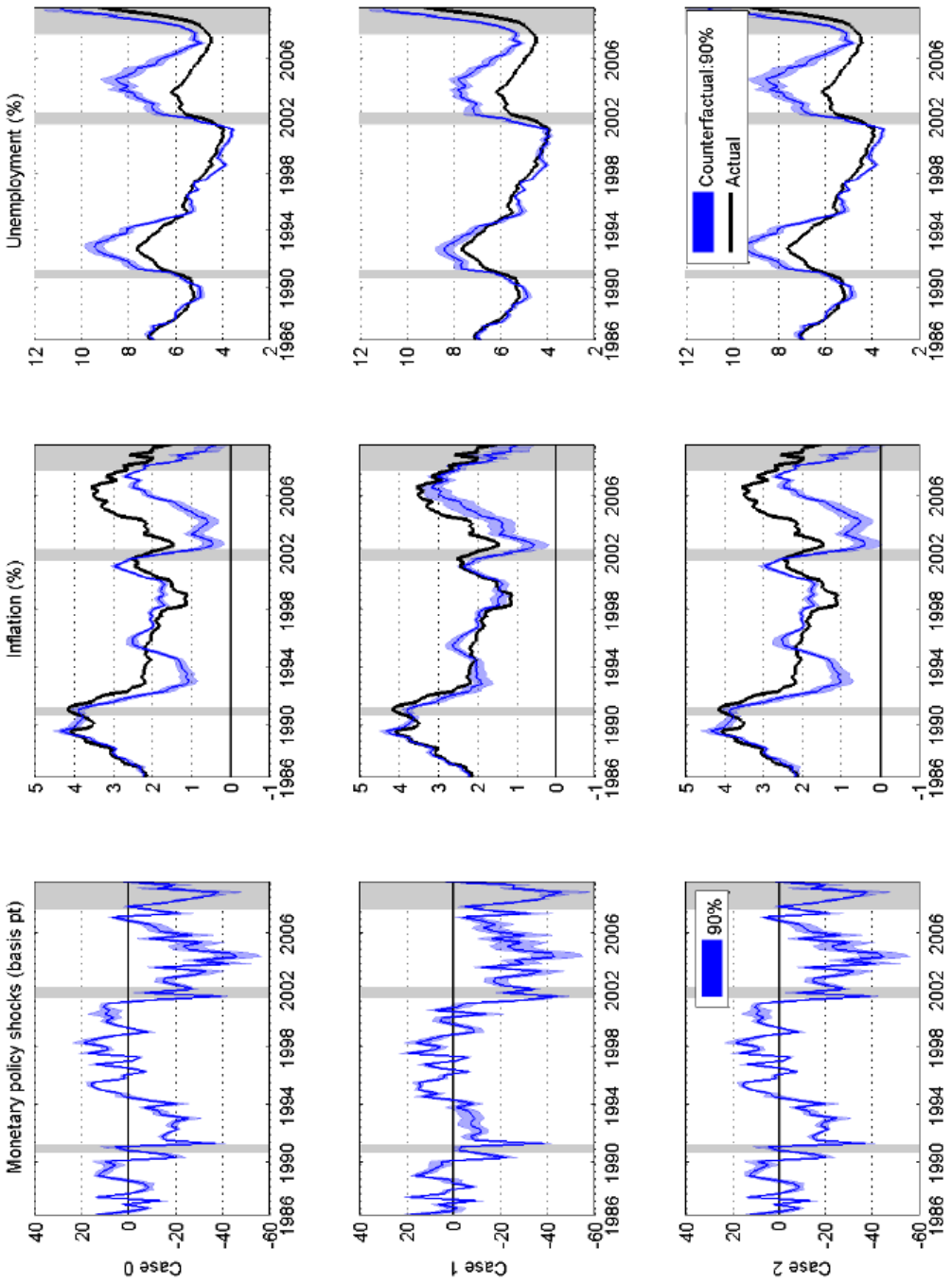

Figure 14: Sensitivity analysis: Counterfactuals with no monetary policy shocks over the whole sample period in the three models. Column 1: Monetary policy shocks. Column 2 and 3: Actual inflation and unemployment versus counterfactual inflation and unemployment when monetary policy shocks are turned off from 1985:Q1 to 2009:Q2. Shaded area are 90% posterior intervals. Blue lines are posterior medians. Black lines are actual data. Case 0 refers to the baseline model with risk-premium shocks and a Taylor rule that responds to output growth. Case 1 refers to the model where the Taylor rule responds to the output gap. Case 2 refers to the model with intertemporal preference shocks instead of risk-premium shocks.

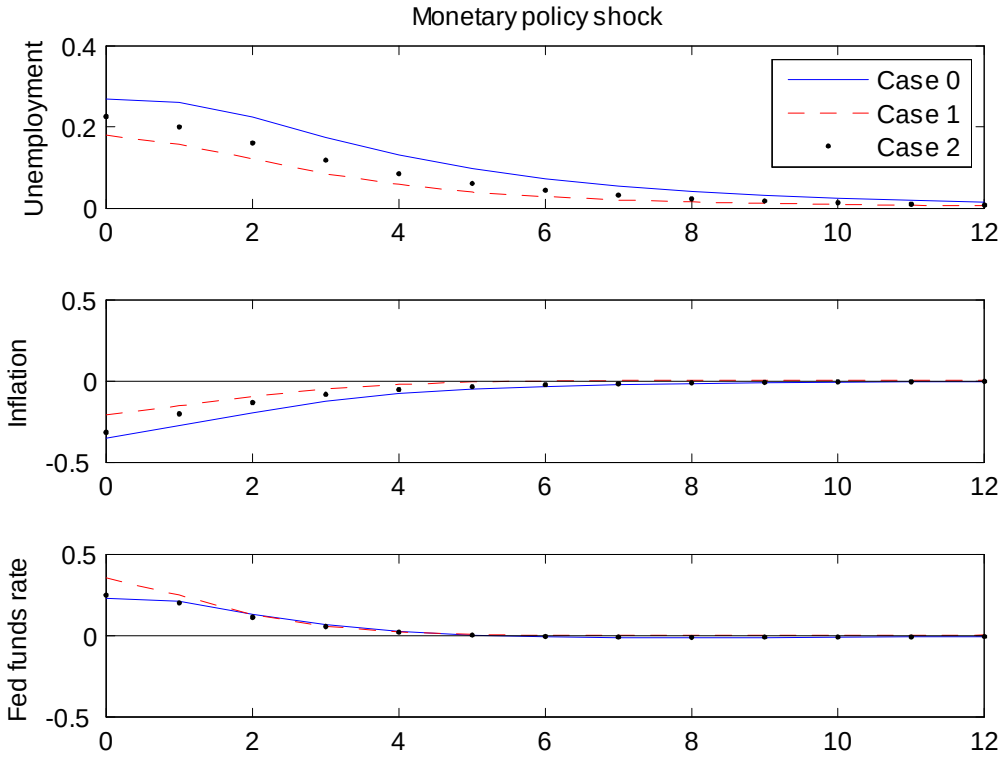

Figure 15: Impulse responses to a one-standard-deviation **monetary policy shock**. The impulse responses are expressed in percentage points. Inflation (quarter-on-quarter) and the interest rate are both annualized. Periods are quarters. "Case 0" corresponds to the baseline specification where the Taylor rule responds to output growth; "Case 1" denotes specification where the Taylor rule responds to the output gap. "Case 2" stands for the specification where risk-premium shocks have been replaced with preference shocks.

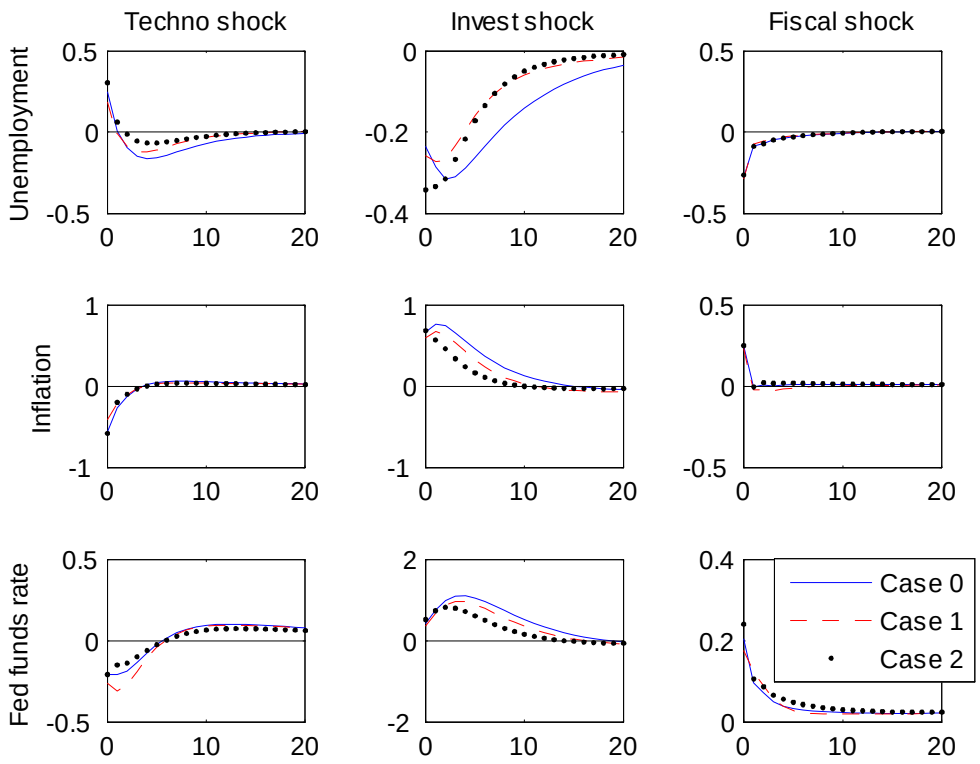

Figure 16: **Column 1:** Impulse responses to a one-standard-deviation **shock to the growth rate of TFP**. **Column 2:** Impulse responses to a one-standard-deviation **investment-specific technology shock**. **Column 3:** Impulse response to a one-standard-deviation **government spending shock**. Responses are expressed in percentage points. Inflation (quarter-on-quarter) and the interest rate are both annualized. Periods are quarters. "Case 0" corresponds to the baseline specification where the Taylor rule responds to output growth; "Case 1" denotes specification where the Taylor rule responds to the output gap. "Case 2" stands for the specification where risk-premium shocks have been replaced with preference shocks.

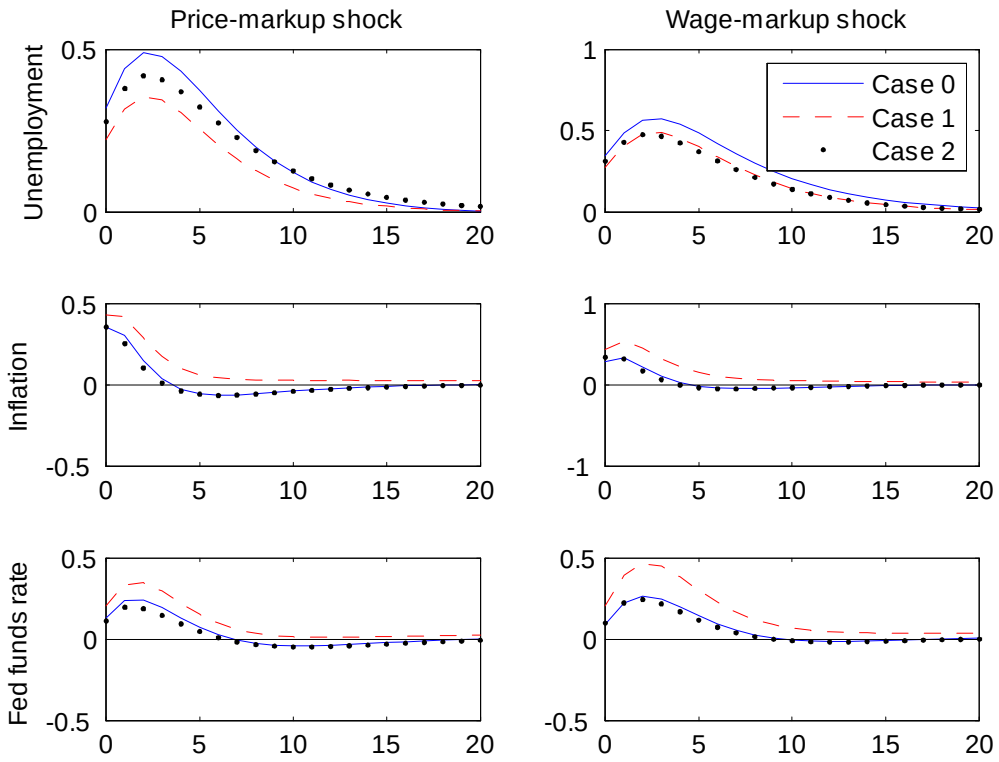

Figure 17: **Column 1:** Impulse responses to a **price-markup shock**. **Column 2:** Impulse responses to a **wage-markup shock**. The size of each shock is one standard deviation. Responses are expressed in percentage points. Inflation (quarter-on-quarter) and the interest rate are both annualized. Periods are quarters. "Case 0" corresponds to the baseline specification where the Taylor rule responds to output growth; "Case 1" denotes specification where the Taylor rule responds to the output gap. "Case 2" stands for the specification where risk-premium shocks have been replaced with preference shocks.

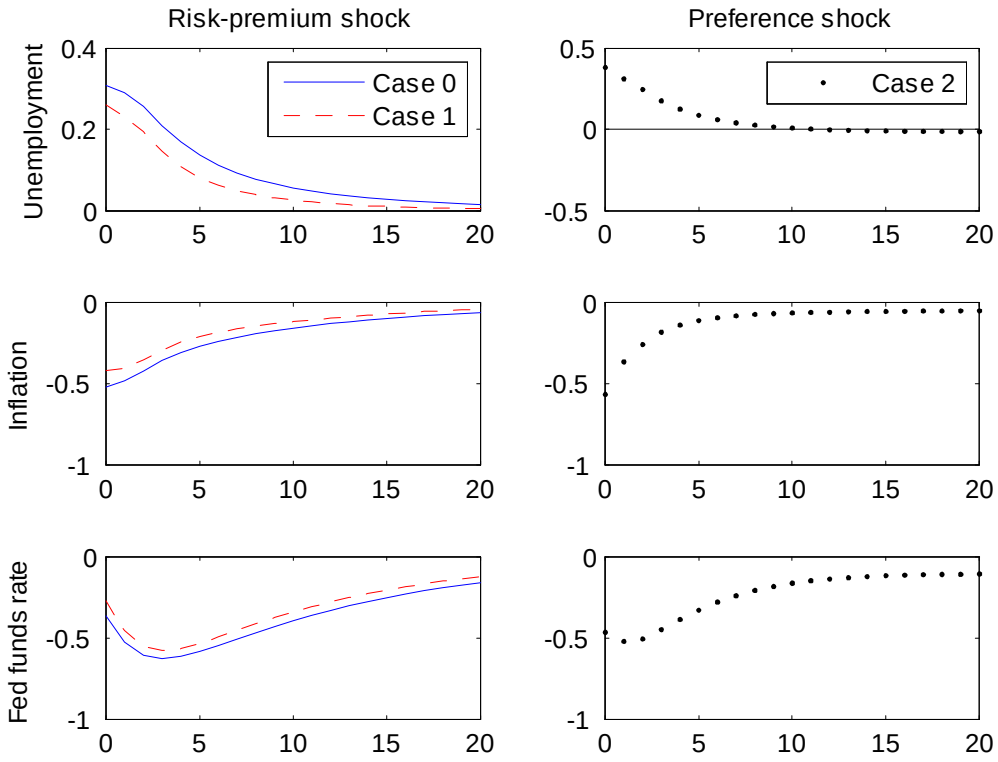

Figure 18: **Column 1:** Impulse responses to a **risk-premium shock**. **Column 2:** Impulse responses to an **intertemporal preference shock** (i.e. discount factor shock). The size of each shock is one standard deviation. Responses are expressed in percentage points. Inflation (quarter-on-quarter) and the interest rate are both annualized. Periods are quarters. "Case 0" corresponds to the baseline specification where the Taylor rule responds to output growth; "Case 1" denotes specification where the Taylor rule responds to the output gap. "Case 2" stands for the specification where risk-premium shocks have been replaced with preference shocks.