Forecast with judgment and models

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by Francesca Monti

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Abstract

This paper proposes a simple and model-consistent method for combining forecasts generated by structural micro-founded models and judgmental forecasts. The method also enables the judgmental forecasts to be interpreted through the lens of the model. We illustrate the proposed methodology with a real-time forecasting exercise, using a simple neo-Keynesian dynamic stochastic general equilibrium model and prediction from the Survey of Professional Forecasters.

JEL-code : C32, C53.

Key-words: forecasting, judgment, structural models, Kalman Filter, real time.

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1 Introduction

Much of the macroeconometric literature of the last decade has focused on making micro-founded dynamic stochastic general equilibrium (DSGE) models a viable option for policy analysis and forecasting. Since Smets and Wouters (2004) have shown that DSGE models estimated with Bayesian techniques seem to perform quite well in forecasting relative to standard benchmark models such as VARs, DSGE models have become an increasingly important tool for policy analysis and forecasting at central banks.

Despite their growing use in practice, model-based forecasts still seem to be outperformed at short horizons -and particularly in the nowcast[1]- by forecasts produced by institutional and professional forecasters, such as the Federal Reserve's Greenbook (e.g. Sims, 2003) or the Survey of Professional Forecasters. Where does the advantage of the judgmental forecasters, as I will define the institutional and professional forecasters from now on, come from?

Judgmental forecasters monitor and analyze literally hundreds of data series, using informal methods to distill information from the available data. Not only they access various data series released by the statistical agencies (as for example, GDP or industrial production), they also gather other information, such as the quantity of goods transported by railway in each month (Bruno and Lupi, 2004), the electricity consumed each month (Marchetti and Parigi, 1998) and survey evidence. Moreover, judgmental forecasters are able to incorporate new data and new information as it becomes available

[1]Nowcasts are estimates of the current value of variables, such as GDP, that are unknown in the current period due to information lags.

throughout the month or the quarter and therefore can take advantage of the *timeliness* of this information. Indeed, as Giannone, Reichlin and Small (2008) point out, timely information seems to play a very important role in improving the quality of the forecasts, and of the nowcasts in particular. Finally, in their forecasts, judgmental forecasters account also for all sheerly judgmental information. A typical example is the adjustments of the forecasts made in 1999 in order to account for the fear of the Y2K bug. At the time this seemed a very important event, but since it had never happened no model could be expected to encompass it, while the judgmental forecasters could.

Hence, judgment - *i.e.* information, knowledge and views outside the scope of a particular model[2] - strongly informs the judgmental forecasts. The empirical evidence at hand suggests that the ability to account for more, more timely and "softer" information is what makes the judgmental forecasts better at nowcasting and forecasting short horizons.

The introduction of DSGE models in a policy and projection environment has given rise to a literature on how the model's outcomes should be combined with judgmental input and off-model information. The aim of this paper is to propose a method for combining judgmental forecasts and model-based forecasts, in order to make predictions that are more accurate but nevertheless disciplined by rigorous economic theory. In particular, we propose to interpret the judgmental forecasts as an estimate of the real signal, which is made with a different, possibly richer, information set and can be filtered in order to extract the information it contains. Modelling the

[2]This definition appears in Svensson (2005).

judgmental forecasts in the context of the theoretical model also enables us to interpret them in the light of that same model.

Recently, other authors have addressed the issue of how to use soft data and judgment in models. Svensson (2005), Svensson and Tetlow (2005) and Svensson and Williams (2005) develop different frameworks that allow accounting for central bank judgment when constructing optimal policy projections of the target variables and the instrument rate. They show that such monetary policy may perform substantially better than monetary policy that disregards judgment and follows a given instrument rule. Our approach differs quite substantially from theirs: our goal is solely to produce model-based forecasts that can account for judgmental and off-model information. Our approach leaves the structure of the DSGE model unchanged while combining the model-based forecasts with the judgmental forecasts.

In a Bayesian framework, Robertson, Tallman and Whiteman (2005) suggest a minimum relative entropy procedure for imposing moment restrictions on simulated forecasts distributions from a variety of models. This technique involves changing the initial predictive distribution to a new one that satisfies specific moment conditions that come from outside of the models, *i.e.* that are judgmental. Therefore, minimum-entropy methods allow adjusting the full posterior distribution of the DSGE models to match a given experts' assessment.

Finally, in a joint paper with Giannone and Reichlin (2008), we allow for the timely information to enter the model directly, not pre-processed by the judgmental forecasters. In particular, we show how to combine reduced form estimates of current quarter macroeconomic variables based on a large panel of monthly information with structural micro-founded models which focus on few key macroeconomic variables (such as GDP, consumption, investment, inflation). The paper differentiates itself from the emergent literature on DSGE in data-rich environments (Boivin and Giannoni, 2005), in that it captures the importance of timely information, allowing for the use of data with different frequencies and with non-synchronous releases.

This paper is structured as follows. In Section 2 we outline the framework and describe the proposed methodology; we illustrate how to extract the weights given to the model-based and the judgmental forecast; and describe how to structuralize the professional forecasts. In Section 3 we apply the proposed methodology on a prototypical new-Keynesian model using the Survey of Professional Forecasters' forecasts to extract judgmental information. Section 4 presents the results of the empirical application described in the previous section. In Section 5 we give some conclusions and outline future extensions of this paper.

2 The Econometric Methodology

2.1 The Framework

Linear or linearized rational expectations models, solved with methods suggested by Blanchard and Kahn (1980) and Sims (2002) among others, allow a representation for z_t in the state space form

$$\begin{aligned} s_{t+1} &= A(\theta)s_t + B(\theta)\varepsilon_{t+1} \\ z_t &= C(\theta)s_t + \nu_t \end{aligned} \tag{1}$$

where s_t is an $n \times 1$ vector of possibly unobserved state variables, z_t is a $k \times 1$ vector of variables observed by an econometrician, and ε_t is an $m \times 1$ vector of economic shocks impinging on the states, such as shocks to preferences, technologies, agents' information sets, and ν_t is an $l \times 1$ vector of measurement errors ($0 \leqslant l \leqslant k$, hence measurement error can be absent or affect some or all of the variables). $A(\theta)$, $B(\theta)$ and $C(\theta)$ are functions of the underlying structural parameters of the DSGE model. The ε_t's are Gaussian vector white noise satisfying $E(\varepsilon_t) = 0$, $E(\varepsilon_t \varepsilon_t') = I$, $E(\varepsilon_t \varepsilon_{t+j}') = 0$, for $j > 0$. The ν_t's are Gaussian vector white noise satisfying $E(\nu_t) = 0$, $E(\nu_t \nu_t') = R$, $E(\nu_t \nu_{t+j}') = 0$, for $j > 0$. The assumption of normality is for convenience and allows us to associate linear least squares predictions with conditional expectations. For notational simplicity we will drop the indication that the matrices A, B, etc. are function of the structural parameters θ.

Associated with the state space representation (1) is the innovations representation[3]

$$
\begin{aligned}
\hat{s}_{t|t} &= A\hat{s}_{t-1|t-1} + K_t u_t \qquad (2)\\
z_t &= CA\hat{s}_{t-1|t-1} + u_t
\end{aligned}
$$

where $\hat{s}_{t|t} = E[s_t|z_t, z_{t-1}, ..., z_0]$ is the estimate of the state vector s_t based on the observations of z_τ up to date t, $u_t = z_t - z_{t|t-1} = z_t - E[z_t|z_{t-1}, ..., z_0]$ is the forecast error made when forecasting z_t given the observations of z_τ up to date *t-1*,

$$K_t = \Omega_{t|t-1}C'(C\Omega_{t|t-1}C' + R)^{-1},$$

and $\Omega_{t|t-1} = E(s_t - \hat{s}_{t|t-1})(s_t - \hat{s}_{t|t-1})'$ converges to Ω, the unique positive semidefinite solution that satisfies the algebraic Riccati equation

$$\Omega = BB' + A\Omega A' - A\Omega C'(C\Omega C')^{-1}C\Omega A'. \qquad (3)$$

2.2 Model of the Judgmental Forecasts

The goal of this section is to show how to incorporate judgmental forecasts into models of the form (1) or, equivalently, (2). In order to do so, we need to somehow formalize these forecasts. More specifically, we need to make assumptions on the model and the information set that the judgmental forecasters use to generate their forecasters.

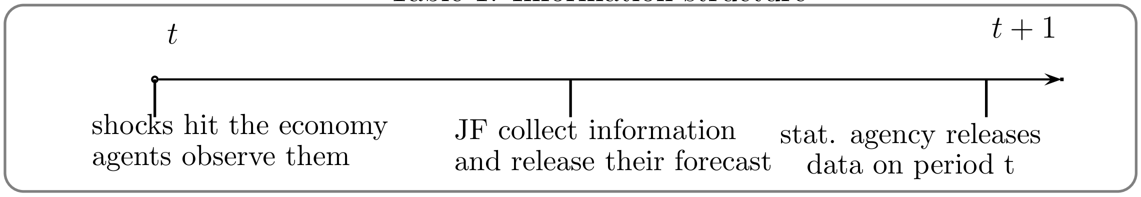
[3]The conditions for the existence of this representation are stated carefully, among others, in Anderson, Hansen, McGrattan, and Sargent (1996). The conditions are that (A,B,C) be such that iterations on the Riccati equation for $\Omega_{t|t-1} = E(s_t - \hat{s}_{t|t-1})(s_t - \hat{s}_{t|t-1})'$ converge, which makes the associated Kalman gain converge. Sufficient conditions are that (A, C') is stabilizable and that (A', B') is detectable. See Anderson, Hansen, McGrattan, and Sargent (1996, p. 175) for definitions of stabilizable and detectable.

The assumptions about the information available in each period t are outlined in Table 1. Shocks hit the economy at the beginning of period t. There are two types of forecasters. The first type generates his forecasts solely on the basis of the model of the economy (1) and the data released by the statistical agency. The statistical agency releases data at the end of each period, so, e.g., in period t there is data available only up to *t-1*. Therefore the information set available to the first type of forecaster at time t comprises exclusively information up to time *t-1*: his information set is $I_{t-1} = Sp\{z_{t-1}, z_{t-2}, ...z_0\}$, *i.e.* the space spanned by $\{z_{t-1}, z_{t-2}, ...z_0\}$. From now on I will call the first type of forecaster 'purely' model-based forecaster.

The second type of forecaster uses a reduced form version of the model of the economy to make its forecasts - *i.e.* he or she knows A, B, C, but not θ - and accesses the information set J, which comprises I_{t-1} but is possibly more informative. This type represents the judgmental forecasters (JF from now on). As highlighted in the Introduction, their information set is plausibly richer than I_{t-1}: they collect intra-period extra-model information, such as business surveys, monthly electricity consumption and quantity of goods transported by railway in each month. This allows them to make a better estimate of the current value of the variables of interest. Finally, in what follows, we also assume that $J \subseteq I_t$. This means that, once the observable variables are actually observed, the informational content of the judgmental forecasts is nihil. Hence, the information the JF can observe does not improve their estimate of past values of the state variable.

Let us formalize rigorously the judgmental forecasters. At any given time

Table 1: Information structure



t their information set J comprises I_{t-1} but is such that, for $h > 0$

$$E\left[u_t J'\right] \neq 0, \tag{4}$$

$$u_{t+h} \perp J$$

For $\tau = 1, 2, ..., t-1$ both purely model-based forecasters and JF are going to construct the innovations representation (2).[4] For $\tau \geqslant t$, judgmental forecasters will report: for h=0,1,...,4

$$z_{t+h|J} = E[z_{t+h}|J] + \xi_t^h \tag{5}$$

where $E[z_{t+h}|J]$ is the least squares forecast made by the JF with their information set J and ξ_t^h is a white noise error that is orthogonal to all the rest of the information. *I.e.* we are assuming that the judgmental forecasters use the reduced form version of model (1) and their richer information set J to generate the forecasts, but we also allow for the presence of a second term, which is orthogonal to the rest of the forecasts and can, for example, be interpreted as a typo made by the forecasters while communicating their forecasts. ξ_t^h, for h=0,1,...,4, has mean zero and variance Σ_ξ^h. We allow for cross-correlation among the elements of ξ_t^h (hence Σ_ξ^h need not be diagonal),

[4]This comes from the assumption that $J \subseteq I_t$.

but we exclude the possibility of them being serially correlated (white noise assumption).

Hence, when the judgmental forecasts are made available, we face the following state-space form:

$$
\begin{aligned}
\hat{s}_{t|t} &= A\hat{s}_{t-1|t-1} + K_t u_t \\
\begin{bmatrix} z_{t|J} \\ z_{t+1|J} \\ z_{t+2|J} \\ z_{t+3|J} \\ z_{t+4|J} \end{bmatrix} &= \begin{bmatrix} CA\hat{s}_{t-1|t-1} \\ CA^2\hat{s}_{t-1|t-1} \\ CA^3\hat{s}_{t-1|t-1} \\ CA^4\hat{s}_{t-1|t-1} \\ CA^5\hat{s}_{t-1|t-1} \end{bmatrix} + \underbrace{\begin{bmatrix} E[u_t|J] + \xi_t^0 \\ CAK_tE[u_t|J] + \xi_t^1 \\ CA^2K_tE[u_t|J] + \xi_t^2 \\ CA^3K_tE[u_t|J] + \xi_t^3 \\ CA^4K_tE[u_t|J] + \xi_t^4 \end{bmatrix}}_{U_t}
\end{aligned} \tag{6}
$$

U_t is the vector of the differences between the judgmental forecasts and what the 'purely' model-based forecasters would forecast: it can contain both useful information and noise. Our goal is to extract the information, while cleansing out the noise. Given information up to time t-1, *i.e.* given I_{t-1}, the vector $[s_t' \;\; z_{t|J}' \;\; \cdots \;\; z_{t+4|J}']$ is jointly distributed as a normal with mean

$$
\begin{bmatrix} A\hat{s}_{t-1|t-1} \\ CA\hat{s}_{t-1|t-1} \\ \vdots \\ CA^5\hat{s}_{t-1|t-1} \end{bmatrix}
$$

and covariance matrix

$$\begin{bmatrix} \Sigma_Q & \Sigma_S \\ \Sigma_S' & \Sigma_R \end{bmatrix},$$

where

$$\begin{aligned}
\Sigma_Q &= K_t E_{t-1}\left[u_t u_t'\right] K_t' \qquad (7)\\
\Sigma_S &= \begin{bmatrix} K_t E_{t-1}\left[u_t E\left[u_t|J\right]'\right] & K_t E_{t-1}\left[u_t E\left[u_t|J\right]'\right] K_t' A' C' & \cdots & K_t E_{t-1}\left[u_t E\left[u_t|J\right]'\right] K_t' A^{4\prime} C' \end{bmatrix}\\
\Sigma_R &= \begin{bmatrix} V_U^0 & E_{t-1}\left[E\left[u_t|J\right] E\left[u_t|J\right]'\right] K_t' A' C' & \cdots & E_{t-1}\left[E\left[u_t|J\right] E\left[u_t|J\right]'\right] K_t' A^{4\prime} C' \\ \cdot & V_U^1 & \cdots & CAK_t E_{t-1}\left[E\left[u_t|J\right] E\left[u_t|J\right]'\right] K_t' A^{4\prime} C' \\ \vdots & & \ddots & \vdots \\ \cdot & \cdots & & V_U^4 \end{bmatrix}
\end{aligned}$$

V_U^i for i=0,1,...,4 is the variance-covariance matrix of the the elements of U_t associated to $z_{t+i|J}$.

We obtain $E\left[s_t|J\right]$ with a 2-step procedure[5]: first we estimate the matrices Σ_Q, Σ_S and Σ_R, then we determine $E\left[s_t|J\right]$ as the expected value of the states conditional on all past information and today's judgmental forecasts. In what follows, we describe the way we obtain estimates for Σ_Q, Σ_S and Σ_R.

First of all, Σ_Q can be easily obtained simply using the fact that

$$E(u_t u_t') = C\Omega_{t|t-1}C' + R$$

[5]Notice that formally we are determining $E\left[\hat{s}_{t|t}|J\right]$. However, thanks to the law of iterated expectations, the following holds:

$$E\left[\hat{s}_{t|t}|J\right] = E\left[E[s|I_t]|J\right] = E\left[s_t|J\right].$$

where $\Omega_{t|t-1} = E(s_t - \hat{s}_{t|t-1})(s_t - \hat{s}_{t|t-1})'$. Then notice that

$$E\left[u_t \left(z_{t|J} - z_{t|t-1}\right)'\right] = E[u_t E(u_t|J)'].$$

This equality derives from the fact that $\xi_t^0 \perp u_t$ by assumption. The u_t's and the $z_{t|t-1}$'s are readily available from the Kalman filter, so we are able to recover empirically the value of $E[u_t \left(z_{t|J} - z_{t|t-1}\right)']$, and therefore of $E[u_t E(u_t|J)']$. Hence, we can determine the various components of Σ_S simply by multiplying $E[u_t \left(z_{t|J} - z_{t|t-1}\right)']$ by the appropriate matrices, as indicated in (7).

Finally, notice that $E(u_t|J)$ is a linear projection of u_t on the space spanned by J, i.e.

$$u_t = E(u_t|J) + \mu_t$$

where μ_t is orthogonal to the space spanned by J. Therefore,

$$E[u_t E(u_t|J)'] = E[E(u_t|J)E(u_t|J)'], \tag{8}$$

i.e. the variance of the expected value of the current period innovation given the information set J, $E(u_t|J)$ is equal to the covariance among the innovation and its expected value. Hence we are able to pin down the value of all the off-diagonal components of Σ_R. The diagonal blocks of Σ_R are the covariance matrices of the single elements of U_t in equation (6) and can obtained empirically simply as the covariance matrices of $\left(z_{t+h|J} - z_{t+h|t-1}\right)$, for $h = 0, 1, ..., 4$.

The matrices Σ_Q, Σ_S and Σ_R are estimated using the information that is available at each point in time, *i.e.* up to *t-1*. The knowledge of the matrices

Σ_S and Σ_R enables us to determine $E[s_t|J]$ simply as:

$$E[s_t|J] = A\hat{s}_{t-1|t-1} + \Sigma_S \Sigma_R^{-1} \underbrace{\begin{bmatrix} (z_{t|J} - z_{t|t-1}) \\ \vdots \\ (z_{t+4|J} - z_{t+4|t-1}) \end{bmatrix}}_{U_t}. \tag{9}$$

The augmented forecasts are then straightforward to derive:

$$z^{+}_{t+h|J} = CA^h E[s_t|J] \tag{10}$$

for $h = 0, 1, ..., 4$.

The forecasts in (10) combine the judgemental forecasts with the model-based forecasts in a non trivial manner, because they use the forecasts of all horizons provided by the SPF, i.e. up to one year ahead. The weights assigned to the judgemental forecasts in generating $E[s_t|J]$ are determined by the matrices Σ_S and Σ_R. Σ_S, the covariance of the innovations and the difference between the judgmental forecasts and the model, is a measure of how much information the judgmental forecasters have on the the current state of the economy. Σ_R is a measure of the volatility of their forecasts and depends also on the variance Σ^h_ξ. The bigger is Σ_S, the more weight is given to the judgmental forecasts in determining the new estimate of the state; a greater Σ_R, instead, causes the judgmental forecasts to be down-weighed. These matrices are re-estimated (recursively or with a rolling window) every period using information up to *t-1* and are, hence, a measure of the JF past performance.

2.3 Using the model to interpret judgemental forecasts

Another interesting aspect of this procedure is that it also allows interpreting the judgmental forecasts through the lens of the model. Storytelling is difficult when it comes to judgmental forecasts; in our set-up we will be able to interpret the forecasts in light of the model and therefore somehow structuralize the forecasts.

We would like to recover the *estimates* of the structural shocks made by the judgmental forecasters. Notice that if we take the expectation of $B\varepsilon_t$ (in the state equation of (1)) given the information set J, we obtain

$$\begin{aligned} E\left[B\varepsilon_t|J\right] &= E\left[s_t|J\right] - E\left[As_{t-1}|J\right] \\ &= E\left[s_t|J\right] - A\hat{s}_{t-1|t-1} \\ &= \Sigma_S \Sigma_R^{-1} U_t. \end{aligned}$$

The equalities above hold because of the law of iterated expectations and because of our assumption that the information the JF can observe does not improve their estimate of past values of the state variable, *i.e.* $I_{t-1} \subseteq J \subseteq I_t$. Then, if B has the appropriate dimensions, we can extract the JFs' estimate of the structural shock by simply multiplying $\Sigma_S \Sigma_R^{-1} U_t$ by $(B'B)^{-1}B'$.

3 An application

We use a simple new-keynesian dynamic stochastic general equilibrium model, as the one used in Del Negro and Schorfheide (2004). The model consists of a representative household, a continuum of monopolistically competitive firms and monetary policy authority that sets the nominal interest rate in response to deviations of inflation and output from their targets. The representative household derives disutility from hours worked and utility from consumption C relative to a habit stock and real money balances $\frac{M}{P}$. We assume that the habit stock is given by the level of technology A.[6] The representative household maximizes expected utility

$$E_t \left[\sum_{s=t}^{\infty} \beta^{s-t} \left(\frac{(C_s/A_s)^{1-\tau} - 1}{1-\tau} + \chi \log \frac{M_s}{P_s} - h_s \right) \right] \tag{11}$$

where β is the discount factor, τ the risk aversion parameter and χ is a scale factor. P is the economy-wide nominal price level that the household takes as given. The (gross) inflation rate is defined as $\pi_t = \frac{P_t}{P_{t-1}}$.

The household supplies perfectly elastic labor supply services to the firm period by period and receives in return real wage W. It also has access to a domestic capital market on which they can trade nominal government bonds B that pay gross interest rate R. Moreover, the household receives aggregate residual profits D and has to pay lump-sum taxes T. Hence, its budget constraint is:

$$C_t + \frac{B_t}{P_t} + \frac{M_t}{P_t} + \frac{T_t}{P_t} = W_t h_t + \frac{M_{t-1}}{P_t} + R_{t-1}\frac{B_{t-1}}{P_t} + D_t \tag{12}$$

The transversality condition on asset accumulation rules out Ponzi schemes.

On the production side, there is a continuum of monopolistically competitive firms, each facing a downward-sloping demand curve, derived in the

[6] This assumption ensures that the economy evolves along a balanced growth path.

usual way from Dixit-Stiglitz type of preferences, for its differentiated product

$$P_t(j) = \left(\frac{X_t(j)}{X_t}\right)^{-1/\nu} P_t, \tag{13}$$

where $P_t(j)$ is the profit-maximizing price that is consistent with production level $X_t(j)$, while P_t is the aggregate price level and X_t is aggregate demand (both beyond the control of the individual firm). The parameter ν is the elasticity of substitution between two differentiated goods. We assume that the firms face quadratic adjustment costs: that is, when a firm wants to change its price beyond the economy-wide inflation rate π^*, it incurs menu costs in terms of lost output:

$$AC_t(j) = \frac{\phi}{2}\left(\frac{P_t(j)}{P_{t-1}(j)} - \pi^*\right)^2 X_t(j). \tag{14}$$

The presence of these adjustment costs determines the presence of nominal rigidities, and the parameter $\phi \geqslant 0$ determines the degree of stickiness within the economy.

The production function is linear in labor, which is hired from the household:

$$X_t(j) = A_t h_t(j). \tag{15}$$

Total factor productivity A_t follows a unit root process of the form:

$$\ln A_t = \ln \gamma + \ln A_{t-1} + \hat{z}_t, \tag{16}$$

where

$$\hat{z}_t = \rho_z \hat{z}_{t-1} + \varepsilon_{z,t}. \tag{17}$$

Hence, there will be a stochastic trend in the model. $\varepsilon_{z,t}$ can be broadly interpreted as a technology shock that affects all firms in the same way.

The maximization problem faced by the firm is the following:

$$\max E_t \left[\sum_{s=t}^{\infty} Q_s D_s(j) \right] \tag{18}$$

subject to (15) and (16), and where the j-th firm's profit $D_s(j)$ is

$$D_s(j) = \left(\frac{P_s(j)}{P_s} X_s(j) - W_s h_s(j) - \frac{\phi}{2} \left(\frac{P_s(j)}{P_{s-1}(j)} - \pi^* \right)^2 X_s(j) \right). \tag{19}$$

Q_s is the time-dependent discount factor that firms use to evaluate future profit streams. Although firms are heterogeneous ex-ante, we only consider the symmetric equilibrium in which all firms behave identically and can be aggregated into a single representative monopolistically competitive firm. Since the household is the recipient of the firms' residual payments, it directs firms to make decisions based on the household's intertemporal rate of substitution. Hence $Q_{t+1}/Q_t = \beta(C_t/C_{t+1})^\tau$.

The monetary policy authority follows an interest rate rule, such that it adjusts its instruments in response to deviations of inflation and output from their respective targets:

$$\frac{R_t}{R^*} = \left(\frac{R_{t-1}}{R^*} \right)^{\rho_R} \left[\left(\frac{\pi_t}{\pi^*} \right)^{\psi_1} \left(\frac{X_t}{X_t^*} \right)^{\psi_2} \right]^{1-\rho_R} e^{\varepsilon_{R,t}} \tag{20}$$

where R^* is the steady-state nominal interest rate and X_t^* is potential output, which we defined as $X_t^* = A_t$ after normalizing hours worked to one. The central bank supplies the money demanded by the households to support the desired nominal interest rate. The parameter $0 \leqslant \rho_R < 1$ governs the degree of interest rate smoothing, while $\varepsilon_{R,t}$ can be interpreted as an unanticipated deviation from the policy rule.

The government consumes a fraction ζ_t of each individual good and levies a lump-sum tax (or subsidy) T_t/P_t to finance any shortfall in government revenues (or to rebate any surplus), so its budget constraint is:

$$\zeta_t X_t + R_{t-1}\frac{B_{t-1}}{P_t} + \frac{M_{t-1}}{P_t} = \frac{B_t}{P_t} + \frac{B_t}{P_t} + \frac{M_t}{P_t}. \tag{21}$$

The fiscal authority accomodates the monetary policy of the central bank and endogenously adjusts the primary surplus to changes in the government's outstanding liabilities. Finally, we define $g_t = 1/(1-\zeta_t)$ and assume that $\hat{g}_t = \ln(g_t/g^*)$ follows a stationary AR(1) process

$$\hat{g}_t = \rho_g \hat{g}_{t-1} + \varepsilon_{g,t} \tag{22}$$

where $\varepsilon_{g,t}$ can be broadly interpreted as a government spending shock.

To solve the model, we derive the optimality conditions from the maximization problem. Consumption, output, wages and the marginal utility of consumption are detrended by the total factor productivity A_t, in order to obtain a model that has a deterministic steady-state in terms of the detrended variables. The loglinearized system can be reduced to:

$$
\begin{aligned}
\hat{y}_t &= E_t\hat{y}_{t+1} + \frac{1}{\tau}E_t\hat{\pi}_{t+1} - \frac{1}{\tau}\hat{r}_t + E_t\hat{g}_{t+1} + \frac{\rho_z}{\tau}\hat{z}_t \\
\hat{\pi}_t &= \beta E_t\hat{\pi}_{t+1} + \kappa(\hat{y}_t - \hat{g}_t) \\
\hat{r}_t &= \psi_1(1-\rho_r)\hat{\pi}_t + \psi_2(1-\rho_r)\hat{y}_t + \rho_r\hat{r}_{t-1} + 0.25\varepsilon_{r,t} \qquad (23) \\
\hat{g}_t &= \rho_g\hat{g}_{t-1} + \varepsilon_{g,t} \\
\hat{z}_t &= \rho_z\hat{z}_{t-1} + \varepsilon_{z,t},
\end{aligned}
$$

where $\beta = e^{\frac{\gamma - r^*/4}{100}}$. The relation between logdeviations from steady state and observable output growth, GDP deflator inflation and the annual nominal interest rate is given by the following measurement equation:

$$
\begin{aligned}
\Delta \ln Y_t &= \ln\gamma + \hat{y}_t - \hat{y}_{t-1} + \hat{z}_t \\
INFL_t &= \pi^* + 4\pi_t \qquad (24) \\
RA_t &= \pi^* + r^* + 4r_t
\end{aligned}
$$

The model given by equations (23) and (24) can then solved with standard techniques, such as those proposed by Blanchard and Kahn (1980) and Sims (2002), among others, and hence cast in a standard state-space model (1).

In what follows, we will perform an out-of-sample real-time forecasting exercise, using as evaluation sample the period 1992-2006. We use *real-time* quarterly data for real GDP, GDP deflator inflation and the Fed Funds rate for the US, which is available from the Philadelphia Fed's website, and choose as a starting point for our data the first quarter of 1982.[7] The Bayesian es-

[7]Due to the unavailability of real-time data on population, we have made the some-

	Prior Distribution			Posterior Distribution		
	Distribution	mean	st.dev	mode	mean	st.dev
γ	Normal	0.5	0.5	0.6815	0.6924	0.1251
π^*	Gamma	5	2	3.8862	4.3852	1.3813
r^*	Gamma	2	1	3.0139	3.0022	0.5148
τ	Gamma	2	0.5	2.8826	2.9628	0.5015
κ	Gamma	0.3	0.1	0.1188	0.1528	0.0500
ψ_1	Gamma	1.5	0.5	1.0369	1.5420	0.3651
ψ_2	Gamma	0.125	0.1	0.0951	0.2719	0.0320
ρ_g	Beta	0.9	0.05	0.9656	0.9648	0.0200
ρ_z	Beta	0.2	0.1	0.3244	0.3265	0.1107
ρ_r	Beta	0.7	0.15	0.8048	0.8279	0.0359
σ_g	InvGamma	1.25	0.65	0.4924	0.5066	0.0706
σ_z	InvGamma	1.25	0.65	0.5927	0.6404	0.0754
σ_r	InvGamma	0.63	0.33	0.7155	0.7310	0.0794

Table 2: Prior and posterior distribution of the parameters of the model estimated over the period 1982Q1 to 1995Q4.

timation of the model's parameters is performed recursively every two years. The forecasting exercise is totally in real time: hence, when forecasting (0 to 4 steps ahead), e.g., in 1996Q1, we will use only data available at that vintage. As an example, Table 2 reports the estimate for the model's parameters made in 1996Q1. We use the Survey of Professional Forecasters (SPF) as example of judgmental forecast. The Survey of Professional Forecasters, conducted by the Federal Reserve Bank of Philadelphia, is based on many individual commercial and academic forecasts, which are then grouped in mean or median forecasts. The Survey is conducted near the end of the second month of each quarter and publishes forecasts for the current quarter and the next 4 quarters in the future. The forecasts for real GDP are avail-

what heroic assumption that the population has been constant throughout the period considered.

able only from 1981Q3 on. Notice that the SPF does not provide forecasts for the Fed Funds rate.

An important data-related issue regards the appropriate "actual" series to use when comparing the various forecasts. Because macroeconomic data is continuously revised, we need to make a choice about which revision to use. Following Romer and Romer (2000), we choose to use the second revision, *i.e.* the one done at the end of the subsequent quarter. The second revision seems to be the appropriate series to use because it is based on relatively complete data, but it is still roughly contemporaneous with the forecasts we are analyzing. This series does not include rebenchmarking and changes in the definition of the economic concepts that occur in the annual and quinquennial revisions and should, therefore, be conceptually similar to the series being forecast.

Let us now present some forecasting results that will highlight the motivation of this paper. Throughout the paper we will compare the forecasts we produced with the forecasts of naive benchmark models. The benchmark model for GDP in levels is a random walk with drift (hence GDP growth in this model is simply constant). We estimate this constant as the mean growth of GDP in the 10 years previous to the date at which we perform the evaluation. The benchmark models for GDP deflator inflation and the Fed Funds rate are random walks, i.e. the forecast of the value of inflation and the interest in the next period is today's value.

The first two columns of table 3 report the out-of-sample performance of the forecasts generated with the simple new-keynesian model and of the SPF relative to the naive benchmark, for GDP growth, GDP deflator inflation and the Fed Funds rate respectively. In the first column of each table is reported, for each variable of interest, the ratio of the mean square error of the purely model-based forecast (NK) against the mean square error of the naive benchmark, while the second column reports the ratio of the mean square error of the SPF against the mean square error of the naive benchmark. Asterisks indicate a rejection of the test of equal predictive accuracy between each forecast and the naive benchmark.[8]

This simple NK model does not have much forecasting power, but it has the advantage of enabling us to tell a consistent economic story about the forecasts. The professional forecasters fare better than the model, in that their forecasts, at least at 0 and 1 step ahead, are better than the naive benchmark in a statistical sense. And this holds both for GDP growth and for GDP deflator growth. Over time, model and judgement seem to contain information that is useful in different points in time (see Figure 2): in few periods the model does even better than the SPF. Many methods, such as optimal-weight combination forecasts (e.g., Stock and Watson, 2004), have been developed to take advantage of the difference in performance through time. The available methods however are statistical, reduced-form methods and therefore do not allow telling compelling stories about the forecasts. Our methodology instead delivers both features.

In the following section we present the results obtained when applying the

[8]Following Romer and Romer (2000), our inference is based on the regression: $(z_{ht} - \hat{z}_{ht}^{m})^2 - (z_{ht} - \hat{z}_{ht}^{naive})^2 = c + u_{ht}$ where z is the variable to be forecasted at horizon h using model -m . The estimate of c is simply the difference between forecast-m and a Naive model MSFEs, and the standard error is corrected for heteroskedasticity and serial correlation over h-1 months. This testing procedure falls in the Diebold-Mariano-West framework.

methodology proposed in Section 2 to the model presented above and using the SPF forecasts. We will show that the methodology we propose allows for generating new augmented model-based forecasts that are more accurate than the original 'purely' model-based ones, but that can still reflect the economic stories that arise from the model. We will compare the our forecasts not only against forecasts produced by a naive benchmark, but also against another forecast obtained by combining model and SPF in a more standard way. In particular, we will use an equal-weights combination of the 'purely' model-based forecasts and the SPF, which, as many authors (e.g. Stock and Watson, 2004) point out, generally outperforms not only the single forecasts but also more sophisticated and time-varying optimal combinations.

4 Forecasting and Structural Analysis

In this section we present the results obtained applying the proposed methodology to the framework described in the previous section. First, we present model-based forecasts for real GDP, the GDP deflator and the Fed Funds rate that can account for the judgmental information contained in the SPF forecasts. We will compare their performance on the basis of their mean square forecast error, *i.e.* deeming better a forecast with a smaller MSE[9]. Second, we will discuss the way the SPF and the 'purely' model-based forecasts are combined, showing the weights associated to the SPF in generating estimates of the underlying states and how they change in time.

[9]The results hold if performance is measured differently, e.g. with Mean Absolute Errors.

GDP growth forecasts relative to constant growth				
EVALUATION SAMPLE: 1992:2 - 2006:4				
Horizon	NK	SPF	COMB	AUGM
Q0	1.2320	0.8199 *	0.9275	0.7579 *
Q1	1.1680	0.9349	0.9930	1.0608
Q2	1.1022	1.0002	1.0160	1.0739
Q3	1.0547	0.9642	0.9819	1.0529
Q4	1.0389	1.0006	0.9972	1.0400

GDP deflator inflation relative to a random walk				
EVALUATION SAMPLE: 1996:2 - 2006:4				
Horizon	NK	SPF	COMB	AUGM
Q0	0.9383	0.6365 **	0.6495 **	0.5599 **
Q1	0.9275	0.6577 **	0.6743**	0.6433 **
Q2	1.0204	0.8286	0.7887	0.9319
Q3	1.1158	0.9862	0.8920	1.0963
Q4	1.0992	0.9055	0.8781	1.0147

Fed Funds rate relative to a random walk				
EVALUATION SAMPLE: 1996:2 - 2006:4				
Horizon	NK	SPF	COMB	AUGM
Q0	2.4154	NaN	NaN	2.4166
Q1	2.0412	NaN	NaN	2.0991
Q2	1.7235	NaN	NaN	1.7854
Q3	1.4957	NaN	NaN	1.5583
Q4	1.3336	NaN	NaN	1.3958

Table 3: Relative MSFE of forecasts of GDP growth, GDP deflator inflation and the fed funds rate with respect to their naive benchmarks. Asterisks denote forecasts that are statistically more accurate than the naive benchmark at 1% (* * *), 5%(**) and 10%(*)

Finally, we will show how the method we propose also allows to read the judgmental forecasts through the lens of the model, and hence enables us to interpret these forecasts.

We construct the augmented forecasts (AUGM) as described in the previous section. The evaluation sample goes from the first quarter of 1992 to the fourth quarter of 2006. The matrices Σ_S and Σ_R are estimated recursively every quarter, *i.e.* at every new release of the SPF. As noted before, the SPF does not provide forecasts of the Fed Funds rate, so we treat this missing observation problem as suggested in Giannone, Reichlin and Small (2008)[10]. We also compare the augmented forecasts with forecasts produced combining the 'purely' model-based and the SPF forecasts with equal weights. The latter are identified in the tables and graphs as COMB.

Table 3 reports the mean square forecast error (MSE) of the purely model-based forecasts (NK), the SPF, the combination forecasts and the augmented forecasts relative to the naive model[11], when forecasting GDP growth. The augmented forecasts outperform all the other nowcasts, including the combination nowcast. At higher horizons, instead, the augmented forecasts converge to the model-based forecasts and hence perform less well (though still better than the model). The reason is that we have assumed that the information set of the judgmental forecasters contains information on the only on the current, *and not on the future*, innovations. Therefore, the augmented forecasts assign virtually no weight to the SPF for higher horizon forecasts[12].

[10]Assigning infinite variance to the noise term when observations are missing, one implicitely sets to zero the weight that is assigned that variable in the filtering problem.

[11]The benchmark model for GDP in levels is a random walk with drift, while benchmark models for inflation and the Fed Funds rate are random walk.

[12]If we made the assumption that the SPF might have information also on future shocks,

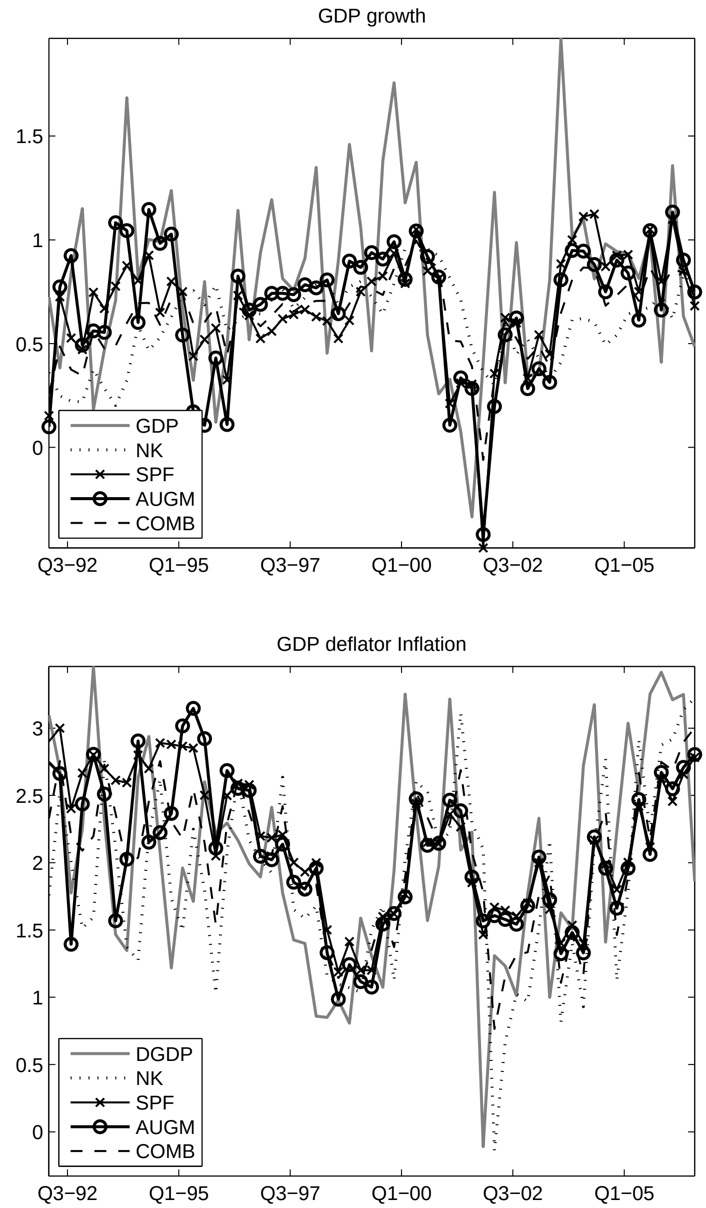


Figure 1: **Nowcast for GDP growth (top panel) and GDP deflator inflation (bottom panel) - EVALUATION SAMPLE 1992:1-2006:4**. The grey thick solid line represents the actual data, the dotted line is the 'purely' model-based nowcast, the line with the x-marker is the SPF, the dashed line is the combination forecast and the thick line with the circle marker is the augmented forecast.

For this reason we will mainly focus our analysis on the nowcast.

Figure 1 reports the nowcasts of the model (NK), of the SPF, of the combination model (COMB) and of the augmented model (AUGM) compared with actual data for GDP growth and annualized quarter-on-quarter-inflation over the full evaluation sample. The augmented forecasts of both variables track more closely the model-based forecasts in the periods in which the model performs better than the SPF, such as in the second half of the 90's, while it mimics the SPF when they fare better than the model.

Figure 2 reports the smoothed forecast errors for the nowcast of GDP and GDP deflator inflation (centered moving average 4 quarters on each side) over the full sample period. The dotted line is the 'purely' model-based nowcast, the line with the x-marker is the SPF, the dashed line is the combination forecast and the thick line with the circle marker is the augmented forecast. These figures confirm that the augmented nowcasts are consistently more accurate than the naive benchmark and that the augmented are able track more closely the 'purely' model-based forecast or the SPF, depending on their respective past performance.

The way these two forecasts are combined is not trivial. The SPF forecasts

then the augmented forecasts would be incorporated also at higher horizons. We do not want to go there, however, because it would put at risk the theoretical consistency of the forecasts. Indeed, the fact that the SPF have more information than the agents, but the latter do not account for that is at odds with the assumption of the rationality of the agents.

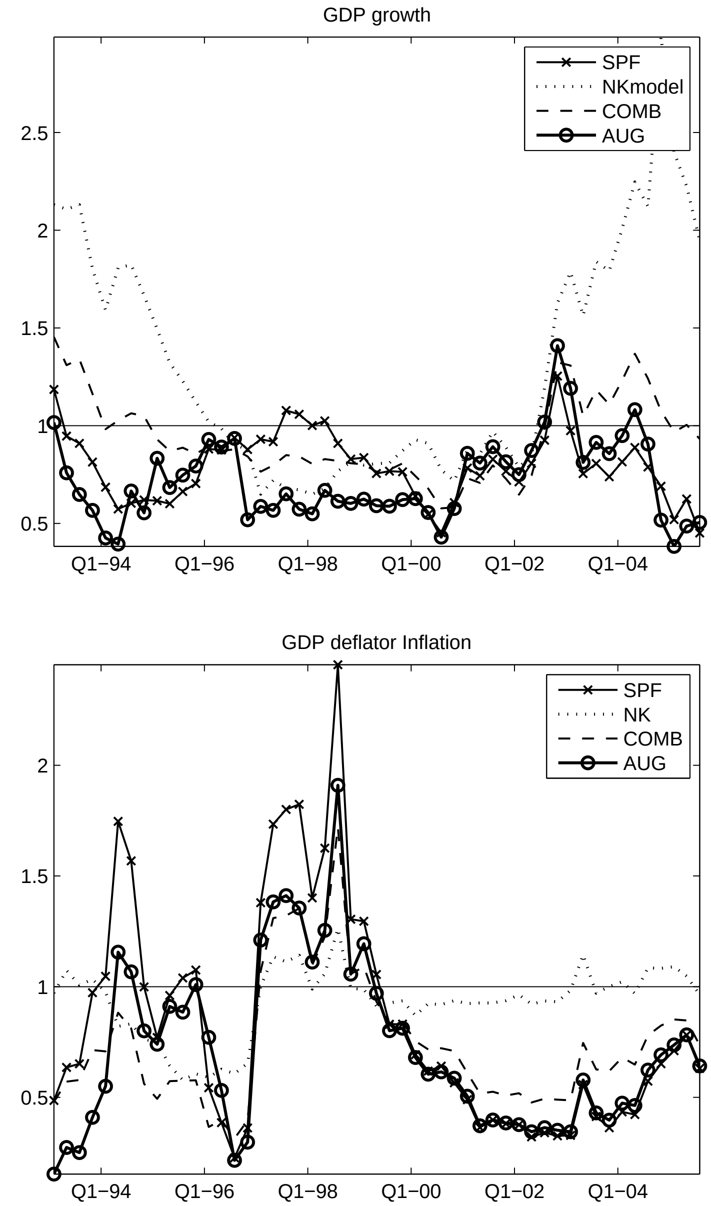


Figure 2: **NOWCASTS: Smoothed Square forecast errors for GDP growth and GDP deflator inflation**. This figure reports the smoothed (centered moving average 4 quarters on each side) forecast errors for the nowcast of GDP growth (top panel) and of GDP deflator inflation (bottom panel) over the full sample period. The dotted line is the 'purely' model-based nowcast, the line with the x-marker is the SPF, the dashed line is the combination forecast and the thick line with the circle marker is the augmented forecast.

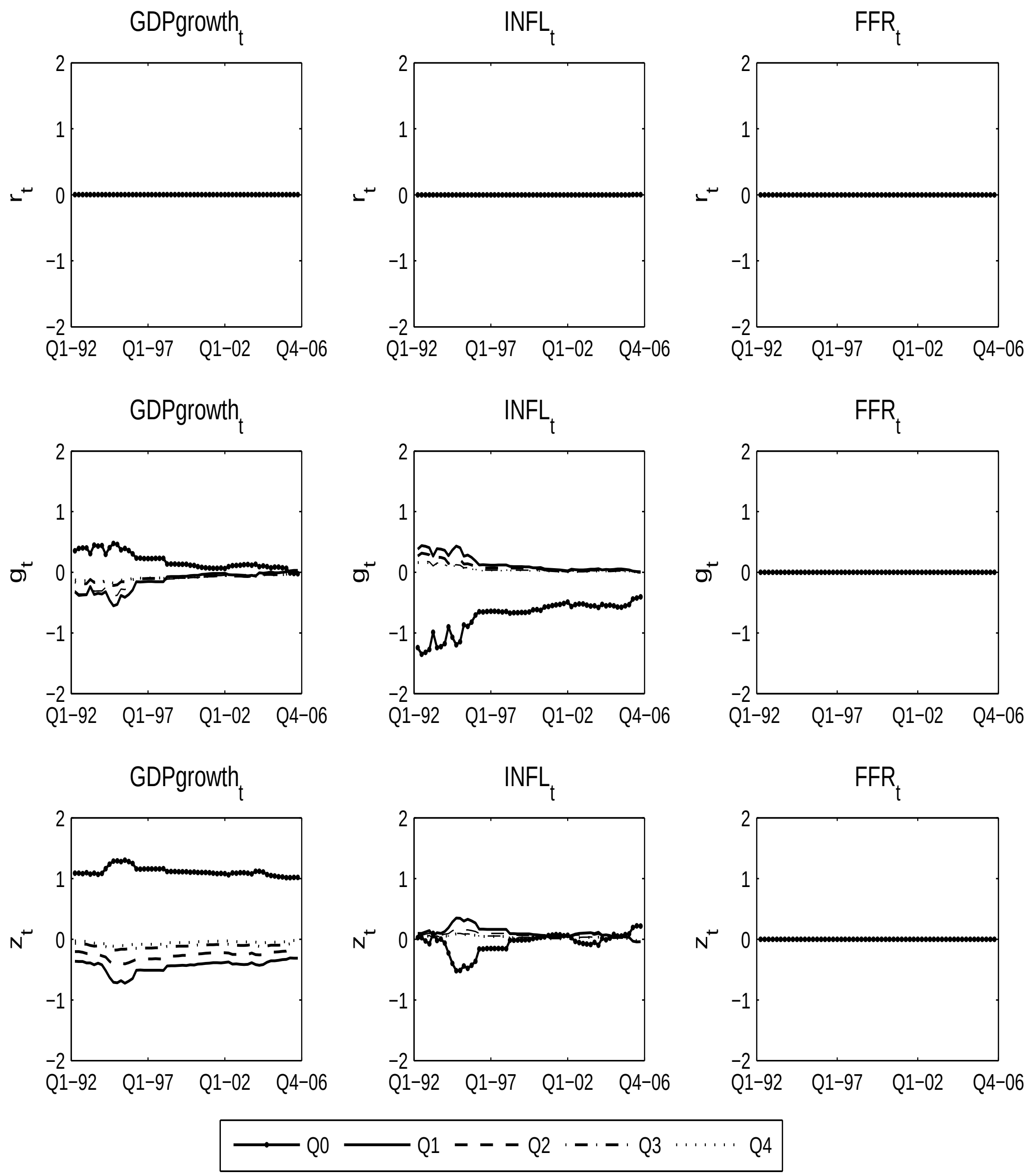


Figure 3: **Weights assigned to the SPF forecasts when estimating the states of the model - from 1992:Q1 to 2006Q4**. Each panel of this figure shows the weight assigned, throughout the evaluation sample, to the SPF forecasts at different horizons. The columns report the role played by the forecasts of a specific variable (e.g. GDP growth in the first column) in determining the estimate of the different states. The rows indicated the contribution of the SPF forecast of each variable for one specific state (e.g. r_t in the first row).

are used to generate new estimates of the state variables as follows:

$$z^{+}_{t|J} = C\left(A\hat{s}_{t-1|t-1} + \Sigma_S \Sigma_R^{-1} \begin{bmatrix} \left(z_{t|J} - z_{t|t-1}\right) \\ \vdots \\ \left(z_{t+4|J} - z_{t+4|t-1}\right) \end{bmatrix} \right)$$

If the SPF forecasts carry a lot of information about a state, they will have a big weight in the determination of $E[s_t|J]$. Figure (3) reports these weights: each plot of the figure shows the weight assigned, throughout the evaluation sample, to the SPF forecasts at different horizons (*i.e.* plot contains 5 lines, one for each forecasting horizon). Each of the three rows of plots shows the contribution of the SPF forecasts of GDP growth, inflation and the Fed Funds rate in the estimation of a specific state (r_t, g_t and z_t respectively). The columns show the weights assigned to the SPF forecasts of a specific variable in determining the states. The last column, for example, is full of zeros, because the SPF do not produce a forecast of the Fed Funds rate and hence it does not contribute to the estimation of the states. Let us now analyze the figure along the rows. The first row of graphs shows the contribution of the SPF forecasts of GDP growth, inflation and the Fed Funds rate in determining the augmented estimate of the state r_t, while the second and third rows of graphs show the contribution of the SPF forecasts of GDP growth, inflation and the Fed Funds rate in determining the new estimate of the states g_t and z_t. The figure suggests that the SPF forecasts carry very little information on r_t, but are instead very useful for g_t and z_t. Obviously, given our assumptions forecasts with shorter horizons are attributed more weight; moreover these weights are higher in the first part of the evaluation sample, because back then the performance of the SPF had been consistently better than the model. Finally, we can infer that, in the estimation of z_t (g_t), most of, but not all, the weight is given to the SPF forecasts of GDP growth (Inflation).

Finally, we present an example of "structural" analysis of the SPF forecasts. Figure 4 reports the ex-post estimates of the technology shock and the government spending shock (thick grey line) and the structural shocks as perceived by the SPF (black with the x-shaped markers). The latter are constructed as described in section 2, while the former are simply obtained premutliplying the innovations deriving from the Kalman smoother on the dataset 1982Q1-2006Q4 by $(B'B)^{-1}B'$. Of course, these are not necessarily the real structural shocks, just the ex-post estimates, hence the best estimates available.

To see how this analysis can be useful, think, for example, of the widely discussed question: why did the most professional forecasters miss out on the real activity boom of the 90's? Figure 4 provides a possible answer: indeed, it seem that they underestimated the technology shocks that were happening in that period. Another episode that is often discussed is the delay with which the professional and institutional forecasters called the 2001 recession. Our decomposition provides a story for this: apparently the forecasters underestimated the negative technology shocks of the first quarters of 2001, while overestimating the negative demand shock in the wake of 9/11.

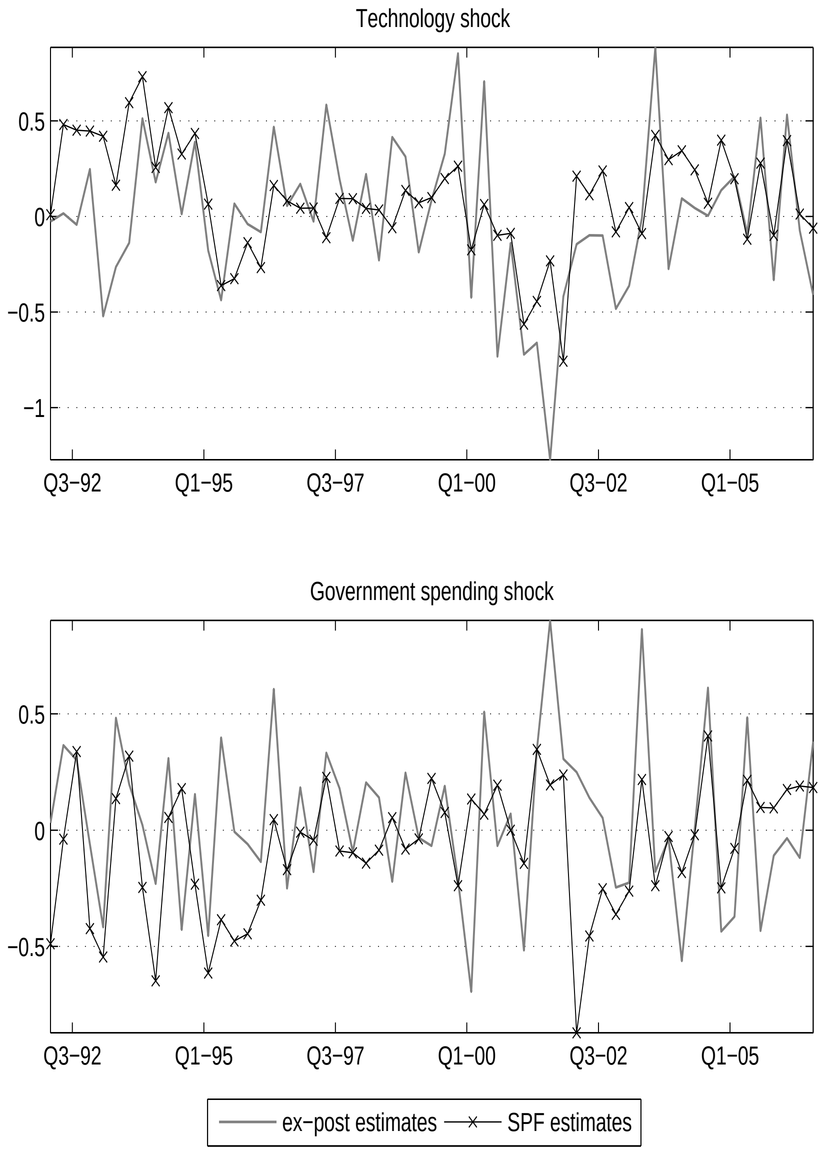


Figure 4: **Ex-post estimates of the technology shock (top panel) and government spending shock (bottom panel) and these shocks as *perceived* by the SPF when nowcasting 1992Q1-2006Q4**. The grey thick line represents the ex-post estimates of shock, while the dotted line with the triangle-shaped markers is the shock as perceived by the SPF.

5 Conclusions and Extensions

In this paper I propose a model-consistent and parsimonious method of combining judgmental and model-based forecasts. I suggest modeling the judgmental forecasts as optimal estimates of the variables of interest, made with a different, possibly more informative, information set. I then show how they can be accounted for in the framework of a linearized and solved DSGE model. The methodology I propose allows generating forecasts that are more accurate than the purely model-based ones, but that are still disciplined by the economic rigor of the model.

I have also highlighted how to infer the information content of the judgmental forecasts from the weights that the augmented forecasts assign to them. More precisely, the more the professional forecasters are able to gather information on the shocks, the more the augmented forecast will use the professional forecasts when combining them with the predictions from the model, but it will down-weigh them if the variance of their forecast errors is too large.

Finally I have described how to interpret the forecasts through the lens of the model, by extracting the structural shocks as they are perceived by the professional forecasters. This can give interesting answers to widely debated questions, as shown in the example.

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