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**Differences in interest rate policy at the ECB and the Fed :
an investigation with a medium-scale DSGE model**

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Differences in Interest Rate Policy at the ECB and the Fed: An Investigation with a Medium-Scale DSGE Model[*]

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Abstract

Using two estimated models for the euro area and the United States, this paper investigates whether the observed difference in the amplitude of the interest rate cycle since 1999 in both areas is due to differences in the estimated monetary policy reaction function, differences in the structure of the economy or differences in the size and nature of the shocks hitting both economies. The paper concludes that differences in the type, size and persistence of shocks in both areas can largely explain the different interest rate setting.

Keywords: Policy activism, DSGE model, interest rates, macroeconomic shocks

JEL Classifications: C51, E52, E58

1 Introduction

Since the introduction of the euro in January 1999, the European Central Bank (ECB) has moved its policy rate much less frequently than the Federal Reserve (Fed). Over the period from January 1999 to January 2006, the ECB has changed its main refinancing rate 16 times, whereas the Fed has changed its target for the federal funds rate about twice as often. This has generated a debate about differences in the degree of central bank activism on both sides of the Atlantic. For example, Aghion, Cohen and Pisani-Ferry (2005) have criticised the ECB for not being responsive enough to changes in the economic cycle. Figure 1 compares short-term interest rates in the euro area and the United States and confirms that, while the correlation between US and euro area rates is very high, the amplitude of the interest rate cycle is much smaller in the euro area than in the United States.

{Insert Figure 1}

In this paper, we investigate the source of this difference using two New Keynesian Dynamic Stochastic General Equilibrium (DSGE) models for the euro area and the United States respectively, estimated over the period 1985:1 to 2004:4. Using estimated DSGE models offers a number of advantages. First, conducting policy exercises in a micro-founded model alleviates the Lucas critique. The estimated "deep" parameters are likely to be more invariant to counterfactual changes in policy regimes. Second, the DSGE model structure allows to describe differences in economic structure and their implications for the transmission of shocks. Third, using the DSGE model structure should facilitates the estimation of the policy rules by providing additional instruments.

Within the context of our estimated DSGE models, there are three main reasons why actual interest rate decisions may differ across the Atlantic. A first reason is differences in the estimated policy instrument rule. Such differences could reflect differences in the objectives, the monetary policy strategy or the institutional set-up of the two central banks. For example, the explicit dual mandate of the Federal Reserve may lead to a larger weight on the stabilisation of output around its sustainable path and a stronger response to developments in the output gap. This could in turn explain why policy rates move more strongly in response to the business cycle. Similarly, differences in the size, the composition and the voting mechanism of the decision-making bodies (the Governing Council in the case of the ECB and the FOMC in the case of the Fed) may imply differences in the speed with which policy rates respond to economic developments. Also these differences should be reflected in differences in the estimated policy rule. A second reason is that the structure of the euro area

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and US economies are different, which given the central banks' objectives leads to different interest rate settings. For example, it could be that in the United States the interest rate sensitivity of various demand components is different from that in the euro area. In the face of similar shocks, this should affect the size of the interest rate changes required to maintain price stability. Similarly, the euro area economy may be more rigid in the face of economic shocks and therefore require a more cautious response of monetary policy to news. A final reason for the different interest rate behaviour may be that the size and source of the shocks hitting both economies are different. For example, while the United States has experienced a boom in productivity growth since the late 1990s, productivity growth has slowed down quite considerably over the past decade in the euro area. The estimated structural models can be used to distinguish between those three possible sources of differences in interest rate setting.

The overall conclusion of the analysis is that differences in the size and the persistence of the shocks hitting the two economies is the main driving force behind the different interest rate behaviour. While one can detect small differences in the reaction functions and the structural parameters of the two economies, these are not sufficiently large to explain the different interest rate behaviour.[1]

The main features of the structural macroeconometric model are described in Section 2. Section 3 focuses on differences in the reaction function. Next, Section 4 and 5 analyze the role of differences in the economic structure and in the sources of shocks respectively. Finally, Section 6 takes a more normative perspective and asks whether differences in structure and shocks implied a different behaviour of the natural real interest rate.

2 The medium-scale macroeconometric model

In this section we briefly describe the macroeconometric model we will use in the subsequent analysis.[2] Households maximise a non-separable utility function in consumption and labour effort over an infinite life horizon. Consumption appears in the utility function relative to a time-varying external habit variable that depends on past aggregate consumption. Each household provides differentiated labour inputs. Monopoly power in the labour market results in an explicit wage equation and allows for the introduction of sticky nominal wages as in the Calvo model (households are allowed to reset their wage each period with an exogenous probability). Households rent capital services to firms and decide how much capital to accumulate given certain costs of adjusting the capital stock. The introduction of variable capital utilisation implies that as the rental price of capital changes, the capital stock can be

used more or less intensively according to some cost schedule. Firms produce differentiated goods, decide on labour and capital inputs, and set prices according to the Calvo model. The Calvo model in both wage and price setting is augmented by the assumption that prices that are not re-optimised in a given period are partially indexed to past inflation rates. Prices are therefore set in function of current and expected marginal costs, but are also determined by the past inflation rate. The marginal cost of production depends on the wage and the rental rate of capital. Similarly, wages also depend on past and expected future wages and inflation. Finally, the model is closed with a generalised Taylor-type rule, where the interest rate is set in function of the inflation and the theoretically consistent output-gap (output in deviation from the efficient flexible-price level of output). In what follows, we briefly describe the log-linearised version of the model.

The *consumption* equation:

$$
\begin{aligned}
c_t \;=\; & \frac{h}{1+h}c_{t-1} + \frac{1}{1+h}\mathbb{E}_t c_{t+1} - \frac{1-h}{(1+h)\,\sigma_c}\left(r_t - \mathbb{E}_t \pi_{t+1}\right) \\
& + \frac{\sigma_c - 1}{\sigma_c\left(1+\lambda_w\right)\left(1+h\right)}\left(l_t - \mathbb{E}_t l_{t+1}\right) + \epsilon_t^b
\end{aligned}
\tag{1}
$$

Consumption c_t depends on a weighted average of past and expected future consumption, the ex-ante real interest rate $\left(r_t - \mathbb{E}_t \pi_{t+1}\right)$, expected employment growth $\left(l_t - \mathbb{E}_t l_{t+1}\right)$ and a preference shock ε_t^b. h captures the degree of external habit formation in consumption and lies between zero and one. σ_c is the inverse of the intertemporal degree of substitution.

The *investment* equation:

$$
i_t = \frac{1}{1+\beta}i_{t-1} + \frac{\beta}{1+\beta}\mathbb{E}_t i_{t+1} + \frac{1/\varphi}{1+\beta}\left(q_t + \epsilon_t^i\right)
\tag{2}
$$

Investment i_t depends on past and expected future investment, the value of the existing capital stock q_t and an investment-specific technology process ε_t^i. β is the rate of time preference and φ is a parameter related to the elasticity of the investment adjustment costs.

The Q equation:

$$
q_t = \frac{1-\tau}{1-\tau+\bar{r}^k}\mathbb{E}_t q_{t+1} - \left(r_t - \mathbb{E}_t \pi_{t+1}\right) + \frac{\bar{r}^k}{1-\tau+\bar{r}^k}\mathbb{E}_t r_{t+1}^k
\tag{3}
$$

The value of the capital stock depends negatively on the ex-ante real interest rate, and positively on its expected future value, the expected rental rate r_{t+1}^k. τ stands for the depreciation rate and $\bar{r}^k$ for the steady-state rental rate of capital so that $\beta = 1/\left(1-\tau+\bar{r}^k\right)$.

The *capital accumulation* equation:

$$k_t = (1 - \tau) k_{t-1} + \tau i_{t-1} + \tau \varepsilon_{t-1}^i \tag{4}$$

The capital stock k_t depreciates with a rate τ.

The *inflation* equation:

$$\pi_t = \frac{\gamma_p}{1 + \beta \gamma_p} \pi_{t-1} + \frac{\beta}{1 + \beta \gamma_p} \mathbb{E}_t \pi_{t+1} + \frac{\left(1 - \beta \xi_p\right) \left(1 - \xi_p\right)}{\xi_p \left(1 + \beta \gamma_p\right)} \left[\alpha r_t^k + (1 - \alpha) w_t - \varepsilon_t^a\right] + \varepsilon_t^p \tag{5}$$

Inflation π_t depends on past and expected future inflation and on the current marginal cost, which itself is a function of the rental rate on capital, the real wage w_t and a productivity shock ε_t^a. $\left(1 - \xi_p\right)$ is the probability that prices can be reset in a given period while γ_p is the degree of indexation of prices to past inflation. ε_t^p is the shock in the price markup.

The *real wage* equation:

$$\begin{aligned}
w_t &= \frac{1}{1 + \beta} w_{t-1} + \frac{\beta}{1 + \beta} \mathbb{E}_t w_{t+1} + \frac{\gamma_w}{1 + \beta} \pi_{t-1} - \frac{1 + \beta \gamma_w}{1 + \beta} \pi_t + \frac{\beta}{1 + \beta} \mathbb{E}_t \pi_{t+1} \\
&\quad - \frac{\lambda_w \left(1 - \beta \xi_w\right) \left(1 - \xi_w\right)}{(1 + \beta) \left(\lambda_w + (1 + \lambda_w) \sigma_l\right) \xi_w} \left[w_t - \sigma_l l_t - \frac{\sigma_c}{1 - h} (c_t - h c_{t-1})\right] + \varepsilon_t^w \tag{6}
\end{aligned}$$

The real wage w_t is a function of expected and past real wages and the expected, current and past inflation rate where the relative weight depends on the degree of indexation γ_w to lagged inflation to the non optimised wages. $(1 - \xi_w)$ is the probability that wages can be reset in a given period, while γ_w is the degree of indexation of wages to past inflation. λ_w represents the demand elasticity for labour and σ_l is the inverse elasticity of labour supply. ε_t^w is the shock in the wage markup.

The *labour demand* equation:

$$l_t = -w_t + (1 + \psi) r_t^k + k_{t-1} \tag{7}$$

Labour demand l_t depends negatively on the real wage (with a unit elasticity) and positively on the rental rate of capital and last period's capital stock. ψ is the inverse of the elasticity of the capital utilisation cost function.

The *goods market equilibrium condition*:

$$\begin{aligned}
y_t &= (1 - \tau k_y - g_y) c_t + \tau k_y i_t + \varepsilon_t^g + \bar{r}^k k_y \psi r_t^k \\
&= \phi \left(\epsilon_t^a + \alpha k_{t-1} + \alpha \psi r_t^k + (1 - \alpha) l_t\right) \tag{8}
\end{aligned}$$

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where k_y is the steady state capital-output ratio, g_y the steady-state government spending-output ratio and ϕ is one plus the share of the fixed cost in production. ε_t^g captures a government spending shock.

The *monetary policy reaction function*:

$$
\begin{aligned}
r_t = {} & \rho r_{t-1} + (1-\rho)\left[r_\pi \pi_{t-1} + r_y\left(y_{t-1} - y_{t-1}^n\right)\right] + r_{\Delta \pi}\Delta \pi_t \\
& + r_{\Delta y}\Delta\left(y_t - y_t^n\right) + \varepsilon_t^r
\end{aligned} \tag{9}
$$

The monetary authorities follow a generalised Taylor-type rule by gradually responding to lagged inflation and the lagged output gap, defined as the difference between actual y_t and natural output y_t^n.[3] The degree of interest rate smoothing is captured by the parameter ρ. In addition, policy rates also respond to current changes in inflation and the output gap. Finally, we assume that there is an interest rate shock ε_t^r.

{Insert Figure 2}

The model contains seven identified exogenous driving forces, which are assumed to be orthogonal to each other.[4] We assume that all exogenous disturbances follow AR(1) processes: $\varepsilon_t^\varsigma = \rho_\varsigma \varepsilon_{t-1}^\varsigma + \eta_{\varsigma,t}$, $\varsigma = a,b,g,i,r$, with the exception of the price and wage mark-up disturbances which follow an ARMA(1,1) process. The latter assumption allows us to better capture the high-frequency fluctuations in inflation and real wages. We employ Bayesian methods to estimate the log-linearised models, using quarterly euro area and US data over the period 1985:1 through 2004:4. The euro area data come from the AWM database compiled by Fagan, Henry and Mestre (2005), and the US data come from the FREDII database. In particular, we treat seven aggregate variables as directly observed: real consumption growth, real investment growth, real GDP growth, real wages growth, hours worked, GDP price inflation, and the short-run interest rate.[5] In order to avoid having to choose a particular detrending method (linear, quadratic, or HP-filter), we use first-differenced real variables. The data used are shown in Figure 2. The prior distribution is summarized in Table 1 and discussed in more details in Smets and Wouters (2003, 2005). The discount factor β is set at 0.99, the quarterly depreciation rate τ is set at 0.025, the share of consumption $(1 - \tau k_y - g_y)$ (resp. investment, τk_y) is 0.57 (resp. 0.21) for the euro area and 0.67 (resp. 0.16) for the United States. The capital-income share in the production function, α is set at 0.29 for the EA and 0.24 for the US. Table 1 also contains the median and the 5 and 95 percent confidence set of all the structural parameters.[6]

{Insert Table 1}

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3   The role of the reaction function

In this section we first focus on the estimated reaction function in the euro area and the United States. We then investigate whether differences in the reaction function can account for the different interest rate behaviour. The lower section of Table 1 compares the full-sample estimation results of the parameters in the monetary policy reaction function. A few differences are worth noting. First, it does turn out that the degree of interest rate smoothing is higher in the euro area than in the United States. The interest-rate-smoothing parameter is 0.87 in the euro area compared to 0.82 in the United States. This implies that on average it takes almost two years for the euro area interest rate to adjust to the target rate, while the corresponding period is five and a half quarters for the US rate. In addition, the persistence of the monetary policy shocks is estimated to be somewhat higher in the euro area (0.55) compared to the US (0.46). Second, the response to inflation is estimated to be lower in the euro area both in the short and the long run, while the response to the output gap is marginally stronger. The latter difference is, however, not significant.

Of course, one may argue that the estimated reaction function is not representative of the ECB's behaviour as the ECB only started operations in 1999. One way of assessing whether this is indeed the case is by investigating whether the monetary policy shocks were larger and more systematic in the last six years of the sample. Figure 3 plots the actual short-term interest rate in the euro area and its counterfactual path when the monetary policy shocks (i.e. the residuals to the reaction function or the non-systematic part of monetary policy behaviour) are put equal to zero since 1999. It is immediately clear that both paths are very similar, suggesting that the ECB's behaviour since the start of EMU in 1999 is not very different from the average estimated behaviour over the longer sample period from 1985 till 2004. Overall, interest rate setting over the EMU period appears to have been somewhat looser than suggested by the estimated reaction function, but the deviations are generally small and approximately zero towards the end of 2004.

{Insert Figure 3}

Are the differences in estimated reaction coefficients reported above large enough to account for the different interest rate behaviour since 1999? Figure 4 provides an answer by comparing the actual euro area interest rate path with the counterfactual path that would have prevailed if the ECB had followed the reaction function estimated for the Fed. In this case, both the shocks and the structure of the economy are the ones estimated for the euro area, but the euro area's reaction function is replaced by the one estimated for the US

economy. Figure 4 makes clear that differences in the estimated reaction function can not explain the less "activist" behaviour of the ECB. In contrast, it is interesting to note that under the Fed's reaction function, the short-term interest rate would, if anything, have been even flatter. In this exercise, the rate would have fallen by less since its peak at the end of 2000 and as a result would have been about 1 percentage point higher towards the end of the sample. The main reason for this appears to be the stronger response to inflation in the Fed's estimated reaction function. As a result, the interest rate gap starts opening up in 2001 when the euro area is hit by a number of positive cost-push shocks pushing up inflation.

{Insert Figure 4}

One preliminary conclusion is therefore that differences in policy behaviour do not appear to have played an important role in explaining the different interest rate setting. At this stage, it is however worth mentioning a major caveat. The estimated reaction coefficients not only reflect differences in the objectives of the central bank, but may also reflect differences in the structure of the economy and the sources of the shocks. Using reduced-form reaction functions it is impossible to distinguish between both. It would be possible, if central bank behaviour was modelled as minimising an explicit loss function. We leave this for future research. We now turn to the role of structure and shocks.

4   The role of economic structure

The comparison of the estimates of the structural parameters (such as the intertemporal elasticity of substitution) of the economy in both areas confirms previous conclusion that it is difficult to detect significant differences between the two areas (Smets and Wouters, 2005). Overall, the estimates are quite similar but the euro area economy appears to be a bit more rigid. The most significant differences concern the habit formation parameter and the probability of price stickiness. The habit formation parameter is estimated to be 0.71 in the euro area and 0.63 in the United States. However, when this is translated in the reduced-form coefficient on lagged consumption in the consumption equation (see equation (1)), this difference translates into a difference of only 0.03. The implied estimated coefficient on lagged consumption is 0.41 in the euro area and 0.38 in the United States. The higher estimated degree of price stickiness in the euro area is consistent with the evidence reported in Altissimo, Ehrmann and Smets (2006), which summarizes the evidence on price stickiness at the micro level from the Eurosystem's Inflation Persistence Network. It translates in a

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significantly lower estimate of the slope of the New Keynesian Phillips curve in the euro area (0.008 versus 0.012). Altissimo *et al.* (2006) argue that a higher degree of price stickiness can imply a less agressive response of monetary policy to cost-push shocks for two reasons. First, with a high price stickiness a given change in the nominal interest rate will result in a larger change in the real rate and will therefore have a larger effect on output. Second, with higher price stickiness a credible central bank has a greater incentive to smooth out its policy response.

{Insert Figure 5}

In order to illustrate the impact of the estimated differences in structural parameters, Figure 5 shows the response of output, inflation and the nominal interest rate to a monetary policy shock in two counterfactual cases and compares them with the benchmark case of the estimated euro area model. In the first case, the two structural parameters discussed above are replaced by their US counterparts. In the second case, all structural parameters are replaced by the US estimates. Both cases basically give the same results. It is clear that the less rigid structure of the US economy implies a stronger response of output and inflation to a monetary policy shock. Similar behaviour prevails in response to other shocks.

{Insert Figure 6}

These differences are, however, quite small. As a result, it is unlikely that they can explain the different interest rate behaviour. Figure 6 confirms this conjecture. It plots the counterfactual euro area interest rate if the structural parameters of the euro area economy were identical to those of the US economy, keeping the policy reaction function and the source of the shocks the same. It is difficult to see any difference in the implied interest rate setting.

5   The role of shocks

Finally, given that differences in neither the reaction function nor economic structure appear to provide a convincing argument for the different policy behaviour, it remains that the size and the source of the shocks to the economy must be an important factor. This is indeed what is shown in Figure 7. In this counterfactual exercise, the stochastic process governing the structural shocks are changed to that estimated for the US economy. As a result, the counterfactual euro area interest rate comes close to the actual path observed for the federal funds rate. Remaining differences are mostly due to the different starting point and the different reaction function.

{Insert Figure 7}

It is therefore worthwhile to investigate somewhat deeper the estimated sources of the shocks. Figure 8 plots a four-quarter moving sum of each of the seven estimated shocks in the euro area and the United States. Figure 9 shows a historical decomposition of the euro area and US annual growth rates, GDP inflation and nominal interest rate.

{Insert Figure 8}

A number of interesting findings can be highlighted. Let us first focus on the developments in annual output growth (first row of Figure 9). First of all, on average supply developments were less favourable in the euro area than in the US.[7] In the US, total factor productivity developments were significantly positive during most of the period since the beginning of 2001, whereas in the euro area no such positive developments can be detected. Moreover, the euro area was hit by more significant positive price mark-up shock (corresponding to the increase in food and oil prices) in the 2001-2002 period, implying a negative impact on output. This development is partly offset by a persistently positive development in the euro area labour market. The wage mark-up is systematically below what could be expected based on the fundamentals of the economy. Overall, this contributes to a negative contribution of supply shocks to euro area growth in 2000 and 2001 and a positive contribution of supply shocks to US growth primarily since 2001. Second, as is clear from Figure 9 most of the short-term variations (and in particularly the first recession of the millennium) appears to be due to demand shocks (consumption, investment and government spending shocks). From Figure 8, the high comovement of particularly the consumption and investment shocks in the euro area and the US is striking. At the same time, it is clear that the contribution of those shocks was larger in the US, explaining the deeper recession in the United States. Finally, it is interesting to see that also the monetary policy shocks appear to be highly correlated. In particular, both the Fed and the ECB appeared to lean against the recession by easing monetary policy by more than has usually been the case.

{Insert Figure 9}

Turning to inflation developments, it is clear that most of the short-term variations are driven by the supply shocks and, in particular, the price mark-up shocks. In addition to changes in profit margins, the price mark-up shocks may reflect a number of other factors including changes in volatile prices such as food and energy and changes in inflation expectations due to learning or imperfect credibility. The contribution of the demand shocks to

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inflation is more pronounced in the US than in the euro area consistent with the finding of higher price stickiness in the euro area. In both areas the contribution of monetary policy to inflation was positive over the 1999-2004 period.

Finally, the lower panel of Figure 9 shows that most of the difference in policy behaviour between the ECB and the Fed is due to the difference in demand shocks. While those shocks appear to be highly correlated across the two areas, they were larger in the United States. Overall, this appears to be the most important reason for why the amplitude of the US short-term interest rate cycle was greater than that of the euro area rate.[8]

6 Comparing the development in the natural real interest rate

Up to now, we have taken the estimated reaction functions as given. While this may be useful as a description of actual policy behaviour, it is also interesting to take a more normative perspective. One tool for doing so is to compute the flexible-price-and-wage level of the real interest rate. Figure 10 compares the evolution of the actual and natural real rate in the euro area and the US using the lens of the New Keynesian models. In the euro area, the actual estimated real interest rate has fallen from its peak close to 4% in the last quarter of 2000 to a level somewhat below 2% at the end of 2004. In the United States, in contrast, the fall in the actual estimated real rate has been more prominent and is estimated to be zero at the end of 2004. The natural rate broadly followed the same pattern as the actual real rate (rising during the 1999-2000 period and falling since then), but it is more volatile than the actual rate. In both currency areas, the natural real rate is higher than the actual rate in 1999 and 2000 and falls below the actual real rate from 2001 onward. The volatility of the natural real rate is higher in the United States compared to the euro area. In particular, what stands out is the large drop in the natural real rate during 2001. This drop is almost twice as high in the United States compared to the euro area and corresponds to large negative investment (and to a less extent consumption) shocks noted in this period. Towards the end of the sample period, the gap between the estimated actual and natural rates appears to be closed.

{Insert Figure 10}

What shocks drive this gap? Figure 11 presents a historical decomposition of the real interest rate gap over the EMU period. In both areas, monetary policy shocks have contributed to closing the gap. In the euro area demand developments appear to play a relatively more

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important role than supply developments. In the United States both contributed to the negative gap before 2000 and the positive gap after 2000.

{Insert Figure 11}

7 Conclusion

In this paper, we run counterfactual exercises using DSGE models of the euro area and the United States to explore various explanations for the different interest rate policies implemented by the ECB and the Fed. We show that the differences in the type, size and persistence of exogenous shocks can largely explain the different interest rate setting in the euro area relative to the U.S. responses.

We treated the United States and the euro area as closed economies. An interesting extension would be to perform a similar exercises in a two-country model that allows for common shocks and interaction between the two central banks.

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Notes

[1]A similar exercise focusing on explaining differences in growth rates in the euro area and the United States is performed in Christiano, Motto and Rostagno (2005).

[2]It is a slightly modified version of the structural models presented in Smets and Wouters (2003, 2005). The main difference is that the number of shocks has been reduced to seven to match the number of observed variables in estimation.

[3]Natural output (or the target level of output for the central bank) is defined as the counterfactual level of output that would prevail under flexible prices and wages. When calculating the target level of output we assume that the price and wage mark-up shocks do not affect potential output. Alternative assumptions imply a deterioration of the empirical fit of the model. For example, assuming that the wage mark-up shock is a labour supply shock and does affect the target level of output leads to a deterioration of the marginal likelihood by about thirty points in both areas.

[4]In contrast to Smets and Wouters (2003, 2005), the estimated model no longer contains an equity premium shock, a labour supply shock and an inflation target shock. The equity premium and inflation target shock turned out to be unimportant for the empirical performance of the model. As a result, it is assumed the central bank pursues a constant inflation objective. The labour supply and wage mark-up shock are combined in one more general wage mark-up disturbance.

[5]Following Smets and Wouters (2003), an ad-hoc Calvo-type employment adjustment equation is used for the euro area to translate hours worked into the employment series used in estimation.

[6]A technical appendix available upon request contains further details of the estimated models and their fit. Smets and Wouters (2003) show that the model's forecasting performance compares relatively well with that of VARs.

[7]The supply developments capture the effects of three supply shocks: the total factor productivity shock, the price mark-up shock and the wage mark-up shock. These are called supply shocks because they lead to opposite movements in output and inflation.

[8]A technical appendix available upon request shows that these findings are robust to changes in the estimated parameters due to looser priors on the "auxiliary" parameters of the shock processes, to different definitions of the output gap in the policy rule and to the re-introduction of an inflation target shock in the policy rule.

Table 1. Prior and Posterior Distribution for the Parameters (1985:1-2004:4)

| | Prior Distribution | | | Posterior Distribution | | | | | |
| | | | | Euro Area | | | United States | | |
	Type	Mean	S.E.	5%	Median	95%	5%	Median	95%
σ productivity shock	inverse gamma	0.250	2.000	0.427	0.536	0.651	0.357	0.412	0.466
σ preference shock	inverse gamma	0.250	2.000	0.067	0.103	0.140	0.064	0.104	0.152
σ government spending shock	inverse gamma	0.250	2.000	0.289	0.334	0.375	0.389	0.450	0.504
σ investment shock	inverse gamma	0.250	2.000	0.484	0.576	0.681	0.233	0.316	0.394
σ monetary policy shock	inverse gamma	0.250	2.000	0.099	0.120	0.141	0.089	0.105	0.122
σ price markup shock	inverse gamma	0.250	2.000	0.093	0.127	0.159	0.091	0.125	0.141
σ wage markup shock	inverse gamma	0.250	2.000	0.116	0.147	0.182	0.187	0.244	0.295
ρ productivity shock	beta	0.750	0.150	0.930	0.962	0.997	0.864	0.920	0.979
ρ preference shock	beta	0.750	0.150	0.552	0.690	0.828	0.435	0.658	0.837
ρ government spending shock	beta	0.750	0.150	0.956	0.981	1.000	0.958	0.977	0.997
ρ investment shock	beta	0.750	0.150	0.759	0.869	0.978	0.642	0.743	0.853
ρ monetary policy shock	beta	0.750	0.150	0.419	0.555	0.687	0.317	0.459	0.606
ρ price markup shock	beta	0.750	0.150	0.766	0.866	0.969	0.753	0.842	0.977
ρ wage equation shock	beta	0.750	0.150	0.956	0.978	0.997	0.711	0.821	0.950
φ price markup shock	beta	0.750	0.150	0.567	0.728	0.892	0.556	0.757	0.883
φ wage equation shock	beta	0.750	0.150	0.798	0.865	0.932	0.505	0.668	0.854
φ investment shock	beta	0.750	0.150	0.614	0.773	0.924	-	-	-
Capital adjustment cost	normal	5.000	2.000	5.675	8.301	10.680	4.930	7.691	9.928
σ consumption utility	normal	1.000	0.375	0.846	1.231	1.606	0.876	1.282	1.652
σ labour desutility	normal	2.000	0.500	1.425	2.204	2.948	1.619	2.361	3.099
h consumption habit	beta	0.700	0.100	0.606	0.707	0.821	0.500	0.629	0.764
λw	normal	0.500	0.150	0.230	0.499	0.766	0.234	0.486	0.722
Calvo wages	beta	0.750	0.050	0.709	0.772	0.850	0.681	0.760	0.833
Calvo prices	beta	0.750	0.050	0.872	0.912	0.956	0.846	0.887	0.924
Indexation wages	beta	0.500	0.150	0.206	0.405	0.628	0.187	0.425	0.654
Indexation prices	beta	0.500	0.150	0.090	0.229	0.357	0.117	0.307	0.474
Calvo employment	beta	0.500	0.150	0.684	0.723	0.772	-	-	-
Utilisation rate inv. elasticity	normal	0.200	0.100	0.298	0.440	0.575	0.240	0.376	0.523
Fixed costs	normal	1.250	0.125	1.282	1.462	1.621	1.326	1.484	1.654
Cste. inflation	normal	0.600	0.100	0.466	0.635	0.797	0.454	0.580	0.704
Cste. Interest rate	normal	0.600	0.100	0.523	0.646	0.783	0.482	0.595	0.721
Cste. Labour	normal	0.100	0.100	-0.032	0.027	0.089	-1.183	0.137	1.366
Trend	normal	0.400	0.100	0.210	0.315	0.430	0.401	0.452	0.499
ρ lagged interest rate	beta	0.750	0.100	0.817	0.869	0.933	0.768	0.818	0.865
ρ inflation	normal	1.500	0.250	1.186	1.529	1.859	1.531	1.831	2.170
ρ d(inflation)	normal	0.250	0.100	0.045	0.120	0.194	0.095	0.162	0.246
ρ output gap	normal	0.125	0.050	0.018	0.071	0.134	-0.010	0.064	0.113
ρ d(output gap)	normal	0.125	0.050	0.130	0.180	0.240	0.093	0.131	0.167

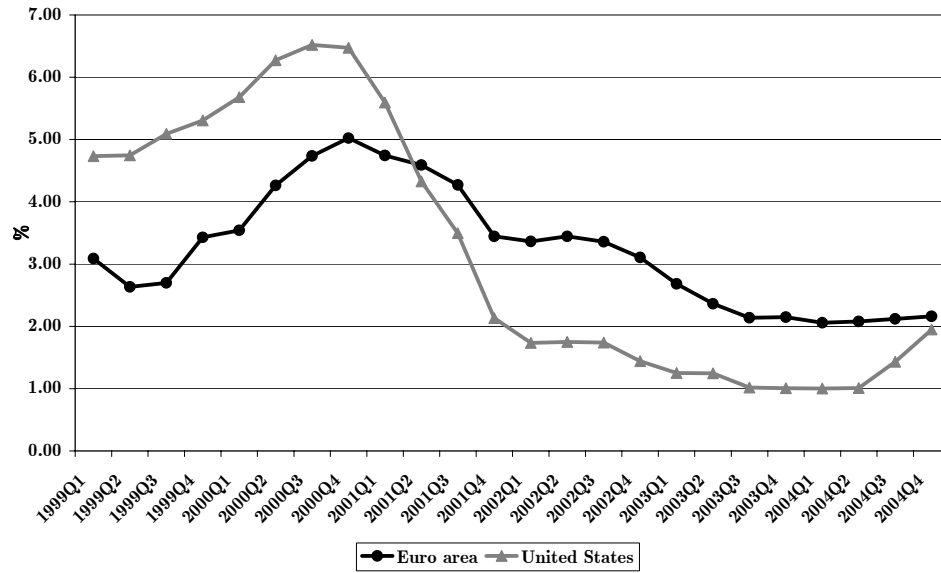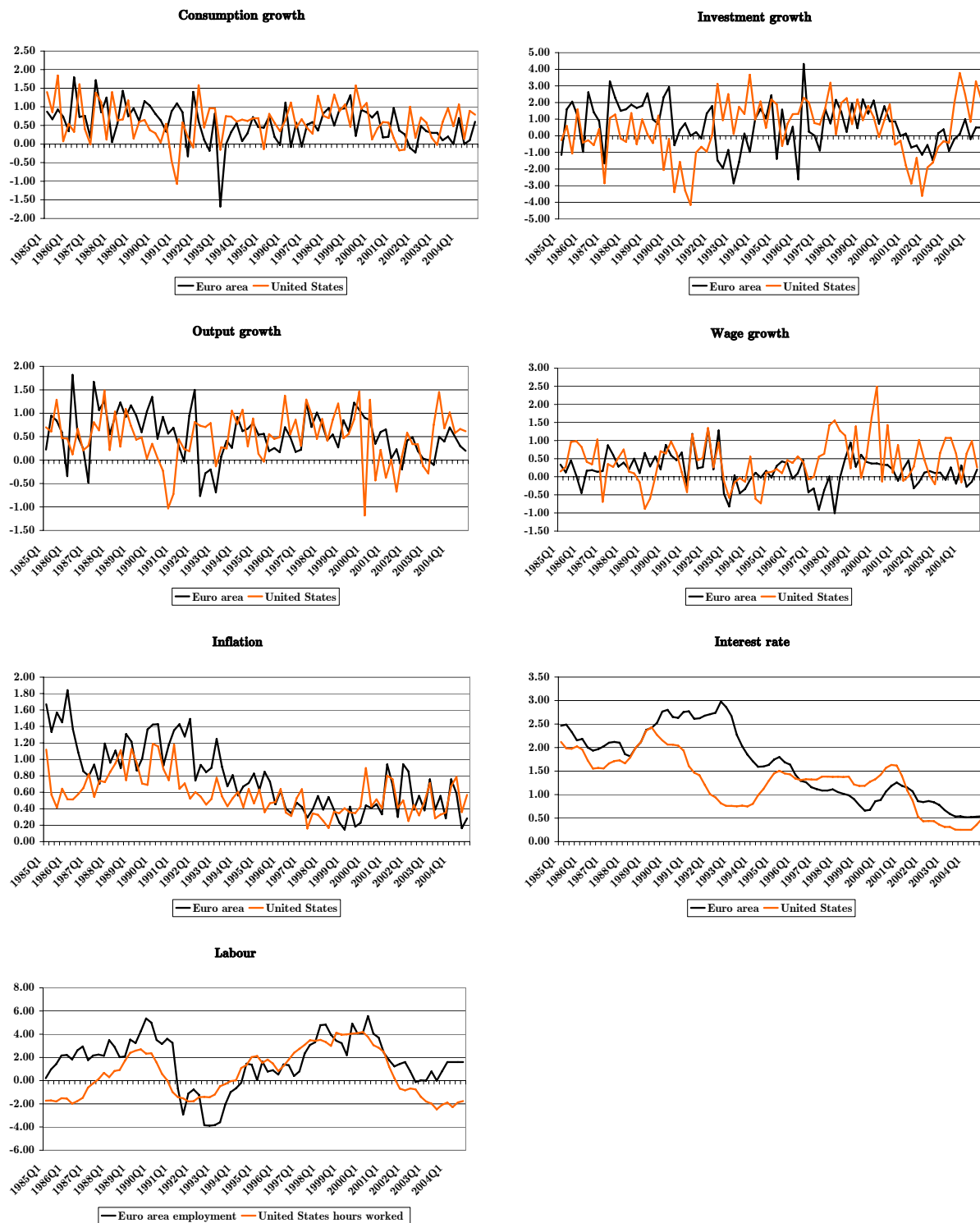Figure 1. Short-term interest rates in the euro area and the United States

Figure 2. Data

Consumption growth

Euro area —— United States

Investment growth

Euro area —— United States

Output growth

Euro area —— United States

Wage growth

Euro area —— United States

Inflation

Euro area —— United States

Interest rate

Euro area —— United States

Labour

Euro area employment —— United States hours worked

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Figure 3. The ECB interest rate setting with and without estimated monetary policy shocks
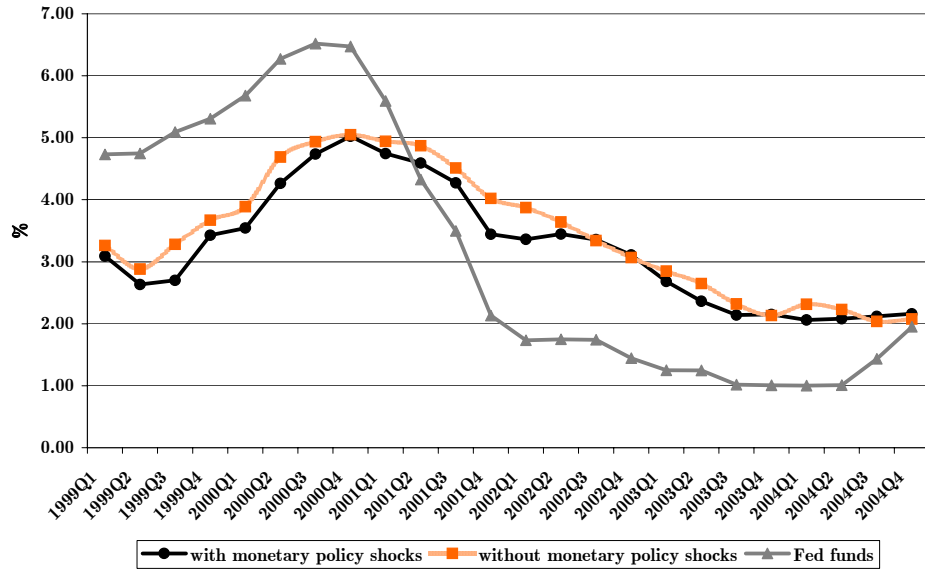
Figure 4. Counterfactual euro area interest rate setting with the Fed's reaction function
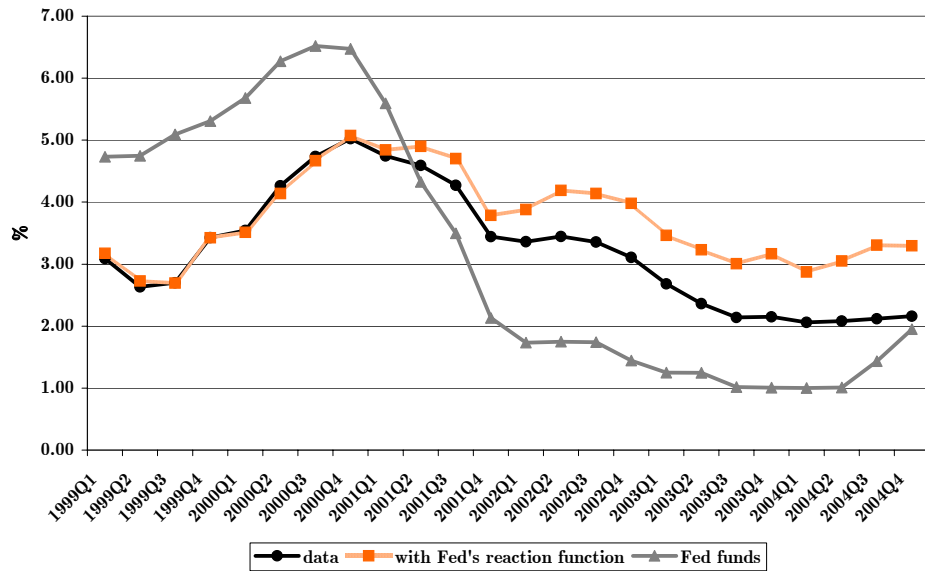
Figure 5. Monetary policy transmission with US structural parameters

Output

Inflation
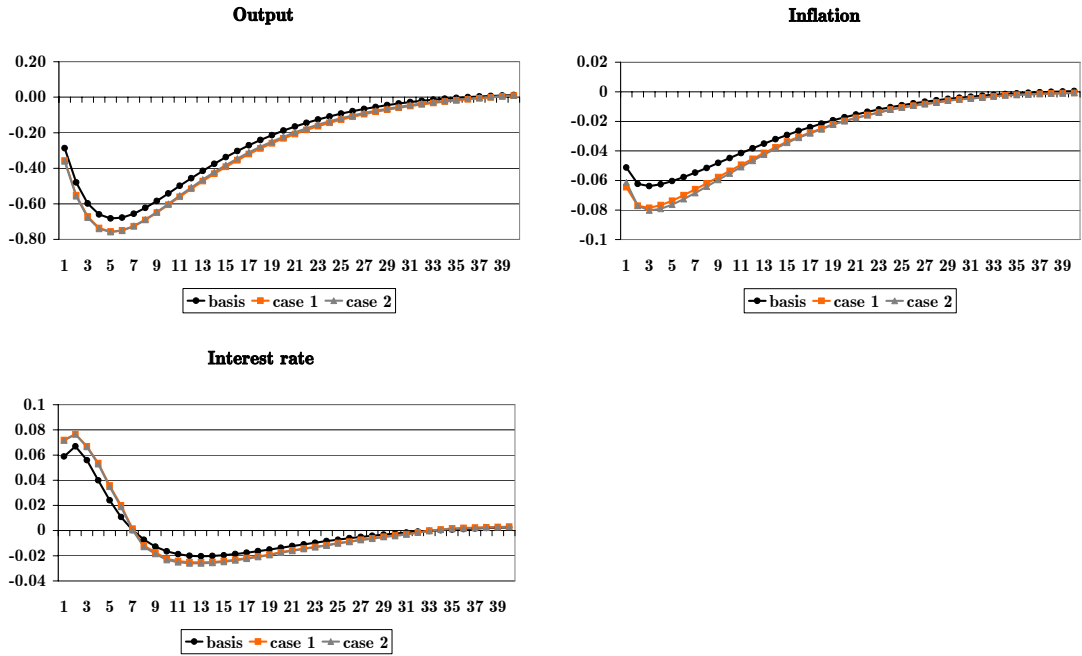
Interest rate

Figure 6. Counterfactual euro area interest rate setting with
US structural parameters
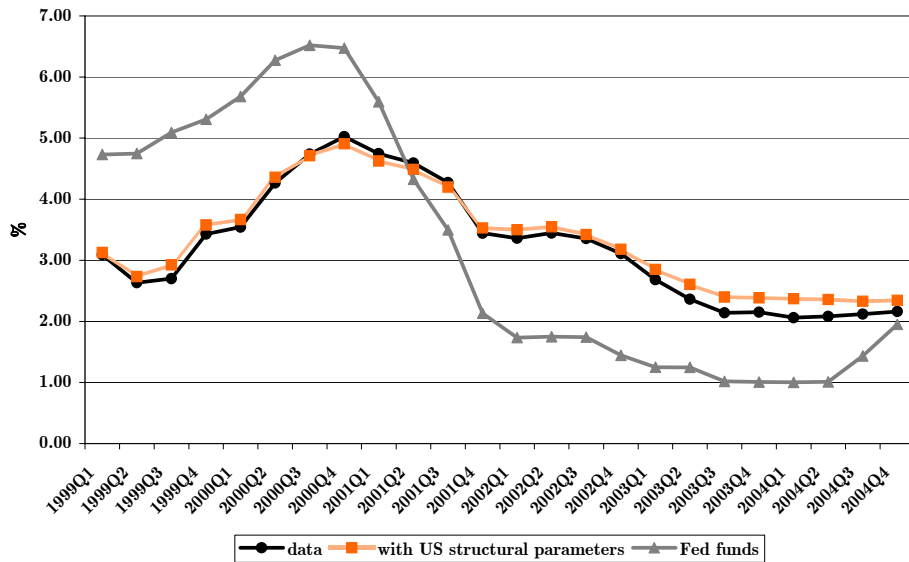
Figure 7. Counterfactual euro area interest rate setting with US shocks
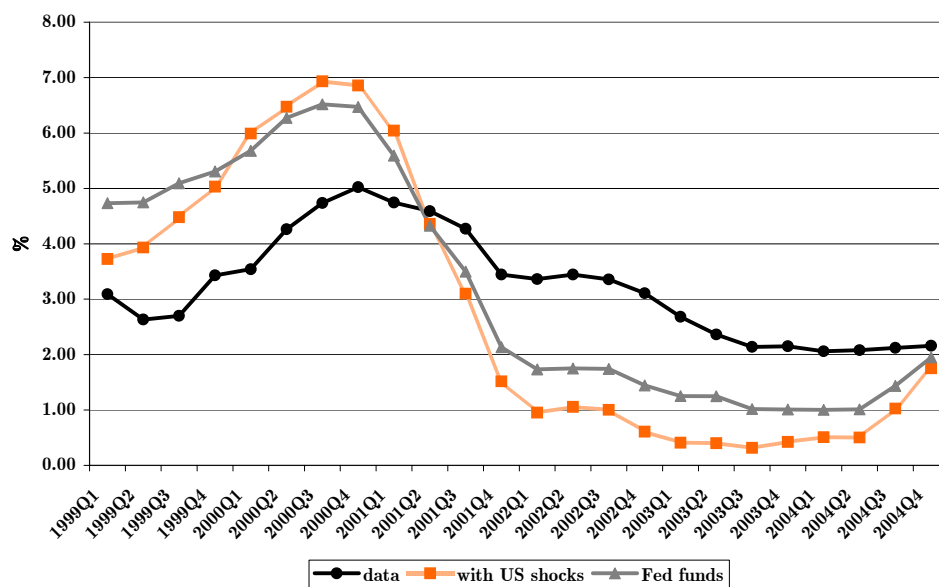
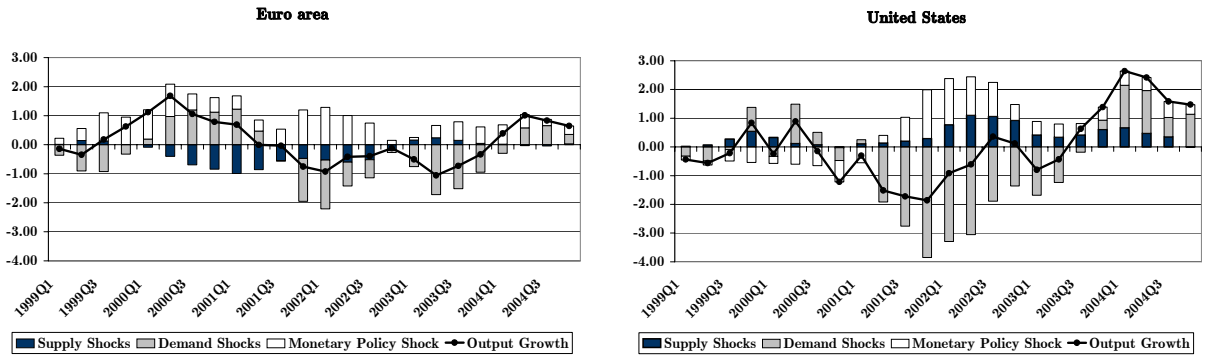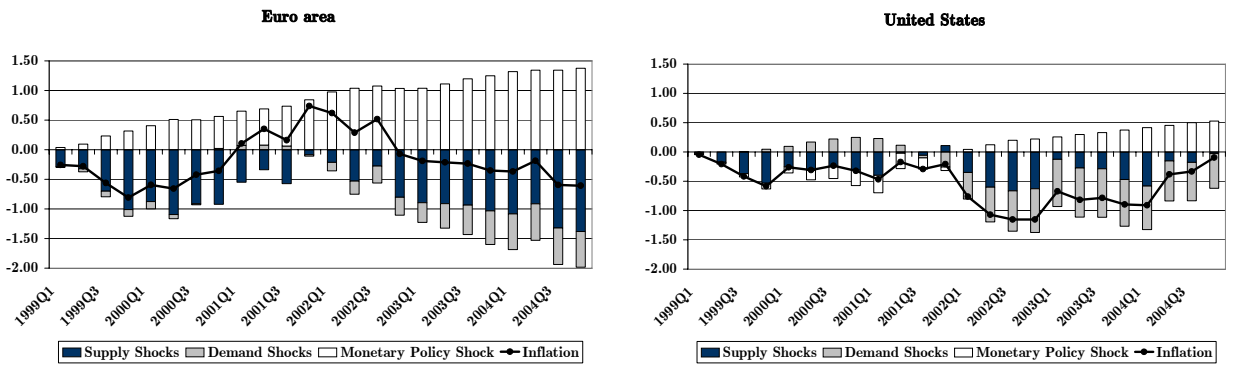Figure 8. Estimated shocks in the euro area and the US (1999-2004)

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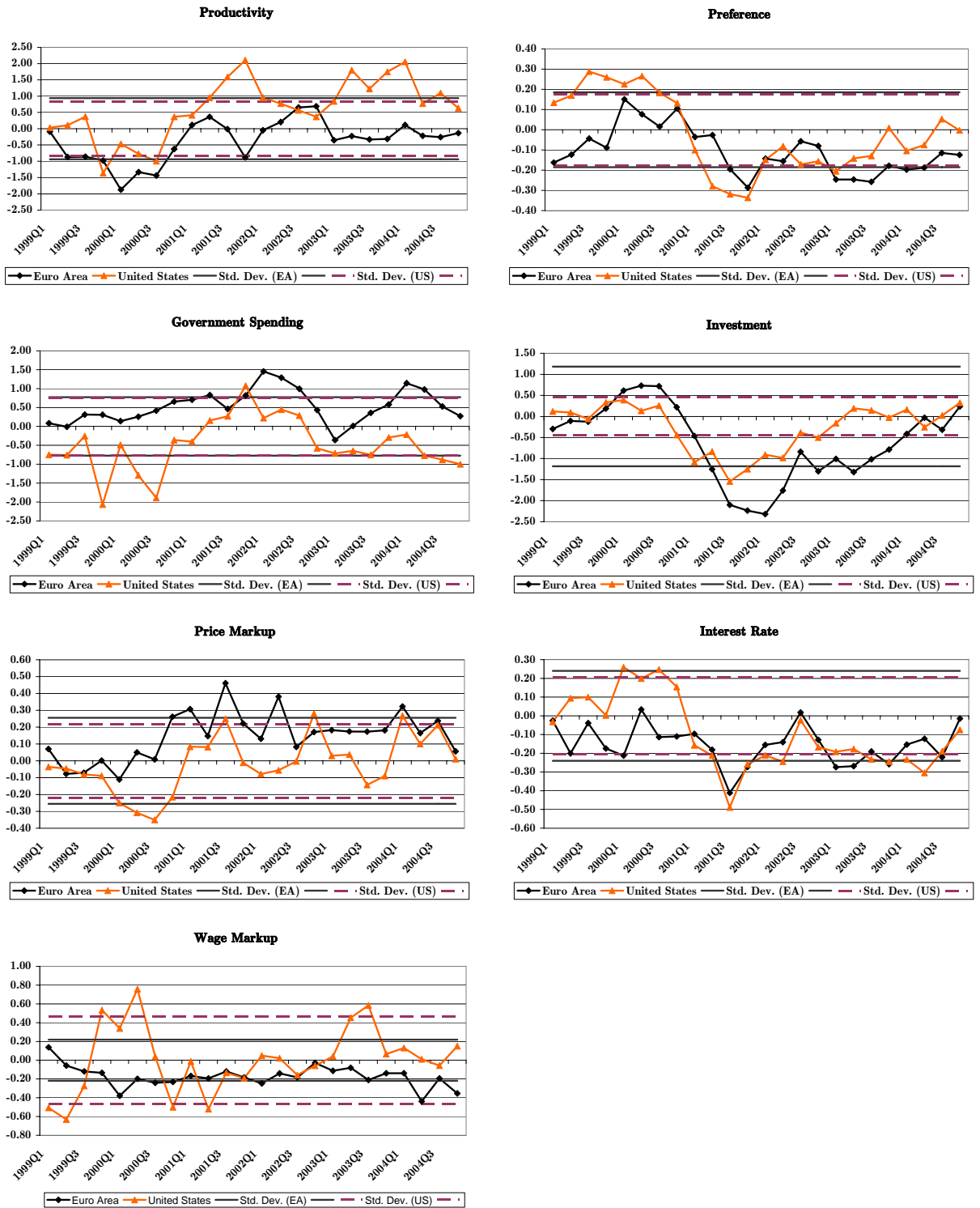
Figure 9. Historical decomposition of annual output growth, inflation and interest rate
in the EA and the US

Annual output growth

Euro area

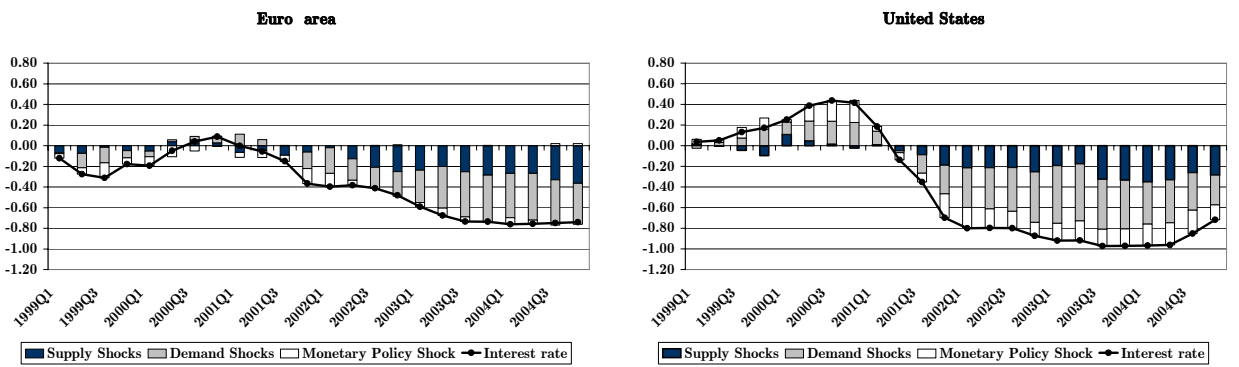United States

Inflation

Euro area

United States

Interest rate

Euro area

United States

Figure 10. Real interest rate in the EA and the US
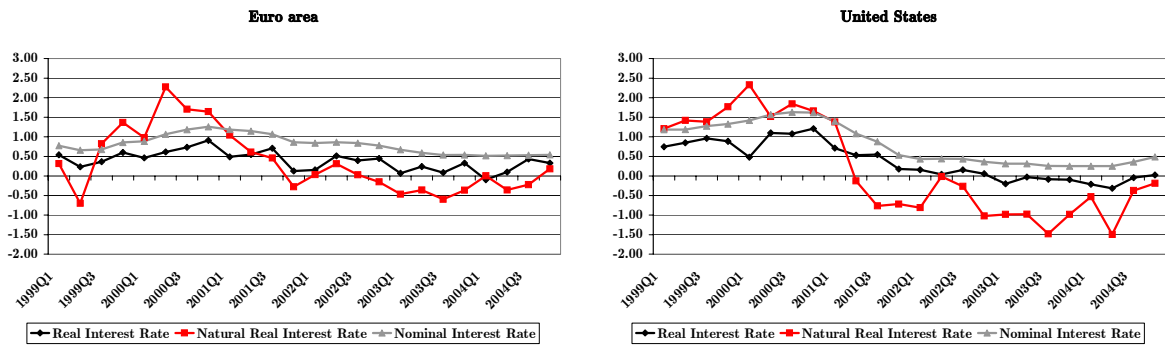
Euro area

United States

Figure 11. Historical decomposition of real interest rate gap in the EA and the US

Euro area

United States