Real-time data, professional forecasters and the output gap in an estimated New Keynesian model*

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Abstract

This paper analyses the real-time forecasting performance of the New Keynesian model of Gali, Smets and Wouters (2011) estimated on euro area data. It investigates to what extent forecasts of inflation, GDP growth and unemployment by professional forecasters improve the forecasting performance. Finally, it examines to what extent the output gap and its underlying structural shocks depend on the real-time nature of the data.

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1 Introduction

Following the seminal work of Croushore and Stark (2001) on constructing a real-time data set for the US economy, it has become standard to use real-time data when analysing the out-of-sample forecast performance

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of alternative empirical macromodels. Moreover, since Orphanides (2001), Orphanides and Van Norden (2002) and many others, it is well known that output gaps are measured with considerable error both because of important data revisions in GDP data and the presence of shock, parameter and model uncertainty in estimating potential output.[1] With a few exceptions much less real-time data analysis has been done on the euro area, partly because a comprehensive real-time euro area data set has only recently become available.[2]

This paper uses the European Central Bank (ECB) real-time data base (RTDB), described at length in Giannone, Henry, Lalik and Modugno (2010) and available on the ECB's website, to perform three types of analysis. First, we investigate the real-time forecasting performance of the model of Gali, Smets and Wouters (GSW, 2012) over the EMU period and compare it with two alternative non-structural linear models. The GSW model is a version of the model by Smets and Wouters (2003 and 2007) which has been shown to forecast reasonably well. It is therefore of interest to see to what extent these results are robust to the real-time nature of the underlying data in the euro area.

Second, we analyse to what extent the forecasts of euro area GDP growth, inflation and unemployment by professional forecasters (from the ECB's Survey of Professional Forecasters) help improving the forecast performance of the DSGE model. We consider two interpretations. Under the "noise " interpretation, the mean professional forecasts are assumed to be noisy indicators of the rational expectations forecasts implied by the DSGE model. Under the "news " interpretation, it is assumed that the forecasts reveal the presence of expected future structural shocks in line with those estimated over the past. This exercise is similar to the one performed by Del Negro and Schorfheide (2012) for the United States.

Finally, we examine the implications of the real-time nature of the data for the uncertainty of the model-consistent output gap. The GSW model is particularly suitable for studying the output gap as it explicitly includes unemployment as an observable variable. As argued in GSW, this allows to better distinguish between mark-up and labour supply shocks. This is im-

[1] See, for example, Croushore (2011) and the literature review on real-time data analysis compiled by Dean Croushore at https://facultystaff.richmond.edu/~dcrousho/docs/realtime_lit.pdf

[2] One exception is Coenen et al (2005). A more recent example is Coenen and Warne (2011).

portant because the implications for the welfare-relevant output gap of these two sources of fluctuations are very different. Variations in wage markup shocks are inefficient and a welfare-maximising government should be interested in stabilising output fluctuations resulting from those shocks (at least partially). In contrast, output and employment fluctuations driven by preference shocks shifting the labor supply schedule, should in principle be accommodated. Put differently, the relative importance of those two shocks will influence the extent to which fluctuations in output during a given historical episode should or should not be interpreted as reflecting movements in the welfare relevant output gap (i.e. the distance between the actual and efficient levels of output). This is indeed the model-consistent output gap that we examine in this paper. we investigate to what extent the real-time nature of the data affects the size and the source of the euro area output gap.

The rest of the paper is structured as follows. Section 2 presents the GSW model. Section 3 presents the real-time data base including the Survey of Professional Forecasts. Section 4 discusses the full-sample estimation results of the benchmark GSW model and provides a brief comparison with the findings for United States reported in GSW (2012). Section 5 contains the findings of the real-time forecast comparison exercise. Section 6 discusses the estimated output gap and its sources. Finally, Section 7 summarises the main findings and concludes.

2 The Gali-Smets-Wouters Model

2.1 Staggered Wage Setting and Wage Inflation Dynamics

This section describes the main features of the GSW model. The model is very similar to Smets and Wouters (SW, 2007). One main difference is that it models the labour supply decision on the extensive margin (whether to work or not), rather than on the intensive margin (how many hours to work). The model assumes a (large) representative household with a continuum of members represented by the unit square and indexed by a pair $(i, j) \in [0, 1] \times [0, 1]$. The first dimension, indexed by $i \in [0, 1]$, represents the type of labor service in which a given household member is specialized. The second dimension, indexed by $j \in [0, 1]$, determines his disutility from work. The latter is given by $\chi_t \Theta_t j^{\varphi}$ if he is employed, zero otherwise, where $\chi_t > 0$ is an exogenous preference shifter (referred to below as a "labor supply shock"), Θ_t is an endogenous preference shifter, taken as given by each individual household and defined below, and $\varphi \geq 0$ is a parameter determining the shape of the distribution of work disutilities across individuals.

Individual utility is assumed to be given by:

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

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

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

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

where $N_t(i) \in [0,1]$ denotes the employment rate in period t among workers specialized in type i labor and $\widetilde{C}_t \equiv C_t - h\overline{C}_{t-1}$.[3] We define the endogenous preference shifter Θ_t as follows:

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

where Z_t evolves over time according to the difference equation

[3] Alternatively, we can take the consumption utility of the household, $\log \widetilde{C}_t$, as a "primitive," without making any assumption on how that consumption is distributed among household members, possibly as a function of employment status.

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

Thus Z_t can be interpreted as a "smooth" trend for (quasi-differenced) aggregate consumption. Our preference specification implies a "consumption externality" on individual labor supply: during aggregate consumption booms (i.e. when $\overline{C}_t - h\overline{C}_{t-1}$ is above its trend value Z_t), individual (as well as household-level) marginal disutility from work goes down (at any given level of employment).

The previous specification generalizes the preferences assumed in SW by allowing for an exogenous labor supply shock, χ_t, and by introducing the endogenous shifter Θ_t, just described. The main role of the latter is to reconcile the existence of a long-run balanced growth path with an arbitrarily small *short-term* wealth effect. The latter's importance is determined by the size of parameter $\upsilon \in [0,1]$. As discussed in detail in GSW, that feature is needed in order to match the joint behavior of the labor force, consumption and the wage over the business cycle.

Note that under the previous preferences, the household-relevant marginal rate of substitution between consumption and employment for type i workers in period t is given by:

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

where the last equality is satisfied in a symmetric equilibrium with $\overline{C}_t = C_t$.

Using lower case letters to denote the natural logarithms of the original variables, we can derive the average (log) marginal rate of substitution $mrs_t \equiv \int_0^1 mrs_t(i)\, di$ by integrating over all labor types:

$$mrs_t = z_t + \varphi n_t + \xi_t$$

where $n_t \equiv \int_0^1 n_t(i)\, di$ is (log) aggregate employment and $\xi_t \equiv \log \chi_t$.

We assume nominal wages are set by "unions," each of which represents the workers specialized in a given type of labor, and acting in an uncoordinated way. As in Erceg et al (2002), and following the formalism of Calvo (1983), we assume that the nominal wage for a labor service of a given type can only be reset with probability $1-\theta_w$ each period. That probability is independent of the time elapsed since the wage for that labor type was last reset, in addition to being independent across labor types. Thus, and by the law of large numbers, a fraction of workers θ_w do not reoptimize their wage in any given period, making that parameter a natural index of nominal wage rigidities. Furthermore, all those who reoptimize their wage choose an identical wage, denoted by W_t^*, since they face an identical problem. Partial wage indexation between re-optimization periods is allowed for, by making the nominal wage adjust mechanically in proportion to past price inflation. Formally, and letting $W_{t+k|t}$ denote the nominal wage in period $t+k$ for workers who last reoptimized their wage in period t, we assume

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

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

When reoptimizing their wage in period t, workers (or the union representing them) choose a wage W_t^* *in order to maximize their respective households utility* (as opposed to their individual utility), subject to the usual sequence of household flow budget constraints, as well as a sequence of isoelastic demand schedules of the form $N_{t+k|t} = (W_{t+k|t}/W_{t+k})^{-\epsilon_{w,t}} N_{t+k}$, where $N_{t+k|t}$ denotes period $t+k$ employment among workers whose wage was last reoptimized in period t, and where $\epsilon_{w,t}$ is the period t wage elasticity of the relevant labor demand schedule.[4] We assume that elasticity varies exogenously over time, thus leading to changes in workers' market power.

The first order condition associated with the wage-setting problem can be written as:

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

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

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

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

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

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

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

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

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

is the (log) average wage markup, i.e. the log deviation between the average real wage and the average marginal rate of substitution. As equation (3) makes clear, variations in wage inflation above and beyond those resulting from indexation to past price inflation are driven by deviations of average wage markup from its natural level, because those deviations generate pressure on workers currently setting wages to adjust those wages in one direction or another.

2.2 Introducing Unemployment

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

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

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

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

Taking logs and integrating over i we obtain

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

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

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

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

Note that under our assumptions, the unemployed thus defined include all the individuals *who would like to be working* (given current labor market conditions, and while internalizing the benefits that this will bring to their households) *but are not currently employed.* It is in that sense that one can view unemployment as involuntary.[5]

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

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

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

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

Note that in contrast with the representation of the wage equation found in SW and related papers, the error term in (8) captures exclusively shocks to the wage markup, and *not* preference shocks (even though the latter have been allowed for in our model). That feature, made possible by reformulating the wage equation in terms of the (observable) unemployment rate, allows us to overcome the identification problem raised by Chari et al (2007) in their critique of New Keynesian models.

Finally, note that we can define the *natural* rate of unemployment, u_t^n, as the unemployment rate that would prevail in the absence of nominal wage

[5] As noted by one of our discussants, unemployed individuals will enjoy a higher utility ex-post, since their consumption will be the same but won't experience any disutility from work. This is, of course, an unavoidable consequence of our assumption of full consumption risk-sharing within the household. Under the latter assumption, and given the infinitesimal weight of each individual in the household, not internalizing the benefits to the latter of an individual's employment would unavoidably lead to no participation.

rigidities. Under our assumptions, that natural rate will vary exogenously in proportion to the natural wage markup, and can be determined using the simple relation:

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

2.3 The rest of the model

The remaining equations describing the log-linearized equilibrium conditions of the model are identical to a particular case of the specification in SW (2007), corresponding to logarithmic consumption utility. In addition to the wage markup and labor supply shocks discussed above, the model includes six additional shocks: a neutral, factor-augmenting productivity shock ($\widehat{\varepsilon}_t^a$), a price markup shock ($\widehat{\varepsilon}_t^p$); a risk premium shock ($\widehat{\varepsilon}_t^b$), an exogenous spending shock ($\widehat{\varepsilon}_t^g$), an investment-specific technology shock ($\widehat{\varepsilon}_t^q$) and a monetary policy shock ($\widehat{\varepsilon}_t^r$).

- Consumption Euler equation:

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

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

- Investment Euler equation:

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

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

- Value of the capital stock:

$$\widehat{Q}_t^k = -(\widehat{R}_t - E_t[\widehat{\pi}_{t+1}] - \widehat{\varepsilon}_t^b) \ + \ q_1 E_t[r_{t+1}^k] + (1-q_1)E_t[Q_{t+1}^k]$$

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

- Aggregate demand equals aggregate supply:

$$\begin{aligned} \widehat{y}_t &= \frac{c_*}{y_*}\widehat{c}_t \ + \ \frac{i_*}{y_*}\widehat{i}_t \ + \ \widehat{\varepsilon}_t^g \ + \frac{r_*^k k_*}{y_*}\widehat{u}_t \\ &= \mathcal{M}_p \ (\ \alpha \widehat{k}_t \ + \ (1-\alpha)\widehat{h}_t + \widehat{\varepsilon}_t^a) \end{aligned}$$

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

- Price-setting under the Calvo model with indexation:

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

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

- Capital accumulation equation:

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

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

- Optimal capital utilisation condition:

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

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

- Optimal capital/labor input condition:

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

- Monetary policy rule:

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

with $ygap_t = \widehat{y}_t$ - $\widehat{y}_t^{flex}$, the difference between actual output and the output

in the flexible price and wage economy in absence of distorting price and wage markup shocks.

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

As productivity is written in terms of hours worked, we also introduce an auxiliary equation to link observed employment to unobserved hours worked as in SW (2003):

$$\widehat{l}_t - l_{t-1} = E_t l_{t+1} - l_t + \lambda_0 (h - l)$$

3 The Euro Area Real-time Data Base (RTDB)

Following GSW(2011), we estimate the DSGE model using eight macroeconomic time series for the euro area: real GDP, consumption, investment, employment, unit labour costs, GDP deflator, the Euribor rate and unemployment, with the first six log differenced. Real-time vintages of these data are available for downloading from the ECB's Statistical Data Warehouse and described in Giannone et al (2010). The frequency of the vintages is monthly corresponding to their publication in the ECB's Monthly Bulletin and the first vintage starts in January 2001. The latest available vintage we use in this paper is March 2011.

Table 1 presents the time flow of data releases available for the RTDB and the Survey of Professional Forecasters. We take the vintage of the last month of the quarter, in order to convert the monthly vintages into a quarterly vintage. As is clear from the Table, this implies that monthly unemployment and HICP inflation are available for the first month of the quarter, whereas the monthly interest rate is available for the first and second month of the quarter. As we need the full quarter of monthly observations to construct the quarterly observation, we ignore the partial information available during the quarter. This implies that quarterly unemployment, HICP inflation and the interest rate are observed with a one quarter lag. Using the vintage of the last month in the quarter implies that the quarterly series are also typically available with one lag, with the exception of employment and wage compensation which are only available with a two quarter lag. In the forecasting exercises of Section 5, we will use the method of Waggoner and Zha (1999) to nowcast employment and wages based on information during the same quarter on real GDP and the other variables.

Each monthly data vintage from the RTDB typically only covers data starting in the mid 1990s. To extend the real-time data backwards, we make use of updates of the quarterly database constructed for estimating the Area-Wide Model (AWM). Since 2000 there have been ten AWM database updates.[6]

Figures 1 to 3 plot the first release and the first annual revision of real GDP growth, GDP deflator inflation and the unemployment rate (left panel), as well as the difference between the first release and the first annual revision

[6] See Fagan et al (2000)

(right panel). The standard deviation of the annual revision in real GDP growth lies between 0.1 and 0.2 and is quite persistent. In the most recent recession, the downward revision was particularly large. The variability of the annual revision in inflation is of the same size but much less persistent. Finally, revisions in unemployment are the most persistent.

One source of revision in the euro area data set is the increasing number of EU countries being a member of the euro area. Over the estimation sample the euro area developed from 12 to 16 members: Updates 4, 5, and 6 cover the euro area 12 data and are taken from 2003, 2004, and 2006, respectively. The euro area 13 composition is available in update 7 from 2007, while the euro area 15 composition is available in update 8, dated 2008. The last two updates, 9 and 10, both cover the euro area 16 composition and were frozen in 2009 and 2010. The available files prior to update 7 are dated in September although the time they were frozen is unknown; the last 4 updates are all frozen at the beginning of August.

Table 1 also shows that the SPF forecasts for HICP inflation, real GDP growth and unemployment typically become available in the first month of the quarter. We associate this forecast with the quarter. The SPF data set contains average 1-year and 2-year ahead forecasts covering the period 1999Q1-2010Q4. Due to the different frequency and lags in the release of HICP inflation, real GDP and unemployment, the end date of the 1-year and 2-year ahead forecasts differs across the variables. For HICP inflation, the Q1-released 1-year ahead forecasts refers to annual inflation in December in the same year, the Q2-release refers to March in the following year, etc. For real GDP growth, the "1-year ahead forecast" in the Q1-release refers to annual growth in the third quarter of the same year, etc. Finally, for the unemployment rate the "1-year ahead" in the Q1-release refers to the unemployment rate in November the same year, the Q2-release to the rate in February next year, etc. If we take the release-quarters as the current date for these forecasts, then for HICP inflation and unemployement we may think of this as having 3 and 7-quarters ahead forecasts and for real GDP growth 2 and 6-quarters ahead forecasts.

The information set available to the professional forecasters is smaller than the RTDB available in the last month of the quarter, as last quarter's national account data are not available early in the quarter. On the other hand, it is clear that the professional forecasters have a lot more information available to nowcast the last quarter than the data we use from the RTDB. As a result, it is not clear whether the net information advantage is positive or negative.

4 Full-sample estimation results

In this section we first discuss the estimation results using the latest-vintage full sample data set and make some comparisons with those reported for the United States in GSW (2011). We estimate the model over the period 1985Q1-2010Q4 using Bayesian full-system estimation techniques as in SW(2003) and (2007). The period from 1980Q1 till 1984Q4 is used as training period.

Table 2 reports the parameter estimates. A few striking differences with the US results are worth mentioning.

First, the average unemployment rate over the 1985-2010 period is quite a bit higher in the euro area (about 9 percent) than in the United States (5 percent). In steady state, the unemployment rate is proportional to the wage mark-up and the labour supply elasticity. For the euro area, the wage mark-up is estimated to be quite a bit higher (around 50 percent) and the labour supply elasticity somewhat lower. In other words, labour supply responds less to changes in real wages in the euro area.

Second, the parameter, ν, governing the short-run wealth effects on labour supply, is quite small (0.06) as in the United States. Roughly speaking this amounts to a preference specification closer to that in Greenwood, Hercowitz and Huffman (1988), in which the wealth effects are close to zero in the short run. As discussed at length in GSW, this helps ensure that not only employment, but also the labour force moves procyclically in response to most shocks.

Third, turning to some of the other parameters that enter the price and wage Phillips curve, the euro area economy appears to be much more sticky than the US economy. The estimated degree of price and wage indexation is relatively small (around 0.25) in both areas, but the estimated Calvo probability of unchanged wages and prices are quite a bit higher. The average wage contract duration is about 4 quarters, whereas the average duration of unchanged prices is higher than six quarters. This is consistent with some of the micro evidence on price and wage adjustment.

Fourth, it is worth pointing out that the monetary policy reaction coefficient to the output gap (defined as the deviation relative to the constant markup output) is quite high (0.19), whereas the coefficient on inflation is quite a bit lower (though higher than one).

Finally, focusing on the volatility and persistence of the eight structural shocks, the striking difference is that the risk premium shock is much more persistent in the euro area, whereas the investment-specific technology shock is much less persistent.

Overall, the estimation results for the euro area point to a less flexible economy with more persistence in the effects of various shocks on economic activity, prices and unemployment. This is also clear from Figures 4 to 6, which show the estimated impulse responses of output, inflation, the real wage, the interest rate, employment, the labour force, the unemployment rate, and the output gap to the eight structural shocks.

Before turning to the real-time forecasting results, it is also worth discussing briefly the forecast error variance decomposition at the 10 and 40 quarter horizon (Table 3). At the business cycle frequency about half of the fluctuations in output are driven by demand shocks and particularly the risk premium shock. The risk premium shock explains almost two thirds of the movement in unemployment at the 2.5 year horizon. The monetary policy shock another 12 percent. The most important shock driving output is the productivity shock. Price inflation is mostly driven by the price mark-up shock (61 percent) and the wage mark-up shock (17 percent).

In the longer run (after ten years), the role of wage mark-up shocks becomes more important in driving both unemployment and inflation. This is, however, much less so than in the United States where those shocks account for between 60 and 80 percent of the movements. The role of demand shocks in explaining real output and unemployment falls somewhat in the longer run, but remains much more important than in the US. Productivity shocks become relatively more important. In the longer run, inflation is mostly driven by price and wage mark-up shocks.

These full-sample estimation results are very similar when we re-estimate the model using the SPF forecasts as noisy indicators of the model-consistent expectations (see Section 5). We find that the estimates of the standard deviation of the iid normal measurement error are relatively large: 0.76 for expected annual real GDP growth, 0.32 for expected GDP deflator inflation and 0.60 for the expected unemployment rate.

5 Real-time forecasting performance

In this section we evaluate the real-time forecasting performance of the GSW model over the EMU period and compare it with five alternative models. Each of these models is re-estimated on an annual basis from the first RTDB vintage in 2001Q1 onwards; i.e. the second estimation is done in 2002Q1 and so on. We compute forecasts for one to four quarters ahead. The forecasts are conditional on the data observed in the last historical period, where the available information in that period is used to backcast the variables that are missing in that period (typically employment and wage compensation). For example, the RTDB vintage 2001Q1 forecasts are computed for 2000Q4-2001Q4 with conditioning assumptions for 2000Q4 based on the historical data available for that quarter. Conditional forecasts are calculated using the Waggoner-Zha (1999) approach.

One question in real-time forecast evaluation exercises is which actual data to use to evaluate the forecast against and to calculate the forecast errors. As is common in the literature, we use the first annual revision of the data (as in Figures 1 to 3). We have checked the robustness of our findings against two possible alternatives for the actual data: (1) the first release data and (2) latest vintage data. Overall, the results are very similar.

We compare the GSW model with five alternative models. The two competing non-structural models are the random-walk model and a BVAR model using the same eight variables. The BVAR estimation follows Villani (2009). It is estimated using a prior on the steady-state mean and standard deviation of the variables which is the same as the prior steady-state mean and standard deviation used in estimating the DSGE model (with the exception of the standard deviation of unemployment). In addition, a fairly standard Minnesota-type prior with a diffuse prior on the covariance matrix is used.

The benchmark GSW model is also compared with three alternative estimated GSW models in which the mean forecasts of real GDP growth, inflation and unemployment from the SPF are used as additional information. We consider two interpretations of those professional forecasts. Under the "noise " interpretation, the mean professional forecasts are assumed to be noisy indicators of the rational expectations forecasts implied by the DSGE model. As discussed in Section 3, the standard deviation of the errors in the measurement equation are quite large. Under the "news " interpretation, it is assumed that the forecasts reveal the presence of expected future structural shocks in line with those estimated over the past. This exercise is similar to the one performed by Del Negro and Schorfheide (2012) for the United States. In this case, the corresponding DSGE model forecast of annual real GDP growth, annual GDP deflator inflation and the unemployment rate will be identical to the SPF forecast. The Waggoner-Zha (1999) methodology is again used to compute the conditional forecasts. We report forecast errors for two cases: one in which we only use the one-year ahead forecasts and another one in which we use in addition the two-year ahead SPF forecasts.

Figures 7 to 9 summarise the results. Figure 7 and 8 report the mean squared forecast errors for the annual growth rate of real GDP, consumption, investment, employment, the GDP deflator and wage compensation per employee, as well as the unemployment rate and the short-term interest rate at each of the four horizons across the six competing models. Figure 9 plots two summary statistics, the log-determinant and the trace statistic of the MSE, as a function of the forecast horizon. A few findings are worth highlighting. First, from the summary statistics it is clear that overall there is no model that dominates. It appears that the random walk model performs the worst at all horizons, but the differences are relatively small. According to the trace statistic, the DSGE model performs similarly to the BVAR model. Second, turning to the individual variables, all models perform equally in predicting annual real GDP growth. However, the DSGE model clearly underperforms in predicting consumption growth and real wage growth. An inspection of the forecast errors reveals that the GSW model systematically overpredicts real wage growth, while it underpredicts consumption. A similar result was found in Christoffel et al (2010) which evaluated the forecast performance of the NAWM for the euro area. The New Keynesian model, which assumes a constant steady-state labour share and consumption to output ratio, has a difficult time explaining the falling labour share and the rising consumption to GDP ratio over this period. The non-structural models do much better in this respect. Finally, adding the additional information from the SPF forecasts has only a limited effect on the forecasting performance of the DSGE model. Adding the SPF HICP inflation forecasts helps reducing the mean squared forecast error of GDP deflator inflation at the 3 to 4 quarter horizon, as it corrects somewhat for the downward bias of the benchmark DSGE model. This improvement is independent from whether the noise or the news interpretation is used. However, the noise versus news interpretation does matter for the predictive performance regarding wage growth. In the news model the higher inflation HICP forecasts are rationalised by higher expected mark-up shocks, which at the same time tend to reduce expected wage growth and thereby alleviate part of the upward bias of the benchmark DSGE model. In the noise model, the overprediction of real wage growth is instead magnified.

Examining the real-time estimates of the parameters of the DSGE model, we find that most of the estimated structural parameters are quite stable, but there is some variation over time. In particular, on occasion those parameters that are weakly identified such as, for example, the degree of habit formation and the persistence of the risk premium shock may covary.

6 Real-time output gap uncertainty and its sources

We are now in a position to calculate the output gap using successive real-time data vintages. Following GSW, the welfare-relevant output gap is defined as the gap between actual output and the constant-markup, flexible-price and-wage level of output. Figure 10 plots estimates of the welfare-relevant output gap over the EMU period using the various data vintages. A few observations are worth making. First, it shows that the output gap reached a maximal size of between 4 and 6 percent in the most recent recession. This is larger than the gap achieved in the early 1990s or the first half of the 2000s. Second, there is quite a bit of uncertainty arising from the real-time nature of the data set used. Overall, this uncertainty is of the size of 1 to 2 percentage points. For example, at the end of 2001 a first estimate suggested a quite modest positive output gap of 1 percent, whereas estimates using the most recent data suggest a much larger positive output gap of 3 percent. Nevertheless, in spite of this uncertainty the sign of the output gap is known in most cases. Third, most of the real-time output uncertainty in the first half of the EMU period seems to be the result from revisions in the data, rather than from updates because future information becomes available. This is visible from panel (b) of Figure 10 which shows that the difference between the two-sided (smoothed) and the one-sided estimate of the output gap is relatively small in this period. Finally, the lower panel of Figure 10 plots the ex-post estimate of the output gap together with a 70 and 90 confidence set. It captures the shock uncertainty associated with the fact that the output gap is an unobservable variable and thus depends on the model explicitly. The confidence set of the smoothed simulator appears to be smaller than the real-time data uncertainty depicted in the upper panel, whereas the end-of-sample uncertainty is of the same order. Including the SPF forecasts in the estimation of the DSGE model results in a very similar picture, although the gap is shifted somewhat downward.

Figure 11 shows real-time snapshots of the output gap decomposition at the beginning of 2001, 2003, 2005, 2007, 2009 and using the most recent data set. It is quite striking how the risk premium shock is the main determinant of the output gap over the full sample and explains all of the output gap in the most recent recession. Similar results can be shown for the decomposition of the unemployment rate. Over time, the decomposition is quite stable, but early on in the EMU period there was quite a bit of uncertainty about the size and the nature of the output gap. For example, seen from the vantage point of the first quarter of 2003, risk premium shocks did not contribute to the positive output gap in 2001.

7 Conclusion

(To be written)

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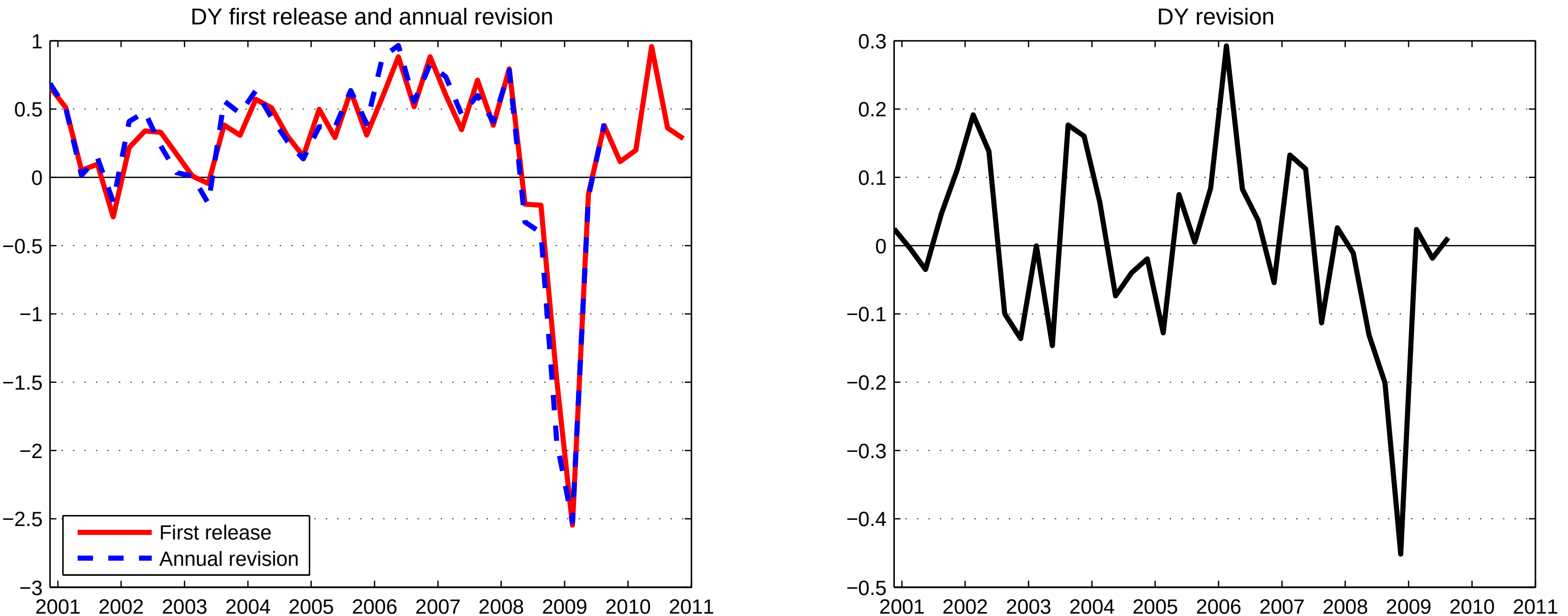
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First release
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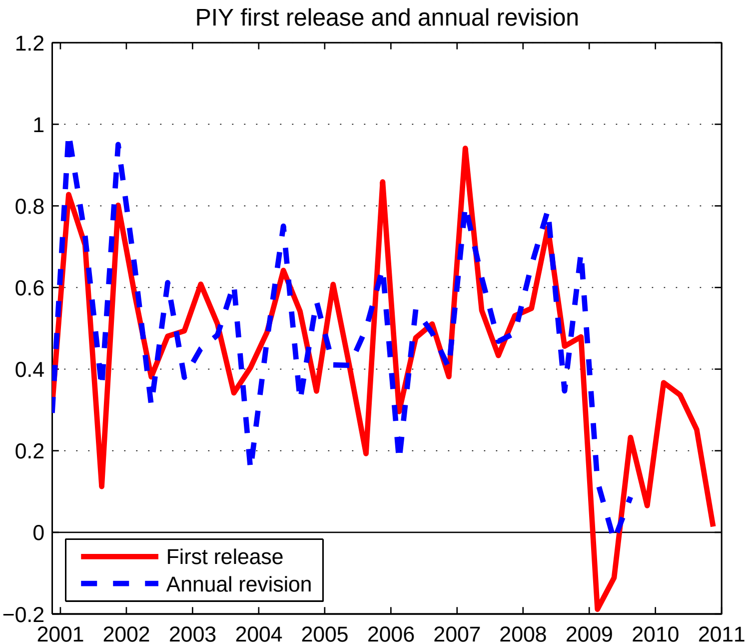
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First release
Annual revision
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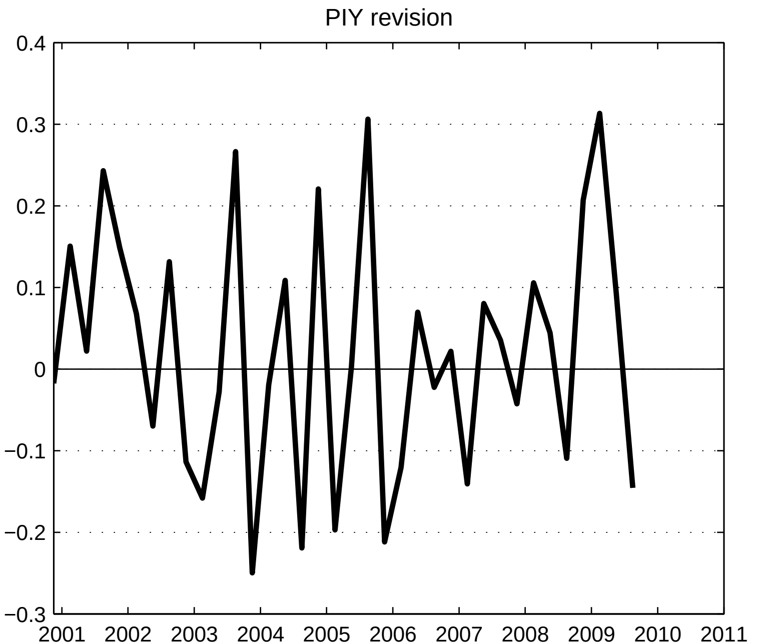
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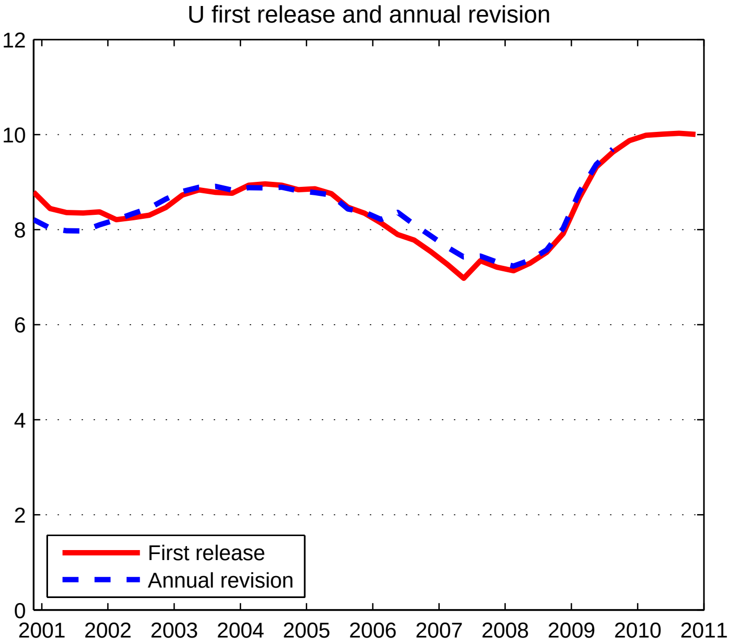
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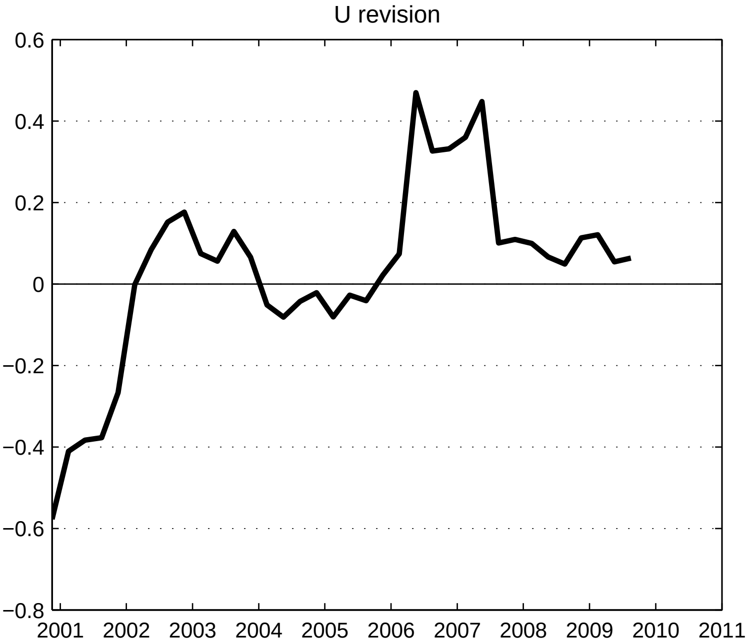
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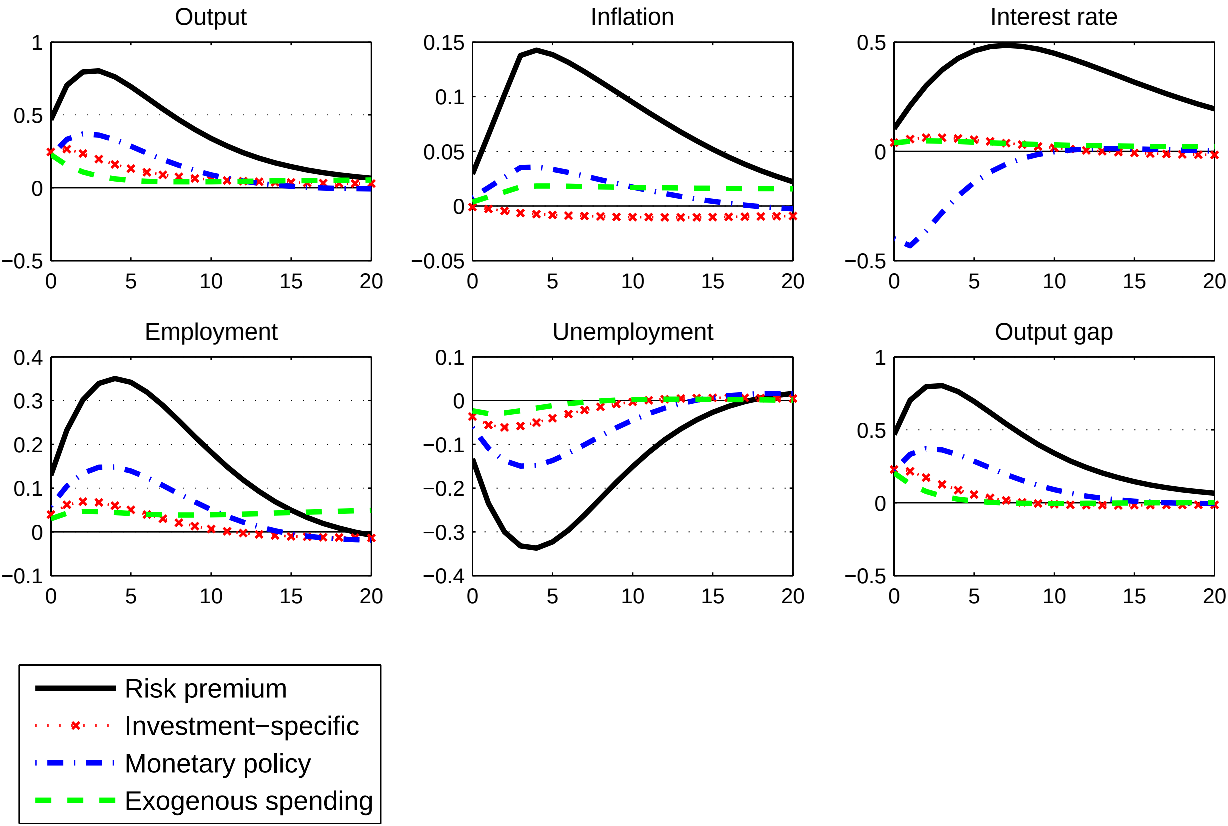

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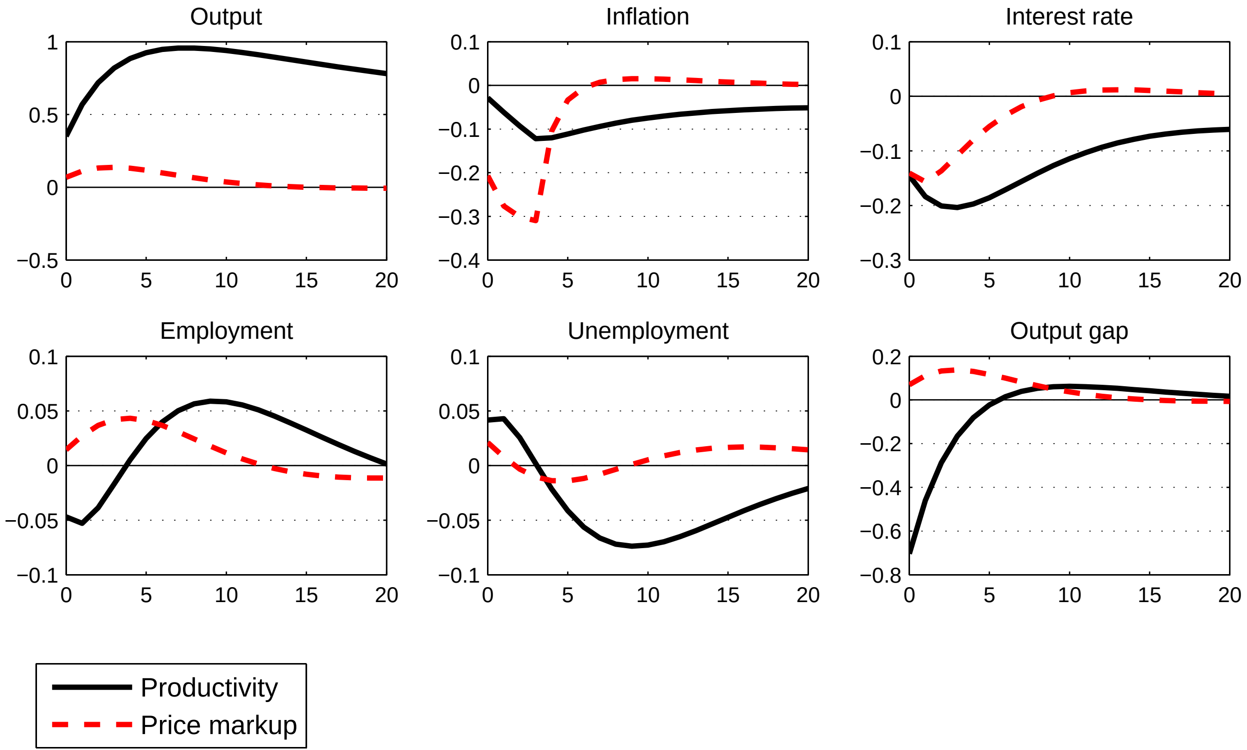
Interest rate
Employment
Unemployment
Output gap
Risk premium
Investment−specific
Monetary policy
Exogenous spending


Output
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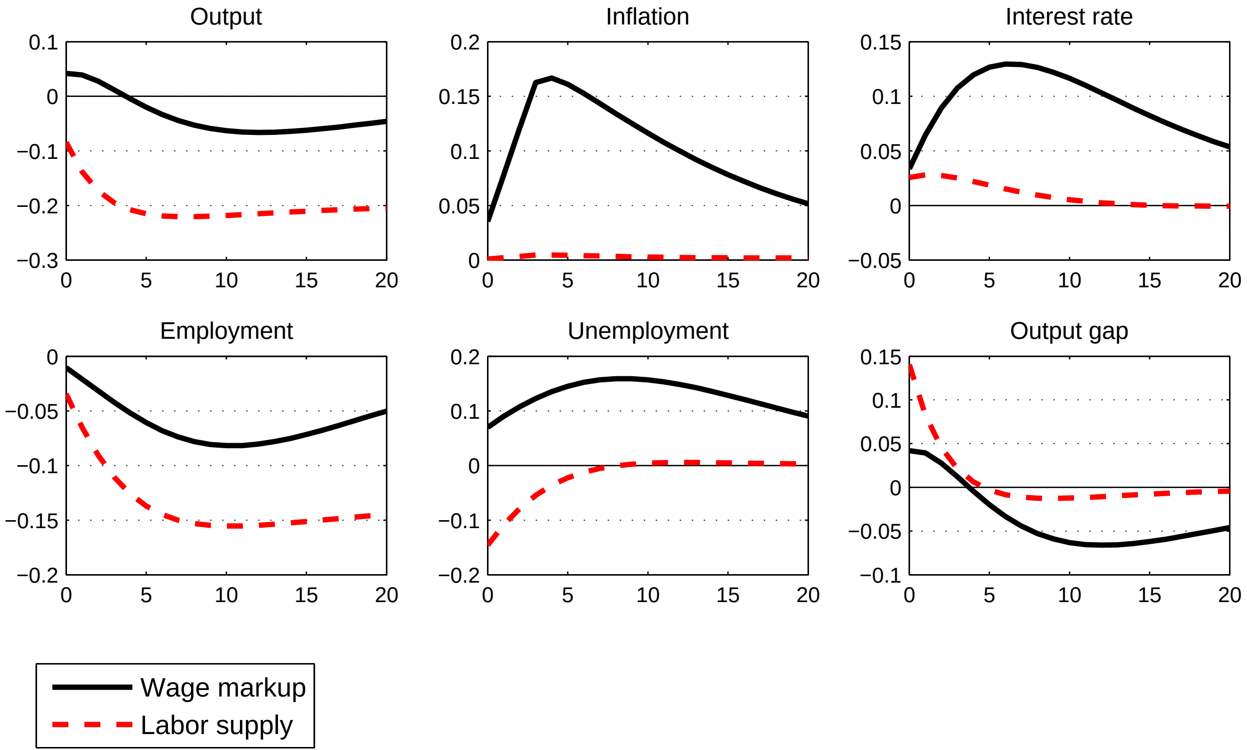
Interest rate
Employment
Unemployment
Output gap
Productivity
Price markup



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Interest rate
Employment
Unemployment
Output gap
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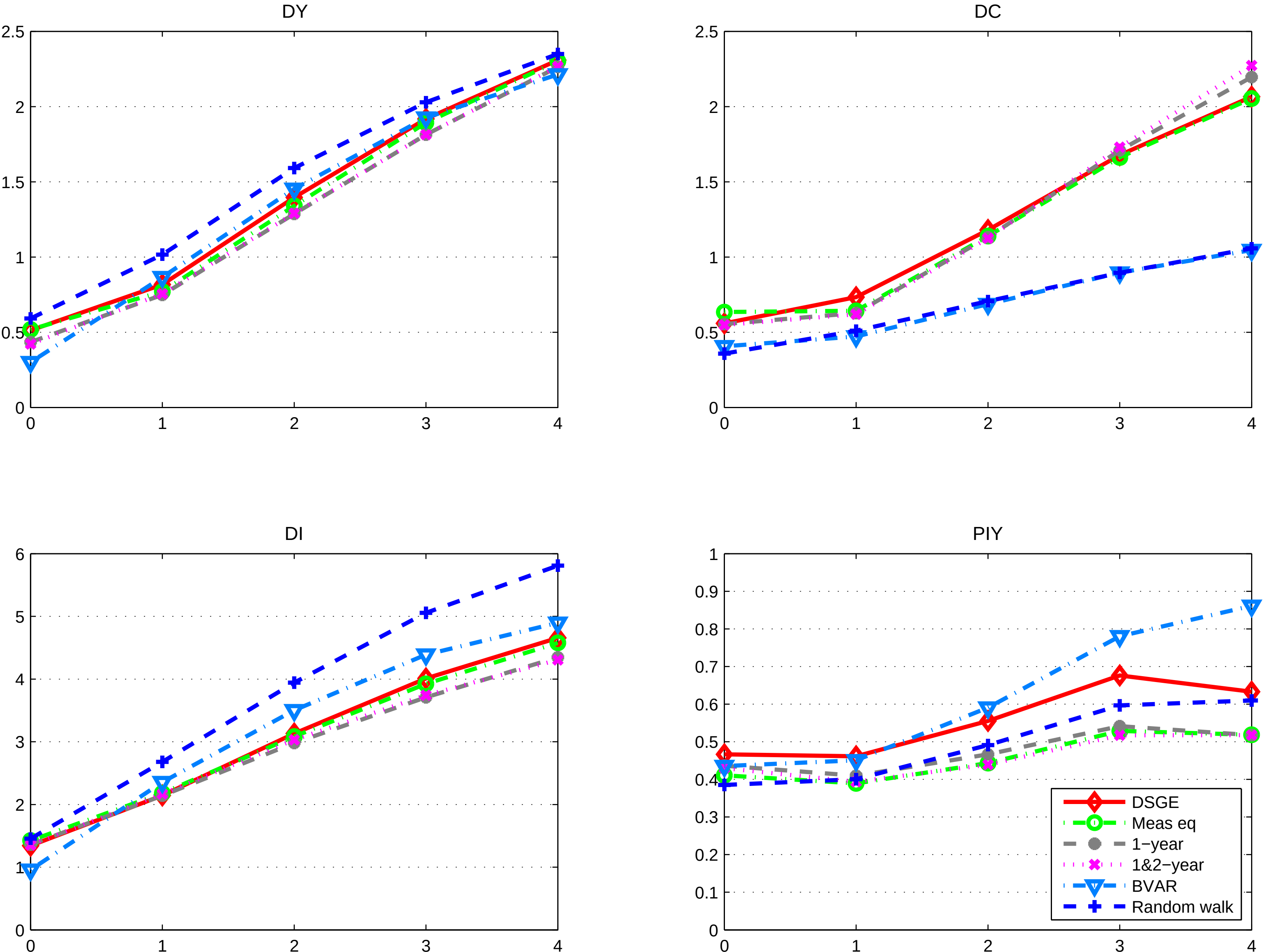
Wage markup
Labor supply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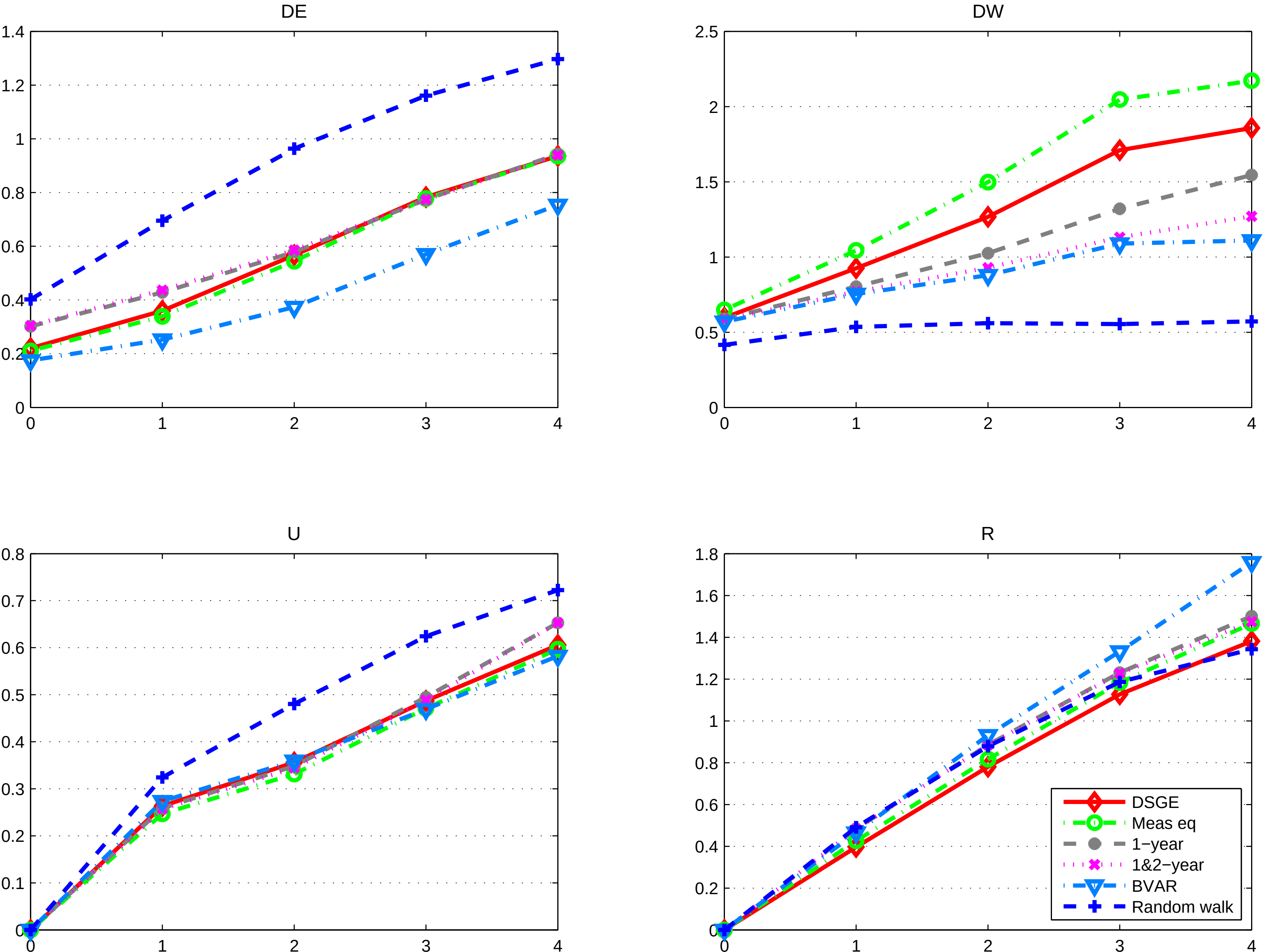
BVAR
Random walk



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Meas eq
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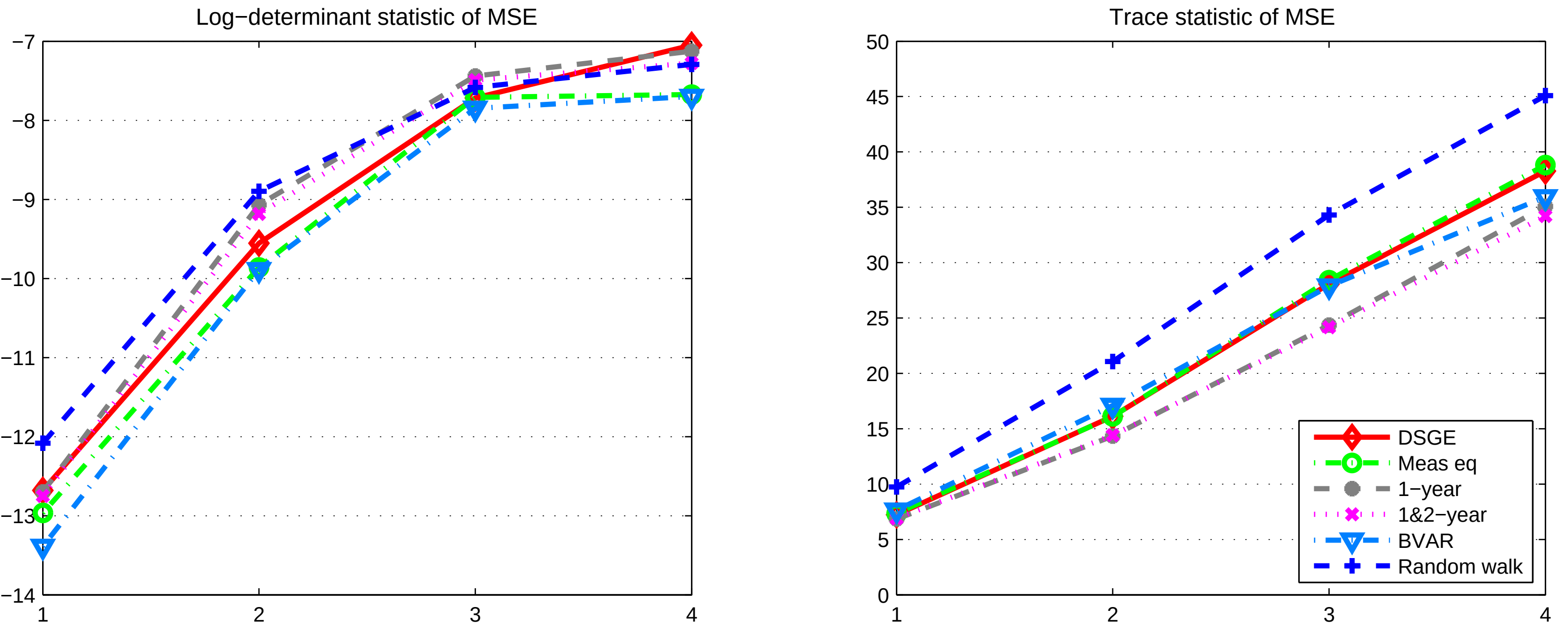
BVAR
Random walk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Trace statistic of MSE
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Meas eq
1−year
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BVAR
Random walk

Figure 10

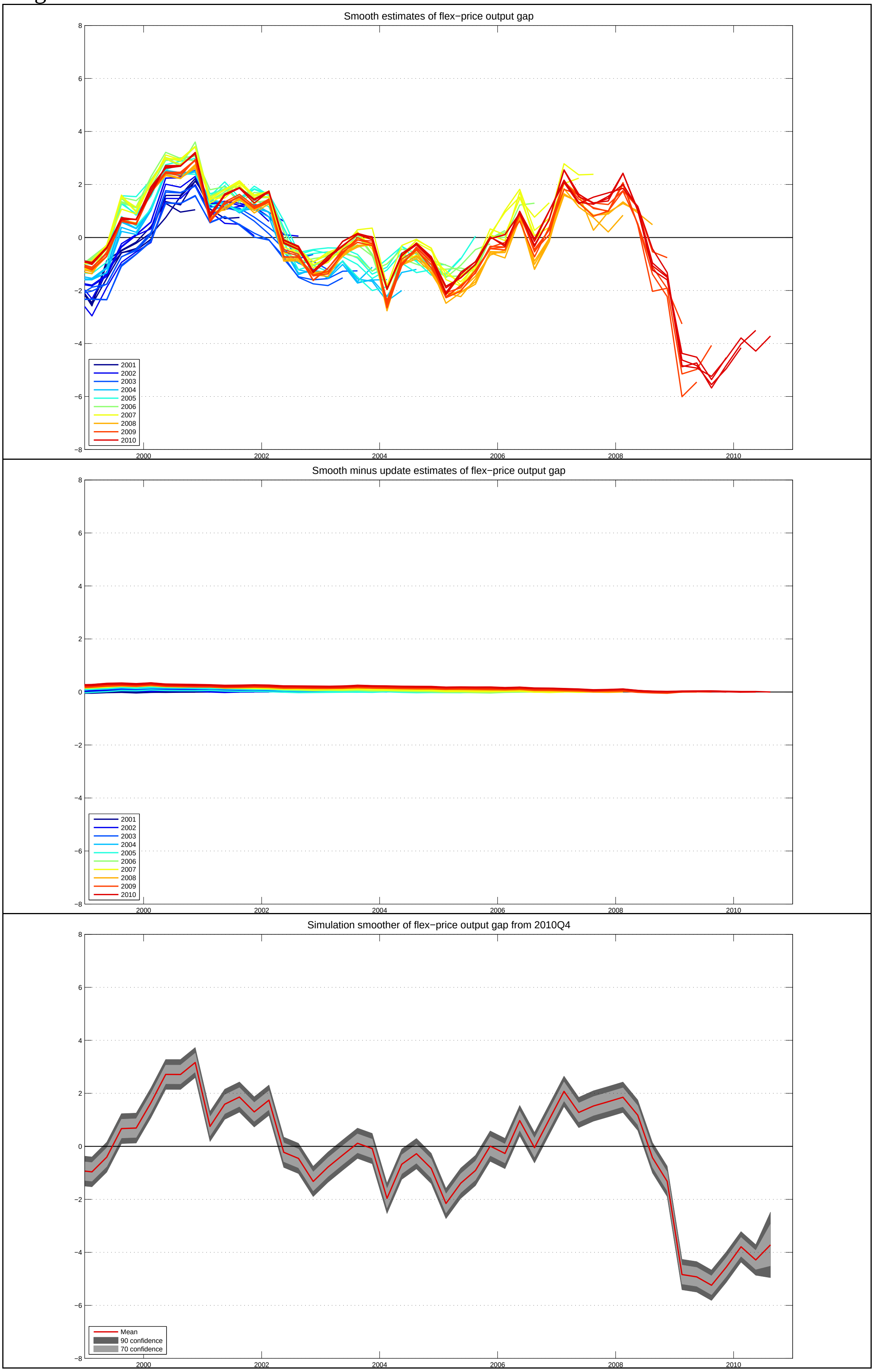
Smooth estimates of flex−price output gap
Smooth minus update estimates of flex−price output gap
Simulation smoother of flex−price output gap from 2010Q4
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Figure 11: Real-time output gap decomposition

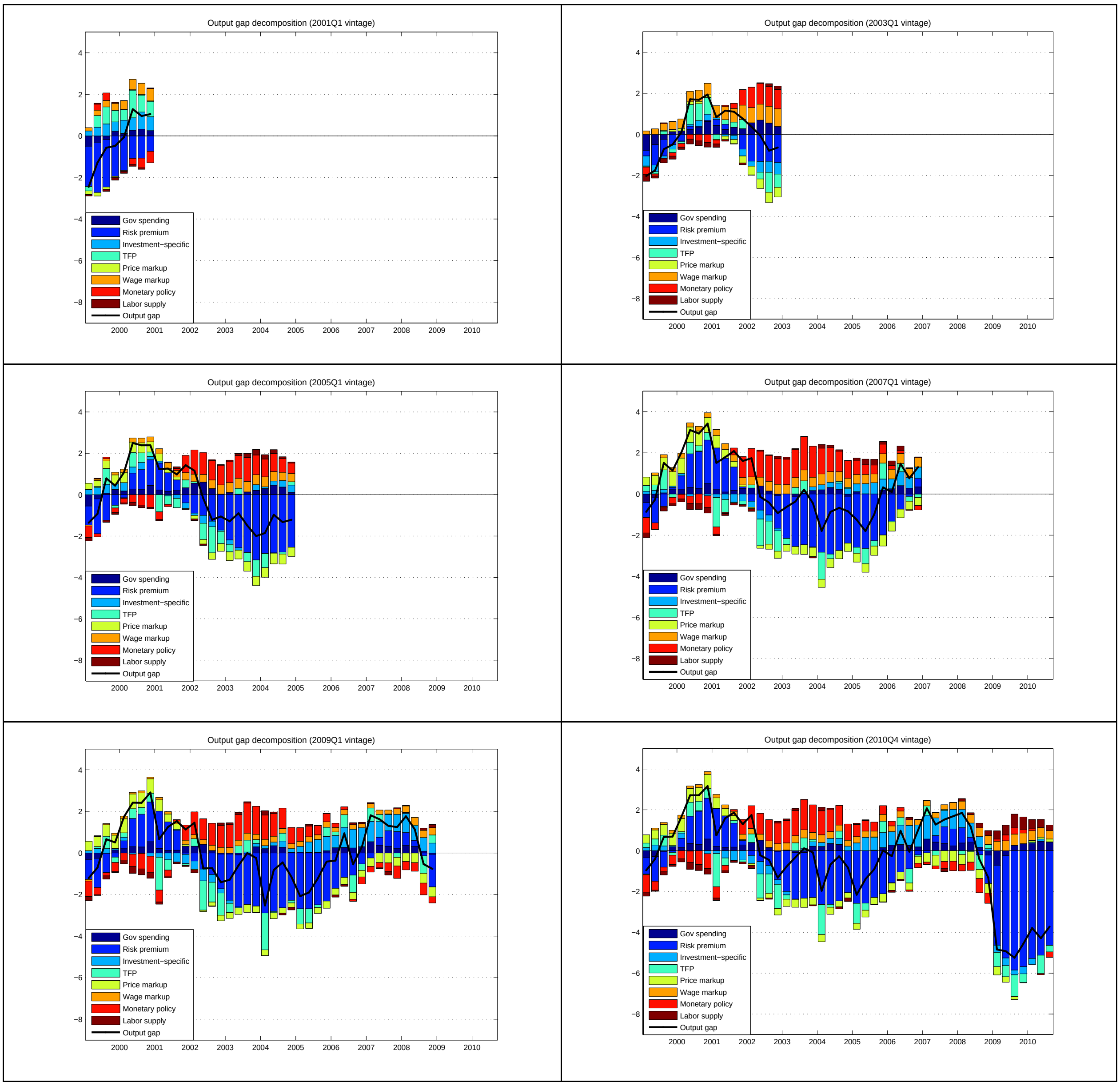

Table 1: Time flow of data releases available for the RTDB and the SPF over a quarter.

	Month 1		Month 2	Month 3
	$\Uparrow$ RTDB M1	$\Uparrow$ SPF	$\Uparrow$ RTDB M2	$\Uparrow$ RTDB M3
Monthly series	u_{m-2}	u_{m-2}	u_{m-2}	u_{m-2}
	π_{m-2}	$\boldsymbol{\pi_{m-1}}$	π_{m-2}	π_{m-2}
	r_{m-1}	r_{m-1}	r_{m-1}	r_{m-1}
Quarterly series	y_{q-2}	y_{q-2}	y_{q-2}	y_{q-1}
	c_{q-2}	c_{q-2}	c_{q-2}	c_{q-1}
	i_{q-2}	i_{q-2}	i_{q-2}	i_{q-1}
	$p_{y,q-2}$	$p_{y,q-2}$	$p_{y,q-2}$	$p_{y,q-1}$
	e_{q-2}	e_{q-2}	e_{q-2}	e_{q-2}
	w_{q-2}	w_{q-2}	w_{q-2}	w_{q-2}
	u_{q-2}	u_{q-2}	u_{q-1}	u_{q-1}
	r_{q-1}	r_{q-1}	r_{q-1}	r_{q-1}

NOTE: Unemployment is denoted by u, HICP by π, the average quarterly 3-month nominal interest rate by r, real GDP by y, real private consumption by c, the GDP deflator by p_y, total employment by e, and wages by w.

Table 2: Prior distributions and posterior estimates for the US and euro area models.

	Prior			Posterior							
				United States (1966:1–2007:4)				Euro area (1985:1–2009:4)			
parameter	type	mean	st.dev	mode	mean	5%	95%	mode	mean	5%	95%
structural parameters											
Ψ	N	4.0	1.0	4.09	3.96	2.34	5.58	4.65	4.77	3.34	6.31
h	B	0.7	0.1	0.78	0.75	0.65	0.85	0.65	0.64	0.54	0.72
φ	N	2.0	1.0	3.99	4.35	3.37	5.32	5.66	5.56	4.49	6.63
υ	B	0.5	0.2	0.02	0.02	0.01	0.04	0.06	0.12	0.03	0.34
θ_p	B	0.5	0.15	0.58	0.62	0.53	0.71	0.85	0.85	0.79	0.90
θ_w	B	0.5	0.15	0.47	0.55	0.44	0.66	0.74	0.72	0.60	0.89
γ_p	B	0.5	0.15	0.26	0.49	0.20	0.78	0.22	0.27	0.11	0.49
γ_w	B	0.5	0.15	0.16	0.18	0.07	0.29	0.22	0.25	0.12	0.42
ψ	B	0.5	0.15	0.57	0.56	0.36	0.75	0.46	0.48	0.29	0.69
$\mathcal{M}_p$	N	1.25	0.12	1.74	1.74	1.61	1.88	1.48	1.48	1.31	1.65
$\mathcal{M}_w$	N	1.25	0.12	1.18	1.22	1.15	1.29	1.53	1.51	1.41	1.62
α	N	0.3	0.05	0.17	0.17	0.14	0.20	0.22	0.22	0.19	0.26
θ_e	B	0.5	0.15	–	–	–	–	0.71	0.71	0.65	0.76
ρ_R	B	0.75	0.1	0.85	0.86	0.82	0.89	0.86	0.86	0.81	0.89
r_π	N	1.5	0.25	1.91	1.89	1.62	2.16	1.25	1.27	1.02	1.57
r_y	N	0.12	0.05	0.15	0.16	0.11	0.22	0.19	0.19	0.14	0.25
$r_{\Delta y}$	N	0.12	0.05	0.24	0.25	0.20	0.30	0.02	0.02	−0.00	0.06
$\bar{\pi}$	G	0.62	0.1	0.62	0.66	0.49	0.83	0.55	0.56	0.44	0.70
$\bar{\beta}$	G	0.25	0.1	0.31	0.31	0.17	0.43	0.24	0.27	0.13	0.43
$\bar{l}$	N	0.0	2.0	−1.65	−1.52	−3.83	0.77	–	–	–	–
$\bar{e}$	N	0.2	0.5	–	–	–	–	0.22	0.22	0.20	0.25
τ	N	0.4	0.1	0.34	0.34	0.30	0.37	0.14	0.14	0.08	0.20
τ_{wE}	N	0.2	0.1	0.07	0.08	0.03	0.12	–	–	–	–

Note: The parameter $\bar{\beta} = 100(\beta^{-1} - 1)$. The parameter $\mathcal{M}_w$ has prior mean 1.5 and standard deviation 0.25 for the euro area, while the parameter τ has prior mean 0.3 and standard deviation 0.1 for the vintages prior to 2008 and standard deviation 0.05 thereafter. The US results are taken from Galí, Smets and Wouters (2012).

Table 2: Continued.

	Prior			Posterior							
				United States (1966:1–2007:4)				Euro area (1985:1–2009:4)			
parameter	type	mean	st.dev	mode	mean	5%	95%	mode	mean	5%	95%
st.dev. of the innovations											
σ_a	U	2.5	1.44	0.41	0.42	0.37	0.46	0.58	0.60	0.46	0.78
σ_b	U	2.5	1.44	1.73	1.60	0.56	2.50	0.24	0.28	0.16	0.44
σ_g	U	2.5	1.44	0.47	0.48	0.43	0.52	0.30	0.31	0.28	0.35
σ_q	U	2.5	1.44	0.42	0.42	0.34	0.49	0.49	0.49	0.39	0.60
σ_r	U	2.5	1.44	0.21	0.22	0.19	0.24	0.11	0.11	0.10	0.13
σ_p	U	2.5	1.44	0.05	0.11	0.03	0.18	0.35	0.49	0.21	1.02
σ_w	U	2.5	1.44	0.04	0.06	0.01	0.13	0.30	0.76	0.16	3.66
σ_s	U	2.5	1.44	1.07	1.17	0.89	1.45	1.02	1.07	0.85	1.33
persistence of the exogenous processes: ρ = AR(1), μ = MA(1)											
ρ_a	B	0.5	0.2	0.98	0.98	0.97	0.99	0.98	0.98	0.97	0.99
ρ_b	B	0.5	0.2	0.36	0.42	0.19	0.67	0.91	0.91	0.84	0.96
ρ_g	B	0.5	0.2	0.97	0.97	0.96	0.99	0.99	0.99	0.98	1.00
ρ_{ga}	N	0.5	0.25	0.69	0.69	0.55	0.83	0.18	0.19	0.09	0.30
ρ_q	B	0.5	0.2	0.72	0.75	0.62	0.88	0.36	0.35	0.18	0.53
ρ_r	B	0.5	0.2	0.09	0.10	0.02	0.17	0.30	0.30	0.16	0.44
ρ_p	B	0.5	0.2	0.76	0.43	0.07	0.79	0.56	0.53	0.27	0.76
μ_p	B	0.5	0.2	0.59	0.57	0.24	0.96	0.44	0.47	0.25	0.71
ρ_w	B	0.5	0.2	0.99	0.98	0.97	1.00	0.91	0.89	0.81	0.95
μ_w	B	0.5	0.2	0.67	0.63	0.35	0.91	0.85	0.80	0.65	0.90

Note: The parameter ρ_{ga} measures the effect of TFP innovations on exogenous demand.

Table 3: Variance decompositions in percent for the US and the euro area models.

variance decomposition	output	inflation	employment	unemployment
10 quarter horizon				
demand shocks				
risk premium	6 / 32	2 / 12	16 / 67	20 / 64
exogenous demand	3 / 0	1 / 0	7 / 1	8 / 0
investment spec. tech.	9 / 2	3 / 0	12 / 2	10 / 1
monetary policy	5 / 6	8 / 0	11 / 11	11 / 11
supply shocks				
productivity	59 / 54	6 / 8	5 / 1	4 / 2
price mark-up	2 / 0	27 / 61	3 / 0	0 / 0
labor market shocks				
wage mark-up	6 / 0	53 / 17	18 / 2	41 / 15
labor supply	11 / 3	0 / 0	29 / 12	5 / 4
40 quarter horizon				
demand shocks				
risk premium	2 / 14	1 / 12	6 / 43	7 / 54
exogenous demand	1 / 0	1 / 0	3 / 4	3 / 0
investment spec. tech.	5 / 1	2 / 0	4 / 1	3 / 1
monetary policy	2 / 2	5 / 0	4 / 7	4 / 9
supply shocks				
productivity	56 / 75	4 / 12	3 / 0	1 / 0
price mark-up	1 / 0	18 / 53	1 / 2	0 / 0
labor market shocks				
wage mark-up	17 / 0	67 / 19	39 / 4	80 / 27
labor supply	17 / 5	0 / 0	40 / 0	2 / 3

Note: The first entry gives the variance decompositions for the US (1966:1–2007:4) from Galí, Smets and Wouters (2012); the second entry for the euro area (1985:1–2009:4).