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Reserve requirements as a macroprudential instrument – Empirical evidence from Brazil

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ABSTRACT

Emerging market central banks are often reluctant to raise interest rates when facing credit booms driven by capital inflows, and they instead use reserve requirements as an additional instrument. We compare the macroeconomic effects of interest rate and reserve requirement shocks by estimating a structural vector autoregressive model for Brazil. For both instruments, discretionary tightening results in a credit decline. Contrary to an interest rate shock, however, a positive reserve requirement shock leads to an exchange rate depreciation, a current account improvement, and an increase in prices. The different effects highlight the role of reserve requirement policy as a complement to rather than a substitute for interest rate policy. The results support the bank lending channel as the main transmission mechanism for reserve requirement policy.

1. Introduction

Emerging countries are often reluctant to increase interest rates in response to credit booms financed by capital inflows. Credit booms are a sign of risks in the financial system and frequently followed by financial crises and credit busts (Gourinchas and Obstfeld, 2012; Schularick and Taylor, 2012). Raising interest rates to stop the boom is, however, a risky strategy, as higher interest rates may attract even more capital inflows and appreciate the currency, thereby creating further vulnerabilities.[2] Authorities therefore look for alternative ways to tighten credit conditions, using macroprudential instruments (Claessens et al., 2013). In this context, reserve requirements have received particular attention in emerging countries (Cordella et al., 2014; Reinhart and Reinhart, 1999; Montoro and Moreno, 2011; Terrier et al., 2011). The Turkish central bank, for instance, considers the interest rate to be the main instrument for price stability and reserve requirements to be the main macroprudential instrument for achieving financial stability (Başçi, 2010). Other countries that adjust reserve requirements with a similar objective are, among others, Brazil, Croatia, Colombia, Peru,

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[2] Calvo and Reinhart (2002), Calvo et al. (1994) and others discuss the reasons why emerging countries may display a "fear of floating" (and therefore limit fluctuations of their currency) and are wary of large capital inflows.

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and Russia (Lim et al., 2011). In advanced economies, the stronger focus on the financial stability aspects of central bank policy since the global financial crisis has also led to a renewed interest in reserve requirement and reserve remuneration policy (Kasyhap and Stein, 2012, Ireland, 2012, Reinhart and Rogoff, 2013). Against this backdrop, the present study provides empirical evidence on the macroeconomic effects of reserve requirement changes.

A possible argument in favor of using reserve requirement policy as a macroprudential instrument is as follows: when reserves are remunerated below market rates, an increase in reserve requirements acts as an implicit tax on the banking sector. The tax increases intermediation costs and widens the spread between deposit and lending rates. The higher intermediation costs make it less attractive for investors to deposit their money in domestic banks and capital flows out of the country. At the same time, it becomes more expensive for the domestic sector to borrow from banks, and credit falls as a result. The argument implies that reserve requirement increases may achieve a contraction in domestic credit, without attracting capital inflows and appreciating the currency. However, for reserve requirement changes to have macroeconomic effects, banks need to have a special role in the economy that cannot be easily circumvented. In that sense, an empirical evaluation of the effects of reserve requirement changes also provides insight into the macroeconomic importance of the bank lending channel (Bernanke and Blinder, 1989; Kashyap and Stein, 2000).

Reserve requirement policy is also under discussion as an alternative monetary instrument to stabilize inflation. Market observers perceive that some countries, for example China, use reserve requirement policy as a substitute for interest rate policy in their efforts to contain inflationary pressures.[3] An increase in reserve requirements reduces the money multiplier. If the monetary authority keeps the monetary base stable, a reserve requirement increase reduces broad money and raises the interest rate level, which should lower inflation. Today, most countries have an interest rate or exchange rate target to which the monetary base adjusts endogenously. Under such a framework the effects of reserve requirement increases on inflation are therefore less clear and depend on the financial frictions in place and the economic structure (Glocker and Towbin, 2012; Gray, 2011; Vargas et al., 2010). So far there is little empirical evidence on how reserve requirement changes affect inflation.

The main contribution of the present paper is to provide empirical evidence on the effects of reserve requirement changes on key macroeconomic variables. In particular, we are interested in the effect of reserve requirement shocks on (a) domestic credit conditions, (b) the external balance and the exchange rate, and (c) domestic inflation and overall macroeconomic activity. To that purpose, we estimate a structural vector autoregressive (VAR) model for the Brazilian economy and identify interest rate and reserve requirement policy shocks. Brazil is well-suited for such a study: first, it has followed a homogeneous monetary policy framework since 1999 (when it adopted inflation targeting), using the short term interest rate as its main instrument. A homogeneous policy framework is important, as there are important interactions between interest rate policy and reserve requirement policy. As detailed below, we expect reserve requirements to have very different effects when the central bank targets money growth instead of interest rates. The effects of reserve requirement changes can therefore only be analyzed within the context of the overall monetary policy framework. Second, Brazil has a long history in the application of reserve requirements, with sufficient time variation. Finally, the Brazilian authorities provide an excellent supply of key macroeconomic time series data at a monthly frequency. Many other countries that use reserve requirements as a policy instrument lack at least one of these characteristics.[4]

Since both interest rate and reserve requirement policy changes affect the demand for nominal bank reserves, we need to account for simultaneity and aim to disentangle the two policy shocks with a novel identification scheme, based on a combination of sign and zero restrictions.[5] Different movements in nominal bank reserves in response to either shock are crucial to our identification approach. To characterize the overall stance of the reserve requirement policy, other variables in addition to the aggregate reserve ratio may have to be considered, such as the rate of reserve remuneration and the type of funding to which the requirement applies. We therefore also provide a brief overview of the reserve requirement system of Brazil and discuss alternative measures of the reserve requirement policy stance in some detail.

To preview our results, we find that both interest rate and reserve requirement increases lead to a contraction in domestic credit and economic activity, but have very different effects on other macroeconomic variables. A discretionary increase in reserve requirements leads to an exchange rate depreciation, an improvement in the current account, and an increase in the price level. A discretionary interest hike leads to lower prices, an exchange rate appreciation, and a deterioration of the current account. Our results indicate that, in Brazil, reserve requirement increases are a way to reduce credit growth without appreciating the exchange rate, but an inadequate policy step for reducing inflation. The findings are robust to alternative reserve requirement measures and across subsamples.

[3] For example, Financial Times (2011) writes that "China ordered banks to hold more of their deposits on reserve [...] in a move [...] aimed at tackling inflation".

[4] A lack of sufficient data and time variation can, in principle, be overcome by pooling multiple countries. This is, however, problematic, if the reserve requirements are not directly comparable or the countries are too heterogeneous. Colombia and Peru, for example, have made use of marginal reserve requirements that are not directly comparable to the average reserve requirements used in Brazil. Tovar et al. (2012) pool several countries and account for heterogeneities by using dummies for reserve requirement changes, which, however, leads to a loss of information regarding the magnitude of the changes.

[5] See IMF (2012) for a general discussion of the interaction between macroprudential and monetary policy.

The study also sheds light on the importance of the bank lending channel. It is challenging to evaluate the importance of the bank lending channel empirically with macroeconomic time series data, because it is difficult to distinguish between credit demand and credit supply effects when considering the responses to policy rate movements (Kashyap and Stein, 2000).[6] With the interest rate as the main policy instrument, reserve requirements mainly act as a tax on deposits and do not directly affect non-bank lending. For reserve requirement changes to have macroeconomic effects, two conditions need to be fulfilled. First, banks cannot easily find alternative sources of funding that are not subject to reserve requirements. Second, the private sector cannot easily substitute bank credit with other sources of financing. Our finding of a fall in domestic credit implies that banks cannot substitute deposits by other means of financing and have to reduce their lending. Moreover, the effect on macroeconomic activity and inflation shows that the non-financial sector cannot perfectly substitute bank credit as a form of financing. Our results therefore indicate that the bank lending channel has some macroeconomic importance in Brazil.

Regarding previous work, the empirical literature has mainly focused on partial equilibrium aspects of reserve requirement policy and has not investigated the joint dynamics of macroeconomic variables. Gelos (2009) looks at a sample of Latin American countries and finds that higher reserve requirements increase banking spreads. As far as Brazil is concerned, studies have estimated the effect of reserve requirement changes on banks' stock returns (Carvalho and Azevedo, 2008) and banking spreads (Takeda et al., 2005; Cardoso, 2004). Related studies for other emerging countries include Binici and Köksal (2013), Cerda and Larrain (2005), Saade and Pérez (2009), Grosz et al. (2008), and Vargas et al. (2010). All studies focus on the credit market and do not look at the effects on external variables, aggregate macroeconomic activity, or inflation.

Among the empirical papers that analyze reserve requirements from a macroeconomic perspective, Federico et al. (2014) provide a descriptive analysis of cyclical properties of reserve requirement policy. Loungani and Rush (1995) investigate the effects of reserve requirement changes on investment and output for the United States in a single equation framework, but do not account for the contemporaneous interactions between interest rate and reserve requirement policy, and do not analyze the effects on other variables. In independent contemporaneous work, Tovar et al. (2012) and Cordella et al. (2014) have studied reserve requirements in a Panel VAR. The studies differ in their identification strategies, which we discuss in more detail in Section 4.2. Despite using different identification strategies, these studies obtain qualitatively similar results regarding the effect of reserve requirement shocks on economic activity and credit market variables. This supports the robustness of these findings. In contrast to the present paper, the studies do not consider the effect on external variables and the price level. While the effects of reserve requirement policy on credit and economic activity may suggest that interest rate and reserve requirement policy are substitutes, the markedly different effects on capital flows, exchange rates and prices emphasize the complementary role of the two instruments.

In the remainder, Section 2 reviews the theory regarding the effects of reserve requirement changes on macroeconomic activity and the interaction with interest rate policy. Section 3 discusses the policy framework of the Brazilian central bank, with special attention to the design of the reserve requirement system. Section 4 presents the econometric specification and details the identification strategy. The main results are discussed in Section 5. Extensions and diagnostic checks are reviewed in Section 6. Section 7 summarizes and concludes.

2. Review of the transmission channel of reserve requirements

In the present section we provide a short discussion of the transmission channel of reserve requirement policy. We first review how the general monetary framework and financial imperfections, in particular the bank lending channel, affect the transmission on domestic and external variables. We then discuss theoretical predictions regarding the effects of reserve requirement changes on credit conditions, external variables, and domestic macroeconomic activity. The discussion remains informal and draws on previous theoretical work, in particular on Glocker and Towbin (2012), who analyze the effects of reserve requirements in a DSGE model for a small open economy.[7]

2.1. The monetary channel

Reserve requirements are the minimum percentage of deposits that banks need to keep as reserves. This part of deposits cannot be used to provide private credit or to buy securities. Higher reserve requirements reduce the money multiplier: For a given monetary base, broad money will decrease with higher reserve requirements.[8]

If the central bank targets quantities and keeps the monetary base constant, the effects of an increase in reserve requirements are analogous to a standard monetary contraction. Higher reserve requirements increase the level of interest rates: in order to fulfill the reserve requirements without reducing extended credit, banks need to attract more deposits, which drives

[6] In response to a monetary contraction, bank credit can fall because of lower credit demand that derives from the generally higher interest rate level and lower economic activity, but is unrelated to the funding costs structure of commercial banks. Many studies (see Takeda et al., 2005 for Brazil) have therefore focused on the cross-sectional dimension, exploiting heterogeneities in the funding composition of banks. Cross-sectional microstudies make it possible to assess whether a bank lending channel is present, but it is not straightforward to draw conclusions about its macroeconomic importance.

[7] For other theoretical work on the effects of reserve requirements on macroeconomic variables see, for instance, Baltensperger (1982), Cifuentes (2001), Edwards and Vegh (1997), Horrigan (1988), le Fort (1998), Reinhart and Reinhart (1999), Siegel (1981), Souza Sobrinho (2010).

[8] If we abstract from cash holdings, the following relationship holds between the monetary base R, broad money D (deposits) and the reserve requirements ratio μ : $\mu \cdot D \leqslant R$. If the inequality constraint binds, the money multiplier is $1/\mu$.

up deposit rates. The increased marginal funding costs will in turn drive up lending rates and raise the general level of interest rates.

If the central bank sets the price of money and targets a specific interest rate, we expect very different effects of an increase in reserve requirements. In order to counter a potential deviation of the policy rate from the target, the central bank needs to increase the monetary base and thereby accommodates the contractionary effects of the reserve requirements hike. In relatively simple models, reserve requirement changes are neutral if the central bank targets interest rates (Horrigan, 1988). However, we expect real effects if reserves are not remunerated or at least remunerated below the market rate (Glocker and Towbin, 2012; Reinhart and Reinhart, 1999). In this case, higher reserve requirements act as a tax on bank deposits. As financial intermediation becomes more costly, spreads between lending and deposit rates should rise. If the central bank stabilizes the interbank rate, we expect lending rates to increase and deposit rates to fall, as the stable interbank rate typically lies between deposit and lending rates. Under an interest rate targeting framework, reserve requirement changes are therefore unlikely to affect the general level of interest rates, but may affect interest rate spreads.

Fig. 1 provides evidence of accommodative interest rate policy in Brazil. The lower middle panel displays the path of total nominal bank reserves. Movements in the required reserve ratios, displayed in the upper right panel, are positively correlated with movements in nominal reserves.[9] For example, the tightenings of reserve requirements in 2002/2003 and 2009/2010 are followed by increases in compulsory reserves, consistent with an endogenous expansion of central bank liquidity.

2.2. The bank lending channel

As reserve requirements typically only apply to commercial banks, the effects of reserve requirement changes on the general economy crucially depend on the importance of bank lending and, in particular, on the bank lending channel of monetary policy (Kashyap and Stein, 2000; Bernanke and Blinder, 1989).

In order for reserve requirement changes to have real effects, two conditions need to be fulfilled: The first is that deposits cannot be easily substituted as a funding source. Otherwise, banks could compensate the higher deposit funding costs by other financing means, such as wholesale funding. Robitaille (2011) analyzes the effects of reserve requirement changes on banks' liability structure in Brazil and finds evidence that banks react to higher reserve requirements by moving away from deposit funding to issuing more certificates of deposits. In general, we would not expect any macroeconomic effects if alternative funding sources are perfect substitutes for deposit funding.

The second condition is that firms cannot easily substitute bank credit with other financing sources. If bank lending could be easily substituted, a reserve requirement increase would lead to a decrease in bank credit that would be compensated by an increase in other types of liabilities such as, for example, capital market funding. Claessens and Sakho (2013), Motoki and Funchal (2009) and Zonenschain (1997) provide an overview of the importance of bank funding for firms in Brazil and find bank funding to be important. Cabezon (2014) documents that firms finance an important fraction of their working capital with bank credit.

2.3. Theoretical predictions

In the following, we review the theory regarding the effects of reserve requirement changes on credit conditions, external variables, and the domestic macroeconomy under an interest rate policy framework.

We start with domestic credit conditions. If deposits that are subject to reserve requirements are not perfectly substitutable with other sources of funding, higher reserve requirements increase marginal costs for banks. We therefore expect an increase in the lending deposit rate spread and a fall in aggregate credit.

The third panel of Fig. 1 displays two aggregate measures for reserve requirement ratios as well as the interest rate spread between the lending and the deposit rate.[10] The spread and the aggregate reserve requirement measures co-move closely. Between 1999:07 and 2000:04 the decline in reserve requirements is associated with a fall in the spread. The rise in reserve requirements between 2001:10 and 2003:02 coincides with an increase in the spread. A similar pattern emerges for the recent loosening of requirements between 2008 and 2009. The pattern is consistent with the hypothesis that reserve requirements do have an effect on banking spreads, but it is difficult to draw any conclusions about the macroeconomic consequences.

As far as external variables are concerned, we expect an increase in reserve requirements to trigger an exchange rate depreciation and capital outflows (see, for instance, Reinhart and Reinhart, 1999; Montoro and Moreno, 2011). If the key assumption that a lot of funding has to be intermediated by banks that are subject to reserve requirements is correct, the fall in deposit rates decreases the attractiveness of investing in a country from the point of view of domestic and foreign investors. Capital flows out and the exchange rate depreciates. Again this effect will depend importantly on the bank lending channel: if banks can be easily circumvented, higher lending rates could even attract capital from abroad.

Regarding the effect on the domestic macroeconomy, the overall effects of reserve requirements on economic activity and inflation are ambiguous from a theoretical perspective (Glocker and Towbin, 2012). If we focus on the first-round, partial

[9] Section 4 discusses the data sources in more detail.

[10] Banking spreads in Brazil are exceptionally high by international standards (Gelos, 2009). There is a debate on the extent to which the high level of reserve requirements can explain the high spread. Cardoso (2004), de Souza Rodrigues and Takeda (2004), Souza Sobrinho (2010) and Carvalho and Azevedo (2008) find a role for reserve requirements, whereas Koyama and Nakane (2002a,b) do not find a significant effect.

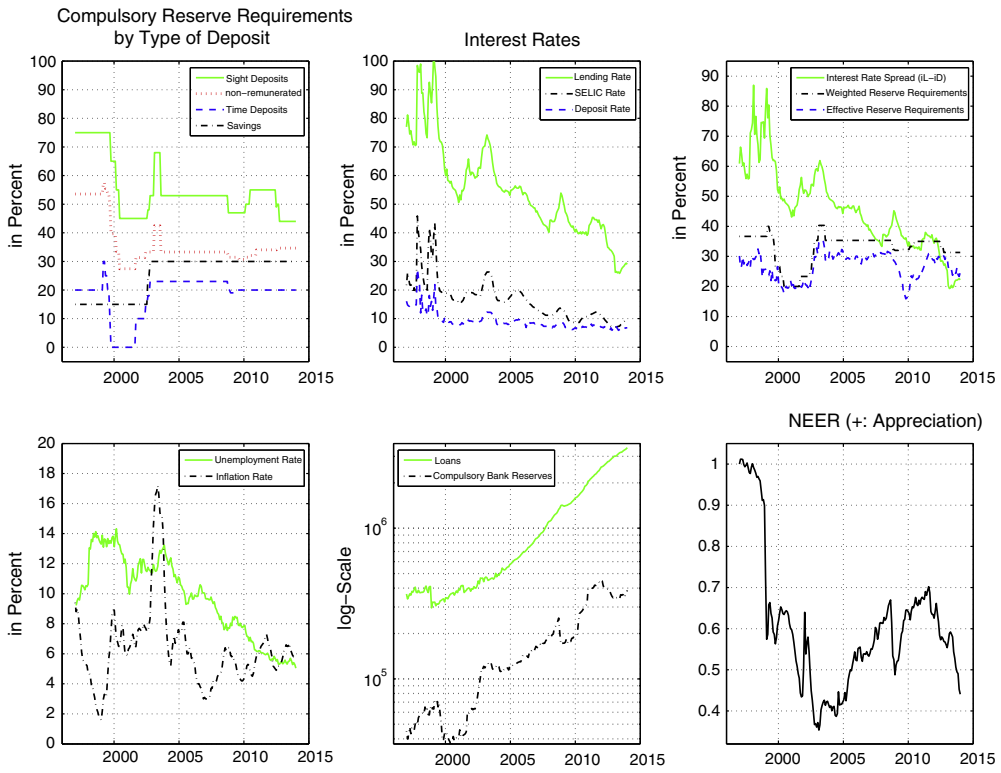

Fig. 1. Macroeconomic variables in Brazil, 1997–2014. **Remarks:** The figure reports statutory reserve requirements next to key macroeconomic variables. The first panel reports the statutory reserve requirements for sight (*depósitos a vista*), time (*depósitos a prazo*) and saving deposits (*depósitos de poupança*). For each of the three categories, the numbers include the additional requirements (*exigibilidade adicional*). Next to the statutory requirements, panel 1 and panel 3 show our three measures for the reserve requirement policy: (1) the *Weighted Non-Remunerated Reserve Requirements* measure (shown by means of the red dotted line in the first panel), (2) the *Effective Reserve Requirements* measure (represented by the blue dashed line in the third panel) and (3) the *Weighted Reserve Requirements* measure (represented by the black dashed dotted line in the third panel). The SELIC (*Sistema Especial de Liquidação de Custódia*) rate is an overnight interbank rate and the key policy instrument of the Brazilian monetary authority. The interest rate spread shown by means of the green line in the third panel is the difference between the lending and the deposit interest rates as shown in the second panel. The variable for reserves is the sum of private banks' reserves on savings, time and sight deposits. Further information concerning the data and the sources can be found in Appendix A. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

equilibrium, effects of a reserve requirements hike, we expect the demand of borrowers and lenders to move in opposite directions. The fall in deposit rates should discourage savings and increase savers' spending. The raise in lending rates should discourage spending by borrowers. The first round effect on economic activity is ambiguous will depend on the relative strength of the two responses. In addition, second round, general equilibrium, effects have to be considered. To determine the overall effect on inflation, we need to consider three channels. First, there is an effect through aggregate demand. As just pointed out, the effect on aggregate demand is ambiguous. Second, reserve requirements act as an implicit tax on deposits. The tax increase may increase inflation through a cost channel. Third, there is the exchange rate channel. The predicted exchange rate depreciation tends to push prices up through higher import prices. The total effect on inflation is ambiguous and will depend on the relative strength of the three channels.

3. Central bank policy in Brazil

Section 3.1 provides a brief overview of the monetary policy in Brazil and discusses important regime changes. Section 3.2 discusses reserve requirement policy.

3.1. Monetary policy in Brazil

Monetary policy in Brazil has experienced fundamental changes over the last thirty years (BIS, 1999; Bogdanski et al., 2002; Lima et al., 2007). The high inflation episodes of the late 1980s led to a series of inflation stabilization attempts, of which most, however, were not successful. The Real Plan (*Plano Real*) in 1994 brought about a sustained decline in inflation. The plan involved a de-indexation of the economy to reduce inflation inertia, the introduction of quarterly targets for monetary aggregates to stabilize inflation expectations, and the adoption of a floating exchange rate. After the Mexican crisis in

1995, the floating exchange rate regime was abandoned and replaced with a crawling peg. While Brazil weathered the Asian crisis well, Russia's 1998 default had severe negative spillover effects for Brazil. Investors that previously displayed confidence in Brazil's economy lost faith in the government's ability to maintain the crawling peg. The crawling peg was abandoned in January 1999 and in July a formal inflation targeting framework was adopted.

The inflation target is set by the National Monetary Council every June for the next two years. The Monetary Policy Committee (Copom) decides on the central bank's policy rate, which is the overnight interbank rate or SELIC (*Sistema Especial de Liquidação de Custódia*) rate. The SELIC rate is steered by open market operations. As can be seen in Fig. 1, yearly inflation has been below 10% most of the time. An exception is the period between 2002 and 2003, during which a high level of uncertainty prevailed as a result of the election of Luiz Ignácio Lula da Silva (2002–2010) as the successor of Brazilian President Henrique Cardoso (1995–2002), a domestic energy crisis, and Argentina's default. In response to the high level of uncertainty, capital fled out of the country and the nominal exchange rate depreciated sharply. This in turn created severe inflationary pressures. Brazil entered an IMF program. President Lula da Silva pledged to adhere to the inflation targeting regime and inflation subsequently stabilized. The central bank initiated several policy tightenings through interest rate increases, in particular in 2004, 2008 and during the aftermath of the financial crisis in 2011 (see Fig. 1).

3.2. Reserve requirement policy in Brazil

Under the present inflation targeting framework the reserve requirement policy has been communicated as a tool to achieve financial stability and control credit fluctuations. In its inflation report, the central bank discusses the use of reserve requirements as a macroprudential tool to "attenuate fluctuations in the credit volume over the economic cycle" (Banco Central do Brasil, 2011, p. 99),[11] in particular in the context of capital inflows. Furthermore, during the recent financial crisis reserve requirements were lowered to increase liquidity in the banking system (Jornal do Commércio do Rio de Janeiro, 2009; Montoro and Moreno, 2011) and, through the use of heterogeneous reserve requirements, to transfer liquidity from big banks to small banks (Robitaille, 2011; Terrier et al., 2011).

Historically, reserve requirements have served a broad set of purposes and have a long history.[12] Cardoso (2004) argues that until 1993 reserve requirements mainly served as an instrument for taxing bank profits that accrued with high inflation rates. Reserve requirements have also been used for distributional purposes, with required ratios being higher for banks located in richer regions of the country (Carvalho and Azevedo, 2008). Under the Real Plan in the mid-nineties, reserve requirements had an explicit monetary policy purpose. Requirements were increased as part of a set of measures to control accelerating inflation and reduce liquidity (Carvalho and Azevedo, 2008; Robitaille, 2011). The high compulsory reserve holdings today are partly a legacy of this period (OECD, 2009). Given its various objectives, the characteristics of reserve requirements as a policy instrument appear closer to those of standard fiscal policy tools than those of an interest rate policy. Whereas the main aim of interest rate policy is to stabilize prices and the business cycle, reserve requirement policy and fiscal policy usually also pursue distributional or microeconomic, and potentially distortive, objectives apart from business cycle stabilization.

Reserve requirements have substantially varied over the period considered. First, reserve requirements where lowered after the introduction of the inflation targeting regime in 1999 and the associated stabilization of inflation. They were again raised in 2002, against the backdrop of the heightened uncertainty described above and a strong depreciation of the currency. Reserve requirements were loosened during the global financial crisis and again increased in its aftermath, when credit grew strongly. Finally, in the most recent period reserve requirements decreased, when financial conditions tightened.

4. Empirical model and identification

Section 4.1 discusses the model specification and data sources. In particular, we propose three different measures for reserve requirement policy. Section 4.2 presents our identification scheme. Section 4.3 describes the inference procedure.

4.1. Model specification and data

We estimate a Bayesian vector autoregressive (BVAR) model of the form:

$$\mathbf{y}_t = \mathbf{\Psi}\mathbf{x}_t + \sum_{i=1}^{p}\mathbf{A}_i\mathbf{y}_{t-i} + \mathbf{e}_t, \quad \text{with} \quad \mathbf{e}_t \sim \mathrm{N}(\mathbf{0}, \mathbf{\Sigma}) \quad \forall t = 1, \ldots, T \tag{1}$$

$\mathbf{y}_t$ is a vector of endogenous variables, $\mathbf{x}_t$ is a vector of exogenous variables, $\mathbf{e}_t$ is a reduced-form error term with covariance matrix $\mathbf{\Sigma}$, p is the lag length and $\mathbf{A}_i$ and $\mathbf{\Psi}$ are coefficient matrices.

Our sample comprises monthly data that cover the period from 1999:07 to 2014:06. We choose the implementation of the inflation targeting regime as the starting date in order to ensure a homogeneous monetary policy framework. While the period covered is relatively short, there are two full tightening and three loosening phases of reserve requirement policy. The

[11] Translation by authors.

[12] Fernandes (1992) mentions that reserve requirements were first introduced in Brazil in 1932.

pattern is therefore comparable to an interest rate policy cycle of major central banks such as the ECB, which are routinely studied over such a sample length.

4.1.1. Measures for reserve requirement policy

The current reserve requirement policy in Brazil is complex. Reserve requirement ratios vary across different types of deposits. Additional policy parameters include reserve remuneration, exemption thresholds, and deductibles. We propose three different reserve requirement policy measures and provide a brief overview of the reserve requirement system in Brazil in this context, mainly based on Robitaille (2011), Banco Central do Brasil (2010, 2011, 2012) and Terrier et al. (2011).

The first measure is a weighted average of all reserve requirements (entitled *Weighted Reserve Requirements*). Different reserve requirement ratios apply for sight deposits (*depósitos a vista*, 45% plus 0% additional requirements or *exigibilidade adicional* in June 2014), saving deposits (*depósitos de poupança*, 20% plus 10% additional requirements in June 2014) and time deposits (*depósitos a prazo*, 20% plus 11% additional requirements in June 2014).[13] Fig. 1 displays the time path of total requirements on sight, saving and time deposits. Our first measure for aggregate reserve requirement policy is the weighted average of the three series, also displayed in Fig. 1.[14]

The second measure is *Weighted Non-Remunerated Reserve Requirements*. Sight and saving deposits are not remunerated or at a rate substantially below the SELIC rate. One part of time deposit reserves has to be invested in government bonds, the other is remunerated at the SELIC rate (Robitaille, 2011). The aforementioned additional requirements on sight and saving deposits earn the SELIC rate. The second measure is a weighted average of reserve requirements on sight and savings deposits excluding the additional requirements, again displayed in Fig. 1.

The third measure is called *Effective Reserve Requirements*. Small banks are partly exempted from reserve requirement regulation. An exemption threshold exists on a variety of deposits, above which compulsory reserve requirements apply. If a bank's deposit volume is below the exemption value, the reserve requirement regulation becomes obsolete.[15] As a result, reserve requirements are progressive in bank size and effective reserve requirement ratios can be substantially below statutory ratios. The Brazilian central bank has used variations in the exemption threshold as an additional policy instrument and substantially increased its size for time deposits as a response to the global financial crisis.[16] The weighted reserve requirements measure only captures the policy changes of statutory reserve requirements. It ignores the policy changes that are specific to changes in the exemption thresholds and deductibles. In order to also include these policy changes in an overall measure for the reserve requirement policy, we calculate a measure for aggregate effective reserve requirements as total reserves over total deposits. As can be seen in Fig. 1, our effective reserve requirements measure tends to be below the weighted reserve requirement measure, but broadly follows the same cyclical pattern.

Each measure has its own advantages and disadvantages. Weighted reserve requirements characterize the aggregate stance of reserve requirements, but mix different rates of remuneration. The weighted non-remunerated reserve requirement measure focuses on a segment of reserve requirements in which the remuneration is homogeneous, but neglects changes in other reserve requirements. While we expect the macroeconomic effects of non-remunerated reserves to be stronger because of the higher implicit tax on deposits, even reserves that are remunerated at market rates can affect the distribution of lending. In addition, it deprives banks of a potential mark-up they charge on lending rates and may reduce profits. Both weighted measures neglect changes in the deductible and the exemption threshold. While the effective reserve requirement ratio captures the deductible and the exemption threshold, it is not directly controlled by the central bank, as it is also affected by changes in the relative weight of the respective deposit categories. In what follows, we use weighted total reserve requirements as our main policy variable and compare it to the other two measures.

4.1.2. Other variables

The vector of endogenous variables includes the consumer price index (CPI), the unemployment rate, the spread between deposit and lending rates, a measure for reserve requirement policy (described above), the policy (SELIC) interest rate, the log of the nominal effective exchange rate, the log of nominal total credit, the current account to GDP ratio, and the log of nominal compulsory bank reserves. The current account measures net capital inflows as the flip side of the financial account. The unemployment rate is our main measure for real economic activity. As a robustness check, we will use industrial production and the gross domestic product as alternative measures. Total bank reserves are computed as the sum of compulsory reserves due to sight, saving and time deposits, including additional requirements. In Section 6 we show that our results are robust to alternative measures of central bank liquidity.[17]

In order to control for external effects we include four global variables with two lags as exogenous variables. The federal funds rate controls for US monetary policy. The VIX index (implied stock market volatility of the S & P 500) controls for

[13] See for instance Banco Central do Brasil (2010), Banco Central do Brasil (2012) and Banco Central do Brasil (2014).

[14] The weights are 26.8% for time, 30.7% for saving and 52.3% for sight deposits, based on the average holdings between 1999 and 2014.

[15] As of December 2007, Brazil had 101 banks, of which only 41 were required to hold reserves at the central bank (Robitaille, 2011).

[16] In particular, this threshold was raised from 100 million to two billion Reais for time deposits and to one billion Reais for the additional requirements (OECD, 2009). In addition, during the crisis there were further deductibles if large banks lent to small banks, which allowed the central bank to distribute liquidity (Robitaille, 2011).

[17] For all measures, we abstract from accounting for reserves borrowed over the discount window. Since the adoption of inflation targeting, discount lending does not play an operational role in the implementation of monetary policy and the amount extended is small.

variations in global risk, which typically spikes during financial crises. Global industrial production captures fluctuations in global demand. Finally, a commodity price index is added, as fluctuations in commodity prices can be an important driver of domestic inflation. As deterministic variables the vector of exogenous variables further includes a quadratic time trend and monthly dummies to control for seasonal affects.

We choose a lag length of one[18] and estimate the parameter matrices of the BVAR in Eq. (1) based on Bayesian techniques as outlined in Uhlig (1994) using an uninformative Normal-Wishart prior density for the coefficient matrices and the covariance matrix. Following a large body of literature on VARs that studies monetary policy (see, for example, Christiano et al., 1999), we include all variables in levels.

4.2. Identification

We can think of the one step ahead prediction error $\mathbf{e}_t$ as a linear combination of orthonormal structural shocks $\mathbf{e}_t = \mathbf{B} \cdot \mathbf{v}_t$, with $E(\mathbf{v}_t'\mathbf{v}_t) = \mathbf{I}$. The matrix $\mathbf{B}$ describes the contemporaneous response of the endogenous variables to structural shocks. With no additional information or assumptions $\mathbf{B}$ is not identified. The only restriction on $\mathbf{B}$ that comes from the data is that the matrix multiplied by its transpose must equal the covariance matrix of the prediction errors $\mathbf{\Sigma} = E(\mathbf{e}_t\mathbf{e}_t') = E(\mathbf{B}\mathbf{v}_t\mathbf{v}_t'\mathbf{B}') = \mathbf{B}\mathbf{B}'$. This leaves many degrees of freedom in specifying $\mathbf{B}$ and further restrictions are necessary to achieve identification.

The challenge for structural VAR models is to find credible restrictions on $\mathbf{B}$. We pursue a partial identification approach to identify a reserve requirement shock and an interest rate policy shock. The main interest of the present study is how macroeconomic variables respond to unexpected changes in reserve requirements. In order to control for the effects of interest rate policy, we also identify an interest rate shock that is orthogonal to the reserve requirement shock. We identify the two shocks with a combination of timing and sign restrictions. The identification restrictions are summarized in Table 1.

Regarding the timing (or zero) restrictions, we assume that there is a block of "slow moving variables" that does not respond contemporaneously to changes in central bank policy (changes in interest rates and reserve requirements). The block of slow moving variables includes the unemployment rate, the price level, and the current account. The assumption of a block of slow moving variables is standard in the VAR literature that studies monetary policy and relies on some rigidities in the adjustment of prices and quantities that impede an immediate response of these variables to changes in central bank policy. As we use monthly data the imposed delay is relatively short.[19] The block of fast-moving variables that are allowed to respond to central bank policy shocks within a month, is a set of financial variables and comprises the nominal exchange rate, total credit, bank reserves, and the spread between lending and deposit rates.

In order to distinguish the two central bank policy shocks from each other and from shocks that originate from fast-moving variables, we complement the zero restrictions with a set of sign restrictions. Sign restrictions have been proposed in Canova and de Nicoló (2003) and Uhlig (2005) and narrow down the set of acceptable $\mathbf{B}$ matrices by restricting the sign of the impulse responses of a set of variables to a structural shock. The sign restrictions should be based on well-established economic theory, while the responses of variables for which there is no consensus on the sign of their responses are left unrestricted. We impose the sign restrictions for three months.

A positive reserve requirement shock leads to an increase in bank reserves and reserve requirements. The assumption implies that monetary policy accommodates the consequences from a reserve requirement increase on interest rates. If the Brazilian central bank sets the interest rate, it needs to expand nominal reserves in order to avoid an increase in the policy rate. However, our restriction on nominal reserves does not impose complete accommodation as pure interest rate targeting would imply, but only that the central bank aims to stabilize the interest rate to some degree.

A positive interest rate shock is associated with a fall in bank reserves and an increase in prices. The restriction on bank reserves follows from the fact that, in order to implement an interest rate increase, the central bank needs to withdraw liquidity, which is reflected in lower reserves (see Bernanke and Mihov (1997) and Uhlig (2005) for a discussion for Germany and the United States). The identification restriction follows directly from the assumption that the central bank steers interest rates by adjusting central bank liquidity, and they hold for a broad class of models.[20] Note that it is crucial for our identification scheme that the interest rate target is implemented through open market operations. For example, our identifying assumptions would not be valid for a developing country with thin financial markets, where authorities steer the policy rate by adjusting reserve requirements instead of adjusting base money. Furthermore, we impose that the price level responds negatively in the second period. This sign restriction is in line with Canova and de Nicoló (2003) and Uhlig (2005).[21]

[18] The lag length is chosen by the Schwarz Information Criterion. A Ljung-Box test cannot reject the null-hypothesis of no autocorrelation in the residuals.

[19] The current account is added to the block of slow-moving variables, as the adjustment of import and export quantities is assumed to be slow. An alternative ordering where the current account is in the block of fast moving variables does not substantially affect our results (available on request).

[20] As an example, we provide a short discussion that motivates the sign restrictions with the results from a dynamic stochastic general equilibrium (DSGE) model in an appendix available on request.

[21] Restricting the price level to respond negatively excludes the presence of "price puzzle" due to a working capital channel (Barth and Ramey, 2002). Cabezon (2014) finds the role of the working capital channel to be small in Brazil due to the openness of the Brazilian economy and a strong exchange rate channel that works through aggregated demand. Among the papers that study the effects of monetary policy in Brazil, Mallick and Sousa (2012) also restrict the response of prices in an SVAR with sign restrictions. With alternative SVAR approaches, Céspedes et al. (2008) find a negative response of prices. Catão and Pagan (2010) find a negative response of inflation, that is, however, not statistically significant.

Table 1
Identification restrictions.

	RR Shock	Interest rate shock
U	0	0
CPI	0	$\leqslant 0$
CA	0	0
Spread	0	0
RR	$\geqslant 0$	•
SELIC	•	$\geqslant 0$
Loans	•	•
NEER	•	•
Reserves	$\geqslant 0$	$\leqslant 0$

Note: Zero restrictions apply to the first month, while sign restrictions apply to the first quarter. The response of CPI to an interest rate shock in the first month is restricted to zero. • means that the variable is unrestricted. The variables are: nominal effective exchange rate (NEER), total aggregate credit (Loans), reserves of commercial banks (Reserves), the SELIC rate, reserve requirements (RR), the interest rate spread between lending and deposit rates (Spread), the current account over GDP (CA), the price level as measured by the CPI and the unemployment rate (U).

The identification scheme described above allows for an immediate response of the central bank to movements in fast-moving variables. A large number of VAR studies identify interest rate policy shocks with a completely recursive ordering, which imposes that the central bank does not respond immediately to changes in fast-moving variables. Similarly, Tovar et al. (2012) use a recursive identification scheme to identify reserve requirement shocks. Typically, the recursive identification scheme applied assumes that the central bank does not respond to movements in the volume of credit and foreign exchange market within a month. While such an assumption may be more reasonable for advanced economies, we believe it to be too restrictive for an emerging country, where central banks closely monitor developments in the financial sector and the exchange rate. Second, the ordering of reserve requirement ratios and interest rate policy is not obvious, as there are important interactions between reserve requirement and interest rate policy. We therefore prefer the approach outlined above that mixes zero and sign restrictions. An advantage of exact identification schemes is that they usually give more precise impulse response function estimates, because for a given parameter estimate there is a unique matrix $\mathbf{B}$ that satisfies the restrictions. All uncertainty therefore derives from sampling uncertainty. An identification based on sign restrictions is inexact as there is a set of $\mathbf{B}$ matrices that satisfy the restrictions. Total uncertainty is a combination of sampling and identification uncertainty. The researcher therefore faces a familiar trade-off between less restrictive assumptions and more precise estimates.

In related work, Cordella et al. (2014) have identified reserve requirements shocks in a Panel-VAR using a narrative approach (with details in Federico et al., 2012). In particular, they rely on historical documents from central banks and the IMF to distinguish between reserve requirement changes motivated by output fluctuations (“endogenous changes”) and reserve requirement changes motivated by other reasons, such as financial liberalization and microprudential regulation (“exogenous changes”). The underlying assumption is that the timing of the identified microprudential actions and the financial liberalization steps are exogenous to the macroeconomic business cycle. The present study controls for the state of the business cycle using regression analysis. First, we only consider changes in reserve requirements at point t that were not predictable given the state of the economy in $t-1$. Second, our identification assumption decomposes the forecast error of reserve requirements into contemporaneous responses to other economic shocks and idiosyncratic changes, i.e. the actual reserve requirement shock. The narrative and the sign restriction approach are two conceptually different ways to identify reserve requirements shocks. A comparison of the results will allow us to assess the robustness of the two approaches.

4.3. Computational implementation

We sample the regression coefficients $\mathbf{A}_i$ and covariance matrix $\mathbf{\Sigma}$ from the posterior distribution.[22] Given the draws, we implement the sign restrictions as follows: we compute the Cholesky factorization $\mathbf{V}$ of the covariance matrix with the slow moving variables ordered first. We then multiply $\mathbf{V}$ with an orthonormal matrix $\mathbf{Q}$ ($\mathbf{B} = \mathbf{VQ}$) and compute candidate impulse responses, where $\mathbf{Q}$ is a block diagonal matrix of the following form:

$$\mathbf{Q} = \begin{bmatrix} \underset{N_S \times N_S}{\mathbf{I}} & \underset{N_S \times N_{F,P}}{\mathbf{0}} \\ \underset{N_S \times N_{F,P}}{\mathbf{0}} & \underset{N_{F,P} \times N_{F,P}}{\mathbf{Q}_2} \end{bmatrix} \tag{2}$$

and N_S is the number of slow-moving variables and $N_{F,P}$ is the total number of fast-moving and policy variables. Because $\mathbf{Q}$ is block diagonal, the property from the Cholesky factorization $\mathbf{V}$ that slow-moving variables do not respond immediately to

[22] $\mathbf{\Sigma}$ is drawn from an Inverted-Wishart Distribution $IW(\mathbf{\Sigma}_{OLS}, T)$, $\mathbf{A}_i$ from a Normal Distribution $N(\mathbf{A}_{i,OLS}, \mathbf{\Sigma})$, where T is the number of observations and subscript *OLS* stands for the OLS estimates.

variations in policy and fast-moving variables is maintained.[23] $\mathbf{Q}_2$ is a random orthonormal matrix of dimension $N_{F,P} \times N_{F,P}$. Following Rubio-Ramirez et al. (2010) we compute $\mathbf{Q}_2$ by drawing an independent standard normal matrix $\mathbf{X}$ of size $N_{F,P} \times N_{F,P}$ and apply the QR decomposition $\mathbf{X} = \mathbf{Q}_2\mathbf{R}$. If the corresponding $\mathbf{B}$ matrix implies impulse response functions that are consistent with the sign restrictions for both shocks, we keep the draw and proceed with the next parameter draw until we have 2000 accepted draws. Otherwise, we draw a new $\mathbf{Q}$ matrix until the sign restrictions are fulfilled. We report as coverage bands the 10% and 90% percentile of the distribution.

5. Results

The following section discusses the results for the two central bank policy shocks. Sections 5.1 and 5.2 focus on the impulse response functions for the reserve requirement and the interest rate (SELIC) shock. Section 5.3 summarizes the commonalities and differences of interest rate and reserve requirement shocks and discusses their contribution to overall economic fluctuations.

5.1. Reserve requirement shock

Fig. 2 displays the impulse response functions to a one percentage point reserve requirement shock. The solid black line shows the median responses based on the weighted reserve requirements measure. Note that impulse response functions should be interpreted as a deviation from the deterministic quadratic trend.

We start with a discussion of the credit market, where we observe a tightening of lending conditions. In response to the increase in reserve requirements, the spread between the lending and deposit rate rises and peaks after about 6 months at more than 100 basis points. The increase is significant and lasts for more than a year. The rise in the spread is consistent with the effects we would expect from a rise in the implicit tax on deposits. Domestic credit initially falls in the medium run by almost 1% and reverts back to zero after about 40 months.

Turning now to the external sector, we observe an immediate 5% depreciation of the domestic currency and an improvement of the current account by more than 0.4% of GDP after a year. A possible interpretation of the finding is that the increase in the tax makes investing in the domestic economy less attractive, capital flows out and the exchange rate depreciates. The depreciation leads to a gain in external competitiveness, which improves the current account balance.

The effects on the unemployment rate and the price level have the characteristics of an aggregate supply shock rather than those of a demand shock. The increase in the unemployment rate coincides with a rise in the price level. Unemployment rises more than 0.2 percentage points within a year. Prices increase by about 1% within a year. As discussed in Section 2.1, both the effect on overall economic activity and prices are ambiguous from a theoretical perspective. The results indicate that on the real activity side the effects from a decline in the demand of lenders dominates.[24] On the price side, inflationary pressures that arise from the exchange rate depreciation and the increase in intermediation costs prevail.

Regarding the interaction between the interest rate and reserve requirement policy, we observe an increase in the SELIC rate, which indicates that the reduction in central bank liquidity that follows from the reserve requirement hike is only partially accommodated through an increase in nominal reserves. A possible explanation for the increase is an endogenous response of interest rate policy to higher inflation prospects.

Our results are robust to the use of alternative reserve requirement measures. The impulse response functions based on the non-remunerated reserve requirement measure are shown in Fig. 2 by the blue[25] dashed lines. Both quantitatively and qualitatively there are no substantial differences. If we use effective reserve requirements as a measure for the policy stance (dash dotted green line), the results are again very similar.

5.2. Interest rate shock

Fig. 3 displays the impulse response functions to a positive one hundred basis points interest rate shock. Note that impulse responses should again be interpreted as deviation from the deterministic quadratic trend.

The responses of the variables are in line with theoretical predictions of the mainstream literature on monetary policy. The monetary policy shock has the standard features of an aggregate demand shock: the unemployment rate increases, whereas prices fall. The response of unemployment peaks at about 0.1 percentage points after about half a year. The price level responds in a hump-shaped fashion, the dynamic response reaches a trough at roughly minus 0.5% after about a year.

Regarding external variables, the results are again in line with the standard theoretical literature. The nominal exchange rate appreciates by 5%, before depreciating back to its initial level. Blanchard (2005) builds a theoretical model that characterizes the turbulent 2002–2003 period and shows that interest rate increases in Brazil can have perverse effects on exchange rates. If higher interest rates lead to a sharp worsening of macroeconomic conditions, interest rate premia

[23] Because we are only interested in the responses to interest rate shocks and reserve requirement shocks, the ordering of the slow-moving variables does not matter (Christiano et al., 1999).

[24] Although certainly interesting, we cannot investigate the separate responses of consumption and investment or an even finer decomposition of aggregate spending, as they are not available at a monthly frequency.

[25] For interpretation of color in Fig. 2, the reader is referred to the web version of this article.

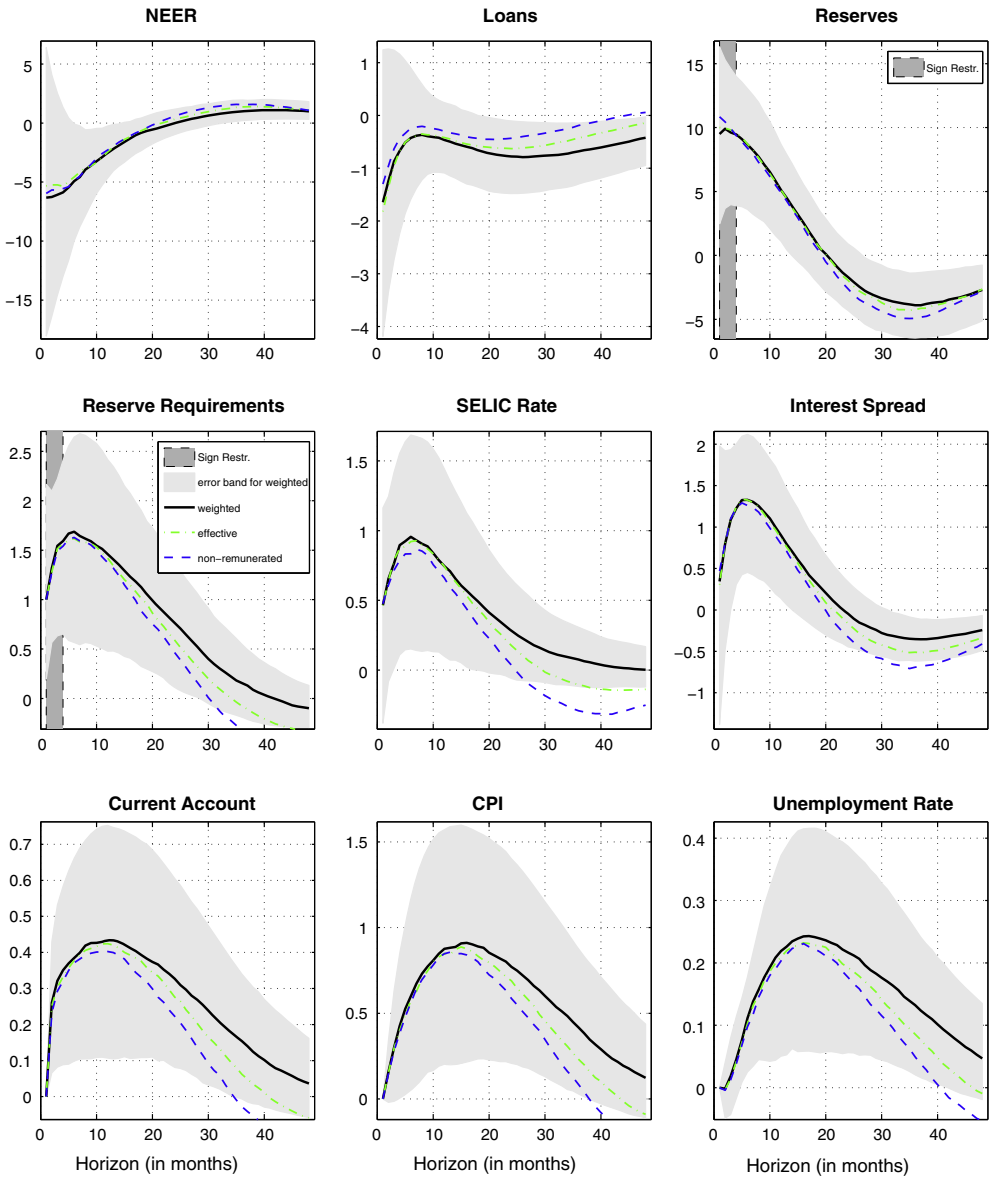

Fig. 2. Reserve requirement shock. The figure reports the impulse response functions to a reserve requirement shock, using the identification scheme described in Table 1. Periods for which the sign restrictions are imposed are marked in dark gray. The impulse response functions are shown for a horizon of up to 48 months (4 years). A decrease in the nominal effective exchange rate (NEER) implies a depreciation.

may rise, triggering capital outflows and an exchange rate depreciation. Our results indicate an exchange rate path consistent with the predictions of standard open economy models. The deterioration of the foreign balance is consistent with the effects we would expect from an exchange rate appreciation and a loss in external competitiveness.

The interest shock also has the predicted effects on the credit market. Loans initially decline by about 1% and the spread between lending and deposit rates rises by about 50 basis points in the medium run.

Regarding the interaction between the two considered policy instruments, the reserve requirement ratio tends to fall in response to an interest rate shock. A negative response of reserve requirements is consistent with an endogenous response to the deteriorated credit conditions.

5.3. Reserve requirement and interest rate policy shocks: a comparison

A rise in interest rates and a rise in the reserve requirement ratio are two different possibilities for a central bank to engineer a contraction in credit. Table 2 lists credit "sacrifice ratios": what does a 1% reduction in loans achieved either through a

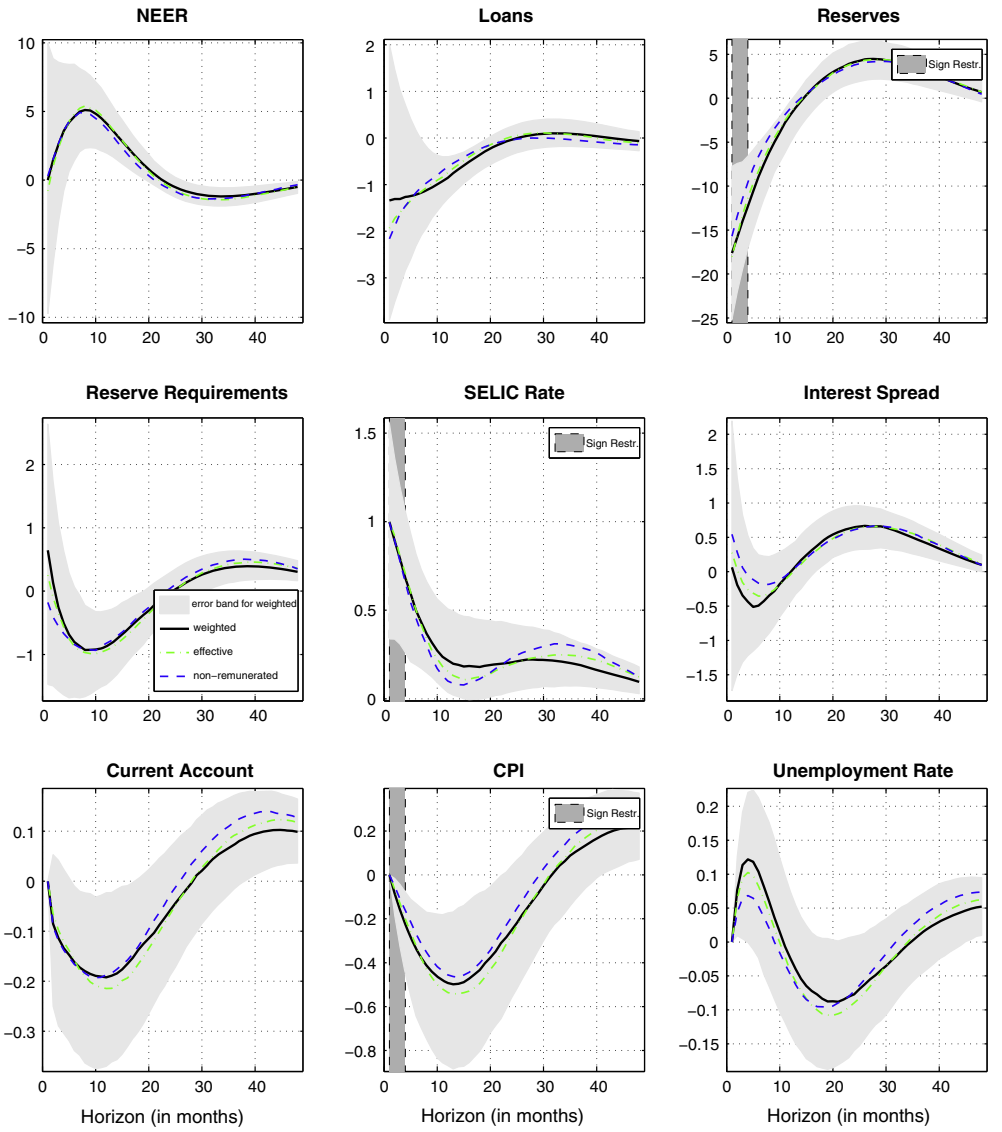

Fig. 3. Interest rate shock. The figure reports the impulse response functions to an interest rate shock, using the identification scheme described in Table 1. Periods for which the sign restrictions are imposed are marked in dark gray. The impulse response functions are shown for a horizon of up to 48 months (4 years). An increase in the nominal effective exchange rate (NEER) implies an appreciation.

tightening of interest rates or reserve requirements imply for the movements in other macroeconomic variables? All reported values are averages over the first twelve months, using the specification with the weighted reserve requirements measure. We observe that the two instruments have very different effects on other macroeconomic variables. The exchange rate, the current account and prices move in opposite directions. A discretionary increase in reserve requirements leads to an exchange rate depreciation, an improvement of the current account, and increase in prices. A discretionary interest hike leads to an exchange rate appreciation, a deterioration of the current account deficit, and a decrease in prices. For both shocks a reduction in credit is associated with an increase in the unemployment rate. However, the increase under the SELIC rate shock is almost twice as large as under the reserve requirement policy shock.

Our result that a positive reserve requirement shock triggers a decrease in private credit, a widening of spreads, and a decline in economic activity is in line with Cordella et al. (2014) and Tovar et al. (2012). As these studies use different methods and identification assumptions, this supports robustness of these results. The present paper additionally investigates the effect of reserve requirement policy on exchange rates, capital flows and prices. While the effects of reserve requirement policy on credit and economic activity may suggest that interest rate and reserve requirement policy are substitutes, the markedly different effects on capital flows, exchange rates and prices emphasize the complementary role of the two instruments.

Table 2
Quantitative impact of contractionary monetary policy – interest (SELIC) rate and reserve requirement (RR) shock.

	Interest rate shock		RR shock	
Loans	−1	Percent	−1	Percent
NEER	3.48	Percent	−6.33	Percent
Reserves	−6.78	Percent	12.43	Percent
RR	−0.48	Percentage points	2.32	Percentage points
SELIC	0.48	Percentage points	1.26	Percentage points
Spread	−0.26	Percentage points	1.66	Percentage points
CA	−0.12	Percentage points	0.54	Percentage points
CPI	−0.46	Percent	0.66	Percent
U	0.16	Percentage points	0.09	Percentage points

Notes: The numbers shown refer to the reaction of the variables at the initial stage of the shock (one year). The variables are: nominal effective exchange rate (NEER), total aggregate credit (Loans), reserves of commercial banks (Reserves), the SELIC rate, reserve requirements (RR), the interest rate spread between lending and deposit rates (Spread), the ratio of the current account to GDP (CA), the price level as measured by the CPI and finally the unemployment rate (U).

Table 3
Forecast error variance decomposition.

Horizon	4	12	24	4	12	24
	Interest rate shock			RR shock		
NEER	4.4	5.9	5.3	6.3	6.9	7.4
Loans	5.4	6.3	4.9	8.3	7.6	8.4
Res	23.9	14.3	12.2	17.1	15.9	13.8
RR	6.6	5.2	3.7	18.4	18.7	17.6
SELIC rate	16.4	21.9	20.5	7.6	6.7	6.7
Spread	5.6	3.3	3.7	10.6	13.1	11.5
CA	5.9	5.2	4.1	7.8	12.7	13.9
CPI	1.8	3.8	7.6	2.1	5.8	6.1
U	0.3	2.7	4.1	0.2	3.0	5.0

Notes: The numbers are in percent. The variables are: nominal effective exchange rate (NEER), total aggregate credit (Loans), central bank reserves (CB Res), the SELIC rate, reserve requirements (RR), the interest rate spread between lending and deposit rates (Spread), the ratio of the Current Account to GDP (CA), the Consumer Price Index CPI and the unemployment rate (U).

Table 3 reports the forecast error variance decomposition for interest and reserve requirement shocks that is, the percentage of the variance of the k-step-ahead forecast error that can be explained by the two shocks. Note that forecast error variance decompositions indicate the importance of random policy shocks, but do not allow any statements about the importance of systematic policy. Investigating the response of other macroeconomic variables to policy shocks allows improving our knowledge of the transmission mechanism of the two policy instruments, even if the contribution of random policy to overall fluctuations is small.

Both interest rate and reserve requirement shocks are not very important for unemployment and price level fluctuations. At a two year horizon, they explain between 4% and 5% of the variation. Regarding credit variables, reserve requirement shocks are more important than interest rate shocks for fluctuations in loans and credit spreads. They explain around 8% at long horizons, compared to 5% of fluctuations explained by interest rate shocks. Similarly, reserve requirement shocks drive about 12% of the fluctuation at long horizons, while the contribution of interest rate shocks amounts to only 4%.

Reserve requirement shocks explain about 18% of the fluctuations in reserve requirements at all horizons. Interest rate shocks explain about 6%. Taken together, about three quarters of the variation in reserve requirements can be explained as a response to other macroeconomic, non-policy, shocks. Interest rate shocks explain around 20% of the variation in the SELIC rate, whereas reserve requirement shocks only explain about 7%. Again about three quarters of unexpected movements in interest rates can be explained by an endogenous response to other macroeconomic shocks.

6. Robustness and diagnostic checks

In this section we investigate the extent to which the previous results are robust to different measures of prices, real activity and central bank liquidity, instabilities due to different inflation targets, possible subsample instabilities, and the role of omitted variables.

6.1. Different measures for the prices indices

The first and second subplot in Fig. 4 show impulse response functions for different price measures. Next to our base measure, the CPI, we plot the responses of the Producer Price Index (PPI), the price index for tradable goods (TGPI) and the price index for nontradable goods (NTGPI).

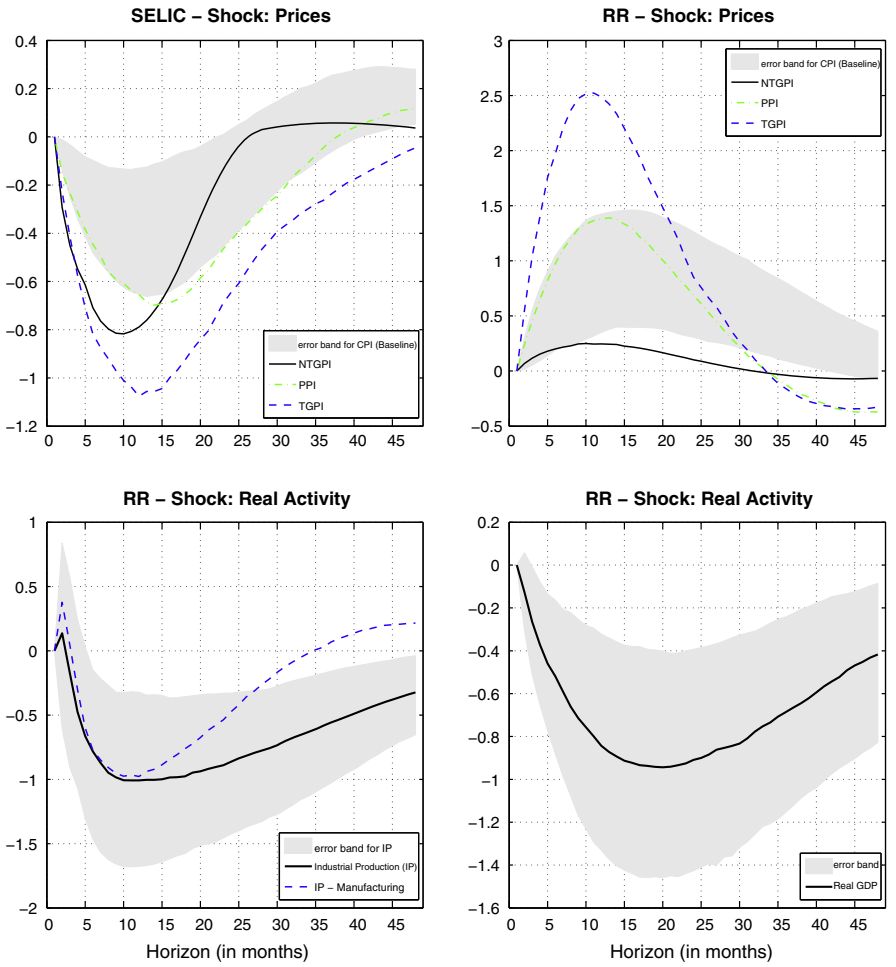

Fig. 4. Price indices and real activity. The figure reports the impulse response functions for different price indices and different measures for real activity to a reserve requirements and interest rate shock, using the identification scheme described in Table 1. The impulse response functions are shown for a horizon of up to 48 months (4 years).

Our discussion focuses on prices, since the results for the other variables are very similar to the baseline case. Each of the price measures shows a positive reaction in response to a reserve requirement shock. The price index for nontradable goods shows a weaker response than the other two price measures. Since nontradable goods prices primarily contain domestically produced goods and hence have a lower exposure to exchange rate fluctuations, their reaction can provide some insights regarding the importance of the exchange rate pass through. The dampened reaction of the nontradable goods price index relative to the impulse response functions of the CPI, PPI and the tradable goods price index is consistent with the hypothesis that a large part of the observed inflationary pressure derives from the exchange rate depreciation, as opposed to higher capital costs. For the interest rate shock, the magnitude of the response is comparable for all three price measures. This is consistent with the explanation that tighter monetary policy leads to a general decline in aggregate demand that lowers prices in all segments.

6.2. Different measures for real activity

We substitute the unemployment rate by other measures of economic activity. Fig. 4 shows the impulse response functions to a reserve requirement shock when we use the General Industrial Production Index, the Industrial Production Index for the Manufacturing sector, and real GDP[26] as a measure for economic activity.

For all three measures, we can again observe a contraction in overall economic activity. For all three measures the decline in economic activity is persistent and reaches its trough after one to two years. Results for the other variables are again similar to the baseline case for all three specifications (not shown).

[26] Since a measure for real GDP on a monthly frequency is unavailable, we instead use nominal GDP in domestic currency units deflated by the CPI.

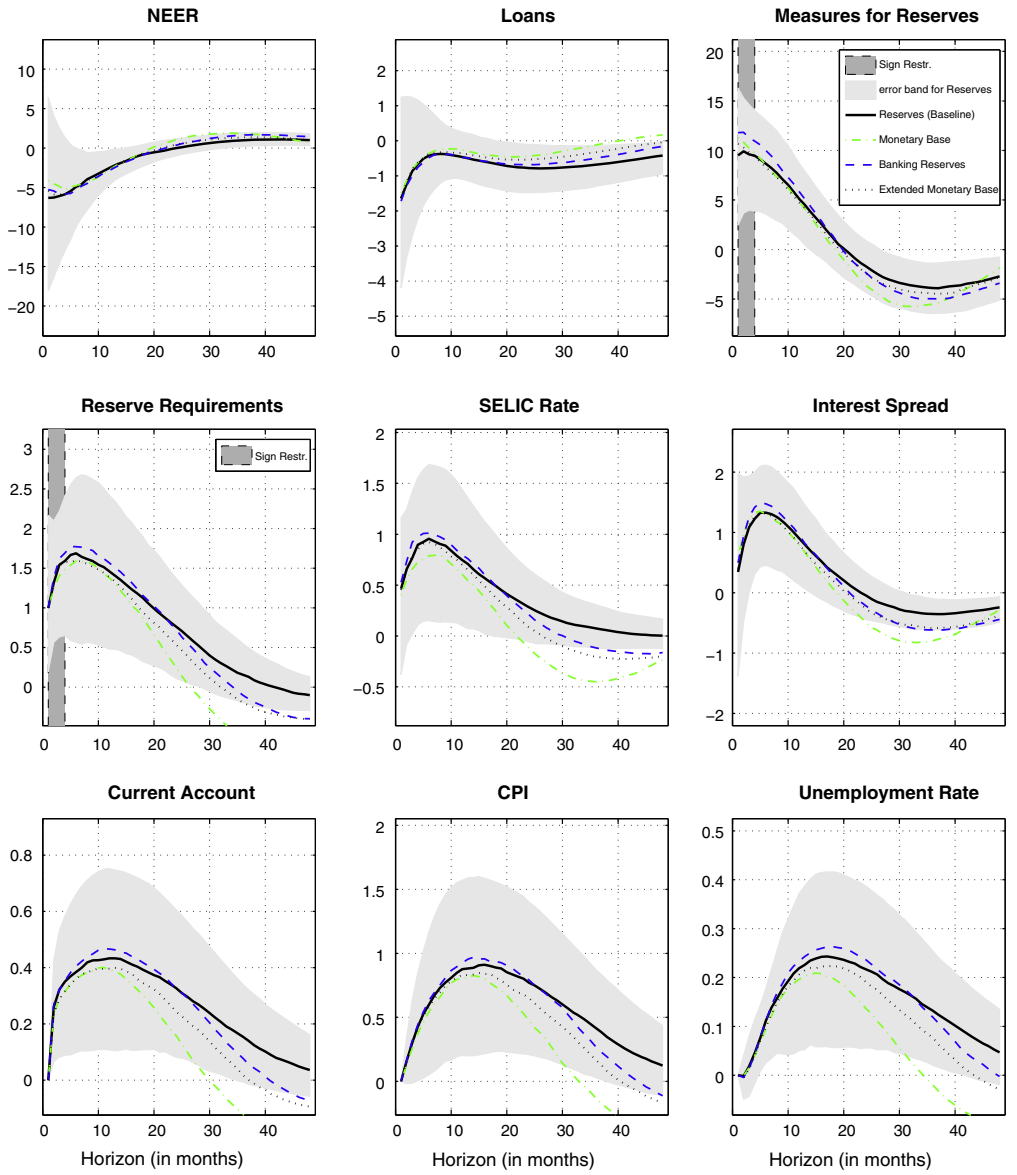

Fig. 5. Alternative reserve measures. The figure reports the impulse response functions to a surprise innovation in reserve requirements, using the identification scheme described in Table 1. Periods for which the sign restrictions are imposed are marked in dark gray. The impulse response functions are shown for a horizon of up to 48 months (4 years) for different measures of reserves.

6.3. Different measures for central bank liquidity

We proceed by using alternative measures for central bank liquidity. The measure used for the results discussed in Section 5 considers the sum of commercial banks' required reserve holdings. The measure is broader than the reserve money component of the monetary base, because banks can hold a fraction of their reserve holdings in their own vaults or in remunerated accounts. We consider our baseline measure more appropriate, since it captures the total holdings of official liquidity. As alternative measures for central bank liquidity, we use the reserve money component of the monetary base, the overall monetary base (including currency and notes), and the extended monetary base.[27]

Fig. 5 shows that the overall results are not affected. Impulse response functions for the different measures employed are very similar and remain within the confidence bands of the baseline specification most of the time.

[27] The extended monetary base includes additional mandatory cash deposits and custody positions in central bank and National Treasury securities. Brazilian authorities consider the extended monetary base more relevant than the narrow monetary base when assessing price stability, "as they more accurately reflect the capacity for substitution between money, narrowly defined, and other financial assets" (see http://www.bcb.gov.br/pec/sdds/ingl/ctasanal_autmon_i.htm).

6.4. Changes in the inflation target

Brazil's inflation targeting policy is explicitly announced by means of a point inflation target and a range by the National Monetary Council. As Arestis et al. (2008) and Barbosa-Filho (2008) indicate, both the inflation target and the range have been continuously adjusted in response to severe macroeconomic shocks. The inflation targeting regime started in 1999 with a target value of 8% and a range of 6–10%. Since 2006, the target is 4.5% with a range of 2.5–6.5%.

A change in the target level will change the intercept of the interest rate policy rule. In order to account for changes in the level of the inflation target, we add separate dummy variables for each change in the target rate to the BVAR model. None of the dummy variables' estimated coefficients is significantly different from zero at the 90% level. The impulse response functions to the two structural shocks also change little (available on request).

A change in the target or the range can also change the aggressiveness of the monetary authority in reacting to inflation, which in turn would affect the response of the economy to policy shocks. Such changes would be reflected in different slope coefficients in addition to different intercepts. The next section will check for sample instability and changes in the transmission mechanism.

6.5. Subsample instability

The short period which is covered by our sample does not leave much room for a sophisticated analysis regarding sample instabilities. We proceed by splitting the sample in the middle, hence one period from 1999:7 to 2006:10 and another one from 2006:11 to 2014:06. Each subsample is now characterized by one recession episode as well as by a period of normal economic fluctuations.

The main aim of the exercise is to ascertain that our results are not driven by a particular episode. Our results indicate that this is not the case. For both subsamples the structural impulse response functions to the two monetary policy shocks follow those in Figs. 2 and 3 closely. Due to the small sample size, the degree of uncertainty is larger, but most responses remain significant (available on request).

6.6. Omitted variables

Separate Ljung-Box tests on each residual time series cannot reject the null that they follow a white noise process. However, it is still possible that omitted variables matter for the results. To check whether the two identified monetary policy shocks are correlated with other variables we follow Canova et al. (2009) and compute correlations of the estimated structural disturbances with variables that a large class of general equilibrium models suggests as being jointly generated by various shocks.

Specifically, we compute correlations up to six leads and lags between the shocks and the growth rate of the Brazilian stock market index (BVSP), the oil price,[28] the policy interest rates of the Bank of Japan, the ECB and the Bank of England.

The cross-correlations indicate that none of the omitted variables correlates significantly with the two structural shocks.

7. Conclusion

The aim of the present paper was to identify the macroeconomic consequences of changes in reserve requirements when the central bank additionally sets the interest rate. We take the example of Brazil, where we have both a homogeneous monetary policy framework and sufficient variation in reserve requirements. Based on a structural vector autoregressive model, we find that a discretionary increase in reserve requirements leads to a contraction in domestic credit. Moreover, the tightening leads to an increase in the unemployment rate, a depreciation of the exchange rate depreciation, an improvement of the current account, and an increase in the price level. Regarding interest rate policy, our results are consistent with standard economic theory. Positive interest rate surprises coincide with a contraction in credit, and increase in the unemployment rate, an appreciation of the exchange rate, a deterioration of the current account, and a decline in prices. The results are therefore in line with arguments that ascribe interest rate policy an important role in controlling price and output fluctuations, but also with arguments that emphasize the dilemma monetary policy faces when dealing with capital inflows (IMF, 2007). Our results indicate that reserve requirements provide a potential way of curbing credit growth without attracting net capital inflows and appreciating the exchange rate. It is, however, doubtful that reserve requirements are an appropriate tool for achieving price stability under an interest rate policy framework. In that sense, reserve requirement policy can serve as a complement to interest rate policy for financial stability considerations, but cannot be its substitute to achieve price stability. Our finding that reserve requirement changes have macroeconomic effects supports the importance of the

[28] We use the cyclical component according to a Hodrick–Prescott filter applied on the log of the oil price.

bank lending channel: banks cannot easily substitute away from deposit funding and firms cannot easily substitute away from bank credit.

This study has focused on Brazil. An important question is how our results can be generalized to other countries. From the discussed theory, two aspects appear particularly important. The first is the monetary policy framework. We have studied the effects of reserve requirement changes when the central bank simultaneously sets the interest rate through open market operations. We expect substantially different effects under other central bank policy frameworks, for example, if reserve requirements are used to achieve a pre-specified money growth target. The second aspect is the importance of banks. If banks can be easily substituted through other funding sources, reserve requirements will be a less effective policy instrument. Our analysis has focused on the short term effects of reserve requirement changes. The effect of higher reserve requirement levels on the costs of financial intermediation and long term growth prospects is another important aspect that policy makers need to consider.

Acknowledgments

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Appendix A. Data

The data used are monthly Brazilian data from the period 1999:07 to 2014:06. The series were taken from the OECD database, from the IFS (International Financial Statistics) database, Datastream (DS), from the World Bank (WB), the Fundação Getúlio Vargas (FGV) and the Banco Central do Brasil (BCdB) (see Table 4).

Table 4
Data: definitions and sources.

	Description	Source	Coding
1	National Consumer Price Index	IFS	223″64″M
2	Lending Rate	BCdB	.
3	Nominal Effective Exchange Rate	IFS	223″__NEC
4	Brazilian Federal funds rate – SELIC (*Sistema Especial de Liquidação de Custódia*)	BCdB	.
5	Saving Deposits Rate	IFS	223″60K″M
6	Unemployment: Rate, all persons (ages 15 and over) SA	OECD	BRA″UNRTSA
7	US Federal funds rate	OECD	USA″IRSTF
8	Statutory Reserve Requirements and additional Requirements (*exigibilidade adicional*) on Sight, Time and Saving Deposits	BCdB	.
9	World Raw Materials Price Index	WB	RMPIdx
10	Financial institutions reserve requirements – Total balance	BCdB	17633
11	Saving Deposits, Time Deposits, Sight Deposits, Value	BCdB	.
12	Claims on private sector	BCdB	.
13	Monetary Base	BCdB	1788
14	Banking Reserves	BCdB	1787
15	Extended Monetary Base	BCdB	1833
16	Producer Price Index	FGV	200053
17	Price Index of domestic nontradable goods (BR broad national CPI (IPCA) – non-tradable goods (%mom) SA, cumulated)	DS	BRCPINT%R
18	Price Index of domestic tradable goods (BR broad national CPI (IPCA) – tradable goods (%mom) SA, cumulated)	DS	BRCPITD%R
19	Current Account – monthly (in US Dollars)	BCdB	.
20	Gross Domestic Product (GDP) – monthly, current prices	BCdB	4380
21	Gross Domestic Product (GDP) – monthly, in US Dollars	BCdB	4385
22	General Industrial Production Index	BCdB	11064
23	Industrial Production Index – Manufacturing	BCdB	11066
24	S&P 500 Volatility Index (VIX)	DS	CBOEVIX
25	Global Industrial Production Index	WB	.

Notes: SA refers to *Seasonally Adjusted*.

Appendix B. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jmacro.2015.02.007.

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