Reassessing the effects of foreign monetary policy on output: new evidence from structural and agnostic identification procedures.

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Abstract

What are the effects of foreign monetary policy on the Chilean output? From a policy point of view, the question aims to an interesting point that many Central Banks will soon have to face during the period of monetary normalization signaled by the FED. We tackle the analysis using a traditional approach and compare the impulse responses functions of recursive VAR and a DSGE model. We also include a novel approach following the works of Uhlig (2005) and Arias et al. (2014) on which identification of the shock is done by imposing sign and zero restrictions to the impulse responses directly. Our approach offers a challenging benchmark that allow us to reassess the traditional view of the propagation mechanism of a foreign monetary policy shock and the policy implication derived from DSGE models. Our results suggest that the Cholesky identification scheme does not identify properly the monetary policy shock and its implications are counterintuitive. The "agnostic" approach provides results that are in line qualitatively with the impulse responses computed using the DSGE model. Both show that higher foreign rates are contractive for local activity and inflationary in the short run due to depreciation, causing an increase in domestic interest rates. However we find interesting differences between the models. In the DSGE model the shock propagates more slowly through the economy; and according to the agnostic SVAR model the monetary authority is able to smooth out the inflationary effects of the shock whereas the DSGE model reveals significant effect over the inflation.

Keywords: Monetary policy shocks; Small open economies; Structural VAR; VAR identification; sign and zero restrictions, DSGE model.

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1 Introduction

In the seminal paper of Uhlig (2005), the author presented an agnostic procedure to identify the effect of monetary policy on output for the US economy. A key finding was that neutrality of monetary policy is not inconsistent with the US data. This conclusion raises important policy implications for small open economies because the propagation of that shock activate different channels (interest rate spread, exchange rate depreciation, etc.) which will not imply necessarily a neutrality on the domestic economy. Therefore, our objective will be to address this point. In particular we propose to answer the following question: what are the effects of foreign monetary policy on the Chilean output? We tackle the analysis using the traditional empirical approach that compares the impulse responses functions (IRFs) of recursive VAR models (Sims (1980)) and a standard Dynamic Stochastic General Equilibrium (DSGE) model for a small open economy with nominal and real rigidities that is closely related to models developed by Christiano et al. (2005) and Smets and Wouters (2003, 2007). We also include a novel approach that extends the works of Uhlig (2005) and Arias et al. (2014) on which identification of the shock is achieved by restricting the IRF directly based on conventional wisdom. Our approach offers a challenging benchmark that will allow us to explore and reassess the traditional view of foreign monetary policy on output, in terms of: depth, length and duration; as well as its effects on the rest of the variables of the economy that help to amplify the shock.

Our main results are:

- First, based on IRF analysis, we notice that identification of foreign monetary shock is not straightforward in recursive VAR models. This is consistent with several studies: Bernanke et al. (2005), and Mojon (2008) and Castelnuovo (2015). Then, the recursive VAR model fails to provide an informative benchmark to judge structural micro-funded models.

- On the contrary, the SVAR model with sign and zero restrictions (SZR) offers a challenging benchmark to micro-funded models. Overall, the impulse responses show results in line with macroeconomic theory. The identification seems robust to several puzzles that are found in recursive VAR models.

- The main drawback of the DSGE model is that convergence to the steady state is reached only in the long run mainly because many micro-founded restrictions in the transmission of the shock are added to the model.

- As these mechanisms are added to fit better the persistence observed in the data, we spot a trade off since the responses seem to be too persistent.

From a policy point of view, our question is well-timed since several Central Banks are evaluating the likely effects that the US monetary normalization will have. This particular normalization takes place in exceptional circumstances, where unconventional policies dominated the scene[1]. So far, the normalization combines two signals: (i) concrete policy measures and (ii) forward guidance[2]. Our empirical framework will prove to be a valuable asset to the policy maker to asses the effect of a foreign monetary policy shock over the Chilean economy, since it compares different methodologies offering new lights and insights that have not been explored in the literature so far and also by pointing out the differences and similarities between the models as well as the main drawbacks or advantages among them.

What are the effects of foreign or domestic monetary policy on output? The traditional way to tackle this question has been through the use of: (1) recursive VAR models on which identification is achieved using a specific order of the variables of the system; and (2) DSGE models on which the complete structure of the economy is specified. Intuitively; if the answer to this question is straightforward then a VAR model should be able to uncover the main propagation mechanisms through the variables of the economy, providing a challenging benchmark to the real structural model (i.e. the DSGE model) in order to asses its potential bias or misspecification which in turn will motivate further lines of research to improve the propagation mechanisms of the economy. However, what the literature have found is that identification of monetary policy shock through VAR models has always been a subject of debate and different specifications and models may lead to different responses under a monetary policy shock. Bernanke, Boivin, and Eliasz (2005) provided several reason to understand this result: (1) the policy shock is not properly identified in the VAR system, (2) variables of the VAR do not represent the real state of the economy and (3) the impulse response functions are biased because only a subset of the state variables of the economy were used. Similarly, Weber et al. (2009) argue that structural breaks may be crucial to understand the monetary transmission process. Using data for the Euro area they found two structural breaks in their sample. They report evidence in favor of an "atypical" interim period between 1996-1999; but for the rest of the sample the monetary transmission process remain adequate. Using a

[1]By now it is well known that the exceptional size and scope of the Sub-prime Crisis led the FED to reach the zero lower-bound, which was further complemented with a variety of assets' purchases. The FED had strong reasons to intervene based on historical reasons. The fear was the possibility of a liquidity crisis that could put the economy in a similar path to the one that led the American economy to The Great Depression.

[2]An example for the former is the FED's action to stop increasing its balance sheet. As the US economy continues showing signs of recovery, the FED is carefully communicating its future actions. For example, on March 2015, the FED removed the word "patient" from the formal statement signaling to the market that an interest rate hike may be possible in the near future depending on reaching its traditional objectives of employment and inflation.

completely different approach, Uhlig (2005) discusses identification of a monetary policy shock using an agnostic procedure on which identification is achieved by restricting the impulse response function directly according to conventional wisdom without relying in a particular order of the VAR system. The main result was that neutrality of monetary policy is not inconsistent with the US data. More recently, Castelnuovo (2015) address this point to the Euro area and analyse the neutrality of monetary policy on inflation. He reports that the neutrality of VAR models may be due to a deficient identification of the policy shock, omitted variables or structural breaks.

The “agnostic” identification of Uhlig (1997) impose sign and zero restrictions to a subset of variables in the model, such as Canova and Nicolo (2002), Uhlig (2005), Rubio-Ramírez, Waggoner and Zha (2010) and Arias et al. (2014). Nevertheless, the choice of restrictions is an open debate. More recently, unconventional monetary policies in the US and the Eurozone have encouraged the use of different frameworks to evaluate the impacts of these shocks (including SVARs, Bayesian VARs, DSGE, etc.), such as Carrera et al. (2015), Baumeister and Benati (2012), Castelnuovo (2012), Christensen and Rudebusch (2012), Kapetanios et al. (2012), among others. For example, using a SVAR with sign and zero restrictions, Carrera et al. (2015) have studied the impact of quantitative easing policies on small open economies in Latin America. Baumeister and Benati (2012) analyze the effects of unconventional policies with a time varying structural VAR, while Castelnuovo (2012) and Castelnuovo (2015) use a micro-founded DSGE approach to assess the macroeconomic impacts of an increase in interest rates.

The rest of the paper is organized as follows; the next section presents the VAR models. Section three briefly describes the structural DSGE model economy. Section four reports impulse response functions for each model. Finally, section five concludes.

2 SVAR models with recursive and agnostic identification scheme

The structural VAR model with block exogeneity can be written as:

$$[y_t^{*\prime} \quad y_t{}'] \begin{bmatrix} 0 & A_{02} \\ A_{03} & A_{04} \end{bmatrix} = \sum_{t=1}^{p} [y_{t-1}^{*}{}' \quad y_{t-1}{}'] \begin{bmatrix} 0 & A_{t2} \\ A_{t3} & A_{t4} \end{bmatrix} + [\varepsilon_t^{*\prime} \quad \varepsilon_t{}'] I_{n^*+n} \qquad (1)$$

Where y_t denotes a vector of $n \times 1$ of endogenous variables for the small economy and y_t^* denotes a vector of $n^* \times 1$ of endogenous variables for the rest of the world. The zero blocks in the system reflect the block exogeneity assumption in the spirit of Zha (1999).

The first block is the small open economy (domestic block) and the second block is the rest of the world (foreign block). We leave exogenous variables (constant terms, trends or predetermined variables) out of the model to simplify the notation. The model can be compactly written as:

$$Y_t A_0 = X_t{}' A_+ + \xi_t \tag{2}$$

Where $X_t{}' = [Y_{t-1}, ..., Y_{t-p}]$ and $A_+ = [A_1, ..., A_p]$; the reduced-form model can be written as:

$$Y_t = X_t{}' B + \epsilon_t \tag{3}$$

For the estimation we use monthly data covering the period 1996M1-2014M12[3]. The identification of the foreign monetary shock is achieved using two different identification schemes: Cholesky (recursive) identification and an extended version of the agnostic procedure of Uhlig (2005) and Arias et al. (2014).

The domestic block includes the following set of variables: (1) index of the Chilean economic activity (IMACEC), (2) real machinery and equipment investment, (3) real construction investment, (4) the Chilean Consumer Price Index (IPC), (5) the annual nominal monetary policy rate and (6) the real exchange rate. The foreign block includes: (1) an index of US industrial production, (2) US consumer price index, (3) US Federal Funds rate, (4) the real oil price and (5) the real copper price. All the variables are in logs excluding the interest rate[4]. We use the Chilean External Price Index to deflate price indexes that were available in nominal US dollar terms from their sources. Real GDP, investment and price indexes were seasonally adjusted using the Census X-12 procedure when they were not available in seasonally adjusted form from the original source[5]. In addition, we control for linear time trends and add a constant term to each equation of the model.

2.1 Cholesky identification scheme

The recursive VAR model (Cholesky) was introduced in the seminal work of Sims (1980) and it has become the conventional benchmark that is used in applied macroeconomics to validate responses of micro-founded structural models (Canova 2007, section 4.7). The model is specified as in Fornero, Kirchner and Yany (2015). We choose a 2-month lag

[3]An alternative way would be to estimate the VAR models with quarterly data directly; however for identification purpose it may be problematic. Under this setting, the Cholesky identification scheme will require that some of the variables will not react contemporaneously which seems unrealistic at this time frequency. The same problem arises for the agnostic identification procedure. That is why we prefer to work with monthly data since it will allow us to get a better identification of the foreign monetary shock.

[4]For missing observations due to a change in the periodicity of the data in investment and foreign real activity, we use the Chow Lin procedure to transform quarterly into monthly data

[5]For further details of variables, sources and transformations see Table 1 in the data appendix.

based on standard information criteria and also following the recommendation of Castelnuovo (2015).

Let us define $E(\epsilon_t \epsilon_t') = \Sigma_\epsilon$ as the covariance matrix of the reduced-form errors ϵ_t; the identification of the structural shocks with the Cholesky decomposition of Σ_ϵ maps the reduced form parameters to the structural parameters:

$$\Sigma_\epsilon = A_0^{-1} A_0^{-1'}$$

The matrix Σ_ϵ is not observed directly but it can be estimated using the OLS estimators; finally we can recover A_+ from (2) and (3) using A_0.

In this type of identification the order of the variables in the system matters: the first variable is the most exogenous and the last one the most endogenous. This means that we need to make strong assumptions about the order of causality between the variables in the system which may be problematic and difficult to maintain against different settings.

2.2 Identification with sign and zero restrictions

The recursive monetary VAR requires a strong set of identification assumptions to uncover the structural shocks. The literature has established that monetary policy shocks are problematic in several applications for developed countries because the methodology leads to counterintuitive results, see for instance Christiano et al (1999), Mojon(2008) and Castelnuovo (2015). This motivated a new literature that developed new identification schemes, achieved through economic sound arguments –a formal theory or economic intuition instead of a specific recursive order for the variables in the VAR system.

In the seminal work of Uhlig (2005), the author developed an "agnostic" procedure to identify the effects of a monetary policy shock over the American economy. Identification is achieved by imposing restrictions directly in the IRFs of the model which in turn imply linear and nonlinear constraints in the structural parameters of the model[6]. More recently, new development has been made in this literature: Mountford and Uhlig (2009), Rubio-Ramírez, Waggoner and Zha (2010) and Arias et al. (2014). In this paper we will extend the methodology of Uhlig (2005) and Arias et al. (2014) by incorporating a foreign block into the model. The implication of this identification scheme has not been explored

[6] This idea was not new and it can be traced back to other authors as well: Blanchard and Quah (1989), Faust(1998), Canova and Nicolo (2002). But it was Uhlig (2005) who popularized the method by developing a straightforward procedure to estimate the models.

comprehensively in the literature. Therefore we will be able to challenge the traditional empirical approach to reassess the impact of foreign monetary policy on a small open economy, in terms of: depth, length and duration; as well as it effects on the rest of the variables of the economy that help to amplify the shock. We choose a 1-month lag and add the real copper price and real oil price as exogenous variables.

In this setting, the attention is focused in a subset of the structural shocks; in our case the foreign monetary policy shock[7]. The shock is identified using a set of sign and zero restrictions over the IRFs of the model. Loosely speaking, we choose a foreign monetary policy shock being positive for at least 3 months. The shock does not have a contemporary impact on the domestic activity, foreign activity and foreign price level. We remain agnostic about the reaction of the domestic monetary policy maker and the domestic price level; but we assume a real depreciation that last for at least three months. Finally, in line with the literature we assume that domestic investment will not have a contemporary effect but it will fall for three periods after the shock. The identification is quite general and consistent with the traditional responses obtained with New Keynesian models estimated with quarterly data. Table 1 summarizes these restrictions.

Table 1

Sign and zero restrictions

	h = 0	h = 1,2,..
Foreign block		
-US Federal Funds rate	1	2
-US industrial production index	0	?
-US consumer price index	0	?
Domestic block		
-Interest rate	?	?
-Chilean economic activity index (IMACEC)	0	?
-Chilean Consumer Price Index (IPC)	?	?
-Investment (machinery, equipment and construction)	0	-3
-Real Exchange Rate	1	2

Positive or negative number indicates the length of the sign restriction; (0) indicates impact or zero restriction; question mark (?) indicates that no restriction was imposed in the variable.

[7] By definition the structural shocks are orthogonal to each other therefore this will not bias our results.

As we said before, the main methodological contribution is to extend the traditional model to include a foreign block into the model. In the original formulation Arias et al. (2014) the model only contains a domestic block. The IRFs are computed by taking draws from the posterior of the structural parameters conditional on the restrictions. The main contribution of this paper is to introduce an efficient method to obtain such draws. The algorithm can be summarized as follows:

- Draw $(B;\Sigma)$ from the posterior of the reduced-form parameters.
- Generate $(A_0^*;A_+^*)$ by using a mapping between the reduced-form and the structural parameters[8].
- Draw an orthogonal matrix Q such that $(A_0^*Q;A_+^*Q)$ satisfies the zero restrictions[9].
- Keep the draw if sign restrictions are satisfied.

If each equation of the VAR model has the same number of variables then we can use a direct sampling from the the posterior distribution of the reduced-form parameters by specifying a natural conjugate prior, i.e. a Normal-Wishart Prior. The posterior of the parameters are given by:

$$b|\Sigma, y \sim N(\bar{B}, \bar{\Sigma} \otimes \bar{V}) \quad \text{and} \quad \Sigma^{-1}|y \sim W(\bar{S}^{-1}, \bar{\nu})$$

and

$$\bar{S} = S + \underline{\text{S}} + \hat{B}'X'X\hat{B} + \underline{\text{B}}'\underline{\text{V}}^{-1}\underline{\text{B}} - \bar{B}'(\underline{\text{V}}^{-1} + X'X)\bar{B}$$

Where $\bar{\nu} = T + \underline{\nu}$; $b = vec(\bar{B})$ and $\hat{B}$ is the OLS estimator of B; $\bar{V} = \left[\underline{\text{V}}^{-1} + X'X\right]^{-1}$ and $\bar{B} = \bar{V}\left[\underline{\text{V}}^{-1}\underline{\text{B}} + X'X\hat{B}\right]^{-1}$ and the hyperparameters $\underline{\alpha}$, $\underline{\text{V}}$ and $\underline{\text{S}}$ characterized the prior distributions of the parameters:

$$b|\Sigma, y \sim N(\underline{\text{B}}, \underline{\Sigma} \otimes \underline{\text{V}}) \quad \text{and} \quad \Sigma^{-1}|y \sim W(\underline{\text{S}}^{-1}, \underline{\nu})$$

Following Koop and Korobilis (2010) it is straightforward to obtain draws from the posterior of the reduced-form parameters to implement the method of Arias et al. (2014): (1) estimate $\hat{B}$ by OLS; (2) make a draw of Σ form the posterior; (3) conditional on the draw of Σ make a draw form the posterior of B; (4) compute the impulse response functions.

[8]The mapping between structural and reduced-form parameters can be implemented by using a function $h()$ such that $h(X)'h(X) = X$, i.e. Cholesky decomposition: $(A_0^*;A_+^*) = (h(\Sigma)^{-1}; Bh(\Sigma)^{-1})$

[9]Using the QR decomposition ($X = QR$) which holds for any $n \times n$ random matrix on which each element is $i.i.d.$ from a $N(0,1)$. In addition, Arias et al. (2014) illustrate an algorithm to obtain recursively each column of Q, which improves the efficiency of the algorithm significantly when the researcher is interested in identifying more than one structural shock.

In our setting, the VAR model incorporates a foreign block which is not influenced by domestic developments. This means that the two blocks of the model will have different explanatory variables which violate the assumption required to use the natural conjugate prior. Following Koop and Korobilis (2010), we use the Independent Normal-Wishart Prior which enable us to estimate more general VAR models in which the number of explanatory variables differ across equations (or blocks). To make more explicit the notation to handle equations in the reduced-form model rewrite (3) as:

$$y_{mt} = z'_{mt} b_m + \varepsilon_{mt}$$

Where t is the time index and m indicates the variable (i.e. equation); y_{mt} specify the t^{th} observation of the m^{th} variable and z_{mt} is a vector that contains the explanatory variables for the m^{th} equation at time t. Finally, define b_m as the vector that contains the parameters of the equation and M as the total number of equations. Note that z_{mt} may vary (or not) across equations but in our setting it will only vary across the two blocks.

We stack all the vectors and matrices to write the model more compactly as:

$$y_t = Z_t b + \varepsilon_t$$

Where: $y_t = (y_{1t}, ..., y_{Mt})'$ and $\varepsilon_t = (\varepsilon_{1t}, ..., \varepsilon_{Mt})'$ and defining:

$$b = \begin{pmatrix} b_1 \\ b_2 \\ \vdots \\ b_M \end{pmatrix} \qquad Z_t = \begin{pmatrix} z'_{1t} & 0 & \dots & 0 \\ 0 & z'_{2t} & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ 0 & \dots & 0 & z'_{Mt} \end{pmatrix}$$

The total number of parameters is given by $k = \sum_{j=1}^{M} k_j$; and $\varepsilon_t \sim N(0, 1)$. Note that b is a $k \times 1$ vector and Z_t is an $M \times k$ matrix. We can stack y_t, ε_t and Z_t as a column vectors to write the model in a more convenient way:

$$y = Zb + \varepsilon$$

Where $\varepsilon \sim N(0, I \otimes \Sigma)$. To make draws from the posterior distribution of the parameters we will impose an independent Normal-Wishart prior which allow to deal with VAR models on which the number of explanatory variables are not the same through the equations of the model; the posterior of the parameters are given by:

$$b|\Sigma, y \sim N(\bar{B}, \bar{\Sigma} \otimes \bar{V}) \quad \text{and} \quad \Sigma^{-1}|y, b \sim W(\bar{S}^{-1}, \bar{\nu})$$

and

$$\bar{S} = \underline{S} + \sum_{t=1}^{T} (y_t - Z_t b)(y_t - Z_t b)'$$

Where $\bar{\nu} = T + \underline{\nu}$; $\bar{B} = \bar{V}\left[\underline{V}^{-1}\underline{B} + \sum_{t=1}^{T} Z_t' \Sigma^{-1} y_t\right]$ and $\bar{V} = \left[\underline{V}^{-1} + \sum_{t=1}^{T} Z_t' \Sigma^{-1} Z_t\right]^{-1}$. The hyperparameters $\underline{\alpha}$, $\underline{V}$ and $\underline{S}$ characterized the prior distributions of the parameters which can be written in the following way:

$$p(b, \Sigma^{-1}) = p(b)p(\Sigma^{-1})$$

Where:

$$b \sim N(\underline{B}, \underline{V}) \quad \text{and} \quad \Sigma^{-1} \sim W(\underline{S}^{-1}, \underline{\nu})$$

Note that the posterior of Σ is not independent from the draw of b; therefore conventional Bayesian analysis cannot be implemented as before. Instead, we need to rely on simulation methods, such as the Gibbs sampling algorithm, to approximate the posterior distribution of the parameters. A sequential algorithm can be programmed on which sequential draws are taken from the posterior distribution of $p(b|y, \Sigma)$ and $p(\Sigma^{-1}|y, b)$. Once we have converged to the posterior distribution of the reduced-form parameters, we can implement the algorithm of Arias et al. (2014).

Recently, Carrera et al. (2015) studied the impact of the quantitative easy policy on Latin American economies. They estimate a SVAR model with a foreign and domestic block and the identification of the structural shock is done following Arias et al. (2014). The blocks have different number explanatory variables; however, they circumvent the aforementioned problem by estimating each block independently and specifying a natural conjugate prior for each block. The main drawback of this setting is that the orthogonal matrix Q that satisfies the zero restrictions needs to be computed independently for each block[10]. In this case, define $Q = [Q_1, Q_2]$; where Q_i is the matrix for which the zero restrictions holds for the block i. Finally, they recover the complete model by stacking the two blocks and keep the draw if the sign restrictions are satisfied. Our approach remains closer to the original framework of Arias et al (2014) and we obtain Q in one simple draw which imply a more efficient approach.

[10] First, the draws of the reduced-form parameters for the domestic $(B.\Sigma)$ and foreign block $(B_*.\Sigma_*)$ are obtained. Finally, using these draws compute the structural parameters for each block: $(A_0^*; A_+^*)$ and $(A_{0*}^*; A_{+*}^*)$.

3 A DSGE model for Chile

In this section we describe briefly the DSGE model for Chile. We use the model of Medina and Soto (2007a) to compute the impulses responses to a 1% foreign monetary policy shock. The model is a new Keynesian small open economy model which is closely related to the framework of Christiano et al. (2005), Smets and Wouters (2003,2007), but has additional and specific features to describe the Chilean economy, such as a representative commodity-exporting firm, a "structural" fiscal policy rule and a monetary policy rule that responds to changes of headline CPI inflation (we refer to Medina and Soto (2007a) for a more detailed description of the model).

This model has been extended in several directions to address specific questions and also it has been reestimated to take advantage of recent data. Examples are the learning extension to replicate the the Current Account dynamics of Chile as Fornero and Kirchner (2014) and Fornero, Kirchner and Yany (2015) conduct several policy experiments simulating a copper price shock. In the current version, we abstract from these additions[11].

A full description of the model is beyond the scope of this paper. Therefore, in the remaining of the section, we briefly describe main features. The domestic economy is composed by a continuum of households, where a fraction are non-Ricardians without access to capital market. These non-Ricardian households consume entirely their wage income. The remaining Ricardian households make intertemporal consumption-savings decisions in a forward-looking manner, so as to maximize the present value of utility.

There are three types of sectors in the domestic economy. First, there is a continuum of firms producing differentiated varieties of intermediate tradable goods, with monopoly power and sticky prices à la Calvo (1983). These firms use labor, capital and oil as inputs and sell their varieties to competitive assemblers that produce final domestic goods, that are sold in the domestic and foreign market. There is a representative capital goods producer that rents capital goods to the intermediate goods producing firms. The optimal investment composition is determined through cost minimization, where we assume costs of adjusting investment, following Christiano et al. (2005). All firms are owned by Ricardian households. Second, there is an imported goods sector with a continuum of retail firms that repackage a homogenous good from abroad into differentiated imported varieties. There is a large set of firms that use a CES technology to assemble final imported goods from imported varieties. These firms have also monopoly power and set

[11] Robustness exercises were done using the model of Fornero and Kirchner (2014) and Fornero, Kirchner and Yany (2015) and we did not find any relevant advantage of adding an endogenous commodity-exporting sector in order to compute the IRFs to a foreign monetary policy shock.

their prices infrequently. All firms are also owned by Ricardian households. Third, there is an exogenous commodity-producing sector composed by a unique representative firm. The entire production is exported abroad and the international price of the commodity is taken as given. A fraction of the assets of that firm is owned by the government and the remaining fraction is owned by foreign investors, where the revenue is shared accordingly.

Monetary policy is conducted through a simple Taylor-type feedback rule for the nominal interest rate, where the central bank responds to headline CPI. The fiscal policy follows a structural balance fiscal rule, where government expenditure (government consumption and transfers to households) depends on cyclical adjustments of commodity price and output gap. Also, the model includes distortional taxes in consumption, income and capital gains.

There is a foreign sector which is composed by 5 exogenous variables (GDP, inflation, interest rate, oil price and commodity price). We assume that the dynamics of these foreign variables are described by independent autoregressive processes of order one, AR(1), as in Medina and Soto (2007a) and Fornero and Kirchner (2014). We choose this framework instead of a foreign SVAR block (as in Fornero, Kirchner and Yany (2015)) to avoid selecting a SVAR identification scheme in the DSGE model[12].

Finally, the model is parameterized using estimates from Bayesian estimation techniques with quarterly data covering the period 2001Q3-2014Q4. We use their posterior mean to compute the impulse responses to a foreign interest rate shock[13].

4 Results

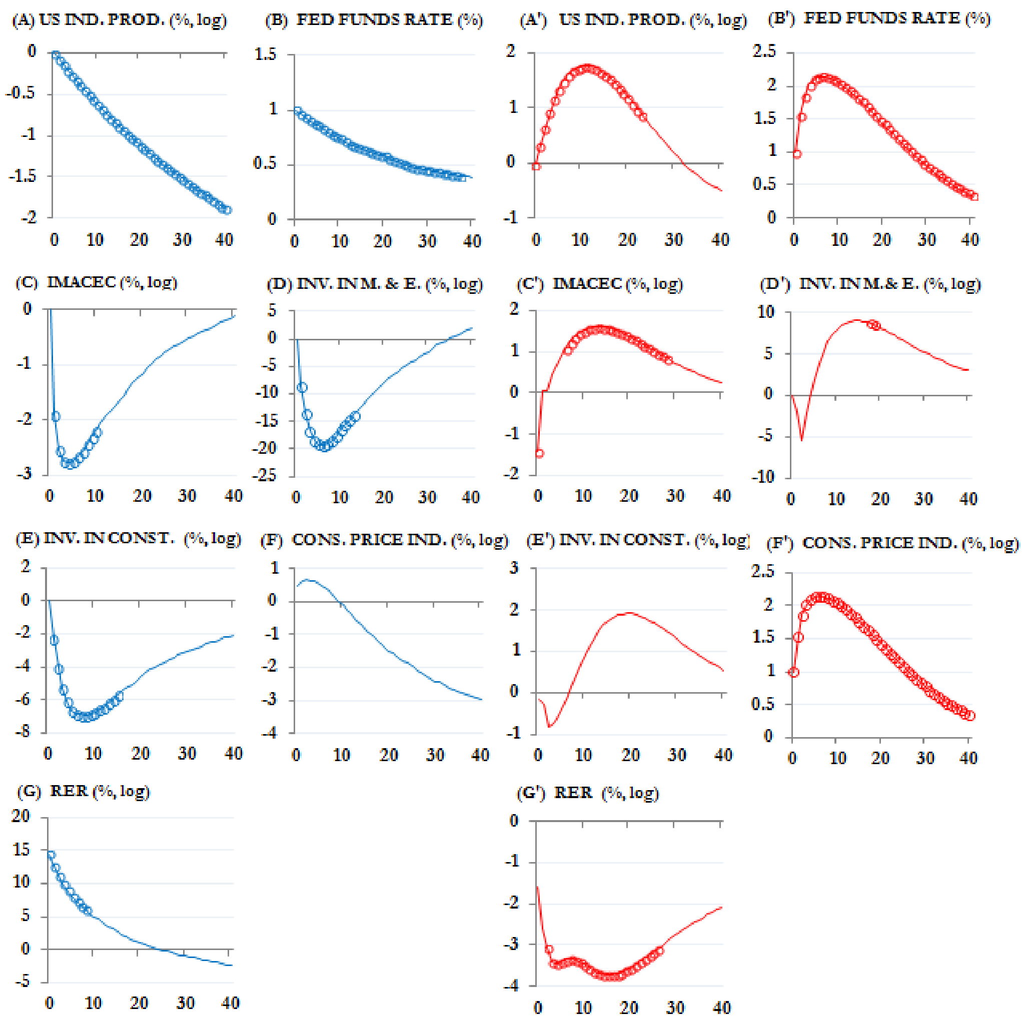
This section tackles the following question: What are the effects of foreign monetary policy on the Chilean output in terms of: depth, length and duration; as well as its effects on the rest of the variables of the economy that help to amplify the shock? Besides considering that question, we challenge the tradition approach comparing SVARs results. Moreover, we complement the discussion with results from a DSGE model. To begin with, we illustrate in Figure 1 impulses responses of the foreign and domestic variables to a 1% positive shock of the foreign interest rate using SVARs. We compare two identification

[12] Using a SVAR foreign block makes difficult to compare the impulses responses computed by the DSGE and the SVARs, since the results of the DSGE would be influenced by the identification scheme chosen for the foreign SVAR block.

[13] Details of the Bayesian estimation are available on request. In particular, the persistence of the shock is calibrated to 0.87 following Medina and Soto (2007a). This persistency arises if the researcher estimates an AR(1) with a sample that ends before the Subprime Crisis.

approaches: (i) one with sign and zero restrictions (left panel, blue lines) and (ii) the conventional Cholesky or recursive (right panel, red lines).

Figure 1
Impulse responses from SVAR models (SZR and Cholesky identification schemes) to a foreign monetary policy shock



* Identification with sign and zero restrictions in the first two columns; Cholesky identification in the last two columns.

* Shock is of size 100 basis points. Circles indicate quarters in which the responses are statistically significant at the 80% level of confidence.

In general, the identification of the recursive VAR (Cholesky) for the SOE yields puzzling responses. In particular, Graphs A' to G' suggest a counterintuitive interpretation for economic the evolution of key variables[14]. The monetary policy shock is associated

[14]Sims (1980) defines a puzzle as a situation on which the impulse response functions from a identification scheme do not match conventional wisdom from theoretical models.

with expansionary conditions in the world economy (a boost in trade partners' activity, increases in foreign prices and in real commodity prices). In the domestic economy, the effect on investment is mostly positive. The local activity reaches positive and significant growth rates of about one percent. The fluctuations of nominal variables also turn out to behave inconsistently because the appreciation of the real exchange rate is associated to *higher* inflation.

The first conclusion we can infer from this exercise is that identification of foreign monetary shock is not straightforward[15]. This is especially true when we take a closer look to our recursive SVAR that contains nine variables; in theory the system should be able to capture the main dynamics of the shock. According to Bernanke et al. (2005) and Castelnuovo (2015), the main reason behind this result is a poor identification of the shock due to omission of state variables or structural breaks. The second conclusion is that the recursive VAR model fails to provide an informative benchmark to judge structural micro-funded models.

The effects in the IRFs (graphs A' to G') resulting from the agnostic approach[16] offer a completely different view of the propagation of the shock. Overall, the impulse responses show results in line with macroeconomic theory. Besides, they are statistically significant at conventional levels (with the exception of inflation). In addition, the dynamics towards the equilibrium of most variables are comparable with findings from the literature. We highlight that both foreign and local activity decrease when an unexpected increase in foreign interest rates take place. In particular, in the local economy there is a strong response of investment, which is mainly due to a large real exchange rate depreciation in line with tighter monetary conditions abroad (outflow of capitals, etc.). Prices increase in the very short term due to this depreciation; but then, the downward pressure exerted by the weak demand dominates and, consequently, prices fall (notice that these negative effects in prices are not significant). This alternative identification scheme describes better a foreign monetary policy shock as judged by these more reasonable impulse responses.

[15] We explored several alternative specifications to confirm these results. The first exercise consists of changing the order of variables (we assume the interest rate to be the most exogenous variable in the foreign block) and the results are qualitatively very similar. Moreover, little changes occur if we permute the order of price index and activity in both the domestic and foreign block. In a third alternative and more invasive exercise, we took out the index of real foreign activity in the foreign block. The results are qualitatively similar even if they improve in the sense that domestic real exchange rate do appreciate less than the baseline case, and local inflation goes down for about eight months. This leads us to conclude that nominal effects turn out to be more reasonable; however, real variables keep increasing as in the baseline case. These results seem to confirm that the foreign monetary policy shock is not identified properly. Results are available on request.

[16] Recall Cholesky restricts the parameter space. To make clearer the contrast in the methodologies applied, we do not combine sign and zero restrictions with other restrictions such as long-term restrictions in (A') to (G') to accelerate convergence.

The agnostic identification scheme offers several interesting conclusions. First, we can solve several of the puzzle that were reported in the recursive VAR model. The agnostic scheme offers a more elegant way to circumvent the puzzle by achieving identification using economic arguments instead of an arbitrary order of the equations of the model. Secondly, the model provides an informative benchmark to judge micro-funded models. This is especially true for the domestic variables[17]. Thirdly, the model reports interesting policy implications regarding the monetary policy maker behaviour. The results clearly show that the local monetary authority is able to smooth out completely the inflationary effects of the shock even though the local economy experiences a significant depreciation during the first quarters. On the contrary the activity sinks sharply during the first quarters. These results reveal the preferences of the Central Bank regarding price and activity stabilization policies; the central bank acts accordingly to its main long run inflationary objective.

We have successfully identified a challenging benchmark for micro-founded models. Next, we compare these impulse responses with the ones obtained from a DSGE model estimation and calibrated for the Chilean economy. Figure 2 illustrates the responses of the DSGE model to a foreign interest rate shock.

In general, the results are qualitatively similar to those reported in the sign and zero restriction approach. The tightening of foreign monetary conditions will lead to capital outflows away from Chile. This will endogenously influence the country risk premium (the debt burden increases if the country is net borrower). Because of this, there will be a depreciation of the local currency both in nominal and in real terms[18]. To fight against inflationary pressures, the Central Bank raises local interest rates. The latter causes a large fall in activity, and, particularly in investment that decreases slightly more than 1% below its steady state value.

The real exchange rate rises persistently and, during the first periods, roughly depreciates eight percent. In consequence, marginal costs increase, causing inflationary effects (more than 0.1% on impact). As nominal prices are rigid, the inflationary peak is reached at

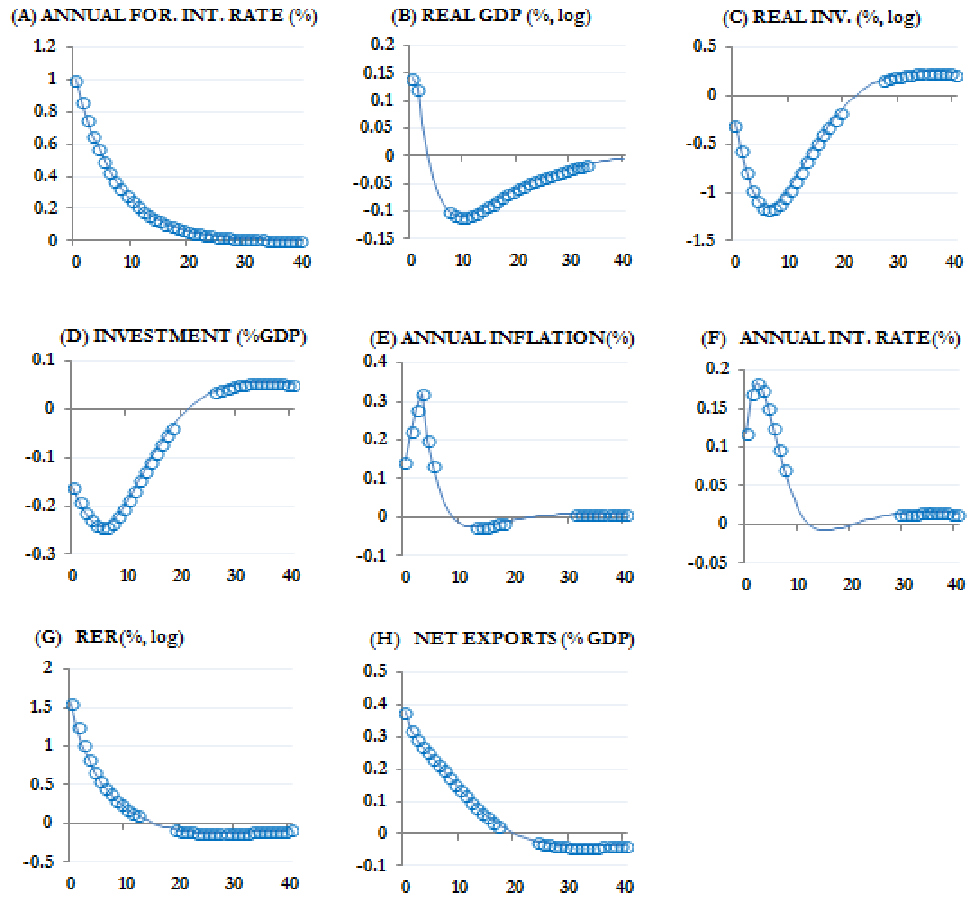
[17]In the foreign block the shock have a permanent effect on foreign variables which could be improved with long run restrictions as in Blanchard and Quah (1989).

[18]Notice that we take a conservative stance regarding the implications of the financial tightening in the U.S.. We can expect additional financial distress triggered by larger volatility in emerging economies such as: (i) an increase of default probabilities of these countries yielding to a boost of country risk premiums; (ii) the appreciation of the U.S. dollar worldwide can lead to unfavorable dynamics in commodity prices and in terms of trade of emerging economies. These further effects can be captured by setting a SVAR for these foreign variables instead of an AR(1) model for each variable. We avoid implementing that SVAR due to strange implications arising from the Cholesky identification discussed above.

the end of the first year. Also, the results suggest that the immediate pass-through is 0.12 and increases towards the end of the first year. Moreover, consumption expenses also fall due to the increase in the real interest rates (not shown in the figure). Consequently, the model predicts a persistent contraction in GDP. Notice that the large persistence of the foreign monetary policy shock drives these important fluctuations. Finally, the persistence of the shock contributes to a large improvement of the current account.

Figure 2

Impulse responses with a DSGE model for Chile to a foreign monetary policy shock



Notes: Shock is of size 100 basis points

Beyond the quantitative differences, we find that the impulse responses of the SVAR with sign and zero restrictions are in line qualitatively with the results of the DSGE model. The main drawback of the DSGE model is that the convergence toward the steady state in the domestic variables is reached only in the long run mainly because many micro-founded restrictions in the transmission of the shock are added to the model such as delay in domestic consumption because of the assumption of consumption habits. Ironically, these mechanisms are added to fit better the persistence observed in the data. Moreover, the peak of the shock over activity occurs during the second and third year after the shock. These results are difficult to argue and the agnostic SVAR model clearly indicates that the shock is much less persistent[19]; the results of the agnostic SVAR model are quite reasonable for the domestic block but seem to exaggerate the foreign GDP downward response. Finally, it is interesting to analyze the different policy implications from both approaches. As we mentioned before, according to the agnostic VAR model, the Central Bank is able to smooth out the inflationary effect of the shock however, this is not the case according to the DSGE model. The differences between models are quite significant in this dimension.

Our result suggest that there is a gap in the interpretation of the persistence of the foreign monetary policy shock in these models. Further research is needed to develop a better propagation mechanism in the DSGE model to solve or improve the short and long run propagation mechanism of the shock. We leave the issue to further work. However, we favor the view that significant gains could be made by improving the time series properties of the foreign shocks in these type of models; the DSGE model combines an AR(1) process to describe the foreign interest rate, which is, admittedly, extremely simple. In brief, this implication provides an opportunity to investigate the causes of these differences, which is left for future work.

5 Conclusions

This paper investigates the following question: What are the effects of foreign monetary policy on the Chilean output in terms of: depth, length and duration; as well as it effects on the rest of the variables of the economy that help to amplify the shock? From a policy point of view, our question aims to an interesting point that many Central Banks will have to face during the next months, which is the period of monetary normalization that has been signaled by the FED. We tackle the question by challenging the conventional empirical approach that is used to judge micro-funded models by incorporating a novel approach that extends the works of Uhlig (2005) and Arias et al. (2014) by incorporating a block exogeneity assumption. The main contribution of the paper was to reassess the effects of foreign monetary policy on output and the economy overall.

First, we notice that identification of foreign monetary shock is not straightforward in recursive VAR models. These results are in line with Bernanke et al. (2005), and Mojon (2008) and Castelnuovo (2015) which conclude that a Cholesky identification scheme in

[19]One implication of the SVAR results is that the prior of the persistence in the AR(1) process of the foreign interest rate shock in the DSGE model could be recalibrated. The latter is equivalent to say that we can inform a better judgement that leads to diminish the persistence and possibly the magnitude of effects in the DSGE model.

monetary SVARs is not a robust approach to identify monetary policy shocks; structural breaks and omitted state variables could be important factors to understand this results. The recursive VAR model fails to provide an informative benchmark to judge structural micro-funded models.

On the contrary, the agnostic VAR model offers a challenging benchmark to micro-founded model. Overall, the impulse responses show results in line with macroeconomic theory. The identification seems robust to several puzzle that are found in recursive VAR models. When we compare the impulse response function from this model to the one obtained from a DSGE model, we notice several interesting points. The main drawback of the DSGE model is that convergence to the steady state is reached only in the long run mainly because many micro-founded restrictions in the transmission of the shock are added to the model. Moreover, the peak of the shock over activity occurs during the second and third year after the shock. These results are difficult to argue and the agnostic SVAR model clearly indicates that the shock is much less persistent. Our results suggest that there is a gap in the interpretation of the persistence of the foreign monetary policy shock in these models. Further research is needed to develop a better propagation mechanism in the DSGE model to solve or improve the short and long run propagation mechanism of the shock.

Finally, from a policy point of view we find an interesting result. According to the agnostic VAR model the Central Bank is able to completely smooth out the effect of the shock on the price level; that is not the case according to the DSGE model on which there is a significant hike in the price level during the first quarters after the shock.

Data appendix:

Table 1

Data used for the estimation of the SVAR models*

Time-series used (short reference)	Time-series (long reference)	Our transformation	Source
Log World real GDP	World real GDP index, US index of industrial production (both SA)	Chow-Lin procedure using monthly world production index for the World real GDP index	CB of Chile, FRED
Log foreign price index	Chilean external price index (IPE) and US consumer price index (both SA)		CB of Chile, FRED
Foreign interest rate	Fed Funds rate		FRED
Log real copper price	Real copper price	Deflated with IPE, (2005=100)	CB of Chile
Log real oil price	Real WTI oil price	Deflated with IPE, (2005=100)	CB of Chile
Log domestic real GDP	Monthly economic activity indicator (IMACEC) (SA)		CB of Chile
Log domestic price index	Consumer price index (IPC, 2013=100) (SA)		CB of Chile
Log real exchange rate (increase means depreciation)	Multilateral real exchange rate		CB of Chile
Domestic interest rate	Monetary policy rate		CB of Chile
Log real investment in machinery and equipment	Real gross fixed capital formation in machinery and equipment (SA)	Chow Lin procedure using monthly imports of capital goods	CB of Chile
Log real investment in construction	Real gross fixed capital formation in construction (SA)	Chow Lin procedure using construction monthly activity indicator	CB of Chile

* All variables in logs are multiplied by 100; interest rates are in percentage points.

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