MONITORING THE SPANISH ECONOMY THROUGH THE LENSES OF STRUCTURAL BAYESIAN VARS

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Abstract

This paper proposes a suite of Structural Bayesian Vector Autoregression (SBVAR) models used (i) to disentangle the main shocks driving the Spanish economy over time and (ii) to provide short and medium term forecasts of output and inflation. The suite consists of a benchmark model, that includes output, prices and interest rate, along with four extensions that gather information from the labor, financial, and international markets, and from the fiscal sector. The identification of the structural shocks is achieved by relying on sign and exclusion restrictions. The models provide a narrative of the contribution of fundamental economic shocks that agrees with main historic events of the Spanish economy. Moreover, the proposed SBVAR models are used to provide forecasts of output and inflation conditional on diferent scenarios about the development of key macroeconomic variables. Therefore, the suite could be incorporated to the toolkit of quantitative models that the Banco de España uses to perform forecasts.

Keywords: structural analysis, vector autoregressions, bayesian estimation, sign restrictions.

JEL classification: E32, C22, E27.

Resumen

Este artículo propone un conjunto de modelos de Vectores Autorregresivos Estructurales Bayesianos (SBVAR), el cual es usado para: distinguir los principales choques que influencian a la economía española a través del tiempo, y proveer predicciones de PIB e inflación de corto y medio plazo. El conjunto de modelos consiste en un modelo de referencia, el cual incluye el PIB, la inflación y el tipo de interés, junto con cuatro extensiones que reúnen información acerca del mercado laboral, financiero e internacional, y también del sector fiscal. La identificación de los choques estructurales se lleva a cabo utilizando restricciones de signo y de exclusión. Los modelos propuestos proveen una narrativa de la contribución de choques económicos fundamentales que concuerda con eventos históricos de la economía española. Además, los modelos SBVAR son usados para proporcionar predicciones de PIB e inflación condicionales a diferentes escenarios acerca del desarrollo de variables macroeconómicas clave. Por lo tanto, los modelos propuestos podrían incorporarse al conjunto de modelos que el Banco de España utiliza para producir predicciones.

Palabras claves: análisis estructural, vectores autorregresivos, estimación bayesiana, restricciones de signo.

Códigos JEL: E32, C22, E27.

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1 Introduction

The last recovery of the Spanish economy, that started in 2013, exceeded expectations, considering the severity and duration of the previous consecutive recessions. Such a recovery was significantly influenced by a variety of factors both foreign, such as low oil prices, the depreciation of the euro and an expansionary monetary policy implemented by the European Central Bank (ECB), and domestic, such as fiscal stimulus and labor market reforms. Given this scenario, it is crucial for policy makers to monitor, on a timely basis, the contribution of those factors to both the business cycle and inflation dynamics. Such information is crucial in order to assess the outlook of the Spanish economy by also understanding what are the main shocks driving such developments. This paper proposes a flexible econometric toolkit useful for such a purpose.

Since the seminal work of Sims (1980) Structural Vector Autoregressions (SVAR) have become a fundamental tool for policy makers in analyzing relationships between key macroeconomic and financial variables. However, an intrinsic feature of VAR models is the proliferation of parameters as the number of variables and lags, included in the model, increase. Due to this feature, classical methods may yield inefficient estimates of the parameters, especially, when the sample of available observations is relatively small. This is the case for the Spanish economy, where harmonized data on most relevant macroeconomic variables, at the quarterly frequency, are available only since 1995.

Bayesian methods offer a flexible framework to estimate SVAR models in that they allow for robust inference when the number of parameters included in the model is significantly larger than the sample size, see Banbura et al. (2010).[1] Also, they provide an easy way to compute the probability distribution of conditional forecasts produced by the model, see Waggoner and Zha (1999). Bayesian methods are not without shortcomings, since under particular circumstances, the estimates may be too sensitive to the prior beliefs of the parameter space. However, there are procedures that help to select in an agnostic way the most appropriate prior information to be imposed, such as, the computation of the marginal likelihood, see Chib (1995), and Carriero et al. (2012).[2]

This paper proposes a suite of structural Bayesian VAR models that is designed for three specific purposes. First, allowing to disentangle the main fundamental shocks driving the Spanish economy over time. Second, delivering forecasts of output growth and inflation that are con-

[1]For the case of the Spanish economy, Ballabriga et al. (2000) proposed a Bayesian VAR for forecasting and simulation exercises.

[2]Throughout the paper, the marginal likelihood criterium is used to choose the specification of the proposed models and the associated hyper-parameters of the prior distributions.

ditional on assumptions about the future paths of other key macroeconomic variables. Third, computing forecasts that mimic the projections of the staff of the Banco de España in order to provide robust assessments about the uncertainty associated to them.[3]

The first model of the suite consists of a small benchmark SBVAR that includes information from output growth, core inflation, oil prices and interest rate, and that allows to assess the contribution of demand, cost-push (or mark-up), oil price and monetary policy shocks to the business cycle and inflation dynamics. The developments of the labor market and the fiscal sector represent key drivers of the Spanish economy, especially during the last decade, where unemployment rate has remained at high levels and public finances have been under significant stress. Taking this into consideration, a second model that incorporates labor market conditions to the benchmark model is included in the suite, in order to assess the contribution of labor supply shocks to the business cycle. Also a third model that adds information from the fiscal sector is considered to investigate the influence that both government expenditure and income shocks have had on output growth.

The episode of the so-called Great Recession showed that adverse conditions generated in the financial sector of a given country may not only propagate to its own real economy but also to other countries with whom experiences tight financial linkages. Therefore, a fourth model that incorporates information from the stock market to the benchmark model is also proposed to measure the importance of financial uncertainty shocks on the real economy. Additionally, due to the strong trade linkages of Spain with the rest of the world, it is included a fifth model that contains information from the international developments.

The results show that the suite of models reproduce a narrative of the contribution of fundamental shocks to output growth and inflation that agrees with main economic events occurred in different sectors of the economy. In particular, it is shown that the Spanish business cycle was mainly influenced by positive labor supply shocks since the mid 1900s until the early 2000s. However, since the introduction of the euro, conventional monetary policy shocks played the most significant role until the arrival of the Great Recession, when negative foreign shocks contributed the most to the 2008-2009 downturn. Instead, the recession occurred between 2010-2013, was mainly driven by shocks coming from the fiscal sector, in particular, by negative government expenditure shocks. Also, it is shown how the last recovery has been greatly influenced by shocks to oil prices. It is important to mention that when analyzing the contribution of unconventional monetary policy shocks, it is found that core inflation has reacted positive

[3]Notice that while forecasts are mechanically produced by an econometric model, projections are produced by incorporating a wider range of information, such as model-driven forecasts from different methodologies, underlying assumptions, and judgment.

and significantly during episodes when major large scale asset purchases where performed by the ECB, providing evidence in favor of the quantitative easing policy to stimulate inflation.

The last SBVAR included in the suite makes reference to a composite model that contains all the blocks of information previously described, that is, labor, fiscal, financial, and international aspects. This model is used to perform conditional forecasts, of output growth and inflation, along with robust assessments about their corresponding uncertainty. Moreover, conditional forecasts performed by the other models in the suite represent useful information for policy makers to understand the sensitivity of their forecasts once some specific aspects of the economy are taken as given.

The remainder of the paper is organized as follows. Section 2 provides a detailed description of the models in the suite along with the assumptions used to identify structural shocks. Section 3 provides the empirical results about both the structural analysis and forecasts. Section 4 concludes.

2 Suite of Models

This section describes the set of SBVAR models along with the identifying assumption for the structural shocks. Throughout the paper, the models will be refereed to as *Benchmark*, *Financial*, *Labor*, *International*, and *Fiscal* models, along with the composite model, which will be named as *One-fits-all* model, since it nests all the information included in the block-specific models. The detailed information about the Bayesian methods used to estimate all the models are presented in Appendix A.

2.1 Benchmark Model

The first specification consists of a small VAR model useful to investigate the relationship between real GDP growth (GDP_t), core inflation (INF_t), oil price growth (OIL_t), and the interest rate (INT_t). The data is at the quarterly frequency and spans from 1995:I until 2017:I. In order to account for the exogeneity of oil prices, restrictions in the autoregressive coefficients of the VAR are included. In particular, consider the following structural VAR model:

$$\begin{bmatrix} GDP_t \\ INF_t \\ INT_t \\ OIL_t \end{bmatrix} = \begin{bmatrix} \phi_{10} \\ \vdots \\ \phi_{30} \\ \phi_{40} \end{bmatrix} + \begin{bmatrix} \phi_{11} & \phi_{12} & \dots & \phi_{14} \\ \vdots & \vdots & \ddots & \vdots \\ \phi_{31} & \phi_{32} & \dots & \phi_{34} \\ 0 & 0 & 0 & \phi_{44} \end{bmatrix} (L) \begin{bmatrix} GDP_{t-1} \\ INF_{t-1} \\ INT_{t-1} \\ OIL_{t-1} \end{bmatrix} + \begin{bmatrix} u_{gdp,t} \\ u_{inf,t} \\ u_{int,t} \\ u_{oil,t} \end{bmatrix}, \qquad (1)$$

where L denotes the lag operator. Notice that in Equation (1), oil prices are allowed to influence the dynamics of the domestic variables, while the domestic variables are not allowed to influence the dynamics of oil prices. All the reduced form innovations are collected in the vector $\mathbf{u}_t = (u_{gdp,t}, u_{inf,t}, u_{int,t}, u_{oil,t})'$, which is assumed to be normally distributed, $\mathbf{u}_t \sim N(0, \Sigma)$.

To be able to perform structural analysis, the reduced form innovations can be expressed as a function of structural innovations, ε_t, and the corresponding impact multiplier matrix, A^{-1}, as follows,

$$\mathbf{u}_t = A^{-1}\varepsilon_t, \tag{2}$$

where ε_t is assumed to be normally distributed, $\varepsilon_t \sim N(0, I)$. The main interest is placed on identifying (i) demand, (ii) cost-push, and (iii) monetary policy shocks, along with accounting for the exogeneity of oil prices. Therefore, to provide an identification as sharp as possible of the structural shocks driving the system, defined as $\varepsilon_t = (\varepsilon_{demand,t}, \varepsilon_{cost\text{-}push,t}, \varepsilon_{mon\text{-}pol,t}, \varepsilon_{oil,t})'$, sign and exclusion restrictions in the impact multiplier matrix are imposed. In particular, by following the line of Fry and Pagan (2011), it is assume that a positive demand shock raises GDP growth, inflation and interest rates; a positive cost-push (or negative supply) shock lowers growth, but raises inflation and interest rates; and a contractionary monetary policy shock raises interest rate, but lowers inflation and GDP growth.

It can be argued that the monetary policy rate of the ECB does not directly reacts to the developments of output and inflation of the Spanish economy. However, as documented in Camacho et al. (2015) there is significant degree of comovement in inflation dynamics and real activity between the four largest economies of the euro area (Germany, France, Italy and Spain), implying that the policy rate may well react to those common dynamics, and hence, to the Spanish economic developments in an indirect way.[4] When assessing the contribution of monetary policy shocks, the limitations associated to the zero lower bound are also taken into consideration. In particular, the ECB policy rate will be replaced by the shadow policy rate of Wu and Xia (2017) that intends to account for the unconventional monetary policy measures, such as quantitative easing.

Also, it is assumed that oil price growth is only driven by its own structural shocks, which in turn have unknown effects on output growth, inflation and interest rate. Formally, all these restrictions can be implemented in Equation (2) as follows,

[4] Moreover, when the policy rate is assumed to be exogenous to the domestic developments in the model, the data does not seem to support such a restriction, since draws of the impact multiplier matrix that satisfy that assumption are rarely found. This indicates that a Taylor rule approximation is a suitable way to model the dynamics of the interest rate for the present case.

$$
\begin{bmatrix} u_{gdp,t} \\ u_{inf,t} \\ u_{int,t} \\ u_{oil,t} \end{bmatrix} = \begin{bmatrix} + & - & - & * \\ + & + & - & * \\ + & + & + & * \\ 0 & 0 & 0 & * \end{bmatrix} \begin{bmatrix} \varepsilon_{demand,t} \\ \varepsilon_{cost\text{-}push,t} \\ \varepsilon_{mon\text{-}pol,t} \\ \varepsilon_{oil,t} \end{bmatrix}, \tag{3}
$$

where $*$ indicates that the corresponding entry of the matrix is left unrestricted.

2.2 Labor Model

According to the Spanish Business Cycle Dating Committee, the last recession occurred between 2010:IV and 2013:II. During this period the unemployment rate continuously climbed to historical values, reaching up to 26 percent. Around that time, the growth rate of wages started to decreased leading the labor market to experience significantly adverse conditions which were reflected in a strong contractionary episode. In dealing with such a situation, labor reforms where implemented with the aim of providing firms with increased flexibility to link wage negotiations to their particular economic conditions.

The aim of this model is to quantify the contribution of labor supply shocks the Spanish business cycle. In doing so, the benchmark model is enlarged by incorporating information form the labor market. In particular, two variables are included in the proposed enlarged model. First, the unemployment rate, in first differences, denoted by UR_t, and second, the growth rate of nominal wages, denoted by WAG_t.[5] Accordingly, the SBVAR with labor block can be defined as,

$$
\begin{bmatrix} GDP_t \\ INF_t \\ INT_t \\ UR_t \\ WAG_t \\ OIL_t \end{bmatrix} = \begin{bmatrix} \phi_{10} \\ \phi_{20} \\ \vdots \\ \vdots \\ \phi_{50} \\ \phi_{60} \end{bmatrix} + \begin{bmatrix} \phi_{11} & \phi_{12} & \cdots & \cdots & \phi_{15} & \phi_{16} \\ \phi_{21} & \phi_{22} & \cdots & \cdots & \phi_{25} & \phi_{26} \\ \vdots & \vdots & \ddots & & \vdots & \vdots \\ \vdots & \vdots & & \ddots & \vdots & \vdots \\ \phi_{51} & \phi_{52} & \cdots & \cdots & \phi_{55} & \phi_{56} \\ 0 & 0 & \cdots & \cdots & 0 & \phi_{66} \end{bmatrix} (L) \begin{bmatrix} GDP_{t-1} \\ INF_{t-1} \\ INT_{t-1} \\ UR_{t-1} \\ WAG_{t-1} \\ OIL_{t-1} \end{bmatrix} + \begin{bmatrix} u_{gdp,t} \\ u_{inf,t} \\ u_{int,t} \\ u_{ur,t} \\ u_{wag,t} \\ u_{oil,t} \end{bmatrix}. \tag{4}
$$

Following the line of Peersman and Straub (2009) and Foroni et al. (2015), it is assumed that positive labor supply shocks raises output growth, but lowers inflation and wages. These relationships between reduced form and structural innovations can be represented as,

[5] Augmented Dicky-Fuller test indicates non-stationarity of the unemployment rate in levels, therefore, the first differences are used.

$$\begin{bmatrix} u_{gdp,t} \\ u_{inf,t} \\ u_{int,t} \\ u_{une,t} \\ u_{wag,t} \\ u_{oil,t} \end{bmatrix} = \begin{bmatrix} + & - & - & + & * & * \\ + & + & - & - & * & * \\ + & + & + & * & * & * \\ * & * & * & * & * & * \\ * & * & * & - & * & * \\ 0 & 0 & 0 & 0 & 0 & * \end{bmatrix} \begin{bmatrix} \varepsilon_{demand,t} \\ \varepsilon_{cost\text{-}push,t} \\ \varepsilon_{mon\text{-}pol,t} \\ \varepsilon_{lab\text{-}sup,t} \\ \varepsilon_{wag,t} \\ \varepsilon_{oil,t} \end{bmatrix}, \quad (5)$$

where $\varepsilon_{lab\text{-}sup,t}$ denote the labor supply shocks. Notice that, since no restrictions are imposed to the innovations of wages, they are not subject to any structural interpretation. However, it is important to control for the interaction between wages and unemployment rate when assessing labor market dynamics.

Since the mid 1990s until the late 2000s the Spanish economy experienced a significant increased in the labor force due to large inflows of immigrant workers. This phenomenon might have had important implications for the contribution of labor supply shocks to the real economy. Therefore, to disentangle its effect, an alternative specification of the *Labor* model will be evaluated. In particular, instead of including unemployment rate as a single variable into the model, information about its two components will be included, that is, the growth rate of number of people in the labor force, and the growth rate of unemployed people. Next, it is assumed that positive labor supply shocks increases the labor force and have unknown effect on the number unemployed people. The rest of sign and exclusion restrictions remain the same as the ones in Equation (5). This version of the model will be referred to as "extended" *Labor* model.

2.3 Fiscal Model

During the crisis of 2008-2009, the Spanish economy incurred in significant fiscal imbalances. In dealing with such imbalances, a number of fiscal reforms, on the revenue and on the expenditure side, were implemented between 2010 and 2013 (Martí and Pérez (2016)). This led to a reduction of the deficit and to commitments with the European authorities to achieve fiscal balances that are compatible with the sustainability of public finances. Therefore, it is important to address how fiscal shocks have contributed to real activity, especially during recent years.

To take into account the effect of shocks to fiscal variables, the benchmark model is enlarged with a block that contains information from the government finances. In particular, two variables are included in the proposed enlarged model. First, the growth rate of national public demand, denoted by NPD_t, where the level of national public demand is defined as the sum of government consumption and government investment. Second, a composite measure of taxes, constructed by Gil et al. (2017), denoted by TAX_t. Hence, the SBVAR model with fiscal block is defined as,

$$\begin{bmatrix} GDP_t \\ INF_t \\ INT_t \\ NPD_t \\ TAX_t \\ OIL_t \end{bmatrix} = \begin{bmatrix} \phi_{10} \\ \phi_{20} \\ \vdots \\ \vdots \\ \phi_{50} \\ \phi_{60} \end{bmatrix} + \begin{bmatrix} \phi_{11} & \phi_{12} & \dots & \dots & \phi_{15} & \phi_{16} \\ \phi_{21} & \phi_{22} & \dots & \dots & \phi_{25} & \phi_{26} \\ \vdots & \vdots & \ddots & & \vdots & \vdots \\ \vdots & \vdots & & \ddots & \vdots & \vdots \\ \phi_{51} & \phi_{52} & \dots & \dots & \phi_{55} & \phi_{56} \\ 0 & 0 & \dots & \dots & 0 & \phi_{66} \end{bmatrix} (L) \begin{bmatrix} GDP_{t-1} \\ INF_{t-1} \\ INT_{t-1} \\ NPD_{t-1} \\ TAX_{t-1} \\ OIL_{t-1} \end{bmatrix} + \begin{bmatrix} u_{gdp,t} \\ u_{inf,t} \\ u_{int,t} \\ u_{npd,t} \\ u_{tax,t} \\ u_{oil,t} \end{bmatrix}. \tag{6}$$

In this extended model, the interest is placed on identifying fiscal shocks that come from both the revenue and expenditure sides. In particular, following Mountford and Uhlig (2009), it is assumed that a positive government expenditure shock rises national public demand and output growth, while a positive government revenue shock rises taxes, but lowers output growth. This goes in line with the results found in Gil et al. (2017), where it is documented that following a 1% of GDP increase in taxes, output falls by 1.3% after one year. These restrictions can be formally expressed as,

$$\begin{bmatrix} u_{gdp,t} \\ u_{inf,t} \\ u_{int,t} \\ u_{npd,t} \\ u_{tax,t} \\ u_{oil,t} \end{bmatrix} = \begin{bmatrix} + & - & - & + & - & * \\ + & + & - & * & * & * \\ + & + & + & * & * & * \\ * & * & * & + & * & * \\ * & * & * & * & + & * \\ 0 & 0 & 0 & 0 & 0 & * \end{bmatrix} \begin{bmatrix} \varepsilon_{demand,t} \\ \varepsilon_{cost\text{-}push,t} \\ \varepsilon_{mon\text{-}pol,t} \\ \varepsilon_{gov\text{-}exp,t} \\ \varepsilon_{gov\text{-}rev,t} \\ \varepsilon_{oil,t} \end{bmatrix}, \tag{7}$$

where $\varepsilon_{gov\text{-}exp,t}$ and $\varepsilon_{gov\text{-}rev,t}$ denote the government expenditure and revenue shocks, respectively.

2.4 Financial Model

The financial sector plays an important role in the propagation of monetary policy shocks to the real economy, as shown in Mishkin (2001). In particular, monetary policy actions have their most direct and immediate effects on the broader financial markets, such as stock, bond, mortgage markets, etc. However, in this paper the focus will be on stock markets since they are viewed as being highly sensitive to economic conditions. Also, stock prices occasionally swing widely, leading to deviations from fundamental values and generating adverse implications for the economy. Therefore, it is important to account for features of the Spanish stock market in analyzing the propagation of shocks between key macroeconomic fundamentals.

A recent study by Gil et al. (2016) documents substantial changes in the uncertainty of financial markets of the Spanish economy. In particular, the authors rely on information from the stock market to construct a synthetic indicator that measures the degree of financial uncertainty, and show that the it has significantly negative effects on real output growth. Motivated by these findings, an enlargement of the *Benchmark* model, with a block that contains information of the Spanish stock market, is included to the suite. In doing so, two variables are incorporated in the financial block. First, the returns from the main index of the stock exchange of Madrid (STO_t), and second, a measure a financial uncertainty (UNC_t), that is based on stock market volatility.[6] The enlarged model can be expressed as follows,

$$\begin{bmatrix} GDP_t \\ INF_t \\ INT_t \\ STO_t \\ UNC_t \\ OIL_t \end{bmatrix} = \begin{bmatrix} \phi_{10} \\ \phi_{20} \\ \vdots \\ \vdots \\ \phi_{50} \\ \phi_{60} \end{bmatrix} + \begin{bmatrix} \phi_{11} & \phi_{12} & \dots & \dots & \phi_{15} & \phi_{16} \\ \phi_{21} & \phi_{22} & \dots & \dots & \phi_{25} & \phi_{26} \\ \vdots & \vdots & \ddots & & \vdots & \vdots \\ \vdots & \vdots & & \ddots & \vdots & \vdots \\ \phi_{51} & \phi_{52} & \dots & \dots & \phi_{55} & \phi_{56} \\ 0 & 0 & \dots & \dots & 0 & \phi_{66} \end{bmatrix} (L) \begin{bmatrix} GDP_{t-1} \\ INF_{t-1} \\ INT_{t-1} \\ STO_{t-1} \\ UNC_{t-1} \\ OIL_{t-1} \end{bmatrix} + \begin{bmatrix} u_{gdp,t} \\ u_{inf,t} \\ u_{int,t} \\ u_{sto,t} \\ u_{unc,t} \\ u_{oil,t} \end{bmatrix}. \quad (8)$$

In this case, the interest is place on assessing the historical contribution of financial uncertainty shocks to real output. Gil, et al. (2016) show that unexpected increases in the levels of uncertainty leads to a decline in real activity, therefore, it is assumed that a positive uncertainty shock rises the overall level of uncertainty in the stock market and lowers output growth and stock returns. These restrictions can be specified as,

$$\begin{bmatrix} u_{gdp,t} \\ u_{inf,t} \\ u_{int,t} \\ u_{sto,t} \\ u_{unc,t} \\ u_{oil,t} \end{bmatrix} = \begin{bmatrix} + & - & - & * & - & * \\ + & + & - & * & * & * \\ + & + & + & * & * & * \\ * & * & * & * & - & * \\ * & * & * & * & + & * \\ 0 & 0 & 0 & 0 & 0 & * \end{bmatrix} \begin{bmatrix} \varepsilon_{demand,t} \\ \varepsilon_{cost\text{-}push,t} \\ \varepsilon_{mon\text{-}pol,t} \\ \varepsilon_{stock\text{-}mkt,t} \\ \varepsilon_{uncertain,t} \\ \varepsilon_{oil,t} \end{bmatrix}, \quad (9)$$

where $\varepsilon_{uncertain,t}$ denote the uncertainty shocks. Note that no restriction is imposed on innovations of the stock returns, $\varepsilon_{stock\text{-}mkt,t}$, therefore, they do not have any structural interpretation.

2.5 International Model

International economic developments both on the real and financial sides may also have a significant influence on a small open economy such as the Spanish one. Accordingly, the suite

[6] Due to data limitations regarding the financial uncertainty index, the sample starts in 1997:Q1 for the *Financial* model.

incorporates an *International* model which consist on an enlargement of the benchmark model that includes information about real and financial international developments. In particular, the bilateral Dollar/Euro exchange rate, in first differences (EXC_t), and the growth rate of global demand (GDM) are included to the *Benchmark* model.

When assessing the effects of foreign variables on a small open economy with an unified econometric framework such as a VAR, it is important to appropriately specify restrictions of exogeneity associated to foreign information. First, it is assumed that none of the domestic variables (output, inflation), nor the interest rate affects global demand. However, global demand is influenced by the bilateral exchange rate and the oil price. Second, it is assumed that the bilateral Dollar/Euro exchange rate is affected by the interest rate and the oil price, but not by the Spanish output growth, inflation or global demand. Hence, the restricted specification of the VAR model with international block can be expressed as,

$$\begin{bmatrix} GDP_t \\ INF_t \\ INT_t \\ GDM_t \\ EXC_t \\ OIL_t \end{bmatrix} = \begin{bmatrix} \phi_{10} \\ \phi_{20} \\ \vdots \\ \vdots \\ \phi_{50} \\ \phi_{60} \end{bmatrix} + \begin{bmatrix} \phi_{11} & \phi_{12} & \cdots & \cdots & \cdots & \phi_{16} \\ \vdots & \vdots & & \ddots & & \vdots \\ \phi_{31} & \phi_{32} & \cdots & \cdots & \cdots & \phi_{36} \\ 0 & 0 & 0 & \phi_{44} & \phi_{45} & \phi_{46} \\ 0 & 0 & \phi_{53} & 0 & \phi_{55} & \phi_{56} \\ 0 & 0 & 0 & 0 & 0 & \phi_{66} \end{bmatrix} (L) \begin{bmatrix} GDP_{t-1} \\ INF_{t-1} \\ INT_{t-1} \\ GDM_t \\ EXC_t \\ OIL_{t-1} \end{bmatrix} + \begin{bmatrix} u_{gdp,t} \\ u_{inf,t} \\ u_{int,t} \\ u_{gdm,t} \\ u_{exc,t} \\ u_{oil,t} \end{bmatrix}. \tag{10}$$

The identification of structural shocks is achieved by combining the sign restrictions from the *Benchmark* model, proposed in Fry and Pagan (2011), along with the exclusion restrictions for global demand and exchange rate mentioned above. Also, since the effects of exchange rate is of particular importance to provide assessments of the pass-through, additional sign restrictions are imposed to identify structural shocks driving the exchange rate. In particular, it is assumed that positive exchange rate shocks, or unexpected exchange rate depreciation, leads to an increase in inflation and to further depreciation, these restrictions are in line with An and Wang (2012). Therefore, the reduced form innovations can be expressed as follows,

$$\begin{bmatrix} u_{gdp,t} \\ u_{inf,t} \\ u_{int,t} \\ u_{gdm,t} \\ u_{exc,t} \\ u_{oil,t} \end{bmatrix} = \begin{bmatrix} + & - & - & * & * & * \\ + & + & - & * & + & * \\ + & + & + & * & * & * \\ 0 & 0 & 0 & * & * & * \\ 0 & 0 & * & 0 & + & * \\ 0 & 0 & 0 & 0 & 0 & * \end{bmatrix} \begin{bmatrix} \varepsilon_{demand,t} \\ \varepsilon_{cost\text{-}push,t} \\ \varepsilon_{mon\text{-}pol,t} \\ \varepsilon_{gdm,t} \\ \varepsilon_{exc,t} \\ \varepsilon_{oil,t} \end{bmatrix}, \tag{11}$$

where, $\varepsilon_{gdm,t}$, and , $\varepsilon_{exc,t}$, denote the global demand and exchange rate shocks. Notice that no additional sign restriction has been imposed to identify global demand shocks, this is in order to avoid imposing assumptions that may not reflect the true underlying relationship between the corresponding structural shocks and reduced form innovations, since there is no clear consensus about the nature of such restrictions for the Spanish case. Also, if the interest is placed on identifying the contributions of all foreign shocks, the aggregation of structural innovations, $\varepsilon_{int,t} = \varepsilon_{gdm,t} + \varepsilon_{exc,t}$, can be defined as a proxy to for "international" shocks.

2.6 One-fits-all Model

The last model in the suite consists of a composite model that nests all the information contained in the previous blocks, that is, *Benchmark*, *Labor*, *Fiscal*, *Financial* and *International* blocks. Although the main purpose of the composite, or *One-fits-all*, model is not performing structural analysis, due to its large dimension, it is useful to compute forecasts of real output growth and core inflation conditional on specific paths for some other key macroeconomic variables included in the model. The forecasts obtained with the *One-fits-all* model could help to improve the projections performed by the staff of the Banco de España since both forecasts and projections are obtained by conditioning on a similar set of information. Moreover, as it is shown in Section A.1 of Appendix A, the priors of the *One-fits-all* model can be chosen in such a way that forecasts that mimic the projections of the staff are generated by the model, and therefore, assessments about their corresponding uncertainty can be easily computed.

Accordingly, the *One-fits-all* model contains information of the variables from all the blocks, which are ordered in the following way,

$$y_t = [OIL_t, GDM_t, NPD_t, GDP_t, UR_t, TAX_t, WAG_t, INF_t, INT_t, EXC, STO, UNC_t]' \quad (12)$$

As it is discussed in Section A.3 of Appendix A, in order to compute conditional forecasts from a Bayesian VAR, estimates of impulse responses, and therefore of structural shocks, are needed. Given the large dimension of the *One-fits-all* model, imposing sign and exclusion restrictions to identify structural shocks results extremely computationally demanding. Therefore, in this case, the identification of shocks is achieved by relying only on exclusion restriction via Cholesky decomposition.

The order of variables in y_t can be justified as follows. Exogenous variables are ordered before domestic variables, following the line of Mumtaz and Surico (2009). In particular, it is assumed that oil price shocks contemporaneously affects global demand, the interest rate, and the rest of domestic variables in the system. Instead, global demand shocks affect contemporaneously domestic variables, the interest rate, but does not affect oil prices. Regarding the block of domestic variables, following the line of Caldara and Kamps (2017), it is assumed that movements in government spending, unlike movements in government revenue, are largely unrelated to the business cycle. Therefore, information about the business cycle, contained in real output and the unemployment rate, are ordered after government expenditure, but before government revenue. Next, wages and inflation are order before the interest rate according to a Taylor rule specification. Finally, it is assumed that movements in the exchange rate are influenced by monetary policy shocks, while the stock market and its corresponding degree of uncertainty are responsive to all the developments in the economy both domestic and foreign.

3 Empirical Results

This section reports the results obtained with the suite of models along two perspectives. First, a structural analysis to disentangle the main shocks driving the Spanish economy. Second, all the models in the suite are used to generate conditional forecasts of output growth and core inflation for the period 2017:II-2019:IV.[7]

3.1 Structural Analysis

In this section, fluctuations in output growth and core inflation are decomposed into the contributions associated to demand, cost-push, monetary policy, oil price, labor supply, government expenditure, government income, uncertainty and foreign shocks. This is done by computing the historical shock decomposition of both real output and core inflation from the SBVAR models proposed in Section 2, for the period from 1995:II until 2017:I.

3.1.1 *Demand, Cost-push, Monetary Policy and Oil Price Shocks*

The structural decomposition of shocks driving output fluctuations obtained with the *Benchmark* model is reported in Figure 1. In particular, output growth is assumed to be driven by four types of shocks: demand, cost-push, monetary policy and oil price shocks. The results indicate that since the beginning of the sample, in the mid 1990s, until 2001, output growth was mainly driven by cost-push shocks, that is, by shocks associated to the supply side of the economy, as can be seen in Chart B of Figure 1. After the recession experienced by the Spanish economy in 1993, the labor reform signed in 1994 helped to its recovery, leading to a persistent decline of the unemployment rate, from 18 percent in 1995 until 10 percent in 2001, therefore, such a decline can be attributed to supply shocks coming from the labor market.

[7] Although, a recursive and real-time forecasting assessment of the conditional forecasts produced by the models is an important exercise to be considered, it is left for further research.

Since 2001 until 2006, monetary policy shocks played the most important role in keeping the sustained growth pattern, as can be see in Chart C of Figure 1. This is compatible with the arrival of a single monetary policy, implemented by the ECB, influencing several European economies. It is important to mention that these shock contributions are specifically associated to conventional monetary policy shocks. The effect of unconventional monetary policy shocks will be analyzed later.

Between 2007 and 2008, demand shocks gained significant importance in driving output growth, as it is shown in Chart A of Figure 1. This period overlaps with the peak that property prices experienced in Spain in 2008, which coincided with the global financial crisis occurred around that time. The first crisis episode in the sample, dated between 2008:II and 2009:IV by the Spanish Business Cycle Dating Committee (SBCDC), was influenced by a mixture of factors, starting mainly with negative demand shocks, and followed by negative mark-up, oil price, and, to a lower extent, monetary policy shocks. Notice that negative mark-up shocks preceded the beginning of such recessionary period, this result agrees with Camacho et al. (2015) who found that the realization of contractionary supply shocks took place a few months before the beginning of that recession.

The *Benchmark* model also indicates that the second crisis episode, dated between 2010:IV and 2013:II by the SBCDC, was instead only driven by a combination between domestic supply factors and oil price shocks. Finally, as it can be seen in Chart D of Figure 1, oil price shocks have played a significant role during the last recovery. However, it is important to mention that oil price shocks are identified only with exclusion restriction based on its exogeneity feature, and therefore, the corresponding estimated contributions should be taken with caution.

The historical decomposition of shocks for the case of core inflation is reported in Figure 2, showing cost-push shocks as the main drivers of inflation dynamics, as can be seen in Chart B of the figure. This is especially true during the so-called "lowflation" period, occurred between 2013 and 2015, where not only European but also other inflation targeting advanced economies experienced persistent low levels of inflation. This period was particularly characterized by a mixture of factors such as declines in world food and energy prices, disinflationary spillovers, and second-round effects via forward-looking inflation expectations, which amplified the sensitivity of the Spanish economy to cost-push shocks around that time.

The contribution of oil price shocks to core inflation is reported in Chart D of Figure 2. The figure shows that the most significant contributions of oil price shocks occurred during 2008 and between 2014 and 2016, periods in which oil prices experienced abrupt and prolonged downturns. This information is useful in order to evaluate the significance of potential second round effects of oil prices on core inflation. Also, notice the increase in the contribution of oil shocks occurred at the end of the sample, which is aligned with rise experienced by oil prices due to the OPEC agreement to cut oil production in the early 2017.

Additionally, the *Benchmark* model reveals that demand shocks have played a relatively minor role for the dynamics of core inflation, with the exception of the period before the Great Recession, which coincides with the housing boom developing at that time, as shown in Chart A of Figure 2. The model also shows that conventional monetary policy shocks had the most significant influence on core inflation since the implementation of the euro, in the early 2000s, until the beginning of the Great Recession. However, since then, the contribution of conventional monetary policy shocks has been relatively minor, as reported in Chart C of Figure 2. This result agrees with the constrains faced by the ECB when the policy rate reached the zero lower bound, period in which unconventional monetary policy measures, such as quantitative easing, started to be used by euro area policy makers to stimulate inflation.

3.1.2 *Unconventional Monetary Policy Shocks*

With the aim of investigating the contribution of unconventional monetary policy shocks to output growth and, especially, to core inflation, the short-term interest rate is replaced in the *Benchmark* model by the shadow rate, proposed in Wu and Xia (2017). Unlike the observed short-term interest rate, the shadow rate accounts for information about quantitative easing policy and is not bounded below by 0 percent, as can be seen in Chart A of Figure 3.[8] The contribution of unconventional monetary policy shocks to output growth is reported in Chart B of Figure 3, showing that they had less negative (slightly more positive) contributions to output growth between 2008 and 2012 (since 2015 until 2017) than conventional monetary policy shocks. Moreover, Chart C of Figure 3 shows that the unconventional monetary policy shocks have significantly contributed to stimulate core inflation in Spain, especially during two episodes. First, during the implementation of the ECB new Covered Bond Purchase Programme (CBPP2) by the end of 2011, and second, when the ECB expanded purchases to include bonds issued by euro area central governments, agencies and European institutions, at the beginning of 2015, as shown in Chart C of Figure 3. These results provide evidence in favor of the effectiveness of unconventional monetary policies adopted by the ECB to carry euro area inflation closer to its target.

Overall, it has been shown that the proposed small *Benchmark* SBVAR model is able to provide a comprehensive narrative of the contribution of key fundamental shocks driving the

[8]The shadow rate is assumed to be a linear function of three latent variables called factors of a Nelson-Siegel-Svensson yield curve. The latent factors and the shadow rate are then estimated with an extended Kalman filter

Spanish economy over time, which agrees with main historic events. However, there are several important features of the economy that may be omitted in the *Benchmark* model due to it contains a relatively small set of information. Therefore, the rest of this section is dedicated to examine the extended models proposed in Section 2.

3.1.3 *Labor Supply Shocks*

The importance of labor supply shocks on the business cycle is analyzed by computing the historical decomposition of output growth from the *Labor* model, and the results are shown in Figure 4. The shock decomposition from the *Benchmark* and *Labor* models are compared in charts A to D. Notice that while demand, monetary policy and oil price shocks obtained from both models look alike, the cost-push shocks from the *Benchmark* model loose importance once accounting for labor market dynamics. In particular, Chart E of Figure 4 plots the contribution of labor supply shocks to output growth, showing two well-defined episodes where they played a significant role. First, since the mid 1990s until the introduction of the euro, positive labor supply shocks contributed to the corresponding expansionary phase. This could have been influenced by the labor reforms carried out around that time. In particular, the reform of 1994 was set out to increase the flexibility of the labor market by fostering part-time contracts, introducing private employment agencies, and strengthening collective bargaining at a decentralized level. The reform of 1997 had three main goals, namely reducing the instability of the labor market, promoting collective bargaining and plugging the void in sectoral regulation due to the abolition of labor ordinances. Also, the "part-time" reform, carried out between 1998 and 2001, was oriented to increase the degree of flexibility in the labor market and to promote part-time jobs.

Instead, during the last two recessions, that is, the period between 2008 until 2013, negative labor supply shocks significantly contributed to the persistent decline in output growth. This is associated to the high levels of the unemployment rate which almost tripled during such a period, going from 9 percent in 2008:I to 26 percent in 2013:I.

Notice that, for the rest of the sample the contribution of labor supply shocks has been relatively minor. However, it is important to mention that during the mid 1990s and the 2000s the Spanish economy experienced large inflows of immigrant workers to the labor force, as shown in Chart A of Figure 5. Izquierdo et al. (2010) show that immigration increases employment through a positive impact on the age structure of the population and a composition effect, and that also has important effects on the investment rate. This phenomenon might have had important implications for the effects of labor supply shocks, which cannot be disentangled by using the *Labor* model. Therefore, the "extended" *Labor* model, that separates unemployment rate into its labor force and unemployment counterparts, is used to reassess the contribution of labor supply shocks to output growth. The results are plotted in Chart B of Figure 5, showing the positive and persistent contribution of labor supply shocks to output since 1997 until 2007, which is obtained once accounting for the significant increase in the labor force around that time triggered by the immigration factor.

3.1.4 *Government Income and Expenditure Shocks*

The high leverage of the private sector as well as the last two consecutive recessions faced by the Spanish economy might have amplified the effect of fiscal policy. Hernández de Cos and Moral-Benito (2016) document that the government spending multiplier is estimated to be larger during recessions and periods of banking stress, but much smaller (or even negative) during periods of weak public finances. Therefore, it is crucial for policy makers assessing the effect of fiscal shocks on key variables of the Spanish economy on a timely basis.

The contribution of shocks originated in the fiscal sector to the Spanish business cycle is measured with the *Fiscal* model, and it is proceeded in the same way as for the case of labor supply shocks. In particular, Chart E of Figure 6 plots the contribution of both government expenditure and revenue shocks to output growth. The results indicate three main features. First, the contribution of both fiscal shocks was relatively mild during the first half of the sample, in particular, since the mid 1990s until the late 2000s. This result is compatible with the relatively large influence of other fundamental shocks, such as monetary policy and labor supply, on output, found in the previous sections. Second, expenditure shocks play, in general, a more important role that revenue shocks from the late 2000s onward. This result agrees with Caldara and Kamps (2017), who that find that spending increases stimulate output more than tax cuts for the US economy, by relying a proxy SVAR that uses non-fiscal instruments to directly estimate the parameters of the fiscal rules. Third, the contribution of government expenditure shocks was about twice higher during the European sovereign debt crisis than during the Great Recession, which also agrees with the significant stress experienced by the Spanish public finances around that time, despite pre-crisis fiscal surpluses and low levels of public debt, as noticed in Martí and Pérez (2016). It is also worth noting the negative contribution of government expenditure shocks to output since 2016, providing evidence of negative expenditure shocks affecting the Spanish economy during recent times.

3.1.5 *Financial Uncertainty Shocks*

In a seminal paper, Bloom (2009) shows that higher uncertainty leads firms to temporarily pause their investment and hiring, generating rapid drops and rebounds in aggregate output and employment that characterize the U.S. business cycle. The effect of uncertainty shocks on the real economy has been assessed not only for advanced but also for emerging economies (Carrière-Swallow and Céspedes (2013)), finding that emerging markets suffer even deeper and more prolonged impacts from uncertainty shocks. For the Spanish case, Gil et al. (2016) document a negative and significant effect of financial uncertainty shocks to real activity, especially to investment.

The assessment of the importance of financial uncertainty shocks is performed by employing the *Financial* model. In Chart E of Figure 7 the contribution of uncertainty shocks to output growth is plotted, showing a negative and significant influence during both the Great Recession and the Euro sovereign debt crisis, episodes that some analysts may consider as a “double-dip” recession. During this period, a combination of factors may have triggered unexpected increases in the levels of uncertainty associated to the stock market, such as the abrupt and large swings in oil prices and in the exchange rate, the drastic fall in global demand, constrains faced by the ECB to conduct monetary policy due to the zero lower bound, rapid rising of bond yield spreads in government securities, among others.[9]

Notice that negative uncertainty shocks contributed positively to output growth around turning points. Specifically, before the beginning of the 2008-2009 recession and after the end of the 2010-2013 recession. In particular, during 2014 and 2015, the Spanish economy grew at an increasing rate, accompanied by significant contributions of negative uncertainty shocks. However, since 2016, output growth stabilized around one percent, and since then, the impact of uncertainty shocks rapidly decreased until the end of the sample.

3.1.6 *Exchange Rate and Global Demand Shocks*

Foreign shocks may also represent an important driving force of the Spanish economy due to its strong ties with international markets. Therefore, the importance of foreign shocks on domestic output and core inflation is assessed by employing the *International* model. In Chart E of Figure 8 it is plotted the contribution of international shocks to domestic growth. The figure indicates a large influence of foreign developments during the 2008-2009 period, which coincides with the timing of spillovers generated by the Great Recession, that affected negatively to most of advanced economies. However, notice that the contribution of international shocks was rather muted during the sovereign debt crisis, indicating that domestic factors played the most important role during such a recessionary episode.

Previous studies have documented the importance of the effect of exchange rate shocks to both output and inflation, see An and Wang (2012). Since the *International* model is able to

[9]These results are in line with Mumtaz (2016) who finds that, for the case of United Kingdom, the effect of uncertainty shocks on industrial production where higher since the Great Recession than before it occurred.

disentangle between global demand and exchange rate shocks, it can be used to provide information about the pass-through form exchange rate to prices and real activity. In particular, Charts F to I of Figure 8 show the contributions of global demand and exchange rate shocks. From 2014 until late 2016 the euro depreciated substantially against main international currencies. In particular, notice that during the last two episodes of depreciation of the euro, occurred at the beginning of 2015 and 2016, inflation and output were positively affected by exchange rate shocks. However, since early 2017 the euro has gained strength in international markets, therefore, it is important to keep monitoring the effects of underlying exchange rate shocks on the Spanish economy.

3.2 Forecasts

This section is focused on comparing the forecasts obtained with all the SBVAR models in the suite, which are computed by conditioning on the path of specific key macroeconomic variables. Table 1 provides a description about the set of information that is conditioned on for each model in the suite. Columns of Table 1 make reference to the models, while rows indicate the variables to be included, with conditional path (✓) or without unconditional path ($*$). Notice that the *One-fits-all* model includes all the variables under consideration, and therefore, conditions on half of the entire set of information.

Chart A and B of Figure 9 shows the conditional forecasts of real GDP growth and core inflation, respectively, obtained with the *Benchmark* model. The estimation sample covers the period 1995:II-2017:I, and the model produces forecasts for the period 2017:II-2019:IV, along with the corresponding probability distribution of each forecast. One of the advantages of the Bayesian estimation is the ability to easily generate credible sets for the forecasts, which help to measure the uncertainty surrounding them.

The median conditional forecast corresponding to the *Benchmark* model and its four extensions are plotted in Chart A of Figure 10. Notice that the *Benchmark* and *Labor* models, which condition on the interest rate and oil prices, produce similar forecasts. However, once conditioning also on the development of the future path of global demand and exchange rate, the *International* model produces forecast that are slightly more optimistic. Instead, when developments of the public finances or the stock market are taken as given, both the *Fiscal* and *Financial* models tend to provide rather pessimistic scenarios for the outlook of output growth. For the case of prices, the conditional forecasts associated to the different models are fairly aligned and indicate an increasing inflation path, as can be seen in Chart B of Figure 10. These exercises are useful for policy makers to understand the sensitivity of their forecasts once some specific aspects of the economy are taken as given.

Table 1. Conditional variables for SBVAR models

	Benchmark	Fiscal	Labor	Internaional	Financial	One-fits-all
GDP	*	*	*	*	*	*
INF	*	*	*	*	*	*
INT	✓	✓	✓	✓	✓	✓
NPD		✓				✓
TAX		✓				✓
UR			*			*
WAG			*			*
GDM				✓		✓
EXC				✓		✓
STO					✓	✓
UNC					*	*
OIL	✓	✓	✓	✓	✓	✓

Note. The table describe the conditional (✓) and unconditional (*) variables for each model.

However, when one is interested in pure forecasting purposes, the *One-fits-all* is the more adequate model, since it considers conditional scenarios for a wider range of variables than the block-specific models. To specify the associated priors from an agnostic perspective, the marginal likelihood is calculated for different configurations of the hyper-parameter values and number of lags, then, the one with the highest likelihood is used to provide forecasts. The results are shown in Table B.2 of Appendix B. The forecasts of real GDP growth obtained with the *One-fits-all* model, along with their corresponding probability distributions, are plotted in Chart A of Figure 11, showing more optimistic predictions than the *Benchmark* model. However, notice that the corresponding fan chart represents a wider credible set, defined between the 10th and 90th percentile. This is a natural feature since the composite model contains much more information than the block-specific models and, therefore, more parameter uncertainty. For the case of inflation, the forecasts follow a more inflationary path that the *Benchmark* model.

An additional utility of the *One-fits-all* model is that it can be used to provide assessments about the uncertainty associated to the projections performed by the staff of the Banco de España (BdE). In particular, the hyper-parameter priors of the model can be calibrated to generate forecasts that mimic, for example, the BdE projections of output growth. Although the BdE projections are not shown in this paper, due to confidentiality reasons, charts A and B of Figure 12 show the conditional forecasts of output growth and core inflation, respectively, obtained with the *One-fits-all* model that uses priors that help to “mimic” the BdE projections of both variables, along with their corresponding fan charts. Even if this procedure does not exactly compute confidence bands associated to the BdE projections, it provides policy makers the ability to build probability statements about projected values of output growth and inflation. As an illustration, Figure 13 plots the probability distribution of the forecasts of real GDP growth for the next four quarters, that is, 2017:II-2018:I, obtained with the *Benchmark* model and the *One-fits-all* model that uses priors that maximize the marginal likelihood, while Figure 14 does the same but for the case of inflation.

4 Concluding Remarks

This paper proposes a set of structural Bayesian VAR models to provide assessments about the underlying shocks mainly influencing the Spanish economy over time. In doing so, sing and exclusion restrictions are employed to achieved identification of structural shocks. The results indicate that the proposed models reproduce a narrative of shocks driving Spanish output growth and inflation rate that agrees with main economic events occurred in different sectors of the economy. Moreover, the proposed set of models provides conditional forecasts that are useful to assess the outlook of the Spanish economy under different scenarios both domestic and foreign, and to quantify their corresponding uncertainty. Therefore, the suite could be incorporated to the toolkit of quantitative models that the Banco de España uses to perform forecasts of key macroeconomic variables.

A Bayesian Estimation

This appendix provides a description of the Bayesian techniques used to estimate the parameters of the models subject to the identification restrictions for structural analysis. Also, it is shown how to compute and perform inference on the conditional forecasts produced by the SBVAR models in the suite.

A.1 Gibbs Sampler

Consider the following structural VAR(p) model:

$$Ay_t = A_0 + A_1 y_{t-1} + ... + A_p y_{t-p} + \varepsilon_t, \tag{13}$$

where y_t is an $n \times 1$ vector that contains information of endogenous variables, for $t = 1, 2, ..., T$, and the structural innovations are assumed to be $\varepsilon_t \sim N(0, I_n)$, and p denotes the number of lags. The reduced form of the VAR(p) can be expressed as

$$y_t = B_0 + B_1 y_{t-1} + ... + B_p y_{t-p} + u_t, \tag{14}$$

where $B_i = A^{-1} A_i$, for $i = 0, 1, ..., p$, and the reduced form innovations, $u_t = A^{-1}\varepsilon_t$, are assumed to be $u_t \sim N(0, \Sigma)$, such that $\Sigma = A^{-1} A^{-1\prime}$. The VAR($p$) can be alternatively written as

$$y_t = X_t B + v_t, \tag{15}$$

where $X_t = [\mathbf{1}, y_{t-1}, ..., y_{t-p}]$ and $B = [B_0, B_1, ..., B_p]'$. Since each equation in the VAR has the same regressors, it can be expressed as

$$y = (I_N \otimes X)b + V, \tag{16}$$

where $y = vec\,(y_t)$, $b = vec\,(B)$ and $V = vec\,(v_t)$.

The prior distribution for the autoregressive coefficients, b, is assumed to be a normal distribution with the following mean and variance,

$$P(b) \sim N(\bar{b}, \bar{H}), \tag{17}$$

where $\bar{b}$ is $(n \times (n \times p + 1)) \times 1$ vector and H is a $[n \times (n \times p + 1)] \times [n \times (n \times p + 1)]$ matrix, whose diagonal elements contain the variance of the prior distribution of the elements in b. Also, it is assumed a prior inverse Wishart distribution of the covariance matrix of the VAR innovations,

$$P(\Sigma) \sim IW(\bar{S}, \bar{\alpha}), \tag{18}$$

where $\bar{S}$ is a scale matrix and α represents the degrees of freedom.

There are several ways to define the elements in $\bar{b}$ and $\bar{H}$ of the prior distribution. For the *Benchmark* model, and for its four corresponding extensions (*Labor, Fiscal, Financial,* and *International*), it is adopted the Minnesota prior due to its flexibility to impose exclusion restrictions in the parameter space of B. However, for the *One-fits-all* model, due to its large dimension, the approach in Banbura et al. (2010) is followed, since it is well suited for large VARs and also follows the principle of the Minnesota prior, which will be the center of the discussion in this appendix.

The Minnesota prior assumed in this paper incorporates the belief that the endogenous variables in y_t follow an AR(1) process, whose corresponding coefficients are computed by OLS. The variance of the prior, H, is given according to the following equations,

$$\left(\frac{\lambda_1}{l^{\lambda_3}}\right)^2, \text{ if } i = j \tag{19}$$

$$\left(\frac{\sigma_i \lambda_1 \lambda_2}{\sigma_j l \lambda_3}\right)^2, \text{if } i \neq j \tag{20}$$

$$\left(\frac{\sigma_i \lambda_1 \lambda_2 \lambda_5}{\sigma_j l \lambda_3}\right)^2, \text{if } i \text{ is } \textit{exogenous} \tag{21}$$

$$(\sigma_i \lambda_4)\text{, for the constant,} \tag{22}$$

where σ_i, for $i = 1, ..., n$, are the variances of the error terms from the AR(1) regressions estimated with OLS. The coefficient λ_1 controls the standard deviation of the prior on own lag, λ_2 controls the standard deviation of the prior on lags of other variables that the dependent variable, λ_3 controls the degree to which coefficients associated to lags higher than one are likely to be zero, λ_4 controls the standard deviation of the constant, λ_5 controls the degree to which a specific variable is only affected by itself and not affected by the other variables. The selection of the λ coefficients was made based on an agnostic perspective, that is, by relying in the configuration of λ's that produced the highest marginal likelihood. Details about the computation of the marginal likelihood along with the corresponding estimates are shown in Appendix B and Table B.1, respectively. Regarding the prior of Σ, the parameters of the inverse Wishart distribution are defined as $\bar{S} = I_n$, and $\bar{\alpha} = n + 1$.

Once the prior distribution has been completely specified, it can be combined with the information from the likelihood to construct the conditional posterior distributions. For the case of b, the posterior normal distribution is given by

$$P(b|\Sigma, y_t) \sim N(b^*, H^*), \tag{23}$$

where the posterior mean and variance are given by

$$b^* = (\bar{H}^{-1} + \Sigma^{-1} \otimes X_t'X_t)^{-1}(\bar{H}^{-1}\bar{b} + \Sigma^{-1} \otimes X_t'Y_t) \quad (24)$$

$$H^* = (\bar{H}^{-1} + \Sigma^{-1} \otimes X_t'X_t)^{-1}, \quad (25)$$

respectively. For the case of Σ, the posterior inverse Wishart distribution is defined as,

$$P(\Sigma|b, y_t) \sim IW(S^*, \alpha^*), \quad (26)$$

where the scale matrix and degrees of freedom, respectively, are given by

$$S^* = \bar{S} + (y_t - X_t B)'(y_t - X_t B) \quad (27)$$

$$\alpha^* = \bar{\alpha} + T. \quad (28)$$

Accordingly, the Gibbs sampler consist on the following algorithm:

- *Step 1*: Set the priors for the autoregressive coefficients, b, and the covariance matrix, Σ.
- *Step 2*: Sample, b, from its posterior distribution, $P(b|\Sigma, y_t)$, conditional on Σ.
- *Step 3*: Sample Σ, from its posterior distribution, $P(\Sigma|b, y_t)$, conditional on b.
- *Step 4*: Repeat Step 2 and Step 3 as many times as desired to construct the empirical distribution of b and Σ.

Although this procedure is useful to estimate Σ, when one is interested in performing structural analysis, additional steps need to be done in order to estimate the impact multiplier A^{-1}. These steps are discussed in the next section.

A.2 Sign and Exclusion Restrictions

The approach of Arias, et al. (2013) is used to estimate the impact multiplier matrix, A^{-1}. The main feature of this method is that it allows to generate draws of A^{-1} that satisfy both sign and exclusion desired restrictions. This section describes how the algorithm is performed for the case of the proposed SBVAR models in the suite. Although, throughout the paper only contemporaneous restrictions will be assessed, the framework of Arias et al. (2013) is general enough to impose restrictions at any specific horizon.

A.2.1 *Sign restrictions*

Sign restrictions on the impulse response functions can be represented by $s_i \times n$ matrices S_i, for $i = 1, 2, ..., n$, that usually have one non-zero entry in each row that corresponds to a specific restriction, where s_i is the total number of restrictions associated to each structural shock. In particular, the corresponding S_i matrices for each SBVAR in the suite is given by:

Benchmark model: S_1, S_2 and S_3correspond to demand, cost-push, and monetary policy shocks, respectively.

$$S_1 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}, \quad S_2 = \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}, \quad S_3 = \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

Labor model: S_1, S_2 and S_3correspond to demand, cost-push, and monetary policy shocks, respectively, and S_4 corresponds to labor-supply shocks.

$$S_1 = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \end{bmatrix}, S_2 = \begin{bmatrix} -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \end{bmatrix}, S_3 = \begin{bmatrix} -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \end{bmatrix},$$
$$S_4 = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 & 0 \end{bmatrix}$$

Fiscal model: S_1, S_2 and S_3correspond to demand, cost-push, and monetary policy shocks, respectively. S_4 corresponds to government expenditure shocks, and S_5 corresponds to government revenue shocks.

$$S_1 = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \end{bmatrix}, S_2 = \begin{bmatrix} -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \end{bmatrix}, S_3 = \begin{bmatrix} -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \end{bmatrix}$$
$$S_4 = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \end{bmatrix}, S_5 = \begin{bmatrix} -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}$$

Financial model: S_1, S_2 and S_3correspond to demand, cost-push, and monetary policy shocks, respectively, and S_5 corresponds to uncertainty shocks.

$$S_1 = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \end{bmatrix}, S_2 = \begin{bmatrix} -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \end{bmatrix}, S_3 = \begin{bmatrix} -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \end{bmatrix}$$
$$S_5 = \begin{bmatrix} -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix},$$

International model: S_1, S_2 and S_3correspond to demand, cost-push, and monetary policy shocks, and S_5 corresponds to exchange rate shocks

$$S_1 = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \end{bmatrix}, S_2 = \begin{bmatrix} -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \end{bmatrix}, S_3 = \begin{bmatrix} -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \end{bmatrix}$$

$$S_5 = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix},$$

A.2.2 *Exclusion Restrictions*

Exclusion restrictions can be also represented with matrices, in a similar way than the case of sign restrictions. In particular, consider $e_i \times n$ matrices E_i, for $i = 1, 2, ..., n$, that contain the exclusion restrictions of the SBVAR models,

Benchmark model: E_i correspond on the exclusion restrictions of shock i on the oil price.

$$E_i = \begin{bmatrix} 0 & 0 & 0 & 1 \end{bmatrix}, \text{ for } i = 1, ..., 3$$

Labor, Fiscal and Financial models: E_i correspond on the exclusion restrictions of shock i on the oil price.

$$E_i = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}, \text{ for } i = 1, ..., 5$$

International model: E_1, E_2, and E_3corresponds to demand, cost-push and monetary policy shocks, respectively, E_4 corresponds to global demand shocks, and E_5 correspond to exchange rate shocks.

$$E_1 = \begin{bmatrix} 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}, E_2 = \begin{bmatrix} 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}, E_3 = \begin{bmatrix} 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

$$E_4 = \begin{bmatrix} 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}, E_5 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

Notice that exclusion restrictions are essentially the same for all the models, with the exception of the *International* model.

A.2.3 *Algorithm*

It is convenient to collect the structural impulse responses matrices to be restricted into a single matrix denoted by **L**. Since the interest is only placed on restricted responses at horizon 0, they are collected in $L_0 = A^{-1}$, and therefore, $\mathbf{L} = L_0$. Once the matrices containing the restrictions have been specified, the following algorithm can be used to generate draws of the impact multiplier A^{-1} that complies with the sign and exclusion restrictions of each SBVAR model.

1. Draw b and Σ from the posterior distribution of the reduced form parameters following the Gibbs sampler form Section A.1.

2. Draw an orthogonal matrix Q, such that L_0Q satisfy the exclusion restrictions, where L_0 =chol(Σ).

   (a) Let $j = 1$.

   (b) Construct $R_j = \begin{bmatrix} E_j\mathbf{L} \\ Q_{j-1} \end{bmatrix}$, where $Q_{j-1} = [q_1, ..., q_{j-1}]$, with $R_1 = [E_1\mathbf{L}]$.

   (c) Find N_{j-1} whose columns form an orthonormal basis for the null space of R_j.

   (d) Draw the $n \times 1$ vector x_j from the $N(0, I_n)$ distribution.

   (e) Let $q_i = N_{j-1}(N'_{j-1}x_j / \parallel N'_{j-1}x_j \parallel)$, where $\parallel \cdot \parallel$ denotes the Euclidean norm.

   (f) If $j = n$, stop, and construct $Q = [q_1, ..., q_n]$ and go to Step 3. Otherwise, let $j = j+1$, and go to Step b.

3. Recompute $\mathbf{L}$ with L_0Q instead of L_0. Retain the draw if $S_j\mathbf{L}_{lj} > 0$ is satisfied for $j = 1, ..., n$.

4. Return to Step 1 until the desired number of draws of the posterior distribution of the restricted impulse responses have been obtained.

A.3 Computation of Conditional Forecasts

The approach proposed in Waggoner and Zha (1999) is applied to compute conditional forecasts from Bayesian VARs. In particular, consider the structural VAR(p) model in equation (13), and assume that $p = 1$, for ease of exposition. By recursive iteration, the K-step ahead forecast can be expressed as follows,

$$y_{T+K} = B_0 \sum_{k=0}^{K} B_1^k + B_1^k y_{T-1} + A \sum_{k=0}^{K} B_1^k \varepsilon_{T+k-j}. \tag{29}$$

Therefore, the forecast y_{T+K} is decomposed into two components. First, the unconditional forecast, or forecast in the absence of shocks $\left(B_0 \sum_{k=0}^{K} B_1^k + B_1^k y_{T-1}\right)$, and second, the dynamic impact of future structural shocks $\left(A \sum_{k=0}^{K} B_1^k \varepsilon_{T+k-j}\right)$. Notice that if a restriction is place on the future path of the j-th endogenous variable, this implies imposing restrictions on the future innovations ε_{T+k-j}. These restriction on the future innovations can be expressed with the following system of equations,

$$C\varepsilon = c, \tag{30}$$

where c is a $(M \times \tau) \times 1$ vector, with M being the number of variables whose paths are constrained, and τ denotes the number of time periods the constrain applies. The vector c contains the difference between the path of the constrained variables and the corresponding unconditional forecasts. The matrix C, of dimension $(M \times \tau) \times (n \times \tau)$, contains the impulse responses of the constrained variables to the structural shocks ε at horizons $1, 2, ..., \tau$. The vector ε, of dimension $(n \times \tau) \times 1$, contains the constraint future shocks that comply with the path of the constrained variables.

Waggoner and Zha (1999) derive a Gibbs sampling algorithm to construct the posterior predictive distribution of the conditional forecasts. In particular, it is shown that the distribution of restricted future shocks is normal, $\varepsilon \sim N(\bar{w}, \bar{\chi})$, where

$$\bar{w} = C'(CC')^{-1}c, \tag{31}$$

$$\bar{\chi} = I - C'(CC')^{-1}C. \tag{32}$$

The following algorithm can be used to generate draws of the conditional forecast.

- *Step 1*: Draw b, Σ, and A from the corresponding posterior distributions following Section A.1, for b and Σ, and Section A.2, for A.
- *Step 2*: Compute unconditional forecasts, $y_{T+1}, ..., y_{T+K}$, and construct c.
- *Step 3*: Compute the impulse responses of the constrained variables to the structural shocks ε at horizons $1, 2, ..., \tau$, and construct C.
- *Step 4*: Draw the constrained shocks from normal distribution $\varepsilon \sim N(\bar{w}, \bar{\chi})$.
- *Step 5*: Calculate the conditional forecasts using the equation (29), that includes the unconditional forecasts, from Step 2, and the constrained shocks, from Step 4.

B Computation of Marginal Likelihood

In order to set the prior hyper-parameters and the number of lags in the SBVAR models, the method marginal likelihood is computed is used, and computed following the estimator of Chib (1995). Let the parameters of the model be collected in the matrix $\Phi = \{b, \Sigma\}$, then the posterior distribution of Φ can be expressed as a function of the likelihood and its prior distribution,

$$P(\Phi|y) = \frac{F(y|\Phi)P(\Phi)}{F(y)}, \tag{33}$$

where $y = \{y_t\}_{t=1}^{T}$, and $F(y|\Phi)$ is the likelihood function, $P(\Phi)$ is the joint prior distribution, and $F(y)$ is the marginal likelihood, the object to be computed.

Notice that equation (33) can be alternatively expressed as

$$\ln(F(y)) = \ln(F(y|\Phi)) + \ln(P(\Phi)) - \ln(P(\Phi|y)). \tag{34}$$

The terms $F(y|\Phi)$ and $P(\Phi)$ can be easily evaluated at a high density point, $\hat{\Phi}$, such as the posterior median. Next, the posterior density, evaluated at $\hat{\Phi}$, can be expressed as

$$\begin{aligned} P(\hat{\Phi}|y) &= P(\hat{b}, \hat{\Sigma}|y) \\ &= P(\hat{b}|\hat{\Sigma}, y)P(\hat{\Sigma}|y). \end{aligned} \tag{35}$$

The term $P(\hat{b}|\hat{\Sigma}, y)$ can be evaluated with the conditional posterior distribution of the VAR coefficients,

$$P(\hat{b}|\hat{\Sigma}, y) \sim N(M, V), \tag{36}$$

where

$$M = (\bar{H}^{-1} + \hat{\Sigma}^{-1} \otimes X_t' X_t)^{-1}(\bar{H}^{-1}\bar{b} + \Sigma^{-1} \otimes X_t' Y_t) \tag{37}$$

$$V = (\bar{H}^{-1} + \hat{\Sigma}^{-1} \otimes X_t' X_t)^{-1}. \tag{38}$$

The term $P(\hat{\Sigma}|y)$ can be evaluated by noting that

$$P(\hat{\Sigma}|y) \approx \frac{1}{D}\sum_{d=1}^{D} P(\hat{\Sigma}|b_d, y), \tag{39}$$

where b_d denotes the d-th draw of the autoregressive coefficients from the Gibbs sampler, for $d = 1, ..., D$. Notice that $P(\hat{\Sigma}|b_d, y)$ is the inverse Wishart distribution specified in equation (26).

Table A.1 reports the marginal likelihood estimates for different configurations of *lambda*'s and number of lags p for the *Benchmark* model. The highest marginal likelihood is achieved with a specification that set $lambda_1 = 0.2$, $lambda_2 = 0.1$, $lambda_3 = 0.5$, $lambda_4 = 0.01$, and $p = 4$. For the other models in the suite, similar approach was followed. The results are not show to save space, although, they are available upon request.

Table B1. Marginal likelihood for different Minnesota priors

				$p=2$	$p=3$	$p=4$
$\lambda_1 = 0.2$,	$\lambda_2 = 0.5$	$\lambda_3 = 1$	$\lambda_4 = 1$	-416.7	-420.3	-418.7
$\lambda_1 = 0.2$,	$\lambda_2 = 0.5$	$\lambda_3 = 1$	$\lambda_4 = 10$	-425.7	-429.3	-427.9
$\lambda_1 = 0.2$,	$\lambda_2 = 0.5$	$\lambda_3 = 1$	$\lambda_4 = 0.1$	-407.9	-411.8	-409.8
$\lambda_1 = 0.2$,	$\lambda_2 = 0.5$	$\lambda_3 = 1$	$\lambda_4 = 0.01$	-401.5	-405.0	-403.3
$\lambda_1 = 0.2$,	$\lambda_2 = 0.5$	$\lambda_3 = 2$	$\lambda_4 = 0.01$	-403.6	-405.5	-401.7
$\lambda_1 = 0.2$,	$\lambda_2 = 0.5$	$\lambda_3 = 0.5$	$\lambda_4 = 0.01$	-400.6	-406.1	-404.6
$\lambda_1 = 0.2$,	$\lambda_2 = 1$	$\lambda_3 = 0.5$	$\lambda_4 = 0.01$	-405.8	-413.6	-413.7
$\lambda_1 = 0.2$,	$\lambda_2 = 0.1$	$\lambda_3 = 0.5$	$\lambda_4 = 0.01$	-391.1	-392.7	-388.6
$\lambda_1 = 1$,	$\lambda_2 = 0.1$	$\lambda_3 = 0.5$	$\lambda_4 = 0.01$	-402.5	-412.4	-410.1

Table B2. Marginal likelihood for different Dummy priors

		$p=2$	$p=3$	$p=4$	$p=5$	$p=6$	$p=7$	$p=8$
$\lambda = 0.05$,	τ=10λ	-165.0	-164.2	-165.0	-163.5	-159.1	-156.8	-152.9
$\lambda = 0.05$,	τ=20λ	-166.8	-166.2	-165.7	-163.5	-160.2	-156.5	-155.3
$\lambda = 0.1$,	τ=10λ	-169.7	-170.3	-170.5	-170.2	-167.4	-164.7	-164.2
$\lambda = 0.1$,	τ=20λ	-172.4	-172.3	-171.7	-171.8	-169.0	-167.6	-164.4
$\lambda = 0.5$,	τ=10λ	-183.6	-190.0	-193.7	-197.5	-200.0	-205.3	-206.3
$\lambda = 0.5$,	τ=20λ	-184.5	-190.9	-194.1	-197.7	-202.0	-205.4	-206.4

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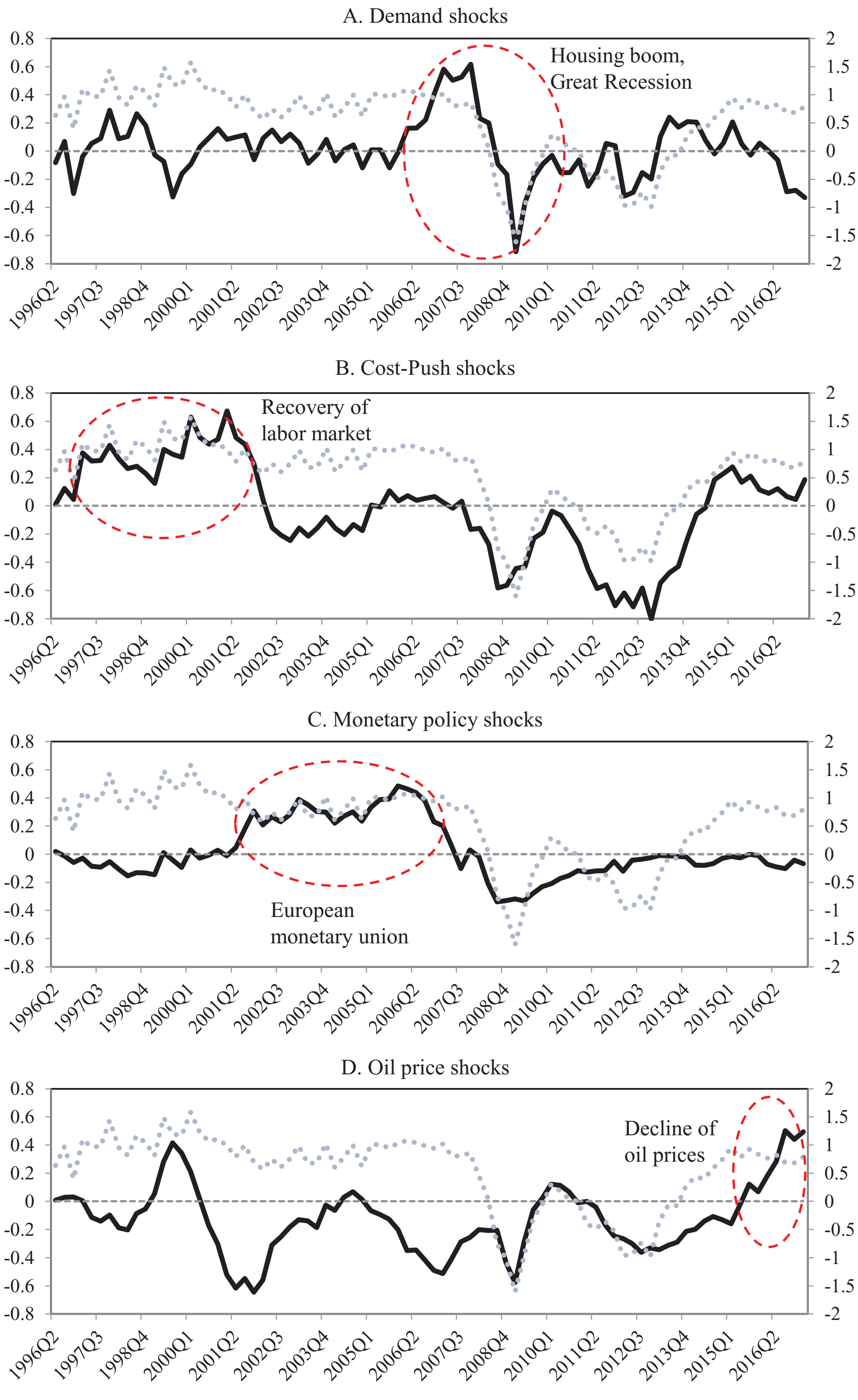
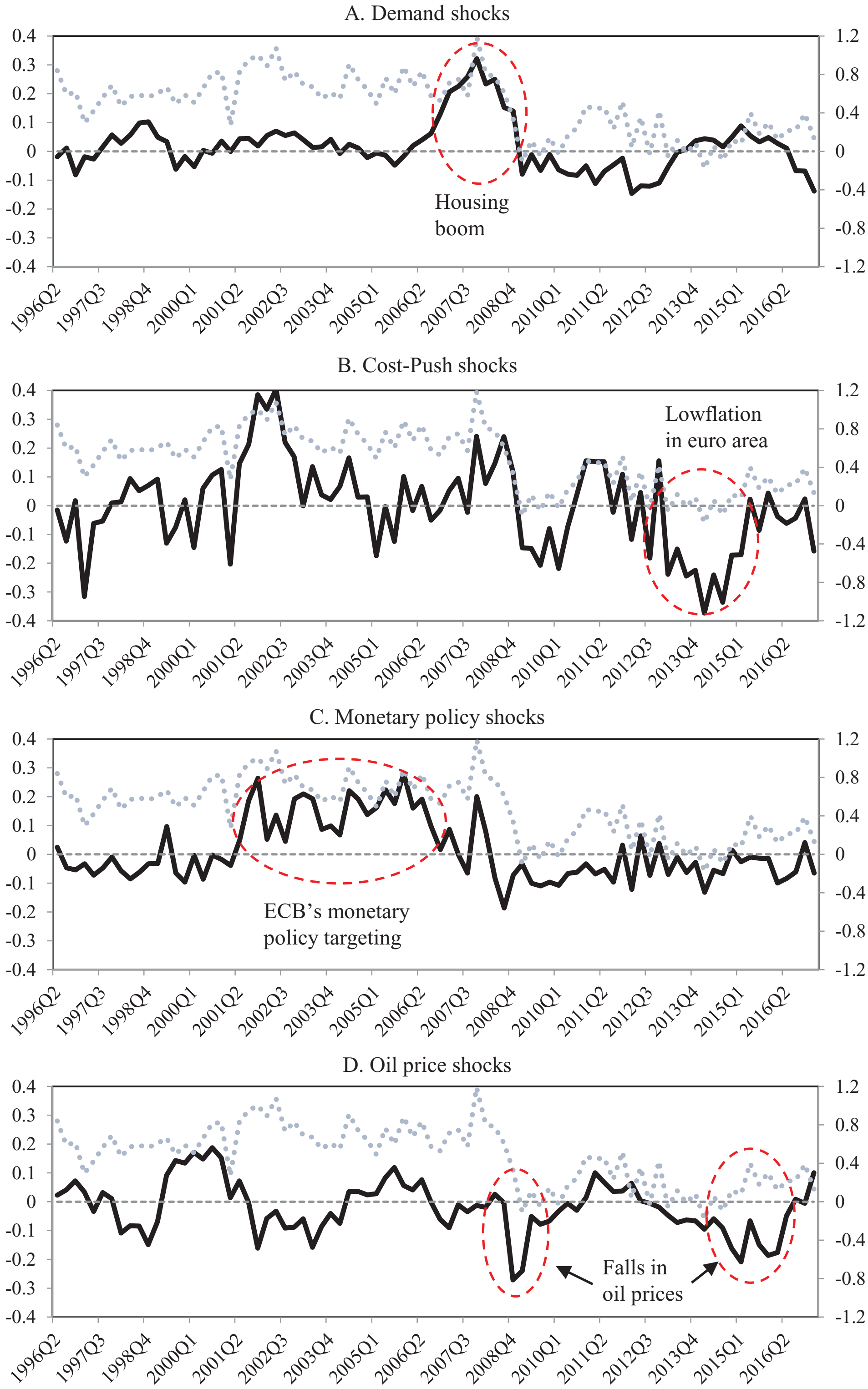
Figure 1. Shock decomposition of real GDP growth using the *Benchmark* model



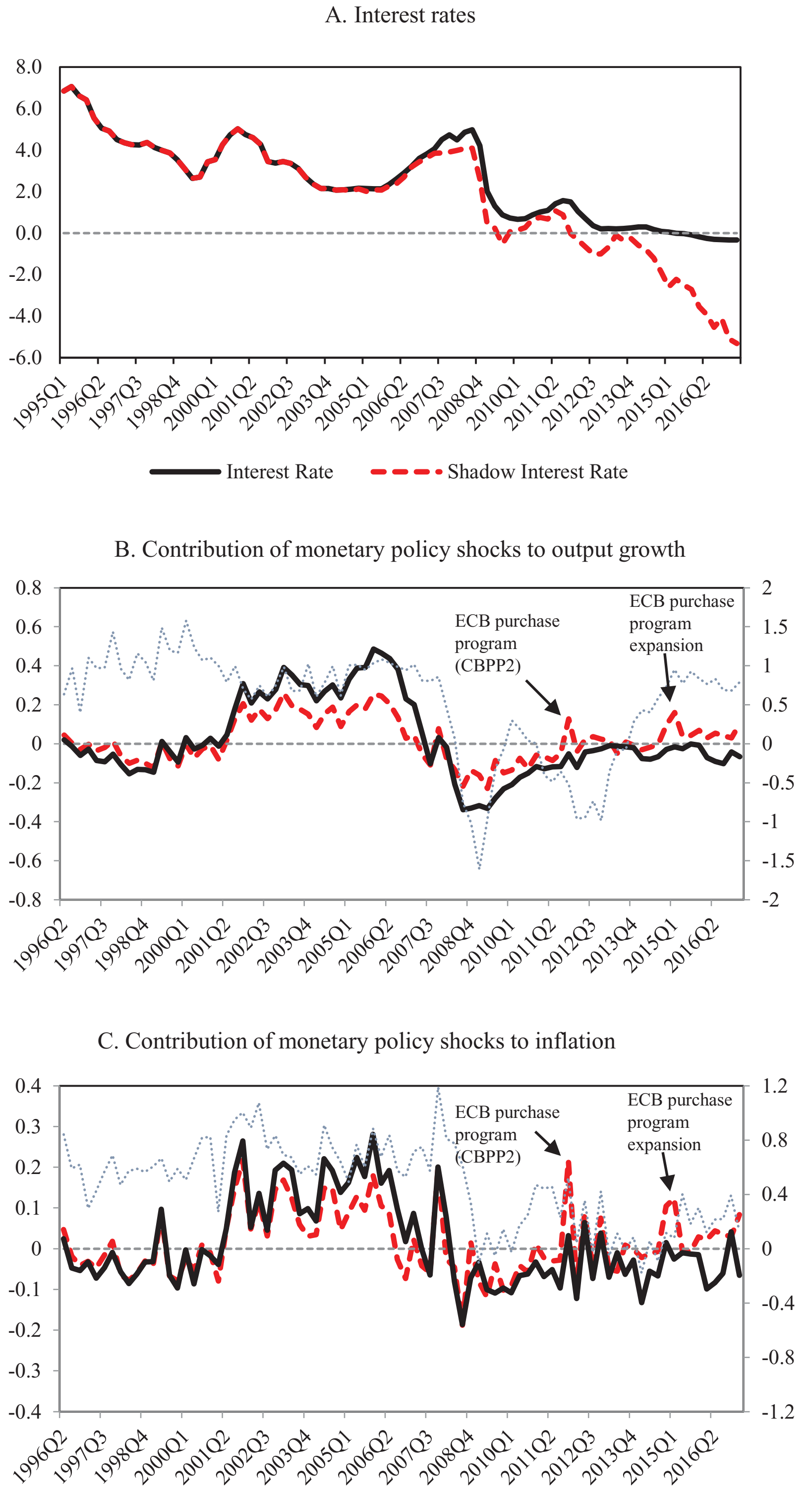
Note. Solid black lines (left axis) make reference to the contribution of structural shocks, and dotted grey lines (right axis) make reference to real GDP growth.

Figure 2. Shock decomposition of inflation using the *Benchmark* model



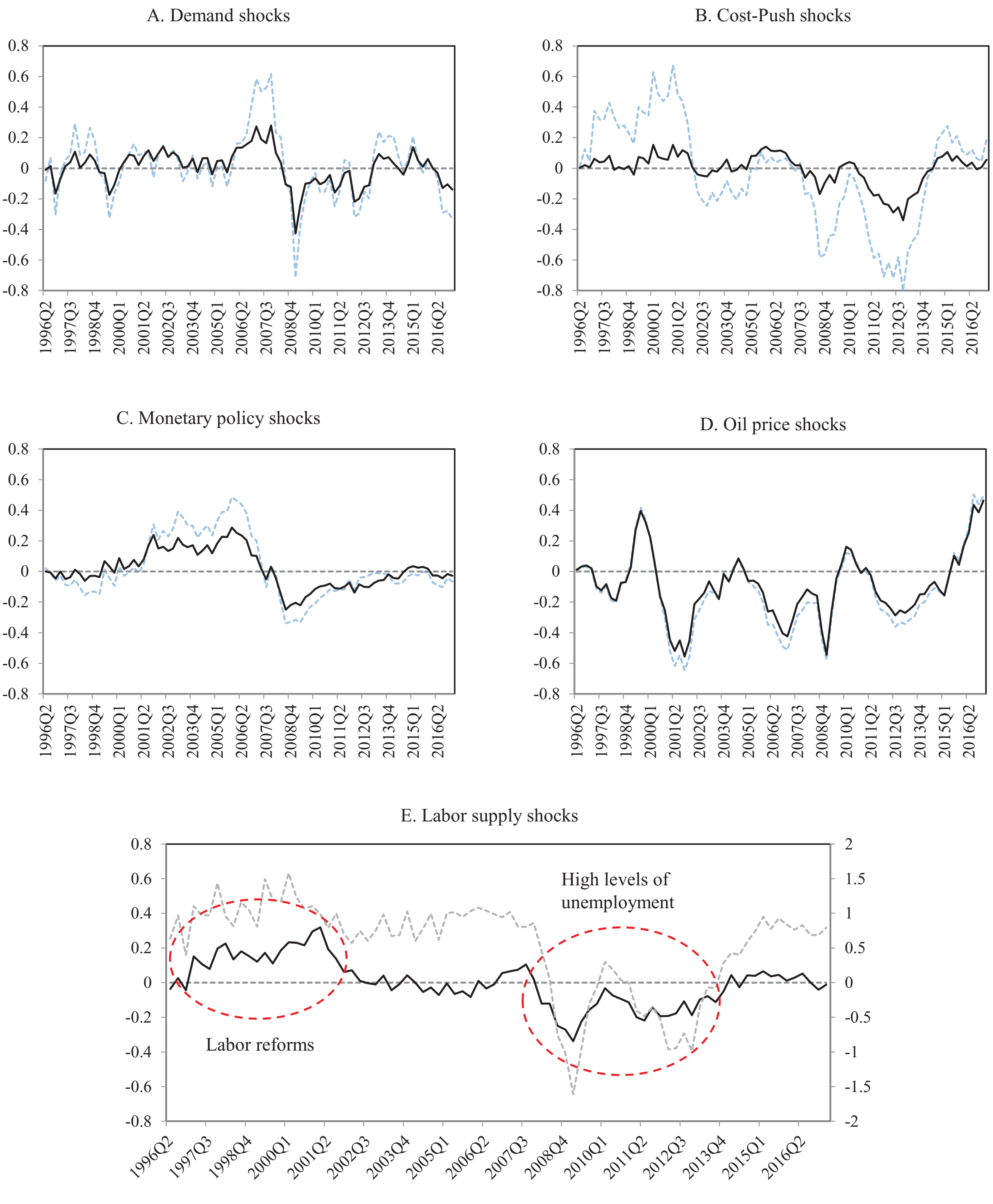
Note. Solid black lines (left axis) make reference to the contribution of structural shocks, and dotted grey lines (right axis) make reference to inflation rate.

Figure 3. Contribution of conventional and unconventional monetary policy shocks using the *Benchmark* model



Note. Solid black lines (dashed red lines) make reference to the contribution of structural shocks obtained with the interest rate (shadow interest rate), and dotted grey lines (right axis) make reference to either real GDP growth or inflation rate.

Figure 4. Shock decomposition of GDP growth using the *Labor* model

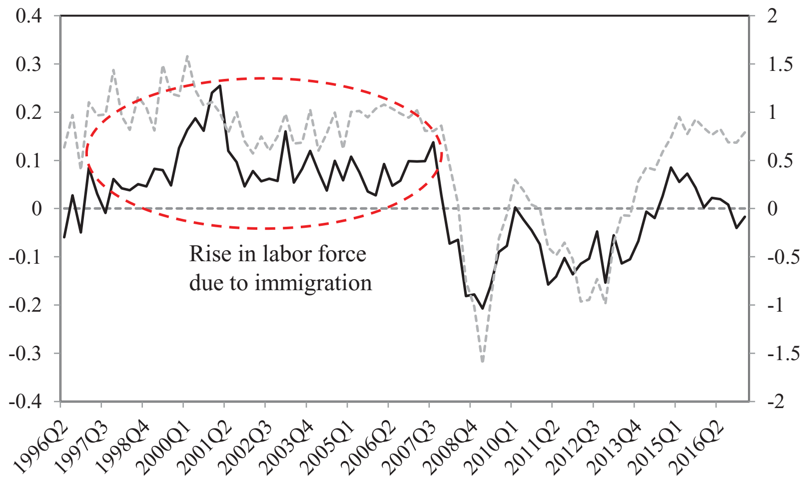


Note. In charts A, B, C, and D, solid black (dotted blue) lines make reference to the contribution of structural shocks from the *Labor* (*Benchmark*) model. In chart E, solid black line (left axis) makes reference to the structural shocks from the *Labor* model, and dotted grey line (right axis) makes reference to real GDP growth.

Figure 5. Shock decomposition of GDP growth using the extended *Labor* model

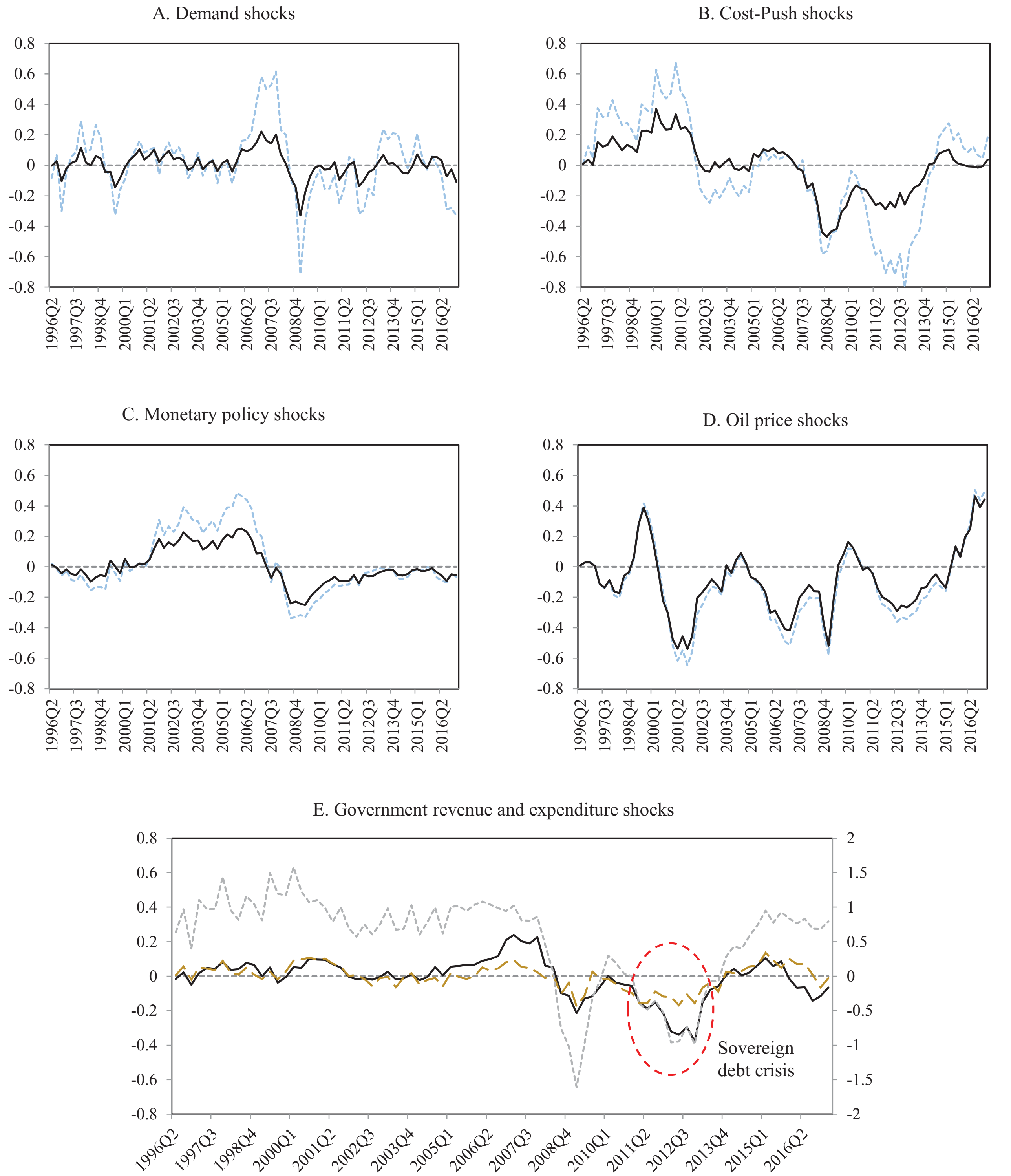
A. Components of unemployment rate

B. Labor supply shocks



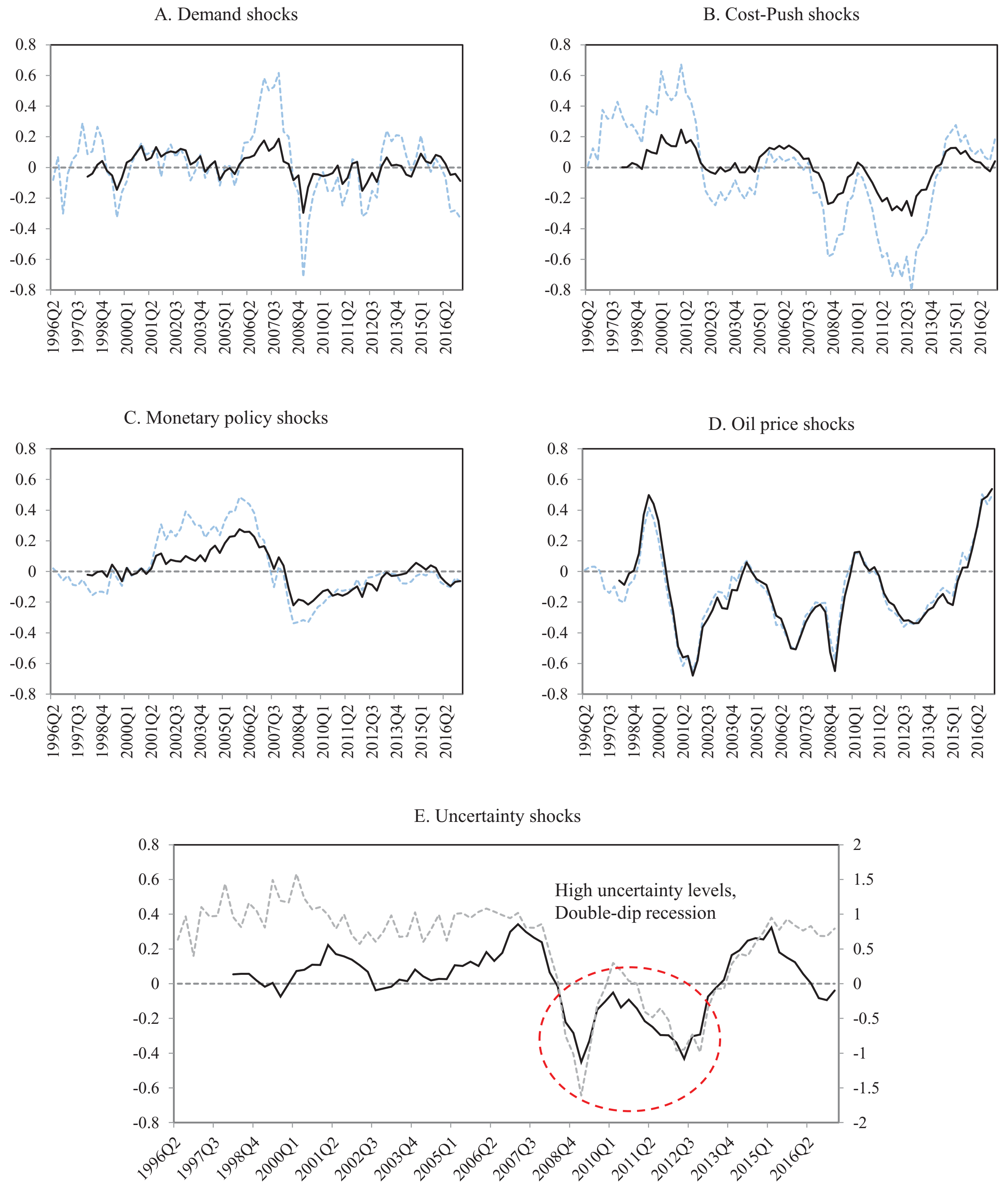
Note. In chart A, solid black (dashed red) line makes reference to growth rate of the people in the labor force (unemployed people) aligned with left (right) axis. In chart B, solid black line (left axis) makes reference to the contribution of labor supply shocks obtained with the extended *Labor* model, and dotted grey line (right axis) makes reference to real GDP growth.

Figure 6. Shock decomposition of GDP growth using the *Fiscal* model



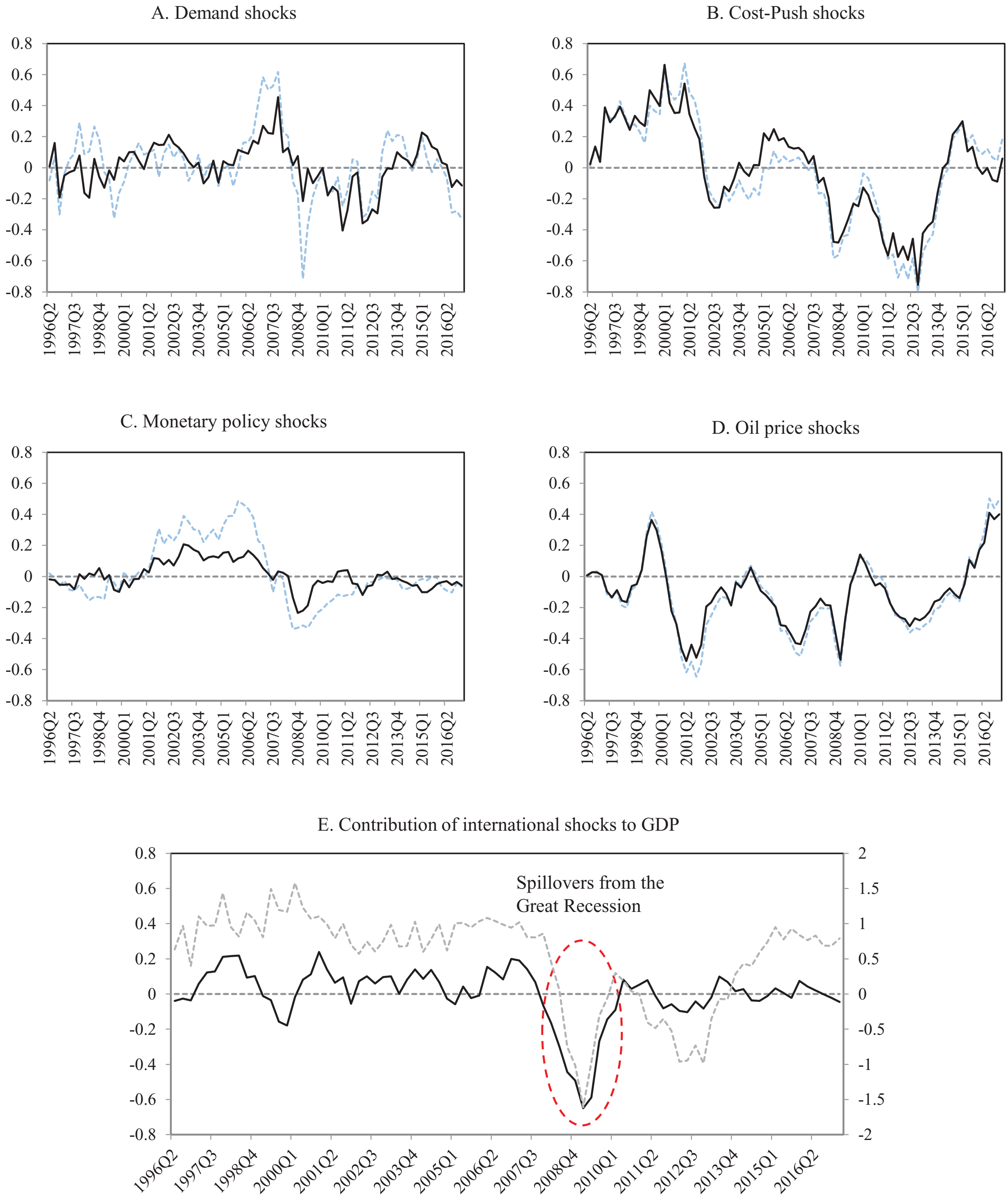
Note. In charts A, B, C, and D, solid black (dotted blue) lines make reference to the contribution of structural shocks from the *Fiscal* (*Benchmark*) model. In chart E, solid black and dashed grey lines (left axis) make reference to the governement expediture and income shocks, respectively, from the *Fiscal* model. Dotted grey line (right axis) makes reference to real GDP growth.

Figure 7. Shock decomposition of GDP growth using the *Finance* model



Note. In charts A, B, C, and D, solid black (dotted blue) lines make reference to the contribution of structural shocks from the *Financial* (*Benchmark*) model. In chart E, solid black line (left axis) makes reference to uncertainty shocks from the *Financial* model. Dotted grey line (right axis) makes reference to real GDP growth.

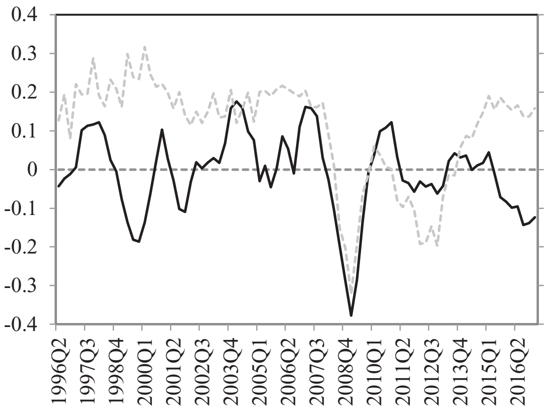
Figure 8. Shock decomposition of GDP growth using the *International* model



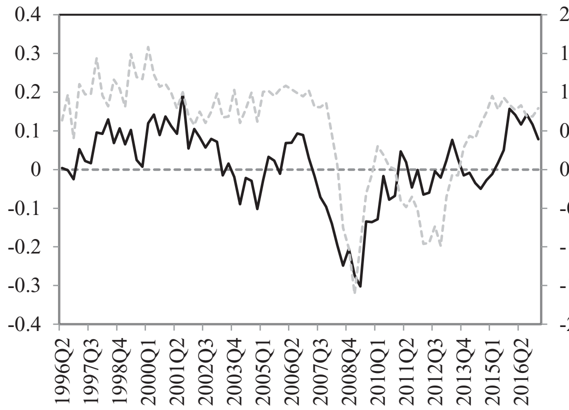
Note. In charts A, B, C, and D, solid black (dotted blue) lines make reference to the contribution of structural shocks from the *International* (*Benchmark*) model. In chart E, solid black line (left axis) makes reference to the foreign structural shocks from the *International* model, and dotted grey line (right axis) makes reference to real GDP growth.

Figure 8 (Cont.). Shock decomposition of GDP growth using the *International* model

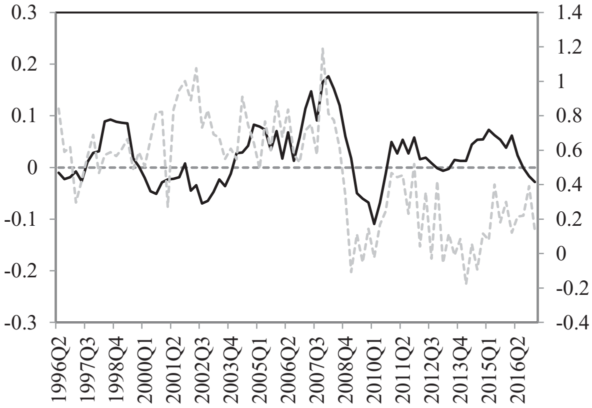
F. Contribution of global demand shocks to GDP



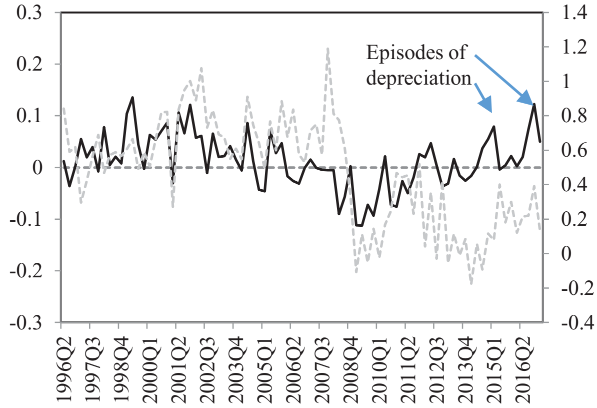
G. Contribution of exchange rate shocks to GDP



H. Contribution of global demand shocks to inflation



I. Contribution of exchange rate shocks to inflation

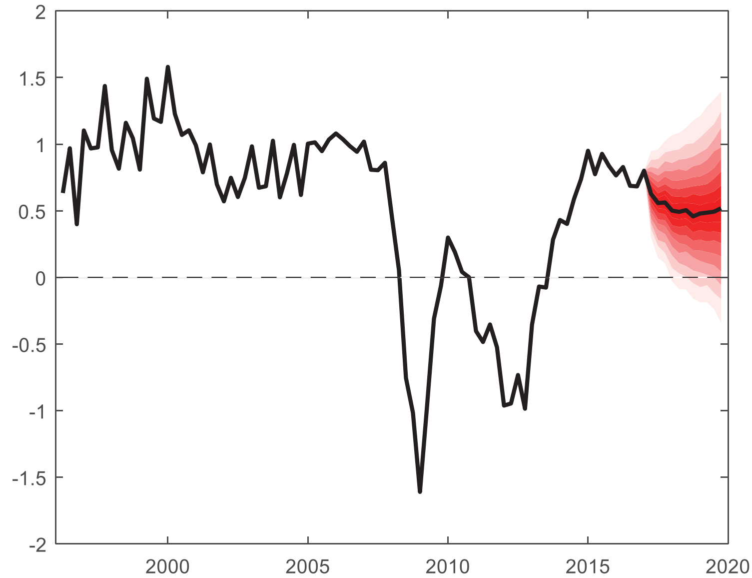


J. Contribution of international shocks to inflation

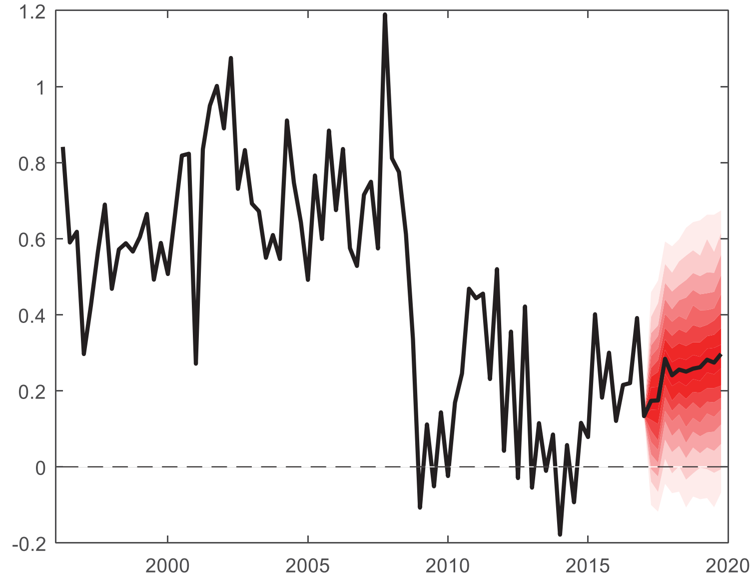
Note. In charts F, G, H, and I, solid black (dashed grey) lines make reference to the contribution of structural shocks from the *International* model (output growth or inflation) and are aligned with left (right) axis. In chart J, solid black line (left axis) makes reference to the foreign structural shocks from the *International* model, and dotted grey line (right axis) makes reference to core inflation rate.

Figure 9. Actual and conditional forecasted values of GDP growth and inflation (*Benchmark* model)

A. Real GDP quarterly growth

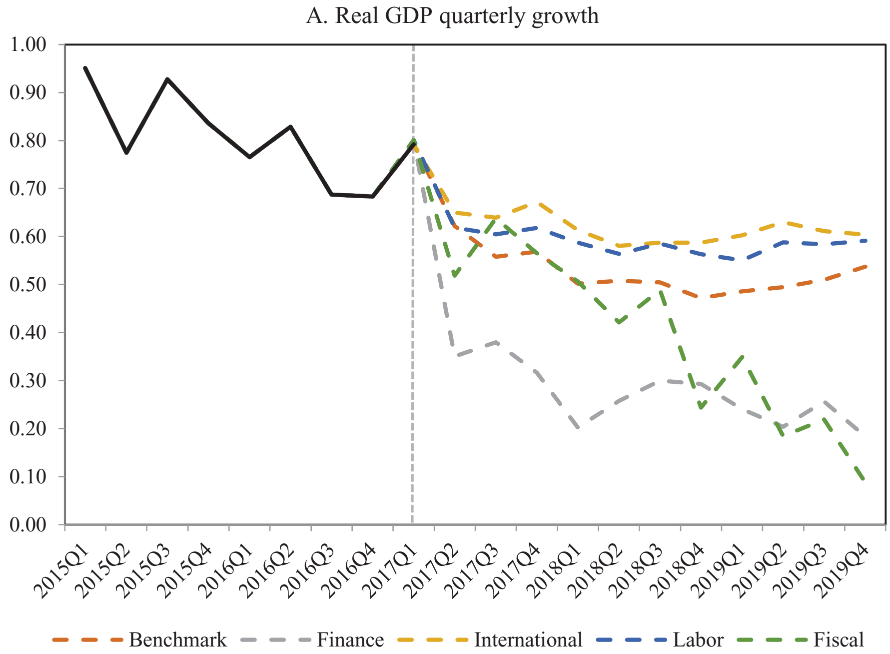


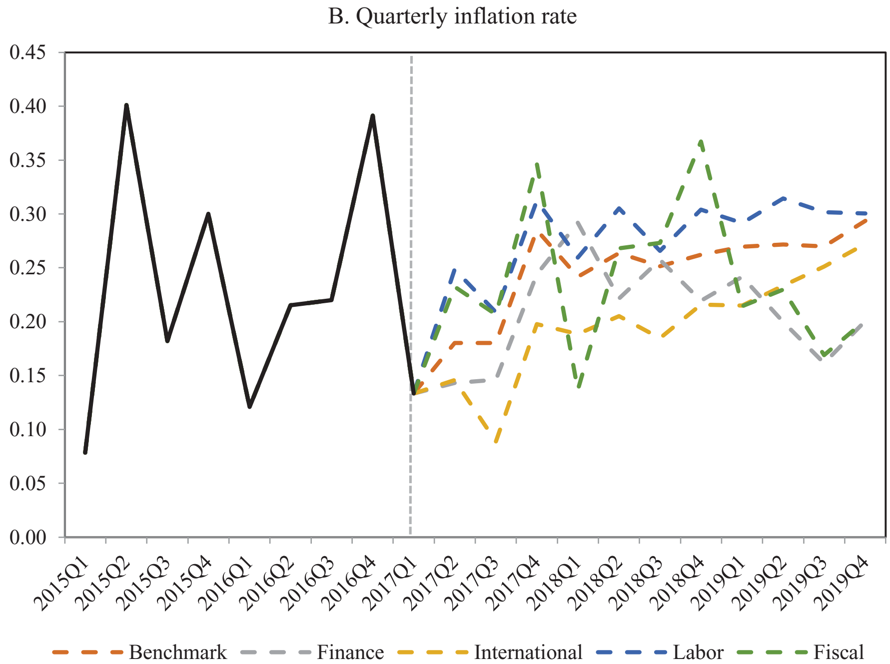
B. Quarterly inflation rate



Note. Both charts shows corresponding actual data until 2017:I. For the forecast horizon, 2017:II-2019:IV, the solid black line plots the median forecasts produced by the *benchmark* model. The fan chart makes reference to the distribution of the forecasts produced by the *benchmark* model.

Figure 10. Conditional forecasts of GDP growth and inflation from different SBVAR models

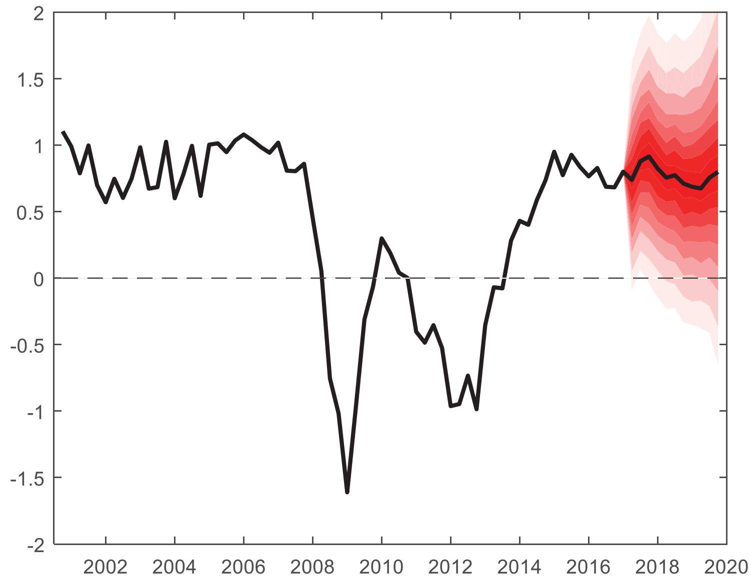




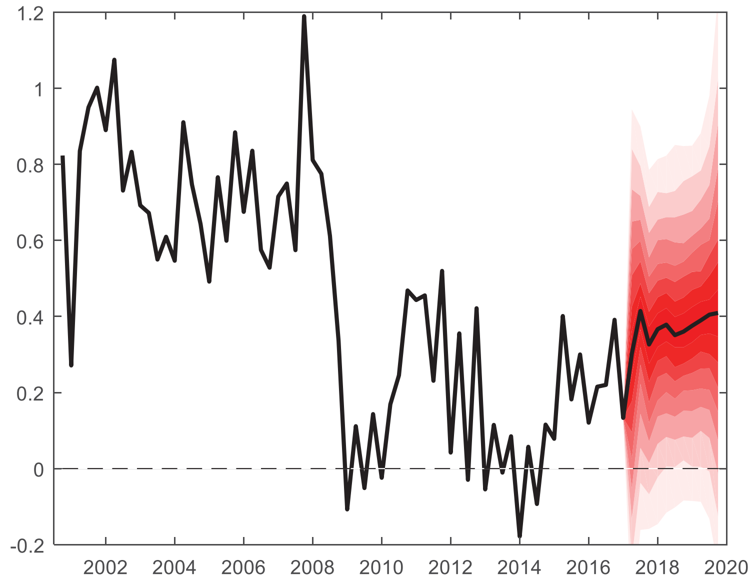
Note. The charts plot the conditional forecasts associated to the different SBVAR models. For the projection horizon , the corresponding conditional scenarios are assigned to the variables: Interest rate, oil price, stock market, global demand, and exchange rate, government expenditure and government income.

Figure 11. Actual and conditional forecasted values of GDP growth and inflation (*One-fits-all* model, agnostic priors)

A. Real GDP quarterly growth



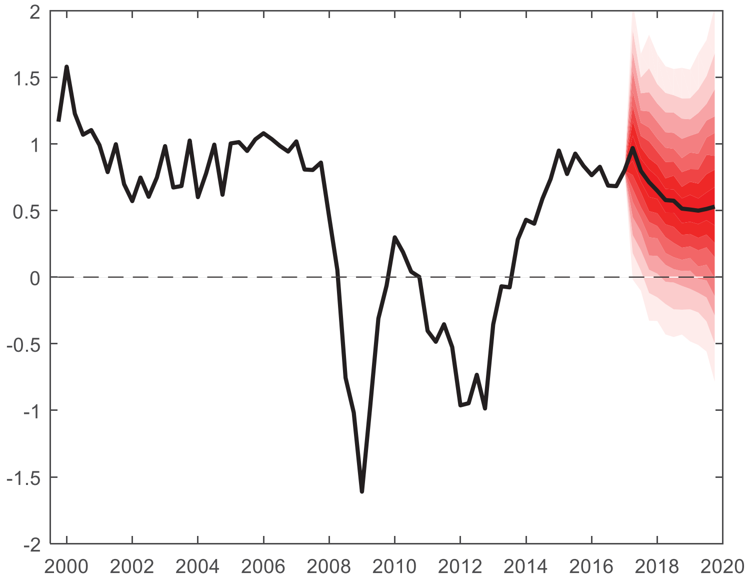
B. Quarterly inflation rate



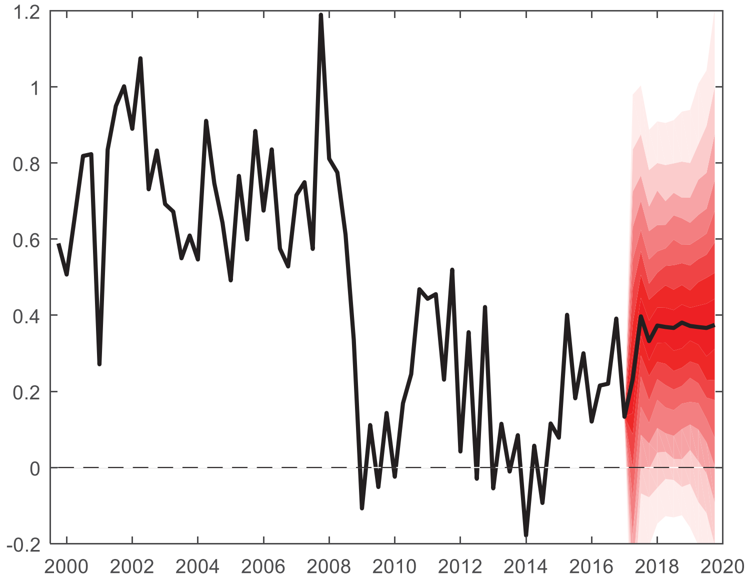
Note. Both charts shows corresponding actual data until 2017:I. For the forecast horizon, 2017:II-2019:IV, the solid black line plots the median forecasts produced by the *benchmark* model. The fan chart makes reference to the distribution of the forecasts produced by the *benchmark* model.

Figure 12. Actual and conditional forecasted values of GDP growth and inflation (*One-fits-all* model, mimic priors)

A. Real GDP quarterly growth



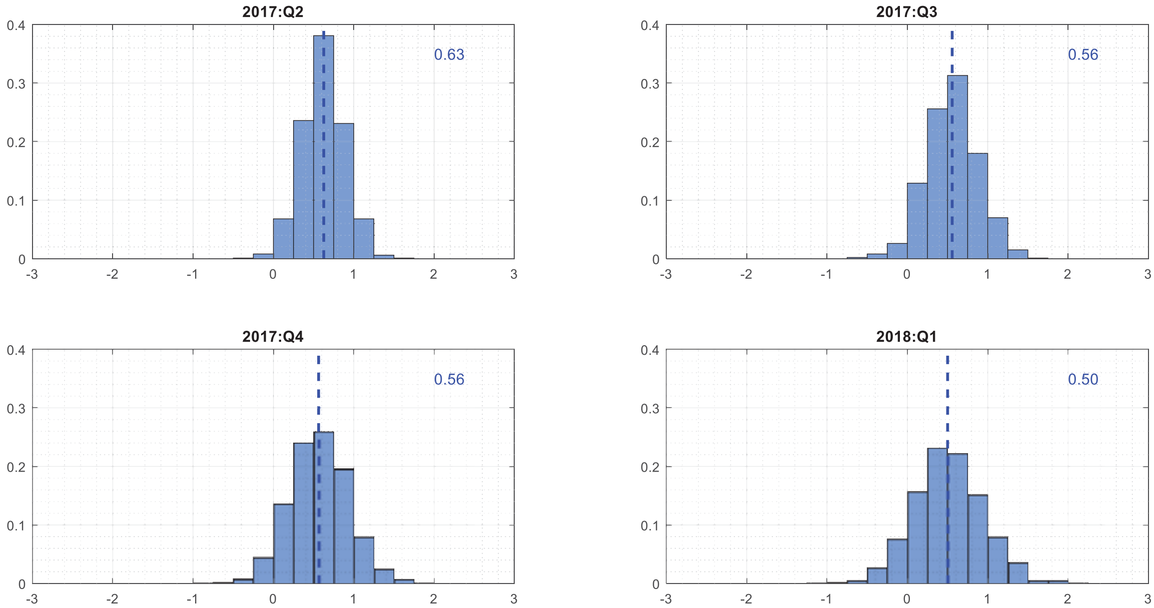
B. Quarterly inflation rate



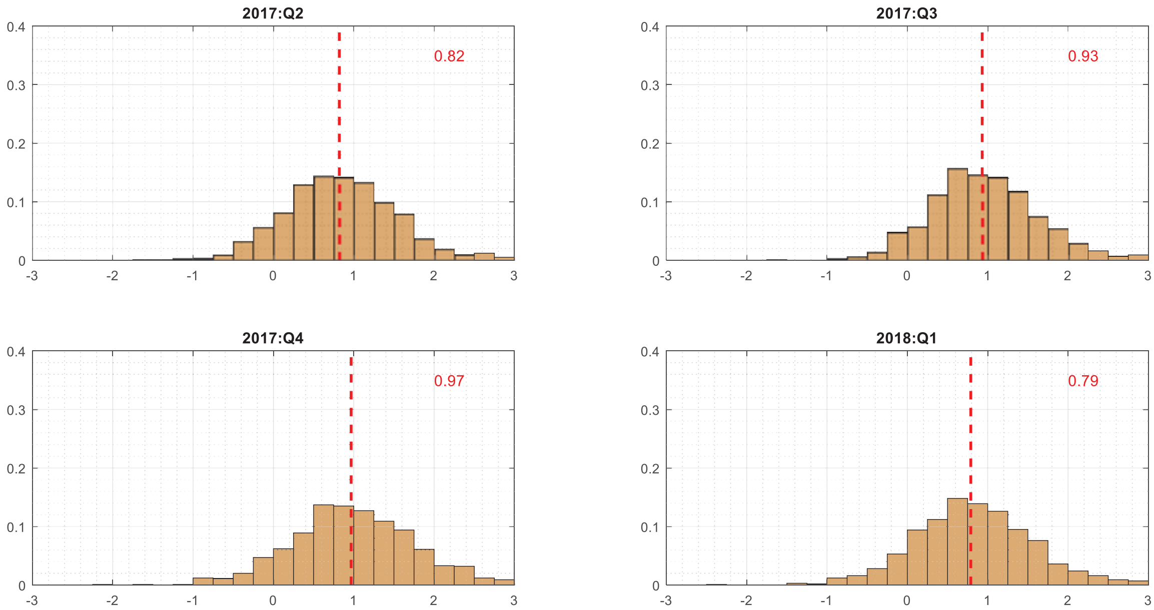
Note. Both charts shows corresponding actual data until 2017:I. For the forecast horizon, 2017:II-2019:IV, the solid black line plots the median forecasts produced by the *benchmark* model. The fan chart makes reference to the distribution of the forecasts produced by the *benchmark* model.

Figure 13. Probability distribution of forecasted values of GDP growth

A. Benchmark model



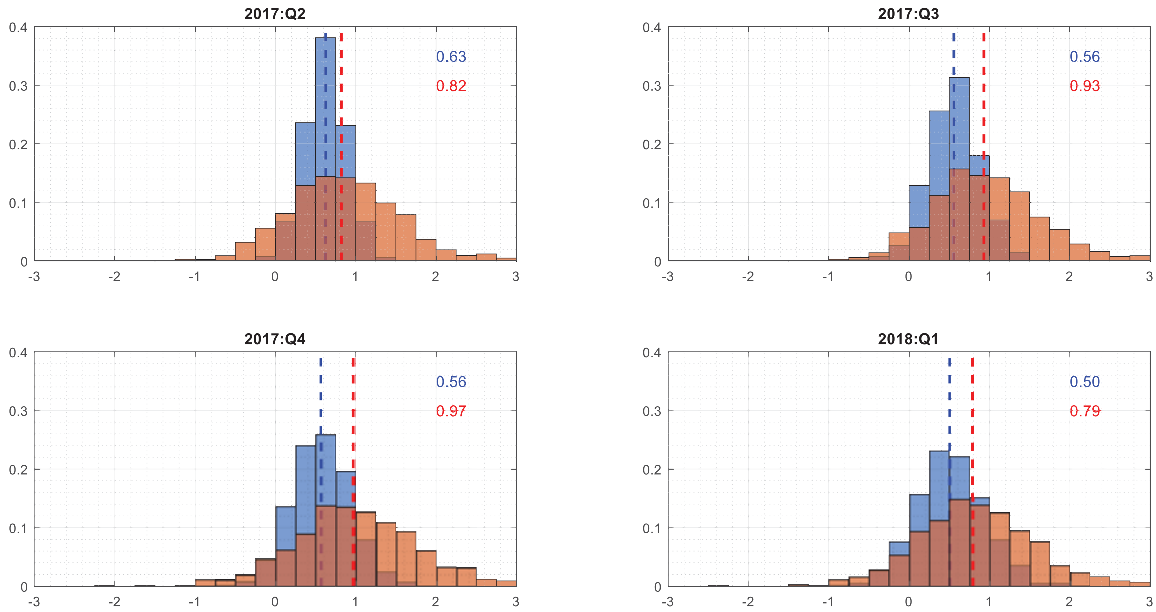
B. One-fits-all model



Note. Each chart plots the forecast probability distribution for the correponsing quarter. The coloured dashed line makes reference to the median forecast.

Figure 13. Probability distribution of forecasted values of GDP growth (Cont.)

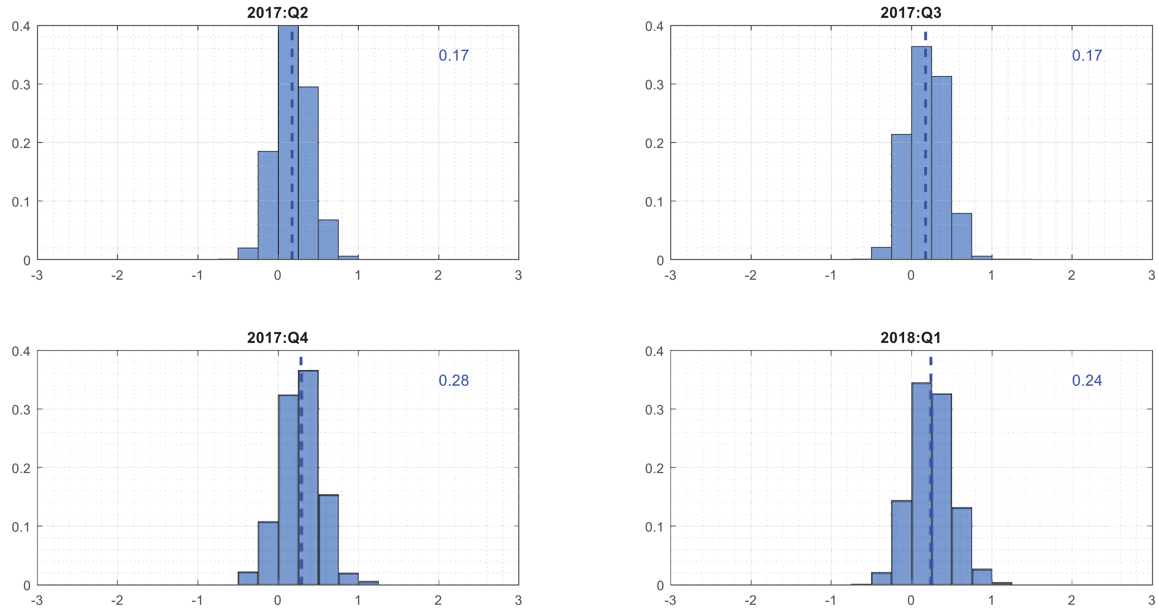
C. Benchmark vs. One-fits-all model



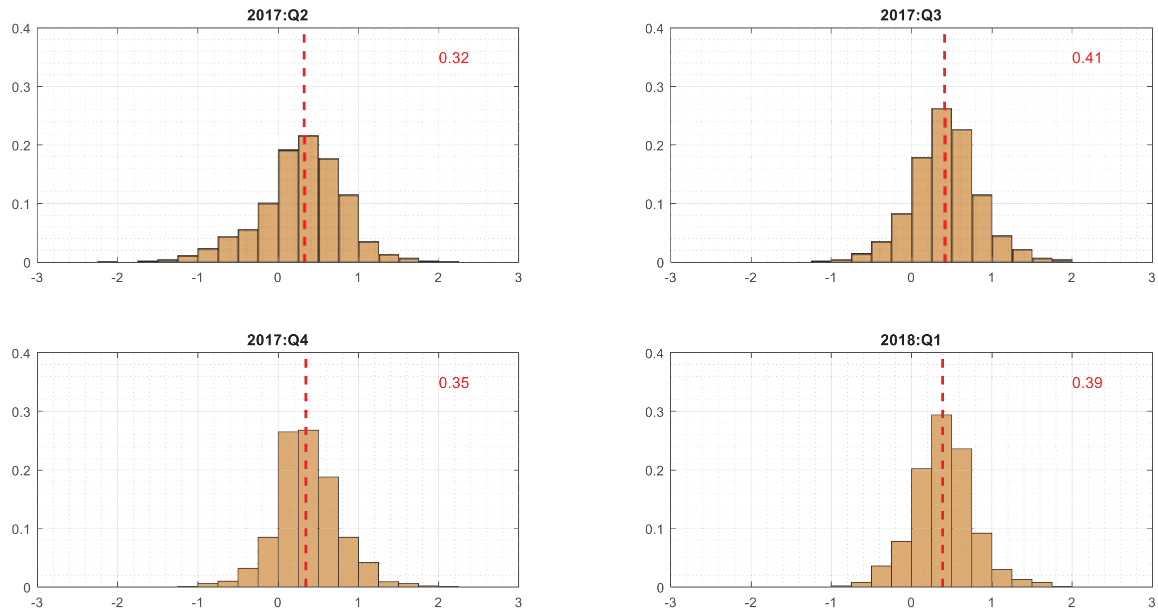
Note. Each chart plots the forecast probability distribution for the correponsing quarter. The coloured dashed line makes reference to the median forecast.

Figure 14. Probability distribution of forecasted values of inflation

A. Benchmark model



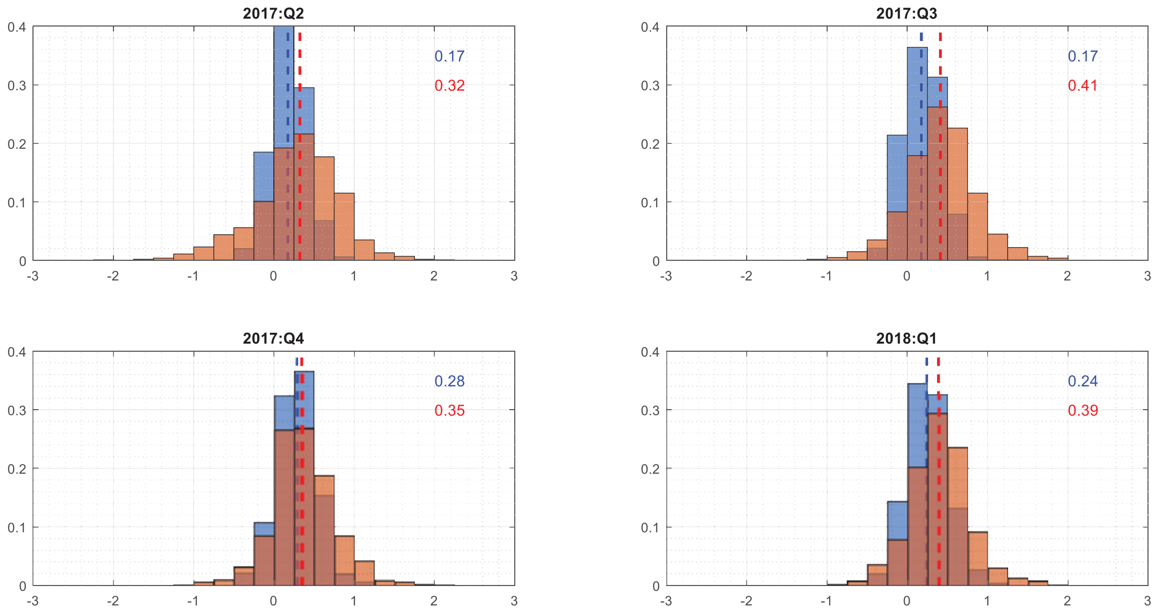
B. One-fits-all model



Note. Each chart plots the forecast probability distribution for the correponsing quarter. The coloured dashed line makes reference to the median forecast.

Figure 14. Probability distribution of forecasted values of inflation (Cont.)

C. Benchmark vs. One-fits-all model



Note. Each chart plots the forecast probability distribution for the correponsing quarter. The coloured dashed line makes reference to the median forecast.

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