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Central Bank Liquidity Management and "Unconventional" Monetary Policies

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Central Bank Liquidity Management and “Unconventional” Monetary Policies

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Abstract*

This paper presents a small open economy model to analyze the role of central bank liquidity management in implementing “unconventional” monetary policies within an inflation targeting framework. In particular, the paper explicitly models the facilities that the central bank uses to manage liquidity in the economy, which creates a role for the central bank balance sheet in equilibrium. This permits the analysis of two “unconventional” policies: sterilized exchange-rate interventions and expanding the list of eligible collaterals accepted at the liquidity facilities operated by the central bank. These policies have been recently implemented by several central banks: the former as a way to counteract persistent appreciations in the domestic currency, and the latter as a response to the recent global financial crisis in 2008. As a case study, the paper provides a detailed account of the Chilean experience with these alternative tools, as well as a quantitative evaluation of the effects of some of these policies.

JEL classifications: E52, E58

Keywords: Unconventional monetary policies, Central bank balance sheet, Sterilized interventions

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1 Introduction

Central banks that work under an Inflation Targeting regime generally use a monetary policy rate as the main instrument to implement monetary policy, in what can be denominated “conventional” monetary policy. Many times, however, they deviate from this usual practice and engage in other policies to deal with particular situations. As these alternatives depart from the usual practice, they are generally labeled “unconventional” policies.

A period of particular activism in terms of these unconventional policies was the recent global financial crisis and recession of 2008 and 2009, in which central banks around the world, and in Latin America (LA) in particular, responded to external shocks in a variety of ways. For example, Canales-Kriljenko et al. (2010) provide a precise description of the reactions by different LA central banks to the US financial crisis shock in 2008, stressing the heterogeneity in the intensity of use of different unconventional monetary policy instruments. For example, while Colombia and Peru lowered reserve requirements in their banking systems,¹ the Central Bank of Chile relaxed the collateral requirements for REPO transactions. Also, Chile and Peru extended the repayment period in REPO transactions. These examples illustrate not only the heterogeneity in responses, but also the common feature of using unconventional instruments. Actually, Ishii et al. (2009) stress that the central bank interest rate for many EM countries, in the months immediately following the fall of Lehman Brothers, actually increased rather than decreased.

In addition, deviations from conventional policies have also been observed in Latin America even before the recent global financial crisis. Most notably, central banks have many times engaged in sterilized exchange-rate interventions, for instance, to smooth the effects of capital inflows (due in part to commodity-price booms) and the resulting nominal exchange rate appreciation. In some countries these interventions are quite frequent, as in the case of Peru, while in others these policies are implemented only after extreme movements in the nominal exchange rate (for instance, in Chile).

Clearly, this combination of use of unconventional monetary instruments without recurring to the active use of the interest rate for LA central banks that implemented inflation target regimes is a puzzle worth explaining. Although a literature on unconventional monetary policies has emerged after such a crisis, it essentially focuses on the action by central banks of OECD countries (in Section 2 we provide a description of this literature). However, one important discussion missing in this line of research is the relationship between inflation targeting regimes and the liquidity management responses, a feature that is completely linked to the events described above but that has not been properly addressed in the literature. Recently, one of the major researchers in inflation targeting, Lars Svensson (2010), stressed the distinction between two possible policies

¹ According to Jara et al. (2009), the Central Bank of Peru lowered the marginal reserve requirement on foreign currency from 49 percent in October 2008 to 30 percent in December.

for the central bank. The first is “monetary policy,” whose main objective remains to be a combination of inflation stability with output stability. The second is “financial stability policy,” which Svensson separates completely from the first. Although Svensson recognizes possible interaction between the two, he emphasizes that, in principle, they should be analyzed from somewhat separate perspectives. However, in EM countries such as those in LA it is at least doubtful that such policies can be separated in this way. The reason is that financial instability may eventually lead to output instability, as long as real activity depends on overall liquidity and solvency conditions of banking systems, as a standard bank-lending channel argument may state.

In this paper we present a conceptual framework that allows us to analyze the role of central bank liquidity management in implementing these alternative policies. In particular, we focus the attention on the role played by the facilities used by central banks to manage the market’s liquidity. We use Chile as our case of study, providing a detailed account of its experience with these alternative tools since the introduction of the flexible inflation targeting framework in 1999, and calibrating the model to analyze the effect of some of the policies implemented.

The theoretical framework we develop is an extension of a New Keynesian model of a small open economy. In particular, the model features banks that take deposits from households, borrow abroad, lend to productive firms and hold bonds issued by the central bank. A key ingredient of our framework is that we explicitly model the facilities that the central bank sets up to allow banks to obtain liquidity. In these facilities, banks can acquire liquidity in exchange for a specific list of assets (in the baseline model, only central bank-issued bonds), and these operations can take two forms: outright purchases and repurchase (repo) agreements. This feature, in turn, allows considering alternative types of monetary policies. On one hand, as the central bank balance sheet will be relevant to describe the dynamics of the economy, we can evaluate policies like sterilized exchange rate interventions. On the other hand, we can also consider the possibility that the central bank accepts other assets (loans in particular) for use as collateral in repo operations.

The main results of the paper are as follows. In terms of the effects of sterilized interventions, we found that while they can have potentially large expansionary effects, their use poses a challenge for the implementation of an inflation targeting regime. This happens because, as the purchases of foreign assets are financed with bonds that can be used in the liquidity facilities that the central bank operates, the sterilization relaxes the liquidity constraint faced by banks. In turn, this has large expansionary and inflationary effects in the model due to the sluggish adjustment of prices and the cash-in-advance constraint. In other words, while the intervention we analyze is sterilized, in our model it has effects akin to those that would appear under non-sterilized interventions in more standard frameworks that neglect liquidity management issues.² Given this result, we

² In fact, this channel for the transmission of sterilized interventions is different from other channels that have been studied in the literature. We discuss this in detail below.

then proceed by analyzing how the central bank can adjust other policy tools to regulate the extra liquidity brought about by the intervention. In particular, we present a calibration that resembles the foreign assets purchase program implemented by the Central Bank of Chile in 2011, specifying not only the size of the purchases but the liquidity management as well. Our analysis suggests that this policy had only a mild effect on the economy.

In terms of the effects of a policy that allows banks to use loans as additional collateral to obtain liquidity from the central bank, we found that the policy can have expansionary effects that depend on how long is that alternative available. These effects appear because such a policy lowers the lending-deposits spread, and because of the extra liquidity generated (which fosters activity due to sticky prices and the cash-in-advance constraint). Moreover, we present an exercise that attempts to capture the unconventional policy implemented by the Central Bank of Chile in response to the Lehman Brothers collapse, finding that the policy had non-trivial expansionary effects.

The rest of the paper is organized as follows. Section 2 presents a review of the related literature. Section 3 documents the Chilean case. Section 4 presents the model used for the analysis and discusses its calibration. In Section 5 we analyze how different types of shocks propagate into the model under a set of monetary policies that we call “conventional.” Section 6 analyzes the different “unconventional” policies we consider: sterilized exchange-rate interventions and expanding the list of eligible collaterals allowed for operations with the central bank.

2 Background Literature

The global financial crises spurred a line of research attempting to incorporate the role of financial intermediation into the core model used in pre-crisis central banking (i.e., the New Keynesian framework). While this literature clearly improves our understanding of these issues, a consensus is far from being reached and there are still many loose ends to tie up. Moreover, this new literature has focused mainly on closed economy models, while advances in a small open economy framework (the relevant one for Latin America) are less frequent. This section briefly reviews this line of research.

In the pre-crisis models incorporating financial frictions, the information asymmetries that generate the friction was between households and the owner of productive technologies (entrepreneurs), but the role of financial intermediaries was quite limited.³ A number of recent studies have added financial intermediaries that are also exposed to financial risk in closed economy models, which seems a more sensible description of recent events, particularly in the United States. Examples are the articles by Gertler and Karadi (2011) and Gertler and Kiyotaki (2011). However, these are gen-

³ The main reference of this literature is the financial accelerator framework in Bernanke et al. (1999). Christiano et al. (2012) is a recent example of this literature; while Céspedes et al. (2004) and Elekdag and Tchakarov (2007), for instance, apply this framework to small open economies.

erally real models and thus, while appropriate for assessing the role of a variety of credit policies, the interaction with the usual monetary policy tools is not clear in those models. In contrast, Adrian and Shin (2010) do consider the interaction between more conventional monetary tools and credit policies. However, they do so in a simplified framework that is silent about the macroeconomic consequences of these interactions.⁴

On the other hand, a different branch of literature has used the reallocation-shock monetary banking model of Champ et al. (1996) to analyze the role of the monetary policy conducted through a discount window in the economy. For example, Antinolfi et al. (2001) introduce a central bank that issues new domestic currency and lends it to banks to cover their liquidity needs. They show that such central bank behavior may lead to multiple equilibria: one that implements the Pareto-efficient allocation but a continuum of others called "hyperinflationary," leading to the non-monetary steady state. A variant of such a model is considered in Antinolfi and Kawamura (2008), who add a solvency-risk dimension together with transactions in incomplete financial-security markets. Antinolfi and Kawamura (2008) show that only with banks, securities markets and a central bank lending money to banks for liquidity needs can implement the Pareto-efficient allocation. The common denominator of these papers is the explicit and simultaneous modeling of money, banks and a central bank with a discount window, which seems an interesting precedent for the project presented in this paper. However, these types of models are not suitable for quantitative analysis, since they all assume an overlapping-generations structure.

As previously mentioned, most of the analysis documented in the paragraphs above focuses on closed-economy models. Such a limitation is clearly not desirable for small open economies like those in Latin America. There are, however, a few exceptions. Carcía-Cicco (2011) uses a New Keynesian, small open economy model with financial wedges that permits consideration of policies associated with changes in the Central Bank balance sheet, such as exchange rate interventions (both sterilized and non-sterilized) and modifying the maturity structure of public debt. However, in that framework financial frictions are imposed in an ad hoc way, there is no role for financial intermediaries and, in addition, the focus is on cases where the lower bound in the policy rate is binding. Another example is the work by Alp and Elekdag (2011), estimating a New Keynesian model including a financial accelerator channel to account for the Turkish experience during the recent global financial crisis, and to assess the importance of the (traditional) monetary policy response.

The work by Céspedes et al. (2011) presents a model where banks are included as in Edwards and Végh (1997), with two additional features: bank lending is constrained by bank capital, and banks face reserve requirements imposed by the government. In particular, they analyze the

⁴ Curdia and Woodford (2010) introduce credit spreads into a New Keynesian framework. Their model, however, does not feature financial intermediaries.

virtues of a policy that reduces reserve requirements when the borrowing-lending spread rises, documenting that this type of policy may be useful to smooth the effects of shock to bank costs. Finally, a recent paper by Céspedes et al. (2012b) presents a simple small open economy model in which financial intermediation can be occasionally subject to collateral constraints. In this framework they study policies such as credit facilities and exchange rate interventions. They find that these policies can indeed be useful in situations in which the financial intermediaries are facing binding constraints. While these two are examples of articles moving in the desired direction, they focus on the role of these “unconventional” policies in isolation, in the sense that the model has some simplification that prevents us from analyzing these tools in tandem with the more usual role of monetary policy under an inflation targets.⁵

3 The Chilean Experience with “Unconventional” Policies

Since the approval of its new regulatory framework in 1989 (through Act 18.840), according to which the Central Bank became independent of the executive power, Chile has become one of the main EM countries in the world in adopting the inflation targeting regime. Until 2006, this regime had been evolving from a version with strong capital controls and real interest rate targets to a more “developed world” version with freely floating nominal exchange rates and nominal interest rate targets.

Since the focus of the paper starts with events related to the 2008 US financial crisis, the relevant time window for this study starts in 2006, two years before that crisis. Thus, a detailed description of the evolution of the inflation targeting regime prior to that year is beyond the scope of the paper. There are many excellent references explaining varied aspects of the different stages in the implementation of this regime,⁶ which the reader may wish to consult.

3.1 The Chilean Reaction to the 2007 US Financial Crisis: “Unconventional” Policies

In 2007 US financial markets entered their worst crisis in several decades, after the burst of the real estate bubble that seemed to have started after the recovery from the 2001 recession. However, such crisis presented several phases itself. The first one started around the second quarter of 2007 and developed until the fall of Lehman Brothers in September 2008. During that period, international food and oil prices continued increasing, following a positive slope beginning in 2002.⁷ This surge in prices (also helped by a sudden drop in the supply of energy from Argentina to Chile) implied further inflationary pressures on the Chilean Central Bank (see Figure 1), who reacted raising the monetary policy rate from 5 percent in the second quarter of 2007 to 5.79 percent in the fourth

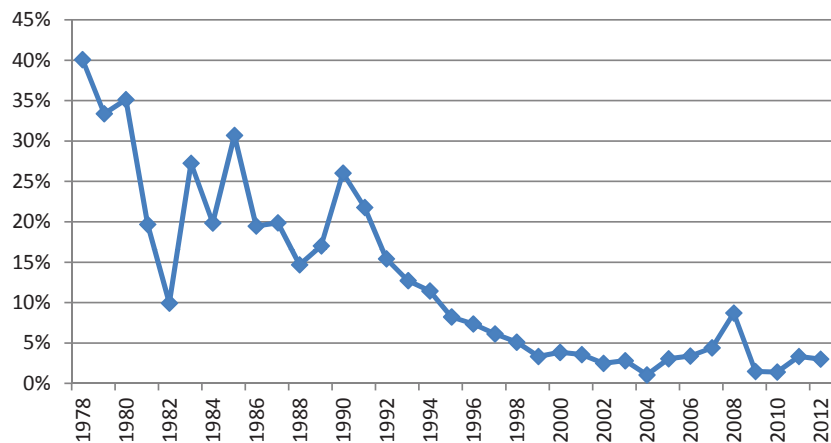
⁵ For instance, in both cases prices are fully flexible.

⁶ See, e.g., Corbo (1998), De Gregorio and Tokman (2004), Fuentes et al (2003), Gallego et al (1999), Morandé (2002), Morandé and Tapia (2002), Tapia and Tokman (2004) and Valdés (2007).

⁷ See, e.g., De Gregorio (2009a) and Céspedes et al. (2012).

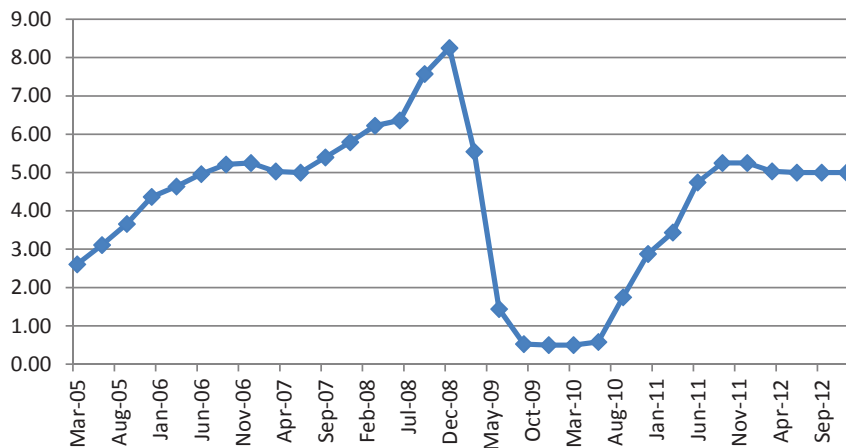
quarter. In fact, this reaction continued throughout the whole year of 2008, up to a peak in the fourth quarter of 8.25 percent, as Figure 2 shows.

Figure 1. Annual CPI-based inflation rate in Chile, 1978-2012



Source: Central Bank of Chile

Figure 2. Quarterly monetary policy rate, Central Bank of Chile, I-2005 to IV-2012



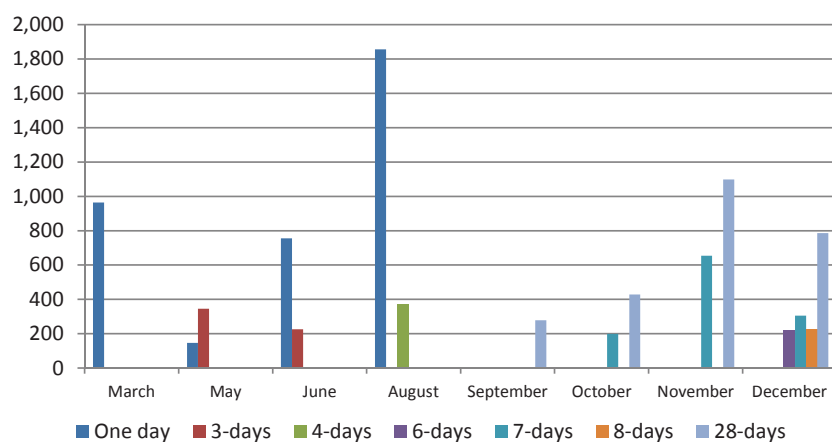
Source: Central Bank of Chile

Notice that the Central Bank kept increasing its rate even though the global economy had already entered the second phase of the crisis (see the paragraph below), starting with the fall of Lehman Brothers. One of reasons found in the policy papers published by the Central Bank was the persistence of inflationary pressures implied by the evolution of international oil prices in that

year.⁸ Another feature of those months was the Central Bank’s purchases of foreign currency to avoid further appreciation of the exchange rate. These purchases occurred between April 14 and September 29, 2008, in daily purchases of US\$ 50 million each, adding up to US\$ 5.75 billion.⁹ This amount was eventually considered by different economists a ”sufficient” amount to work as a ”buffer” for liquidity provision in foreign currency.¹⁰

The October 2008 collapse of Lehman Brothers marked the second phase of the crisis, with an international liquidity crunch that induced different central banks to implement different policy measures to cope with that shock (see Céspedes et al., 2011). In the case of Chile, the first reaction was the above-mentioned interruption in the foreign-currency accumulation. Another reaction was the widening of collateral requirements in the REPO programs as well as an extension of *swap* operations. In terms of the collaterals, in a first phase (starting in October, 2008) banks’ deposits were accepted, while in a second phase (from January, 2009) the list was further expanded, including, for instance, government bonds and term deposits.

Figure 3. Monthly repo purchases by the Central Bank of Chile during 2008, in millions of pesos.



Source: Central Bank of Chile

Figure 3 shows REPO operations by the Central Bank of Chile during 2008. One distinctive feature is the extension of the length of the repurchases: between January and August the typical REPO purchase operation was just overnight (with a maximum length period of 4 days). The total (nominal) amount of overnight REPO purchases was 3.7 billion pesos. Between October and

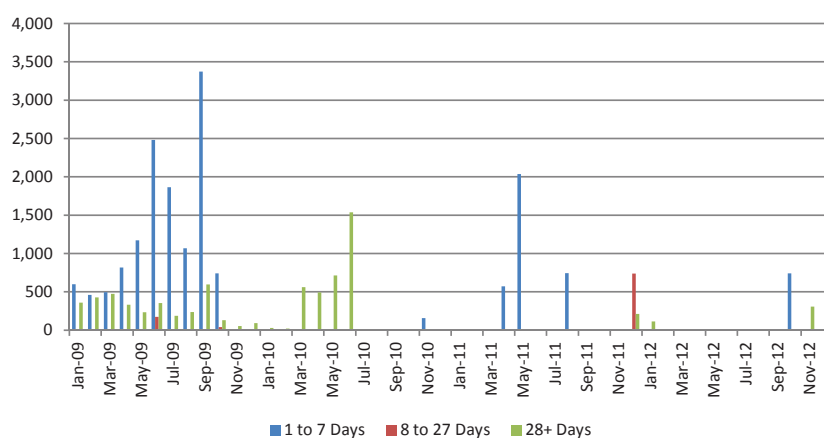
⁸ See De Gregorio (2009b).

⁹ De Gregorio (2009a) states that the original target for the intervention was a US\$ 8 billion purchase. However, the Lehman Brothers shock induced the authorities of the Central Bank to stop it before reaching that target.

¹⁰ See De Gregorio (2009a), page 8.

December 2008 there were no overnight REPO operations. Instead, the majority of the purchases during the last three months of 2008 corresponded to a repurchase length period of 28 days. Also, the minimum maturity length after October 2008 went from 24 hours up to seven days. Clearly, this maturity extension was another way to ease domestic liquidity conditions as a response to international illiquidity conditions. This maturity extension continued until June 2010, as Figure 4 shows.

Figure 4. REPO purchases by the Central Bank of Chile, different maturities, in Millions of Pesos. Period: January 2009-December 2012

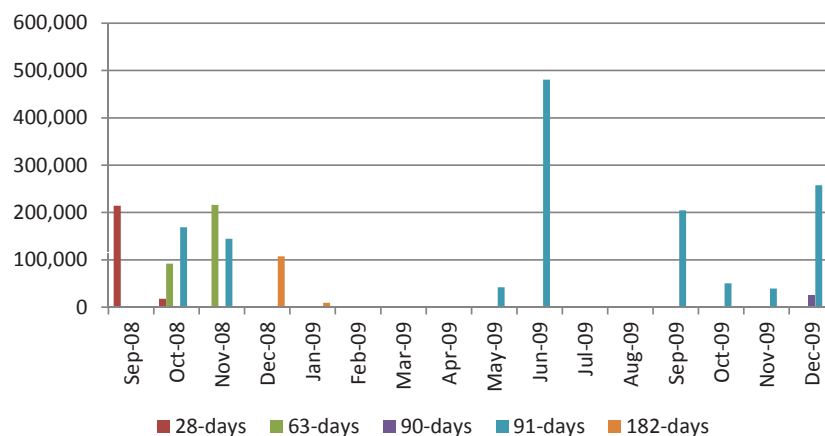


Source: Central Bank of Chile

As a complement of REPOs, the Central Bank implemented a SWAP purchase program beginning September 2008. This program lasted for a shorter period of time, until December 2009. From 2010 onward, there is no official report on this kind of operations by the Central Bank.

Figure 5 illustrates the Central Bank’s swap purchases during the above-mentioned period. These operations added up to Ch\$ 2.07 billion (in nominal units). Out of this total, about 67 percent corresponded to swap purchases with a maturity of 91 days. Only 11.21 percent of this total corresponded to 28-day swap purchases, the shortest term negotiated in this program. Notice that the two main 28-day swap operations were done in the first two months of the program, while most of the 91-day swap purchases were registered during 2009. This difference could be viewed as a consequence of a ”learning process” by the Central Bank. Indeed, by September and October 2008 high uncertainty in international markets arose after the collapse of Lehman Brothers, but that uncertainty may have included how long illiquidity would remain. In such a context, a Central Bank would ease liquidity for very short term periods, waiting for more news to come to either confirm or reverse the negative scenario. Thus, when there was a certain consensus that the illiquidity consequences of the 2008 shocks would remain for most of the following year,

Figure 5. SWAP purchases by the Central Bank of Chile, in millions of pesos



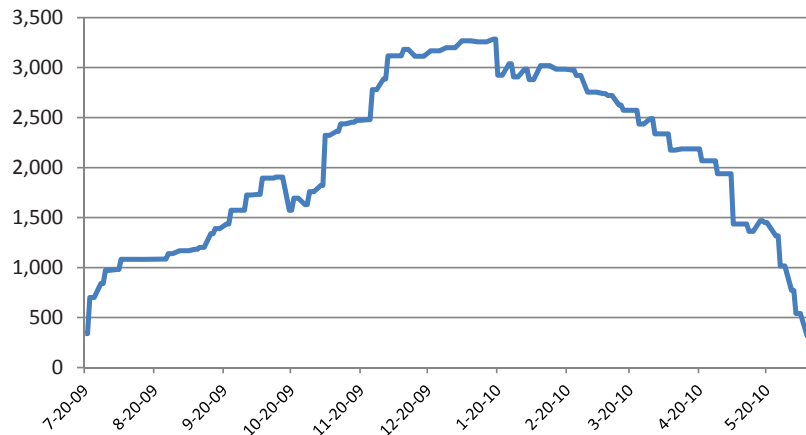
Source: Central Bank of Chile

the Central Bank decided to increase the maturity of these swaps. This may explain both the pattern of the swap purchases as well as the REPO purchase behavior observed in Figure 3.

Another Central Bank decision to ease domestic liquidity conditions was the implementation of a Term Liquidity Program (FLAP) that lasted between July 2009 and June 2010. As stated in Céspedes et al. (2013), this program consisted of a direct short-term (90-day and 180-day) lending program to banks at the prevailing monetary policy rate that complemented other existing programs such as those already mentioned (e.g., repos). The other goal behind the FLAP was related to the fact that the policy rate had reached its lower bound. Therefore, the FLAP also helped as a commitment device for the promise that the policy rate was to remain at its lower bound for a prolonged period of time.

Figure 6 shows the evolution of the standing stock of FLAP given by the Central Bank on a daily basis. It can be seen that the stock reached its peak in January 2010, rapidly decreasing towards 0 by June of that year. Such an evolution seems consistent with the idea of a short-lived program that complemented others that were considered more permanent. In terms of an analysis of its effectiveness, Céspedes et al. (2013) perform an econometric exercise to evaluate the impact of the implementation of this program on asset prices and bank lending. According to their results, this program allowed a drop in the three-month yield of about 50 basis points, while for the one-year yield the drop was in the order of 30 basis points. Corporate spreads also decreased by about 10 basis points. In terms of bank lending behavior, their results stated that a bank that participated in the program presented a loans-to-total-assets ratio 4 percentage points higher than a bank that did not participate in the FLAP. Overall, the implementation of such a short-lived program seemed to have some effectiveness regarding the goal of increasing liquidity.

Figure 6. Daily FLAP standing stock, in billions of pesos



Source: Central Bank of Chile

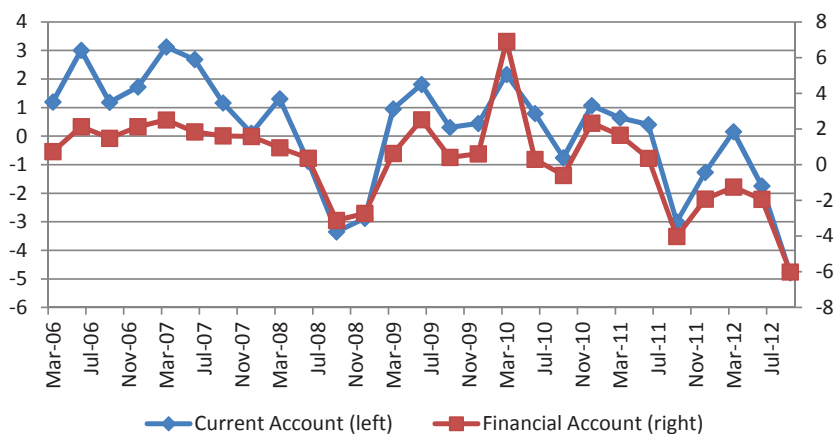
3.2 Back to Normal or the Beginning of a New Cycle? Monetary Policy and Exchange Rate Issues in Chile in the Post-US Financial Crisis Period

Figure 4 above shows that between the second quarter of 2010 and the third quarter of 2011 the Central Bank began to raise the monetary policy rate from 0.50 percent to 5.25 percent, leaving it around that number from that period until the last quarter of 2012. This Central Bank behavior is consistent with the abandonment of the (extraordinary) liquidity programs implemented during the peak of the US crisis mentioned above. Note, however, that the Central Bank did not raise the rate to the values previous to the crisis. This in fact is consistent with the idea that between 2010 and 2012 the pressures from commodity, food and energy prices were not as strong as in 2008.

However, the Chilean economy faced new challenges as some recovery was observed in the international financial markets (at least until the European crisis arose). Already starting from 2009, and especially, in 2010 and until the third quarter of 2011 (when the European crisis began), the financial account presented a surplus (with only the exception of the third quarter of 2010). From that period until the third quarter of 2012, however, the financial account turned to important negative numbers that even implied some deficits for the whole balance of payments during the first and third quarters of 2012. These facts are summarized in Figure 7.

This evolution of capital flows seemed to confirm the idea that the main economists at the Central Bank stressed by the end of the US crisis: the problem in the world recovery phase was the higher volatility in capital flows and the challenge was to determine the way to reduce its consequences in the domestic economy, without implying any substantial change in the inflation

Figure 7. Current Account and Financial Account of Chile, I-2006 to III-2012, in billions of USD



Source: Central Bank of Chile

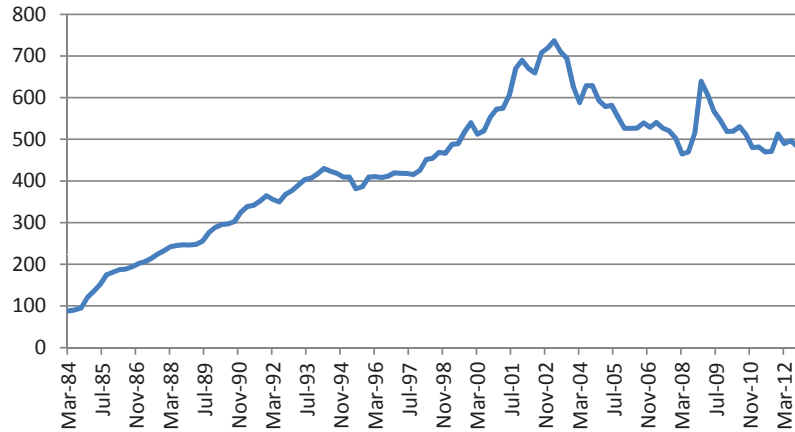
targeting framework.¹¹ Actually, one reaction by the Central Bank when the financial account was still in surplus was a foreign currency purchase intervention program, which was implemented in the same way as the 2008 program: pre-announced daily purchases of US\$ 50 million each. These purchases were all sterilized by the issue of letters and bonds by the Central Bank in order to ensure the achievement of the inflation target of that year. Total foreign currency purchases added up to US\$ 12 billion for the whole year. This foreign reserves accumulation has been seen as part of a “macro-prudential regulation” policy to manage the high volatility of capital flows, as subsequent events seemed to have confirmed.¹² Actually, in the last part of 2012 the pressures in favor of a new intervention increased as both the nominal and the real exchange rate appreciated further, as can be seen in Figure 8.

The fact that most of these interventions are sterilized suggests that the “quasi-fiscal” debt could become a problem. Figure 9 shows the evolution of the monetary base vis-à-vis the stock of non-monetary liabilities (although related to monetary policy decisions). It is clear that the stock of non-monetary debt presented a sudden increase of 47.9 percent in 2011, relative to the 24 percent increase in the monetary base. To avoid typical “monetization” arguments à la Sargent and Wallace (1981), this increase in the stocks of debt instrument issued by the Central Bank should be carefully managed against foreign currency reserves to keep the monetary aggregates under control, thus allowing the inflation targeting policy to remain credible. Otherwise, if this increase in

¹¹ See the discussion in several policy papers by De Gregorio (2010a and 2010b).

¹² For a general discussion on foreign-currency reserves hoarding see De Gregorio (2011a). For the 2011 program see De Gregorio (2011b).

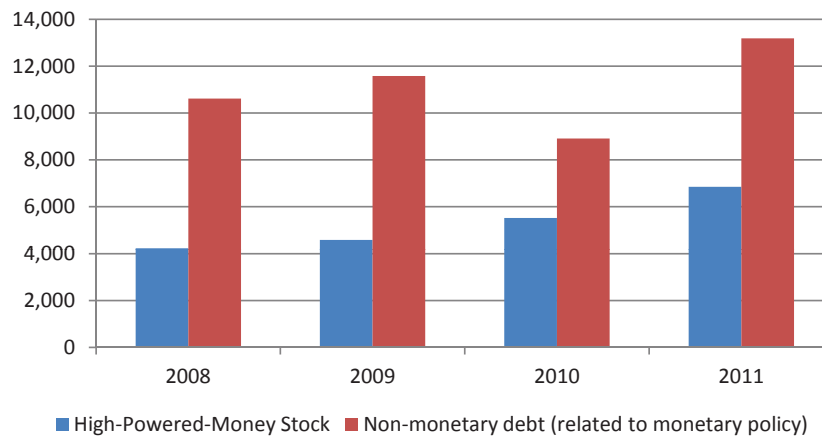
Figure 8. Quarterly real exchange rate index for Chile, I-1984 to IV-2012



Source: Central Bank of Chile

quasi-fiscal debt increases the pressure to monetize it in the future, inflation expectations may start rising. Controlling these expectations is one of the main challenges for Central Bank authorities that follow an inflation target in a more volatile international context.

Figure 9. Central Bank’s monetary base and non-monetary debt, in millions of pesos



Source: Central Bank of Chile

4 Baseline Model

In this and the next sections we present the model-based analysis. In this section we describe the baseline model, i.e., the model containing all the features of the banking system but with a

setup for monetary policy that is meant to capture inflation targeting in normal times, or “conventional” policies. In Section 5 we describe the dynamics implied by the baseline model in response to foreign shocks (interest rate and commodity prices) as well as to monetary policy shocks. In particular, we are interested in analyzing how this model changes the results obtained with specifications in the New Keynesian tradition. In Section 6 we extend the model to consider two different types of policies that go beyond the use of the policy rate, or “unconventional” policies: sterilized exchange-rate interventions and expanding the list of eligible collaterals allowed for operations with the central bank.

In terms of the model, we consider an infinite-horizon, discrete-time economy. There are four agents in this economy: households, firms, banks and the central bank. There are two tradable consumption goods, one domestically produced and one imported. The domestic good is produced using a technology that bundles a continuum of intermediate goods, each of them produced combining labor and imported inputs. There is also an endowment of commodities that is owned by households and that is completely exported. The international prices of imported goods and of commodities are determined abroad.

In each period t the timing of events is as follows.

1. The input markets open (labor and imported inputs). Firms are assumed to pay their inputs costs in advance (i.e., before the goods market opens) and thus they need to borrow a fraction of these costs from banks.
2. The money market opens, where the central bank injects money using open-market operations in exchange for a selected list of assets (in this baseline model, just central bank-issued bonds), under two alternative arrangements: outright purchases or repo agreements.
3. The goods market opens (domestic production and imports). Households face a deposits-in-advance constraint by which their purchases have to be paid using deposits and the cash received as wage payments. Deposits are withdrawn from banks, so they need to have enough cash to cover those withdrawals. In addition, commodities are exported.
4. Dividends are paid, households make new deposits and receive transfers from the central bank. Repo agreements are settled. Assets markets (central bank bonds and foreign bonds) open. Finally, banks decide on their holding of reserves subject to a requirement imposed by the central bank.

In the next subsections we describe each part of the model and present the calibration of the parameters. Appendix A contains the full derivation of the equilibrium conditions as well as the computation of the steady state.

4.1 Households

Households' preferences are represented by

$$E_0 \left\{ \sum_{t=0}^{\infty} \beta^t U(c_t^H, c_t^F, h_t) \right\}, \quad (1)$$

where c_t^H and c_t^F denote, respectively, consumption of home and foreign goods, while h_t represents labor.¹³ Agents enter the period with the right to claim D_{t-1} deposits in pesos from banks. They receive labor income $W_t h_t$ in pesos after the labor market opens. We assume that consumption has to be paid with deposits in pesos and the cash from wage payments. Thus, households are subject to the constraint

$$\alpha^C (S_t P_t^F c_t^F + P_t^H c_t^H) \leq D_{t-1} + W_t h_t, \quad (2)$$

where S_t denotes the nominal exchange rate (pesos per dollar), P_t^H and P_t^F are the prices of home (in pesos) and foreign (in dollars) goods, and $\alpha^C > 0$.

At the end of the period, households decide on deposits for the next period facing the constraint

$$P_t^H c_t^H + S_t P_t^F c_t^F + \frac{D_t}{R_t^D} \leq W_t h_t + D_{t-1} + \Omega_t + T_t. \quad (3)$$

where R_t^D is the gross interest rate associated with deposits, Ω_t are dividends obtained from the ownership of firms and banks, and T_t are transfers from the central bank. Therefore, the household problem is to maximize (1) subject to the sequence of constraints (2) and (3).

4.2 Firms

4.2.1 Intermediate

In this economy there is a continuum of intermediate goods. To simplify notation, each variety is a number in the segment $[0, 1]$. Each intermediate firm produces one particular (variety of) good. The technology for variety i is represented by the following production function:

$$F(h_t^i, x_t^i),$$

where h_t^i denotes the amount of labor used by firm i in period t , and x_t^i denotes the quantity of an imported good (with price equal to P_t^F). Assume that $F(\cdot, \cdot)$ presents constant returns to scale.

We assume that firms need a loan to pay the factors used. As in traditional cash-in-advance-with-liquidity models like Fuerst (1992) and Schlagenhauf and Wrase (1995), the assumption is that, to produce in period t firms need to pay workers and foreign inputs in advance at the beginning

¹³ We use the notational convention that lower-case letters are real variables while upper-case letters are nominal variables. In addition, variables without a time subscript represent steady state values.

of that period. In particular, we assume that firms face the following borrowing constraint,

$$\alpha^L (W_t h_t^i + S_t P_t^F x_t^i) \leq \frac{L_t^i}{R_t^L}. \quad (4)$$

The fraction α^L can be interpreted as a measure of tightness of credit conditions for firms, perhaps reflecting a moral hazard problem between firms and banks.

Profits in domestic currency at the end of period t are given by

$$\Omega_t^i \equiv P_t^i F(h_t^i, x_t^i) - W_t h_t^i - S_t P_t^F x_t^i + \frac{L_t^i}{R_t^L} - L_t^i. \quad (5)$$

Given that credit is completely intra-periodic, the intermediate firm i every period solves the problem of maximizing (5) subject to (4).

4.2.2 Retailers and Final Domestic Goods

There are a continuum of retailers who buy intermediate good i at price P_t^i (taking the price as given), re-packages these goods into retail goods y_t^j and sells them in a monopolistically competitive market to final domestic goods producers. The latter bundles all these varieties into the home good according to the CES production function

$$y_t^H = \left[\int_0^1 (y_t^j)^{1-\frac{1}{\epsilon}} dj \right]^{\frac{\epsilon}{\epsilon-1}}.$$

Therefore, the demand faced by retailers is given by $y_t^j = (P_t^j / P_t^H)^{-\epsilon} y_t^H$, with $(P_t^H)^{1-\epsilon} = \int_0^1 (P_t^j)^{1-\epsilon} dj$. Retailers' profit in each period is then $\Omega_t^j = (P_t^j - P_t^i) y_t^j$. They choose their price each period to maximize the net present value of profits, subject to a staggered price setting as in Calvo (1983), with full indexation to past inflation.¹⁴

4.3 Banks

As mentioned above, the model assumes the presence of financial institutions, called banks, that are owned by households. They extend loans to firms and they hold bonds issued by the central bank and reserves, obtaining funds from households' deposits and from foreigners. Banks face a number of constraints that we merely enumerate here and explain in detail below. First, to obtain liquidity from the central bank, banks need to participate in open market operations, and thus they need to take into account that the central bank may decide to accept certain type of assets and not others for these operations (in the baseline model, only central bank bonds can be used). Second, banks need enough cash to cover for the withdrawals made by households when they enter the goods market. Finally, the central bank imposes minimum reserve requirements.

¹⁴ Under this assumption, the distortion introduced by price dispersion is irrelevant up to first order.

On the asset side of their balance sheet, banks enter the period with holdings of money (reserves) M_{t-1} in pesos and central bank bonds B_{t-1} . On the liabilities side, they have obligations given by deposits D_{t-1} , and foreign debt F_{t-1} denominated in dollars. In the first sub-period, loans are extended to firms (in cash) for the amount $\frac{L_t}{R_t^L}$ and therefore money holdings shrink to $M_{t-1} - \frac{L_t}{R_t^L}$.

In the second sub-period the money market opens. As in Reynard and Schabert (2009), Schabert (2010) and Hörmann and Schabert (2010), money is traded in this market with the central bank in exchange for a selected list of assets (in this baseline case, bonds).¹⁵ These operations can take two forms: outright purchases or repo agreements. Let $\kappa_t \in [0, 1]$ be the fraction of bonds that the central bank decides to purchase and let I_t be the amount of additional domestic currency obtained from the central bank at the beginning of period t . Then, banks face the following constraint

$$I_t \leq \frac{\kappa_t B_{t-1}}{R_t^m}, \quad (6)$$

where R_t^m denotes the interest rate in the money market which, as we will later describe, is the target for monetary policy. After these operations, banks are left with $M_{t-1} - \frac{L_t}{R_t^L} + I_t$ units of pesos and with bond holdings $B_{t-1} - I_t R_t^m$.

In the next sub-period, the goods market opens and households withdraw D_{t-1} . Thus banks need to have enough cash to cover these withdrawals. In other words, they face the constraint,

$$D_{t-1} \leq M_{t-1} - \frac{L_t}{R_t^L} + I_t, \quad (7)$$

After those withdrawals, banks' holdings of money become $M_{t-1} - \frac{L_t}{R_t^L} + I_t - D_{t-1}$.

In the last sub-period banks receive new deposits and repo agreements are settled. Letting B_t^R denote the amount of bonds that are repurchased according to the repo agreements in pesos, money and bonds holdings after this sub-period are $\tilde{M}_t \equiv M_{t-1} + I_t - \frac{L_t}{R_t^L} - D_{t-1} - B_t^R + \frac{D_t}{R_t^D}$, and $\tilde{B}_t \equiv B_{t-1} - I_t R_t^m + B_t^R$.

Finally, asset markets open in which banks sell bond holdings \tilde{B}_t and acquires $\frac{B_t}{R_t^B}$ new bonds. They also repay foreign debt F_{t-1} and get new funds from foreigners $\frac{F_t}{R_t^*}$ (all in dollars), collect loan payments L_t , and decide on money holdings for the next period M_t . Overall, period t

¹⁵ This discount window is very different from that in the “island models” literature such as in Antinolfi et al. (2001) and Antinolfi and Kawamura (2008), where both consider direct lending by the central bank without any explicit collateral requirement and with an implicit perfect enforcement assumption. Given that part of the policies to be analyzed consisted in the relaxation of collateral requirements by central banks, it seems that including this mechanism, although more complex, can better capture how such relaxation implies liquidity provision.

profits (or net-worth) are given by,

$$\Omega_t^b \equiv S_t \left(\frac{F_t}{R_t^*} - F_{t-1} \right) + \tilde{B}_t - \frac{B_t}{R_t^B} + L_t + \tilde{M}_t - M_t.$$

Using the definitions for \tilde{M}_t and \tilde{B}_t given above, we can write

$$\Omega_t^b = S_t \left(\frac{F_t}{R_t^*} - F_{t-1} \right) + B_{t-1} - \frac{B_t}{R_t^B} + \frac{D_t}{R_t^D} - D_{t-1} + L_t \left(1 - \frac{1}{R_t^L} \right) + M_{t-1} - M_t - I_t(R_t^m - 1).$$

This is a standard expression for banks' profits, except for the last term $I_t(R_t^m - 1)$, which represents the cost of acquiring liquidity, and it appears precisely because of the assumption regarding how the money market works in this model.

The goal of banks is to maximize the net present value of these profits, discounted using the nominal stochastic discount factor from households $r_{t,t+s}$, i.e.,

$$E_0 \left\{ \sum_{t=0}^{\infty} r_{0,t} \Omega_t^b \right\}.$$

Banks maximize this objective function subject to money market constraint (6), the withdrawals restriction (7) and an additional constraint: the central bank imposes a minimum-reserve requirement, with δ being the fraction of deposits that need to be backed up with reserves. In other words,

$$M_t \geq \delta D_t. \quad (8)$$

This constraint is similar to that in Edwards and Végh (1997) or Céspedes et al. (2011).

4.4 Central Bank

The central bank injects money through open market operations, creates its own bonds, holds foreign reserves and treasuries (B_t^T , with interest rate R_t^T),¹⁶ and transfers resources to households. The central bank enters the period with holdings of treasuries B_{t-1}^T and dollars given by Z_{t-1} , as well as obligations given by base money (bank reserves deposited at the central bank) M_{t-1} and bonds B_{t-1} . Given the operations previously described, the respective stocks of the latter three before the last sub-period (asset markets) are Z_{t-1} , $\hat{M}_t \equiv M_{t-1} + I_t - B_t^R$ and $\hat{B}_t \equiv B_{t-1} - I_t R_t^m + B_t^R$. Thus, the flow constraint faced by the central bank in the last sub-period is

$$S_t Z_{t-1} + B_{t-1}^T + M_t + \frac{B_t}{R_t^B} = S_t \frac{Z_t}{R_t^*} + \frac{B_t^T}{R_t^T} + \hat{M}_t + \hat{B}_t + T_t,$$

¹⁶ The role of these treasury bonds will become clear below.

or, using the definitions for \hat{M}_t and \hat{B}_t ,

$$S_t Z_{t-1} + B_{t-1}^T + M_t + \frac{B_t}{R_t^B} + I_t(R_t^m - 1) = S_t \frac{Z_t}{R_t^*} + \frac{B_t^T}{R_t^T} + M_{t-1} + B_{t-1} + T_t. \quad (9)$$

There are several variables related to monetary policy: the policy rate (R_t^m), the fraction of bonds allowed for open market operations (κ_t), the amount of pesos held by banks (M_t), money injections (I_t),¹⁷ and the supply of bonds (B_t). The central bank also sets reserve requirements (δ) and decides transfers to households (T_t). Of course, not all these variables are policy instruments, because there are many equilibrium conditions that impose constraints on the behavior of some of these conditional on the others. In what follows we describe how we model the implementation of monetary policy, which is meant to capture policy in normal times (or “conventional” policy).

We assume that the central bank sets the policy rate R_t^m according to a Taylor-type rule,¹⁸

$$\frac{R_t^m}{R^m} = \left(\frac{R_{t-1}^m}{R^m} \right)^{\rho_R} \left[\left(\frac{\pi_t}{\pi} \right)^{\rho_\pi} \left(\frac{y_t^H}{y^H} \right)^{\rho_y} \right]^{1-\rho_R} \varepsilon_t^{R^m}. \quad (10)$$

The fraction κ_t is set to a positive constant. Given these choices, the amount of money injected I_t will be endogenously determined by equation (6). In addition, we assume that the reserve requirement δ is kept at a constant rate.

We also specify that the central bank maintains constant the fraction of money injected under outright purchases. In other words, we set $\frac{M_t - M_{t-1}}{I_t} = \Gamma$, with $\Gamma \in [0, 1]$. Recall that the choice of bank reserves (M_t) is determined by the reserve requirement (8). Therefore, under reasonable calibrations of the model, if all injections were outright then banks may not be able to satisfy the withdrawal constraint (7) if the reserve requirement (8) holds with equality.¹⁹ Therefore, in every period the central bank injects more liquidity than the minimum reserve requirement so that the withdrawal constraint can be satisfied. But as these “extra” injections take the form of intra-periodic repurchase agreements, by the end of the period this “extra” liquidity returns to the central bank and the stock of money held outright (M_t) changes only according to the reserve requirement.²⁰

¹⁷ Notice that the difference between I_t and $M_t - M_{t-1}$ equals the money supplied under repos.

¹⁸ Notice that the interest rate reacts to changes in domestic production and not in GDP, for the former will also be influenced by commodity production, which is exogenous in the model. Recall that variables without time subscripts represent steady state values.

¹⁹ We will later show that, without the reserve requirement, banks will choose not to hold any reserves.

²⁰ A similar assumption, but in a model without banks, is present in Reynard and Schabert (2009), Schabert (2010) and Hörmann and Schabert (2010), where they assume a constant ratio of stock of money supplied under repos (equal to $I_t - M_t + M_{t-1}$ in our model) relative to the stock supplied outright (M_t). Reynard and Schabert (2009) argue that this is consistent with the implementation of monetary policy by the Federal Reserve. Our specification does not exactly match the recent experience in Chile. However, the difference is not related to usual-time or conventional

We assume that the treasury collects lump-sum taxes from households that are simply used to maintain a stock of treasuries that is assumed to grow at a constant rate. These treasuries are held only by the central bank.²¹ In addition, we specify that the central bank uses transfers to rebate to households the profits/losses from money-market operations and also from changes in the valuation of bonds, treasuries and foreign reserves, as in García-Cicco (2011) and Schabert (2010). These assumptions imply that the constraint (9) yields

$$S_t Z_t - S_{t-1} Z_{t-1} + B_t^T - B_{t-1}^T = M_t - M_{t-1} + B_t - B_{t-1}. \quad (11)$$

This equilibrium condition deserves several comments. First, in most models the evolution of the central bank balance sheet is irrelevant for the equilibrium determination. In other words, while it is generally the case that M_t will be a variable showing up in equilibrium, the stock of central bank bonds and the central bank's asset holdings will not appear in other equilibrium conditions. Thus, whenever monetary policy is implemented as an interest-rate rule, the evolution of the stock of money is pinned down by other equilibrium conditions, and an equation like (11) will be irrelevant for the dynamics of other variables. The assumption behind such a result is that either money is dropped from a helicopter, or that open market operations have no costs. In this model, however, this is not the case because obtaining liquidity is costly and banks need to have accumulated bonds in order to acquire it. Therefore, the central bank balance sheet is indeed relevant in equilibrium, for it determines the evolution of B_t , which is relevant as long as the money market constraint (6) holds. In turn, this opens the room to analyze a number of policies that are observed in real life but that cannot be captured with the usual models. This feature is the main result that we borrow from Reynard and Schabert (2009), extended here to a model with banks and in a small open economy framework.

Second, consider the case in which the left-hand side of equation (11) is zero (i.e., the peso value of assets is constant). If that were the case, the equation would state that if, for instance, the stock of money grows over time, the stock of central bank bonds has to decrease by the same amount, reflecting how money is introduced into the economy. In a world with positive steady-state inflation, however, this cannot be the case because nominal variables have to grow, in

policies but rather with the way the Central Bank of Chile manages its liabilities after the implementation of sterilized interventions. We discuss this in more detail below when we analyze the effects of sterilized interventions.

²¹ We could have assumed instead that either banks or households also hold these treasuries. However, as we will not analyze issues related with fiscal policy, this assumption helps to simplify the analysis. Another possibility would have been to assume that only treasuries circulate on the market and that the central bank simply holds some of these in the asset side of its balance sheet (in such a case, the variable B_t^T would indicate private-sector holdings of treasuries while the central bank holdings of treasuries will be $B_t^T - B_t$). In fact, this is how many times monetary policy is modeled, for it represents the way that it is conducted by the Federal Reserve (at least before 2008). However, for many other countries (Chile in particular) central banks implement their operations using their own debt instruments, holding also treasuries on the asset side of its balance sheet.

the long run, at this positive inflation rate; but if the right hand side of (11) is zero then the stock of bonds will need to decrease indefinitely. Therefore in a model like this one, where the central bank balance sheet does play a role in equilibrium, the implementation of a positive inflation target requires asset holdings by the central bank to grow in the long run at a rate equal to the inflation target.²² To satisfy this requirement, we assume that treasuries grow at the long-run inflation rate ($B_t^T/B_{t-1}^T = \pi$) and that the dollar value of foreign reserves are adjusted by the (exogenous) rate of foreign inflation ($Z_t/Z_{t-1} = P_t^F/P_{t-1}^F$).²³ Therefore, even if in a particular period the demand for bank reserves (M_t) does not change, the stock of central bank bonds will still change to compensate for the change in treasuries and foreign reserves.

Finally, notice that although we require foreign reserves to grow by the (exogenous) rate of foreign inflation to implement the long-run inflation target, temporary deviations from this rule can also be considered. These deviations will allow us to consider the effects of sterilized interventions in this model, as we will later analyze.

4.5 Aggregation and Market Clearing

In equilibrium, $h_t = \int_0^1 h_t^i di$, $x_t \equiv \int_0^1 x_t^i di$, and $L_t = \int_0^1 L_t^i di$. Also, given the linear homogeneity of the production function,²⁴ $y_t^h = F(h_t, x_t)$. Letting $c_t^{H*} = y_t^H - c_t^H$ denote exports of home goods, the dollar value of trade balance TB_t can be defined as

$$TB_t \equiv \frac{P_t^H}{S_t} c_t^{H*} + P_t^{Co} y_t^{Co} - P_t^F (c_t^F + x_t), \quad (12)$$

where $P_t^{Co} y_t^{Co}$ are the revenues (in dollars) from commodity exports. We can also define gross domestic product in unit of domestic consumption as

$$gdp_t \equiv \frac{P_t^H}{P_t} y_t^H + \frac{S_t}{P_t} P_t^{Co} y_t^{Co}. \quad (13)$$

Finally, combining households' budget constraint (3) with profits from firms (5) and banks (??), where $\Omega_t = \int_0^1 \Omega_t^i di + \int_0^1 \Omega_t^j dj + \Omega_t^b$, and with transfers from the central bank (9) we obtain the balance of payments equation,

$$\frac{NFL_t}{R_t^*} + TB_t = NFL_{t-1} + \chi P_t^{Co} y_t^{Co}, \quad (14)$$

²² As it turns out, this condition is sufficient but not necessary to attain the long-run inflation target. If this is not the case, to attain its long-run target the central bank would have to set either κ_t or Γ in a particular time-varying fashion. See Proposition 2 in Schabert (2010) for details. We do not consider this case here as this type of fiscal dominance does not seem to be relevant for the Chilean case.

²³ In the long run, as the real exchange rate will be constant in the model, the value in pesos of foreign reserves will grow at the long-run inflation rate.

²⁴ And given the absence of price-dispersion distortions due to full indexation (as explained above).

where $NFL_t = F_t - Z_t$ is net-foreign-liability position of the country, and χ is the share of commodity production owned by foreigners.

4.6 The Rest of the World

The foreign interest rate is

$$R_t^* = \left(\frac{NFL_t}{P_t^F nfl} \right)^\phi R_t^W, \quad (15)$$

where R_t^W is an exogenous process and the term $\left(\frac{NFL_t}{P_t^F nfl} \right)^\phi$ is a debt-elastic country premium that serves as a closing device (see Schmitt-Grohé and Uribe, 2003), and nfl is a parameter describing the value of (real) net foreign liabilities in steady state. In addition, the foreign demand for domestic goods c_t^{H*} is assumed to be equal to

$$c_t^{H*} = \left(\frac{P_t^H}{S_t P_t^F} \right)^\epsilon y_t^*$$

where y_t^* is an exogenous process. Finally, we assume that the commodity price in dollars (P_t^{Co}) follows a unit root process that co-integrates in the long run with P_t^F , which is also exogenous.

4.7 Driving Forces

The exogenous variables in the model are P_t^{Co} , y_t^{Co} , P_t^F , R_t^W and y_t^* . We assume that foreign inflation ($\pi_t^F \equiv \frac{P_t^F}{P_{t-1}^F}$) follows an independent AR(1) process in logs. For commodity prices we assume that $P_t^{Co} = P_t^F \xi_t$, where ξ_t is an independent AR(1) process in logs. The rest of the variables are also assumed to follow independent AR(1) processes in logs, except for the monetary policy shock $\varepsilon_t^{R^m}$ which is i.i.d.

4.8 Interest Rates in Equilibrium: Some Intuition

The main departure of this model from the typical New Keynesian framework comes from the several inequality constraints that agents (banks, in particular) face. This in turn implies that, whenever the constraints are binding, there are going to be spreads between the several interest rates that appear in the model. In this subsection we provide some intuition regarding the conditions under which these constraints bind, and how this is related with the differences between interest rates.

The equilibrium conditions, under the assumption that all the constraints are binding, include the following,²⁵

$$1 = R_t^D E_t \{ r_{t,t+1} (1 + \eta_{t+1}) \}. \quad (16)$$

$$1 = R_t^* E_t \{ r_{t,t+1} \pi_{t+1}^S \}, \quad (17)$$

²⁵ The complete characterization of the equilibrium is presented in the Appendix.

$$1 = R_t^B E_t \{r_{t,t+1}(1 + \nu_{t+1}\kappa_{t+1})\}, \quad (18)$$

$$1 - \vartheta_t \delta_t R_t^D = R_t^D E_t \{r_{t,t+1}(1 + \nu_{t+1})\}, \quad (19)$$

$$1 - \vartheta_t = E_t \{r_{t,t+1}(1 + \nu_{t+1})\}, \quad (20)$$

$$R_t^m(1 + \nu_t) = 1 + \nu_t, \quad (21)$$

$$R_t^L = (1 + \nu_t), \quad (22)$$

where $\pi_t^S = \frac{S_t}{S_{t-1}}$. As mentioned before, $r_{t,t+1}$ denotes the stochastic discount factor for nominal flows coming from households' optimization problem. The variable η_t is the Lagrange multipliers associated with the deposit-in-advance constraints (2) faced by households. In terms of the banks' problem, the multiplier ν_t corresponds to the money market constraint (6), v_t is that related to the withdrawal constraint (7), and ϑ_t is the one related to the reserve requirement (8).²⁶

Equation (16) is the optimal demand for deposits by households. This allows us to relate the gross nominal interest rates on deposits to the fact that deposits-in-advance constraints may be binding or not, as is usual in the cash-in-advance literature. Thus, one way that monetary policy may affect deposit rates is through the consumer's liquidity constraints. Moreover, notice that in steady state the constraint (2) will hold as long as $\beta^{-1} > \frac{R^D}{\pi}$ or, equivalently, if the real rate consistent with intertemporal preferences (β^{-1}) exceeds the real rate offered by deposits ($\frac{R^D}{\pi}$), compensating for the fact that holding deposits makes it possible to satisfy the constraint.

Equations (17) through (22) correspond to the characterization of optimal decisions by private banks. Equation (17) characterizes the optimal decision of foreign debt F_t , (18) characterizes the choice of bond holdings B_t , (19) is the decision for deposits D_t , (20) represents the choice of reserves M_t , (21) is related to money injections I_t , and (22) represents the supply of loans L_t .

We can use these equations to analyze the conditions under which the inequality constraints in the model hold with equality or, equivalently, to check whether the Lagrange multipliers are strictly positive. From (22), the multiplier on the withdrawal constraint (7), v_t , will be positive as long as the lending rate R_t^L is larger than one (i.e., the net rate is positive). This equation states that, while the marginal return from lending is obviously the interest rate, the opportunity cost of lending is that more loans requires having more liquidity in order to satisfy the withdrawal constraint. Thus, as long as the interest rate on loans is positive, the bank will assign a positive value to satisfy that constraint (i.e., $v_t > 0$) and thus it will hold with equality.

Equation (22) also highlights one limitation of our model. As can be seen, the lending rate will only move according to changes in the multiplier v_t . Thus, any change in the model tightening the withdrawal constraint will increase the multiplier and the lending rate, while any shock relaxing

²⁶ Here we have omitted the equation characterizing the choice of loans for firms. That equation reads $R_t^L = 1 + \phi_t$, where ϕ_t is the multiplier associated with the borrowing constraint (4). Clearly, from (22) we have $\phi_t = v_t$.

the constraint will reduce it.²⁷ Of course, we do not claim that this is the only channel affecting the lending rate in reality, and the model could be extended to account for other relevant channels. For instance, financial frictions could be included, either in the relationship between banks and borrowers (e.g., as in Bernanke et al., 1997) or between banks and depositors (e.g., as in Gertler and Karadi, 2011). We leave such an extension for future research and focus in this paper on analyzing the role played by incorporating the liquidity facilities used by the central bank.

Combining equations (19) and (20) we can see that $\vartheta_t = \frac{R_t^D - 1}{R_t^D(1 - \delta_t)}$. Thus, as long as the net deposit rate is positive and the central bank is not required to hold 100 percent reserves, then $\vartheta_t > 0$ and the bank will choose to keep only required reserves. Moreover, from these two equations we can also see that if the central bank does not require banks to hold required reserves (i.e., $\vartheta_t = 0$), the latter will decide not to hold any reserves as long as $R_t^D > 1$.²⁸ This is so because banks can always use the facilities offered by the central bank (I_t) and obtain the required liquidity to satisfy the withdrawal constraint.

In terms of ν_t , combining (21) and (22) shows that it will be positive as long as the lending rate is higher than the money market rate. In other words, banks will choose to take from the liquidity facilities as much as they can according to their bond holdings B_{t-1} , the share of them allowed to be used in these facilities κ_t , and the policy rate R_t^m , as indicated by (6).

Overall, we can see that whether the constraints bind or not in a neighborhood of the steady state will depend on the calibration of the interest rates used. As we explain below, in Chilean data we observe that, on average, $R^m < R^D < R^L$. Thus, the steady-state values of the multipliers will be assigned to replicate these interest rates. As it turns out, under our calibration all the multipliers are positive.

Equation (18) is worth commenting on as well. Combining it with (22), and evaluating them in steady state, we get $R^L = R^B(1 + \nu\kappa)(1 - \vartheta)$. Suppose for the moment that reserve requirements were irrelevant (i.e., $\vartheta = 0$). In that case $R^L > R^B$, reflecting the fact that, because only bonds can be used to obtain liquidity from the central bank's facilities, loans will pay an illiquidity premium in equilibrium. This is important because it leaves the door open for an expansionary effect of a policy that permits the use of other assets (loans in this case) as collateral in these liquidity facilities, by lowering this illiquidity premium in the assets that become eligible.²⁹ More generally, which of these two rates will be lower in steady state will also depend on the value assigned to the reserve requirement constraint (ϑ) which in turn, as discussed above, will

²⁷ One implication of this characteristic is that, in this model, a rise in the reserve requirement will, counterfactually, generate an expansion in the economy. This happens because such a policy change will relax, *ceteris paribus*, the withdrawal constraint as it will force banks to accumulate more reserves.

²⁸ In such a case, the equation (20) will not hold with equality, implying that the implicit constraint $M_t \geq 0$ will hold with equality.

²⁹ This feature is exploited by Hörmann and Schabert (2010) and Schabert (2010) in a closed economy context and without banks.

depend on the values for R^D and δ . Regardless, it will still be true that allowing loans to be used to obtain liquidity will have an expansionary effect by reducing R^L .

Finally, while the goal of this paper is not to provide a thorough welfare-based analysis of optimal policies (as in, for instance, Schmitt-Grohé and Uribe, 2010, or Woodford, 2010), the previous analysis can also be used to understand the goals for optimal policy in the long run. In this economy, there are several inefficiencies that a Ramsey planner would like to eliminate. On one hand, as in most New Keynesian models, we have monopoly power and price dispersions.³⁰ On the other hand, all the constraint appearing in the model would not appear in the Ramsey problem. These are the deposit in advance, borrowing, money market, withdrawal and reserve-requirement constraints. In most of the models in the literature, where there is only one monetary instrument available, there is in general a trade-off to achieve the Ramsey allocation in steady state because the elimination of price dispersion calls for zero inflation, while the elimination of a cash-in-advance constraint calls for the Friedman rule (zero nominal interest rate), which in turns requires negative inflation. Such a trade-off, however, is not present in this model because the policy rate (R^m) is not the same as the rate affecting the cost of holding deposits (R^D), as we now describe.³¹

As stated above, the inefficiencies induced by price dispersion can be eliminated by setting long-run inflation equal to zero ($\pi = 1$). The optimal depreciation rate (π^S) is then the inverse of foreign inflation, given that PPP holds in the long run. The elimination of the distortion generated by the borrowing constraint requires eliminating the cost of borrowing (i.e., $R^L = 1$). From equation (22), we see that if $R^L = 1$ the withdrawal constraint ceases to bind, which is also required by the Ramsey planner. Then, from (21), if $R^L = 1$, the policy rate can be set to zero ($R^m = 1$) and in that way the money market constraint will not be binding. From equation (16), we see that the deposit in advance constraint is not binding if $R^D = \beta^{-1}\pi$ which in turn, given (17), is also equal to $\frac{R^*}{\pi^S}$. In addition, eliminating the reserve-requirement constraint requires $\delta = 0$. Finally, from (18), in the equilibrium that replicates the Ramsey allocation we require $R^B = R^D$. Notice that in such an equilibrium κ and Γ are not relevant to achieving the Ramsey allocation although, as previously discussed, κ and Γ might be relevant to implement the long-run inflation target if fiscal policy (i.e., the growth rate of treasury holdings) is not consistent with long-run inflation.

While this analysis helps in understanding how the model works, it also highlights some of the limitations of the model, and the reason why we do not pursue in this paper the goal of welfare-based analysis. First, one of the inefficiencies in the model is induced by policy whenever $\delta > 0$. Therefore, given that the model does not include a feature that will make $\delta > 0$ desirable, the

³⁰ Assume, as in most of the literature, that there is a subsidy that offsets monopoly power.

³¹ Schabert (2010) provides a detailed analysis in a simplified model of a closed economy without banks, but with money market constraints as in our case.

optimal policy under the constraint that $\delta > 0$ (as observed in real life) would never be able to attain the Ramsey allocation. In addition, as the model does not feature financial frictions (as discussed above), the optimal policy requires $R^L = 1$. But if we were to model a financial friction this would probably not be the case as a positive lending rate would help to overcome some informational friction that is also an inefficiency for the economy. Therefore, given the limitation of the model, it is not clear that a thorough welfare-based analysis of optimal policy, while well defined, will be a meaningful exercise, and thus we leave such an analysis for future research once other features are added to the model.

4.9 Functional Forms and Calibration

In terms of the instantaneous utility function, we assume

$$U(c_t^H, c_t^F, h_t) = \frac{c_t^{1-\sigma}}{1-\sigma} - \psi \frac{h_t^{1+\varphi}}{1+\varphi},$$

with

$$c_t = \left[\omega^{1/\mu} (c_t^H)^{1-1/\mu} + (1-\omega)^{1/\mu} (c_t^F)^{1-1/\mu} \right]^{\frac{\mu}{\mu-1}}, \quad (23)$$

For the production function we use,

$$F(h_t^i, x_t^i) = (h_t^i)^\gamma (x_t^i)^{1-\gamma}. \quad (24)$$

The time unit is set to a quarter. Tables 1 and 2 present the values of the parameters. As the model features a number of parameters that are also present in models in the New Keynesian tradition, we borrow from previous studies that have estimated these using Chilean data. The main reference in this respect is the work by Medina and Soto (2007), who estimated a medium-scale DSGE model for the Chilean economy, and that is the core of the DSGE model used by the Central Bank of Chile for the forecast published in its Monetary Policy Report.³²

The rest of the parameters, including those that are specific to this model, were calibrated to match several steady-state values of endogenous variables to figures from Chilean data. These parameters are those indicated as “endogenous” in the source column.³³ The moments that we choose from the data are the following. We set the steady-state inflation rate at 3 percent on an annual basis, which corresponds to the target for inflation in Chile since 2001. We also select the steady state values for R^* , R^m , R^D and R^L to, respectively, 3.42 percent, 3.96 percent, 4.2 percent and 7.88 percent, as observed on average between 2001 and 2012. In addition, we chose a steady-

³² The only difference with the parametrization in that paper is that we choose a value for the elasticity of the country premium to 0.0001, while they estimate a higher value of 0.01. We do this to isolate the effects of the new channels that we present in this model.

³³ The mapping between parameters and targeted steady state values is not always one to one, so we ran a minimum-distance routine to obtain some of these values.

Table 1. Calibration

| Parameter | Description | Value | Source |
|-----------------------|---------------------------------------|--------|---|
| <i>Households</i> | | | |
| β | Discount factor | 0.978 | Endogenous |
| σ | Risk Aversion | 1 | Medina and Soto (2007) |
| φ | Inverse Frisch elast. | 0.84 | Medina and Soto (2007) |
| ψ | Scaling of labor dis-utility | 6.5 | Endogenous |
| α^C | Deposit-in-adv. Constraint | 1.39 | Endogenous |
| ω | Share of c_t^H in c_t | 0.64 | Medina and Soto (2007) |
| μ | E.o.S. between c_t^H and c_t^F | 1.12 | Medina and Soto (2007) |
| χ | Share of y^{Co} owned by foreigners | 0.5 | Medina and Soto (2007) |
| <i>Firms</i> | | | |
| γ | Share of h_t in y_t^H | 0.66 | Medina and Soto (2007) |
| θ | Calvo price probability | 0.74 | Medina and Soto (2007) |
| ϵ | E.o.S. between varieties of y_t^H | 11 | Medina and Soto (2007) |
| α^L | Borrowing constraint | 1.87 | Endogenous |
| <i>Closing device</i> | | | |
| ϕ | Elast. country premium | 0.0001 | Normalization |
| <i>Policy</i> | | | |
| R^m | S.S. value of R_t^m | 1.0098 | Average MPR (01-12, Annual 3.96%) |
| ρ_R | Response of R_t^m to R_{t-1}^m | 0.74 | Medina and Soto (2007) |
| ρ_π | Response of R_t^m to π_t | 1.67 | Medina and Soto (2007) |
| ρ_y | Response of R_t^m to gdp_t | 0.39 | Medina and Soto (2007) |
| Γ | Share of outright to repo injections | 0.0064 | Endogenous |
| κ | Share of bonds used for injections | 1 | Normalization |
| δ | Reserve requirement | 0.036 | According to Chilean regulation for term deposits |

Note: Whenever the source for one parameter is indicated as “endogenous” it means that the particular value is chosen so that, in steady state, a given value of a variable (or a ratio) matches the chosen value from the Chilean data.

state ratio of deposits to GDP of 0.4 and we set the ratio of loans to GDP to 1.5, both to match their average in the data from 2003 to 2012. Because deposits in the model mature in one quarter, we contrast the model with data for up-to-3-months deposits in pesos. Also, given that in the model loans are taken by firms, we use as data-counterpart information from commercial loans.³⁴

We also include information from the trade balance and copper production. In particular, we choose a 7 percent share of the trade balance in GDP, a fraction of GDP corresponding to copper

³⁴ Unfortunately, there is no information discriminating commercial loans according to their maturity structure.

Table 2. Calibration, cont.

| Parameter | Description | Value | Source |
|-------------------------------------|---|--------|--|
| <i>Driving Forces</i> | | | |
| $\rho_{p^{Co}}$ | Autocorr. p_t^{Co} | 0.9428 | Estimated |
| $\rho_{y^{Co}}$ | Autocorr. y_t^{Co} | 0.4794 | Estimated |
| ρ_{R^W} | Autocorr. R_t^W | 0.9045 | Estimated |
| ρ_{y^*} | Autocorr. y_t^* | 0.8346 | Estimated |
| ρ_{π^F} | Autocorr. π_t^F | 0.3806 | Estimated |
| $\sigma_{p^{Co}}$ | St.Dev. of shock to p_t^{Co} | 0.1362 | Estimated |
| $\sigma_{y^{Co}}$ | St.Dev. of shock to y_t^{Co} | 0.0293 | Estimated |
| σ_{R^W} | St.Dev. of shock to R_t^W | 0.0011 | Estimated |
| σ_{y^*} | St.Dev. of shock to y_t^* | 0.0060 | Estimated |
| σ_{π^F} | St.Dev. of shock to π_t^F | 0.0273 | Estimated |
| σ_{R^m} | St.Dev. of shock to R_t^m | 0.012 | Medina and Soto (2007) |
| <i>Other Calibrated S.S. values</i> | | | |
| h | S.S. value of h_t | 0.3 | Normalization |
| TB/GDP | Trade balance to output ratio | 0.07 | Average in data (01-12) |
| Y^{Co}/GDP | Share of copper in GDP | 0.1 | Average in data (01-12) |
| Y^{Co}/X^{H*} | Share of copper to other exports | 1.01 | Average in data (01-12) |
| y^* | S.S. value of y_t^* | 2.2 | Endogenous |
| y^{Co} | S.S. value of y_t^{Co} | 0.46 | Endogenous |
| R^* | S.S. value of R_t^* | 1.0084 | Average FF rate + EMBIG (01-12, Annual 3.42%) |
| R^D | S.S. value of R_t^D | 1.0192 | Average deposit rate up to 90 days (01-12, Annual 4.2%) |
| R^L | S.S. value of R_t^L | 1.0103 | Average Commercial loan rate (01-12, Annual 7.88%) |
| π | S.S. value of π_t | 1.0074 | Inflation Target since 2001 (Annual 3%) |
| Z/B^T | Foreign reserves to treasury holdings by the Central Bank | 3 | Average in data (01-12) |
| D/GDP | Deposits to GDP | 0.4 | Average ratio of Deposits in Pesos up to 3 months to GDP (03-12) |
| L/GDP | Loans to GDP | 1.5 | Average ratio of Commercial loans in Pesos to GDP (03-12) |

production of 10 percent and a ratio of copper exports to other exports of 1.01, all reflecting the average of these variables between 2001 and 2012. We also choose a ratio of foreign reserves to treasury holdings by the central bank of 3, matching the average ratio of the net external position to other assets according to data from the Central Bank of Chile balance sheet, and we normalize the number of hours worked to 0.3. Finally, the parameters describing the exogenous processes for external variables are estimated using quarterly data from 2001 to 2012. In particular, the external

interest rate (R_t^W) is measured as the sum of the Federal Funds rate plus the J.P Morgan EMBI spread for Chile, foreign inflation ($\pi_t^F = P_t^F / P_{t-1}^F$) is measured by the price index (in dollars) for Chile's commercial partners, foreign activity (y_t^*) is the GDP for Chile's commercial partners (HP filtered), the price of commodities is the price of copper in the LME Market, and domestic production of commodities (y_t^{Co}) is measured as mining GDP (HP filtered).

The solution of the model is approximated using a first-order perturbation approach (log-linearization) around the non-stochastic steady state, assuming that all the constraints are binding in the neighborhood of the steady state. Before proceeding with the study of the dynamics generated by the model and the different policy exercises, we grasp the goodness of fit of the model and the chosen calibration by comparing moments computed using Chilean data to those generated by the model.³⁵ In performing this comparison, it is important to keep in mind that it is not our goal to produce a thorough estimation exercise (nor do we claim that our highly stylized model is up to that challenge).

Table 3. Moments

| Variable | Std. dev. (in %) | | | AC(1) | | |
|------------------|------------------|--------|-------|-------|--------|-------|
| | Data | | Model | Data | | Model |
| gdp_t | 1.81 | (0.17) | 2.05 | 0.86 | (0.15) | 0.66 |
| c_t | 1.62 | (0.15) | 1.36 | 0.89 | (0.17) | 0.60 |
| π_t | 0.72 | (0.09) | 0.74 | 0.63 | (0.21) | 0.62 |
| R_t^m | 2.01 | (0.18) | 1.83 | 0.85 | (0.14) | 0.64 |
| p_t^F | 5.32 | (0.49) | 0.25 | 0.71 | (0.16) | 0.96 |
| π_t^S | 5.68 | (1.08) | 3.38 | 0.22 | (0.19) | 0.32 |
| $spread_t^{L,D}$ | 1.25 | (0.21) | 4.04 | 0.73 | (0.26) | 0.01 |

Note: The first three columns present standard deviations in percentage terms, and the last three display first-order autocorrelations. GMM standard errors in parenthesis.

As can be seen from Table 3, the model generates a slightly higher variance of GDP and a somehow smaller variance of consumption, although both are reasonably close if we consider the GMM standard errors for the data moments. The variances of CPI inflation, the monetary policy rate and the nominal exchange rate are also close to the data. In contrast, the model cannot properly account for the volatility of the real exchange rate and the spread, and it also has problems

³⁵ The data is quarterly and it ranges from 2001 to 2012. gdp_t is measured as the real GDP (in logs and HP filtered), c_t is non-durable private consumption (in logs and HP filtered), π_t is CPI inflation (in logs), R_t^m is the monetary policy rate, p_t^F is the multilateral real exchange rate (in logs), π_t^S is the nominal depreciation of the CLP against the USD (in logs), and $spread_t^{L,D}$ is the spread between the interest rate of commercial loans and that of 90-day deposits. The source of the data is the Central Bank of Chile. To compute the model moments, a simulation of 2,000 periods was run and the last 500 observations were used to compute the moments, transforming the model-generated series in the same way as we did with the data.

replicating the persistence of the series observed in the data. However, it is important to keep in mind that the model does not include many of the features that are usually added in the estimated-DSGE literature (see, for instance, Aldolfson et al., 2007, for a small open economy model) and that could help to improve the fit of the model along these dimensions (e.g., habits in consumption, investment and investment adjustment costs, capital utilization, delayed overshooting, etc.). Overall, the fit of the model is quite decent given that we did not estimate the parameters of the model to match these facts, nor did we include many of the propagation mechanisms or the variety of “extra” shocks that are usually incorporated in the estimated-DSGE literature.

5 Dynamics under “Conventional” Monetary Policy

We begin the quantitative analysis by studying the responses implied by the model to three different shocks: a rise in the world interest rate, an increase in the international price of commodities, and a shock to the domestic monetary policy rate. The first two are of interest due to their importance as business cycles drivers in small open economies (Chile in particular), while studying the last one will shed light on the transmission of monetary policy.

Given that the baseline model adds many features relative to more traditional models, we compare the responses with those obtained under two alternative models of a small open economy. On one hand, we consider a New Keynesian framework (NK for short), i.e., the baseline model without banks (and hence no reserve requirements), no constraints for obtaining liquidity, no borrowing constraints for firms and no demand for liquidity. This last characteristic is consistent with the modeling strategy referred to as the cashless limit, which was the most common choice before 2008, particularly in DSGE models used at central banks. On the other hand, we also consider a New Keynesian model with cash-in-advance and borrowing constraints for firms (which we label CIA-BC).³⁶ However, although this model features borrowing by firms, there is no borrowing-lending spread. We maintain the same calibration for the parameters described before for these two models.

One common feature of these two alternatives models is that the monetary policy rate is the rate on the one-period domestic bond. In contrast, in the baseline model the policy rate is an intra-periodic one, corresponding to that used in open market operations. This is an important difference that, arguably, is a more realistic assumption for monetary policy implementation: the target of monetary policy is not usually a rate from a short-term bond but, instead, that of a monetary market, such as the interbank or the repo market. And while it is true that in these operations treasuries and/or central-bank bonds are generally exchanged for liquidity, the interest rate charged for these operations does not need to (and generally it does not) coincide with that of these assets.

³⁶ The cash-in-advance constraint in this model is $\alpha^C(S_t P_t^F c_t^F + P_t^H c_t^H) \leq \tilde{M}_{t-1} + W_t h_t - \frac{L}{R_t^B}$, where \tilde{M}_{t-1} denotes the demand for money, which differs from M_t in the baseline model as we discuss below. The borrowing constraint for firms is the same as in the baseline, equation (4).

Another relevant difference between the baseline and these two alternative models is that in the latter the central bank balance sheet plays no role in determining the equilibrium dynamics. In the NK framework this is obvious because it is a cashless framework, and in the CIA-BC model, although money demand is well defined, how changes in the stock of money modify the stock of other assets and liabilities of the central bank balance sheet is not relevant. In contrast, in the baseline model this is not the case, a feature brought about by the constraint on obtaining liquidity, equation (6).

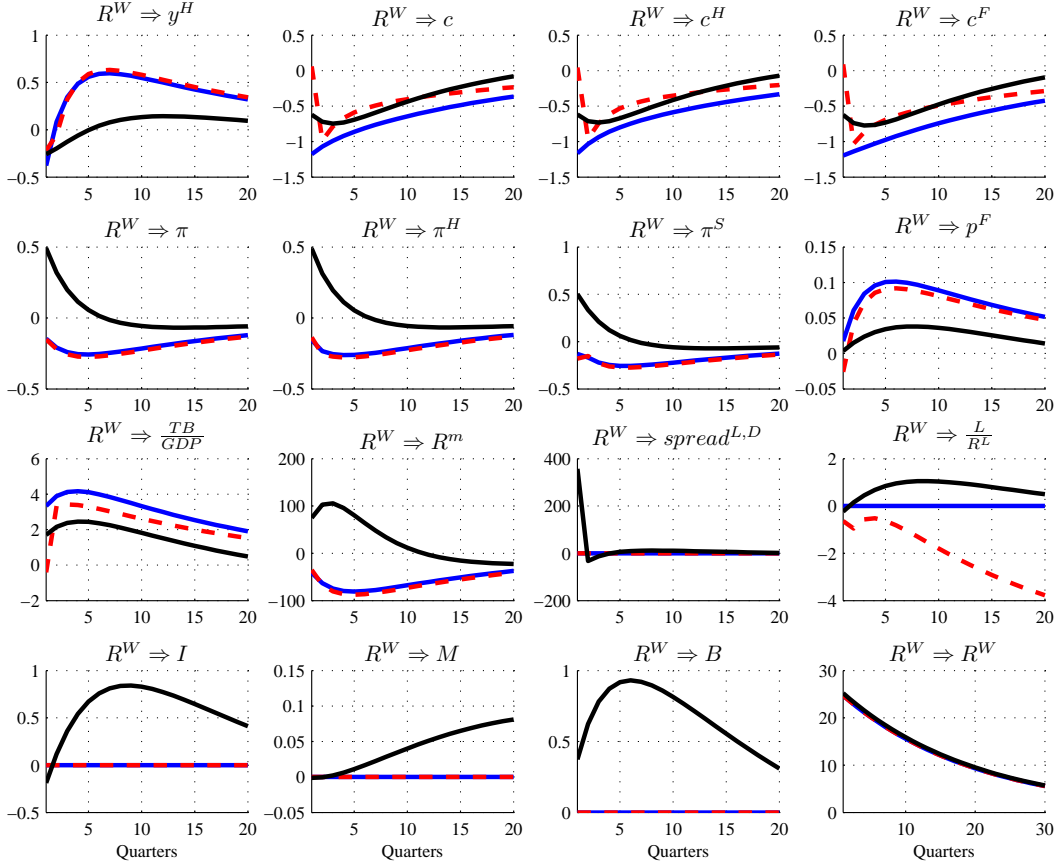
A final difference that is worth highlighting is that concepts like liquidity and money demand and supply have different meanings in the CIA-BC and in the baseline model. In the CIA-BC setup all three objects are the same: liquidity demand is determined by the constraint, this need is satisfied using “money” (which might mean either cash or a bank account paying no interest) and the supply of money is the same thing. In our model, the liquidity demand for households is determined by the same constraint, but for banks it is the difference between the deposits that are withdrawn and the required reserves kept. Moreover, money supply can take two forms: outright and repo operations, and what appears in the central bank balance sheet between one period and the next are the required reserves. Another way to state this difference is that our model features a money multiplier that is closer to what is usually described in introductory textbooks but that in most models is simply equal to one.

Figure 10 displays the responses of selected variables to a shock that increases the world interest rate by 25 annualized basis points. The dashed and dotted blue lines display the responses from the NK framework, the dashed red lines are from the CIA-BC setup, and the solid black lines are those from the baseline model. We begin by discussing the NK and CIA-BC. This shock propagates through both inter-temporal and negative wealth effects; the former appearing because, in our calibration, the country is a net foreign borrower in steady state. These two will tend to decrease consumption demand for all goods and to induce a real depreciation, while domestic production would probably rise as labor supply increases.³⁷ In addition, the trade balance improves. If we add price rigidities, the fall in aggregate demand leads to a drop in inflation, which in the short run attenuates the response of domestic production. As inflation drops, the policy rule implies a reduction in the domestic rate. Finally, as the domestic rate drops but the foreign rate rises, the nominal exchange rate needs to appreciate.

As we can see from the figure, both the NK and CIA-BC replicate these intuitive responses. A difference between them in the short run is the response of consumption (and thus the trade balance): as the domestic rate drops on impact, induced by the response of monetary policy, the shadow value of consumption from households’ perspective (that includes the nominal rate due to

³⁷ However, the effect of a rising labor supply on production is ameliorated because the other productive factor (imported inputs) becomes more expensive in real terms given the real depreciation.

Figure 10. Response to a R^W shock under conventional policy



Note: The solid-blue lines correspond to the simple New Keynesian model, the dashed red lines are from the New Keynesian model with cash-in-advance and borrowing constraints, and the solid black lines are from the baseline model. The responses are deviations from steady state with the following units of measure: y^H , c , c^H , c^F , c^F , L , I , M , B , and p^{Co} , are in percentage deviations, π , π^H , π^S , and $\frac{TB}{GDP}$ are in percentage-point deviations, R^W and R^m are in annualized basis points deviations, and $spread^{L,D}$ is in basis points deviations. The shock corresponds to an increase of 25 annualized basis points in the world interest rates.

the CIA constraint) is reduced and, on impact, it compensates the negative effect of consumption. Notice also that the fact that firms need to borrow does not significantly alter the responses. This is because we have assumed that this is domestic borrowing. If, instead, firms were to borrow abroad, the rise in the foreign rate should contract the demand for productive inputs, reducing the medium-term increase in output or even leading to persistent contraction. Finally, the CIA-BC also has a prediction for the behavior of loans. As we can see, in nominal terms loans fall after the shock, which happens because home inflation drops and also due to nominal appreciation (actually, the real value of loans slightly increases led by the rise in hours worked).

The responses are markedly different under the baseline model, both quantitative and qualitatively. In our model, while it is true that consumption drops and there is real depreciation, this drop in aggregate demand leads to an increase in the lending-deposit spread. This, in turn, leads to a more prolonged contraction on output, as the rise in the lending rate increases the marginal cost of production. Moreover, this increase in marginal costs induces an increase in inflation despite the drop in aggregate demand.³⁸ This channel was not present in the other models because the rate relevant for the firm's lending was also the monetary policy rate, which in those two models falls in equilibrium. Moreover, in this model the policy rule dictates a rise in the policy rate, in response to the rise in inflation. And because this increase is larger than the rise in the foreign rate, the nominal exchange rate actually depreciates. Therefore, in this model the required real depreciation comes about by a nominal depreciation instead of by a fall in inflation as was the case in the two previous models.

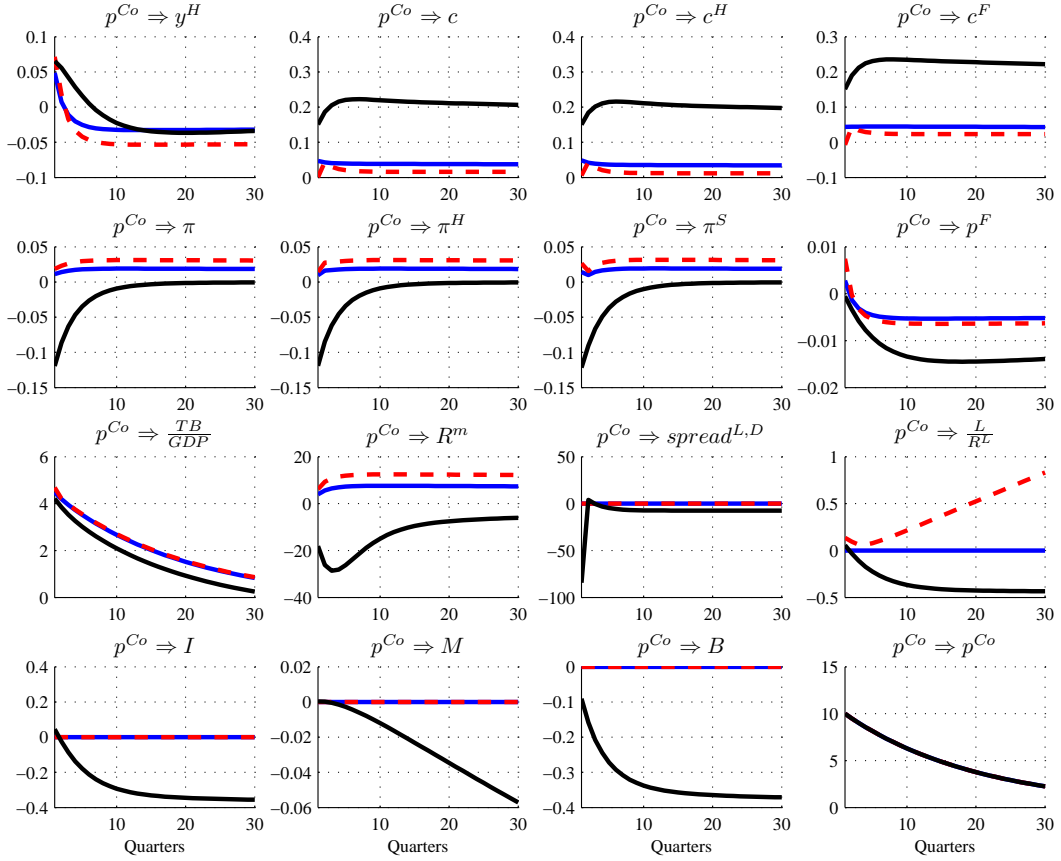
In terms of nominal quantities, we can see the the nominal value of loans falls slightly on impact and then rises. The real value of loans (not shown) decreases in this case, as the demand for both inputs contracts, but the increase in inflation and the nominal depreciation yield the rise in nominal terms. Deposits in nominal terms (not shown) also fall somewhat on impact but then rise, which can be seen from the fact that inflation rises by more than consumption. These two responses dictate that injections should fall slightly on impact but then increase. But because reserves only rise slightly (following the behavior of deposits) this extra liquidity is provided by repo operations and, consistently, the stock of central bank bonds also rises in equilibrium.

Figure 11 shows the responses to a 10 percent increase in the international relative price of commodities, keeping world inflation constant. The shock is quite persistent according to our calibration, reflecting the behavior of the copper price observed in the data. Intuitively, this shock propagates by a positive wealth effect (which is quite substantial given the persistence of the shock). This increases consumption demand and reduces labor supply, the latter probably generating a contraction in domestic production. Moreover, the real exchange rate appreciates due to this wealth effect and the trade balance improves. Both the NK and CIA-BC models display these features, although the real exchange rate depreciates slightly on impact. Due to price rigidities, the rise in aggregate demand increases inflation of domestic goods and, in response, the monetary policy rate rises. Moreover, given the increase in the domestic rate, and because the foreign rate is constant, the domestic currency depreciates in nominal terms. Finally, the rise in inflation increases, in the short run, domestic production and thus, on impact, domestic production rises but then falls.

As before, the differences between these two models is mainly driven by the effect that the rise in the policy rate has on consumption due to the CIA constraint. However, the borrowing

³⁸ Recall that in the Calvo price-setting framework, the price set by those that have the chance to do so will be a weighted average of the future stream of marginal costs.

Figure 11. Response to a p^{Co} shock under conventional policy



Note: See figure 10. The shock corresponds to an increase of 10% in the international relative price of commodities, keeping world inflation constant.

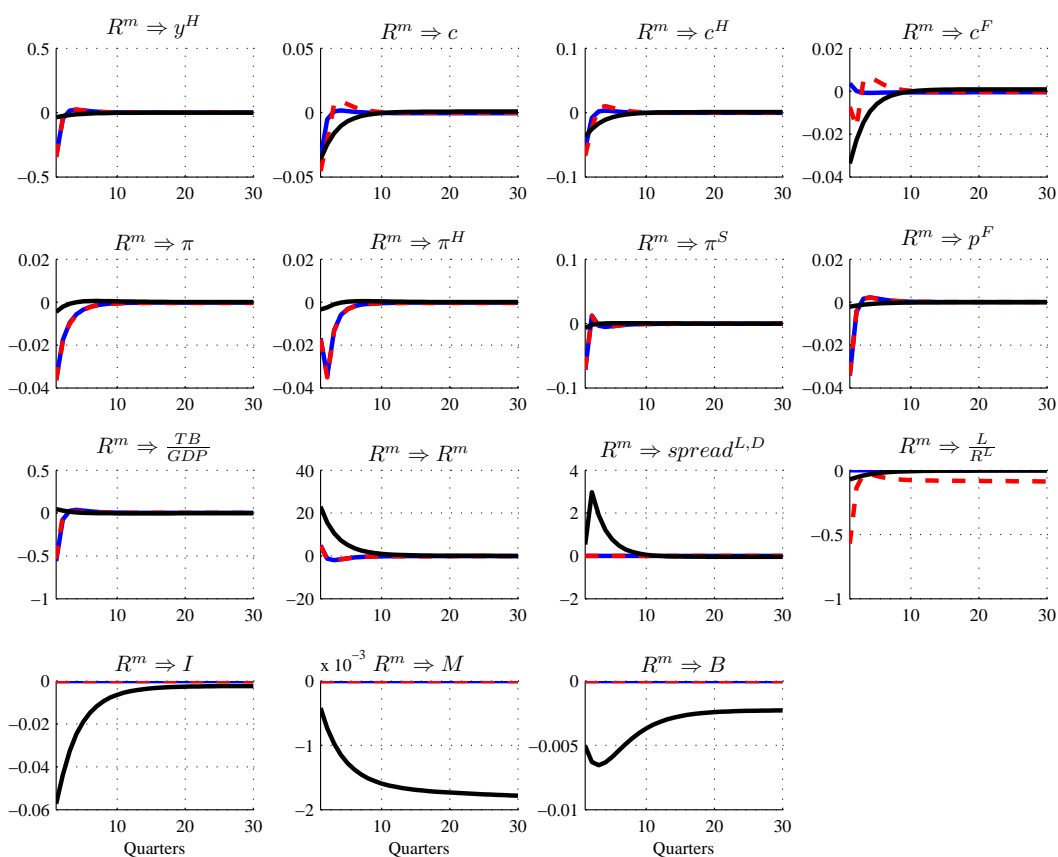
constraint channel, that should act by contracting the supply of inputs due to the interest rate spike, does not seem to quantitatively add much to the dynamics.

Once again, the baseline model displays contrasting responses. The improvement in aggregate demand lowers the lending-deposit spread, motivating a reduction on marginal cost. Therefore, on one hand, the demand for productive inputs increases,³⁹ leading to a more persistent equilibrium rise in domestic production. On the other hand, inflation drops as marginal costs fall. Monetary policy then responds by lowering the policy rate and, as a by-product, the nominal exchange rate depreciates. All these features further increase households' wealth, and therefore the increase in consumption is larger in the baseline model, as well as in real exchange rate appreciation. Finally, nominal quantities all show reductions over time because, although the real value of

³⁹ Actually, hours worked in equilibrium, as well as intermediate inputs, increase by much more in this case than in the other two, where they rise only slightly.

consumption (deposits) and inputs (borrowing) rise, deflation and nominal appreciation dominate in equilibrium.

Figure 12. Response to a R^m shock under conventional policy



Note: See figure 10. The shock corresponds to an innovation in the policy rule that, *ceteris paribus*, rises the policy rate by 25 annualized basis points.

The final set of responses, depicted in Figure 12, correspond to the dynamics generated by an i.i.d. innovation to the monetary policy rule that, *ceteris paribus*, increases the policy rate by 25 annualized basis points. The intuition behind this shock is quite familiar: under sticky prices and the Taylor principle, the rise in the nominal rate increases the real rate, reducing aggregate demand, reducing both output and inflation, and inducing both nominal and real appreciations.

Qualitatively, the three models display these patterns, but quantitatively there are important differences. First, notice that the impact response in aggregate consumption is similar in the three frameworks. However, the response in inflation differs due to the influence of the rising spread on marginal costs. Thus, in the baseline model, this rise in marginal cost ameliorates the

fall in inflation brought about by the contraction in aggregate demand,⁴⁰ although the former still dominates. Moreover, the lower negative impact on inflation is also relevant to understanding the milder contraction in domestic production. In addition, both the real and nominal appreciations are smaller in the baseline. Finally, in the baseline model all nominal quantities move according to the contraction in liquidity generated by the rise in the policy rate.

We conclude this section by highlighting that in order to understand the propagation of these shocks in the baseline model, the most important feature of this setup relative to those in the CIA-BC model seems to be the change in the lending-deposit spread. The additional feature – the modeling of the money market– appears to be only relevant to study the evolution of the nominal quantities in the central-bank balance sheet. However, this other component of the model will be relevant in understanding the role of “unconventional” policies, which is the object of study in the following section.

6 “Unconventional” Monetary Policies

In this section we discuss the effects of two alternative monetary policies that depart from the simple management of the policy rate according to the Taylor rule: sterilized interventions and expanding the list of eligible collateral in operations with the central bank, and the active use of reserves requirement. As we already discussed, this type of policies have been implemented in Chile in the past. While in standard models, such as the NK and the CIA-BC analyzed in the previous section, these policies generate no effect in equilibrium, the baseline model can be modified to evaluate these alternatives.

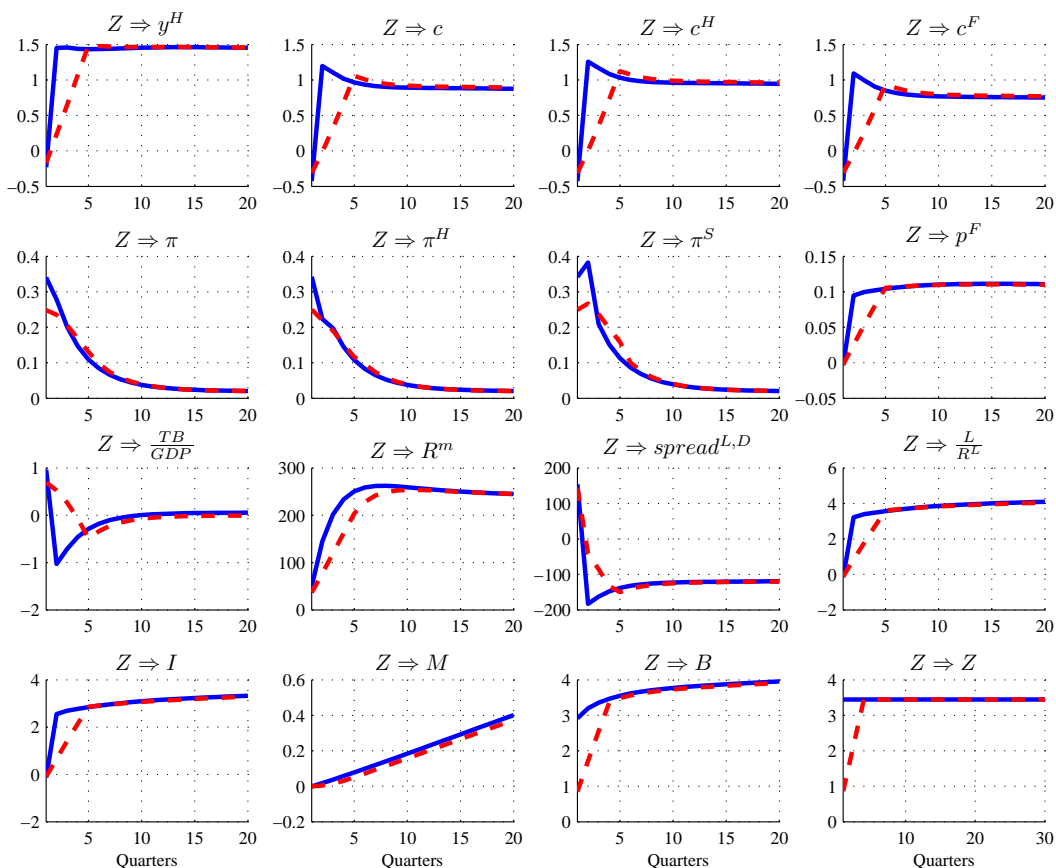
6.1 *Sterilized Interventions*

In the baseline model we assumed that the stock of foreign reserves held by the central bank (Z_t) grew at a rate equal to the (exogenous) rate of foreign inflation. As we discussed, this condition is sufficient (in addition to that regarding B_t^T) to guarantee that the target for inflation will be met in the long run. In the short run, however, we can consider temporary deviations. Moreover, as the stock of money (M_t) that appears in the central bank balance sheet is determined by the reserve requirement δ , changes in Z_t have to be financed by either changes in central bank debt B_t or in the central bank’s treasury holdings B_t^T . Given the assumptions of the model (in particular, that treasuries cannot be used in obtaining liquidity) changes in Z_t compensated by changes in B_t^T will have no effect in equilibrium. On the contrary, if the change in Z_t is financed by additional central bank bonds, the intervention will have an effect in equilibrium. Coincidentally, this representation is in line with the Chilean regulatory framework: the Central Bank cannot freely decide on its

⁴⁰ This effect is also reinforced by the equilibrium rise in the policy rate that, as inflation and output fall by less, it increases more in the baseline.

treasury holdings, and thus the sterilization is done by modifying the stock of central bank-issued bonds.

Figure 13. Permanent increase in Z



Note: The solid blue lines correspond to the case where all the intervention is done in the first period, while the dashed red lines are from the case in which it is spread evenly in four periods. In both cases, the cumulative increase in Z is equivalent to a 5% of nominal GDP in steady state. For units of measure, see the note in figure 10.

Figure 13 displays the dynamics after a permanent increase in Z_t , without making any additional policy changes (although the policy rate is still determined by the Taylor rule and will thus move endogenously as inflation and output change in equilibrium). We consider two different implementations of this operation. In the first (solid blue lines in the figure), the change in Z_t is implemented fully at the period it is announced, while in the other one (dashed red lines), in the first period it is announced that the intervention will be undertaken in four equal parts, starting from the announcement period. This last alternative is in line with the way the intervention in January 2011 was implemented in Chile. In both cases, we normalize the shock so that the cumulative increase

in Z_t is equivalent to 5 percent of the dollar value of nominal GDP in steady state, a number that represents the size of the intervention implemented in 2011.

As we can see from the figure, the intervention generates an almost permanent change in activity, a persistent increase in inflation as well as in the rate of nominal depreciation, and an almost permanent real depreciation. The monetary policy rate increases aggressively as dictated by the Taylor rule, and the spread (while increasing on impact) experiences an almost permanent reduction. Moreover, as we can see, the stock of bonds B_t not only rises on impact (in response to the increase in Z_t) but also afterward, experiencing a permanent change.

What is the intuition behind this result? While the intervention is sterilized (in the sense that the purchase of dollars is not paid by printing money), the permanent increase in the stock of bonds will generate (*ceteris paribus*, in particular, keeping κ_t unchanged) a permanent increase in liquidity due to the binding money market constraint, equation (6). This in turn requires (at least in the long run) a permanent increase in the price-level path.⁴¹ In this model, such a change produces an expansion due to the presence of price rigidities. As the required change in the price level cannot be completed immediately, higher inflation is expected in the future, and therefore the real interest rate relevant for inter-temporal consumption decisions is significantly reduced, increasing consumption demand.⁴² This effect is exacerbated by two other features in the model. First, as liquidity increases but prices do not adjust automatically, the deposit-in-advance constraint is relaxed, leading to a further increase in consumption. Second, as demand rises, the spread is expected to drop and therefore aggregate supply also rises. Finally, as PPP is assumed to hold in the long run, the nominal exchange rate is also expected to depreciate in the long run, also increasing its value today.

This channel for the propagation of sterilized interventions is quite different from those emphasized in the literature, namely, the portfolio balance channel and the signaling channel (see, for instance, Dominguez and Frankel, 1993, and Sarno and Taylor, 2001). The former refers to the presence of some friction that makes bonds and foreign assets imperfect substitutes, so that adjusting portfolio positions is costly for agents, and therefore a change in the relative stock of these assets can modify their relative price. The latter is based on the idea that, by intervening, the central bank is sending information on exchange rate fundamentals, generating an effect under the assumption of imperfect information.

The mechanism present in our model can, however, generate a challenge for the implementation of inflation targeting. In the long run, the jump in the price level path does not generate a problem in reaching the inflation target.⁴³ However, it will take longer for the economy to reach

⁴¹ That the price-level path rises can be seen in the picture from the fact that inflation, after rising initially, converges to the steady state from above. Thus, the integral of this response (i.e., the change in the price level-path) is positive.

⁴² This real rate equals the inverse of the expected real stochastic discount factor.

⁴³ Graphically, the log of the new price-level path, although higher, has the same slope in the long run.

that situation. Therefore, if the central bank also cares about inflation in the short or medium run, its ability to reach such a goal might be compromised. And this is true despite the fact that the central bank is aggressively raising the policy rate, as dictated by the Taylor rule, because temporary changes in the policy rate cannot be used to deal with the permanent rise in liquidity created by the permanent rise in the stock of bonds.

The central bank, however, has a more effective tool to deal with this problem: decreasing the share of bonds allowed to be used in the liquidity facilities, κ_t . Actually, it is clear from the inspection of the money market constraint (6) that the central bank can set, after the intervention, this fraction in a way that it counteracts the change in B_{t-1} . In other words, by setting $\frac{\kappa_t}{\kappa_{t-1}} = \left(\frac{B_{t-1}}{B_{t-2}}\right)^{-1}$ it can fully offset the equilibrium effect originated by the increase in Z_t . Of course, doing this will not be efficient because the goal of the intervention (to affect the nominal exchange rate) will not be achieved. Thus, the central bank would probably wish to undo the change in B_t with gradual changes in κ_t .

Before displaying the responses of this combination of policies, it is interesting to notice that this situation is actually not a bad description of the implementation of monetary policy in Chile. In fact, the central bank has a tendency to drain liquidity from the system. This is precisely because the Central Bank of Chile has a stock of debt that is significantly higher than that of other central banks, due in part to historic events (such as the rescue of the banking system in the 1980s and the exchange rate interventions of the 1990s) and to more recent interventions (see, for instance, Banco Central de Chile, 2011). Thus, the central bank uses its several liquidity facilities to compensate for the effect of these past decisions. In our model, this can be represented with changes in κ_t .

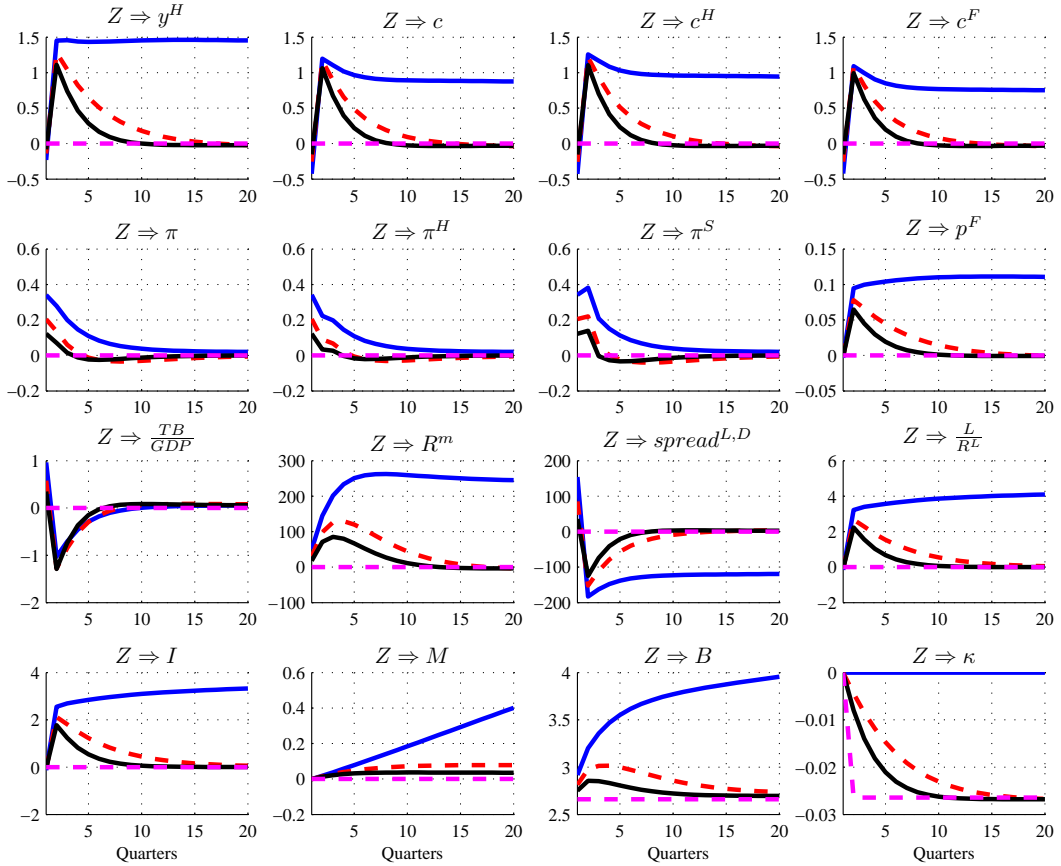
Figures 14 and 15 display the responses to an increase in Z coupled with changes in κ_t . To account for a gradual adjustment for κ_t , we replace the assumption in the baseline model of κ_t with the following rule,

$$\frac{\kappa_t}{\kappa_{t-1}} = \left(\frac{\kappa_{t-1}}{\kappa_{t-2}}\right)^{\rho_\kappa} \left(\frac{B_{t-2}}{B_{t-1}}\pi\right)^{1-\rho_\kappa}.$$

The parameter ρ_κ governs how fast κ_t adjusts to changes in B_{t-1} . In particular, we present four alternative values for this parameter, chosen such that the time that it takes to undo half of the change in B_{t-1} (i.e., the half-life of κ_t)⁴⁴ is either infinity (so that κ_t never adjusts as in figure 14), four, two, or zero quarters (so that κ_t adjusts fully after the intervention). Figure 14 displays the case in which Z_t increases only in the first period, while Figure 15 shows the case where the announced intervention is implemented in four quarters.

⁴⁴ The half-life of the process equals $\frac{\ln(0.5)}{\ln(\rho_\kappa)}$

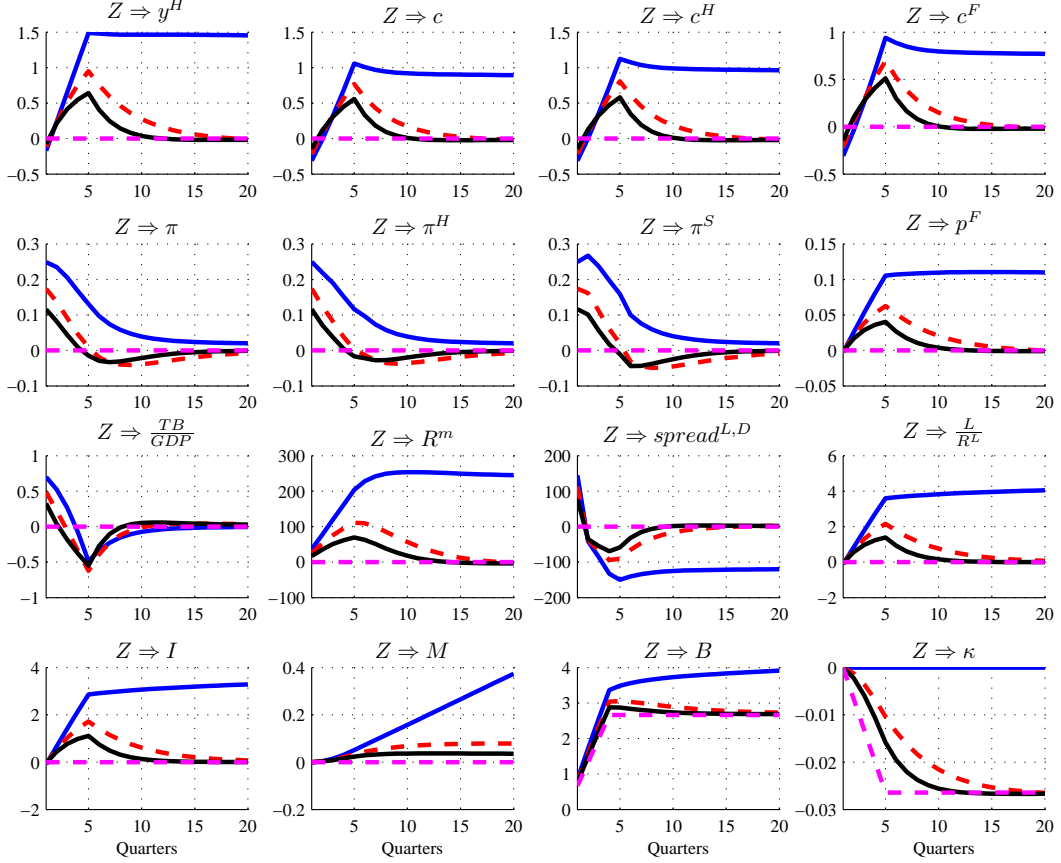
Figure 14. Permanent increase in Z in one period, with decreases in κ



Note: The different lines correspond to different cases for the half life in the response of κ to changes in B : in the solid blue is infinity, in the dashed red is 4, in the solid black is 2 and in the dashed magenta is 0. In all cases the final increase in Z is equivalent to a 5% of nominal GDP in steady state. In terms of unit of measure, κ_t is displayed in levels in differences with respect to its steady state. For the other variables, see the note in figure 10.

Notice first that, as expected, in the case in which κ_t adjusts fully, the intervention has no effect except to rise the stock of bonds. In the two intermediate cases, we can see that the response of inflation and the nominal exchange rate is milder and, additionally, the convergence to the steady state is from below (i.e., the price-level path does not jump, as can be verified numerically). This is also reflected in the response of B_t , which now converges in the long run to the point dictated by the balance sheet after the change in Z_t . The peak effect on consumption and output is slightly lower than when κ_t does not adjust, but it is much less persistent. Thus, the channel that is at work in these two cases is the deposits-in-advance effect and, to a lesser extent, the temporary drop in the spread, while the effect coming from the real rate is almost nil.

Figure 15. Permanent increase in Z in four periods, with decreases in κ



Note: The different lines correspond to different cases for the half life in the response of κ to changes in B : in the solid blue is infinity, in the dashed red is 4, in the solid black is 2 and in the dashed magenta is 0. In all cases the final increase in Z is equivalent to a 5% of nominal GDP in steady state. In terms of unit of measure, κ_t is displayed in levels in differences with respect to its steady state. For the other variables, see the note in figure 10.

We finish this section by calibrating the size of the sterilized intervention and the change in κ_t , trying to replicate the policy implemented by the Central Bank of Chile in January 2011, which is shown in Figure 16. As mentioned above, the size of the intervention announced (US\$ 12 billion) was close to 5 percent of nominal GDP and the purchases of foreign currency κ were evenly distributed during the year that the intervention lasted (this scheme was described at the announcement so we assume agents perfectly anticipated it), so we calibrate the shocks to Z_t in that way. To calibrate the evolution of κ_t , we notice that the Central Bank of Chile also communicated (the day following the intervention announcement) the way in which the sterilization was programmed. In particular, it announced that US\$ 2 billion was going to be financed by the emission of short-term letters and liquidity facilities (repo operations) while the remaining US\$10 billion would be fi-

nanced with long-term bonds (more than two years in maturity). Moreover, during the first month only short-term letters and liquidity facilities were used, and the emission of longer-term bonds began only after the second month. Accordingly, we calibrate the evolution of κ_t so that in the first quarter the percentage of the new bonds issued to finance the intervention that can be used in the liquidity facilities is 25 percent, decreasing gradually to reach 17 percent ($\approx 2/12$) after one year. Afterwards, the remaining extra liquidity generated is gradually eliminated in three years.⁴⁵ The resulting path for κ_t is displayed in the bottom-right graph in Figure 16, which we also assume agents perfectly anticipate.⁴⁶

The solid blue lines in the figure report the policy as described above. As we can see, the model predicts a very mild effect on the nominal exchange rate, rising almost 0.05 percent in the quarter of the announcement, maintaining a positive depreciation rate during the following quarters (the peak cumulative effect, i.e., the maximum effect on the exchange rate level, is around 0.1 percent), and followed by a negative depreciation afterwards. The effect on the other variables is limited as well; for instance, the maximum effect on GDP is close to 0.25 percent and inflation rises by less than 0.05 percentage points.

As a complementary exercise, we show in red broken lines the effects of the same intervention policy but coupled with a fixed monetary policy rate (instead of being determined by the Taylor rule as in the baseline case).⁴⁷ While in this alternative the effects are, as expected, more expansionary, quantitatively the difference is almost nil. In particular, in terms of the effect on the nominal exchange rate, the impact effect is slightly above 0.05 percent and the maximum cumulative effect is 0.12 percent. Thus, while it is not clear whether at the moment of announcing the intervention the central bank was planning to change the expected path of the policy rate to complement the intervention or not, quantitatively it does not seem to be important. Nonetheless, as we have emphasized, the other aspect of monetary policy that is indeed relevant is the liquidity management that follows the intervention.

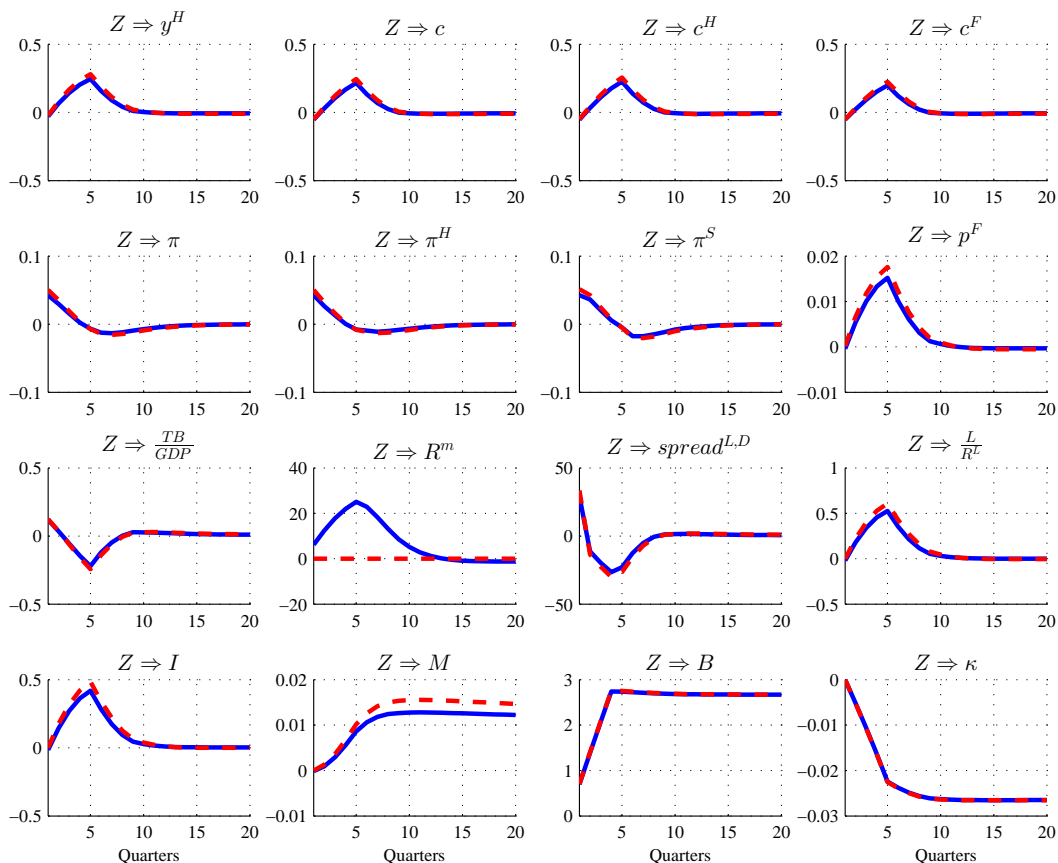
Finally, while to the best of our knowledge there are no studies that empirically identify the effects of this particular Chilean intervention, a first pass to the evolution of the nominal exchange rate hints that it is likely that it had only minor effects: while in the days following the intervention the exchange rate depreciated by more than 6 percent, after one month the exchange rate was only 2.5 percent higher than its pre-intervention level, and a quarter after the intervention it was less

⁴⁵ We assume this extra liquidity is eventually eliminated because if not, as we previously discussed, the remaining liquidity will make the long-run price level jump. Again, this assumption is in line with the fact that the Central Bank of Chile shows a trend toward draining liquidity from the system.

⁴⁶ Specifically, we assume $\frac{\kappa_t}{\kappa_{t-1}} = \left(\frac{B_{t-2}}{B_{t-1}}\pi\right)^{1-\rho_\kappa} \left(\frac{\kappa_{t-1}}{\kappa_{t-5}}\right)^{\rho_\kappa/4}$, with $\rho_\kappa = 0.25$.

⁴⁷ Technically, we can perform this exercise because the Taylor principle is not a required condition for determinacy in this model, a feature that appears in many models that include cash-in-advance constraints (e.g., see Woodford, 2003).

Figure 16. Permanent increase in Z in four periods, with a decrease in κ in line with the Chilean implementation in 2011.



Note: The solid blue lines report the case in which R^m moves according to the Taylor rule, while the red broken lines correspond to the case were R^m remains fixed. See description in the text for the description of the policy, and the note in Figure 14 for units of measure.

than 1 percent higher than the pre-intervention level. Clearly, this simple look at the data is not an identification exercise, but it seems reasonable to think that if the policy had some effect on the exchange rate it was quite limited, in line with the prediction of our model.

6.2 Expanding the List of Eligible Collaterals

Another policy alternative that can be evaluated with our model is the addition of other assets to the list of eligible collaterals to be used in liquidity facilities offered by the central bank. As we have described, such a policy was in fact implemented by the Central Bank of Chile in the onset of and after the Lehman Brothers collapse. In the model, the central bank may want to include loans as eligible collateral, reducing in that way the spread between lending and deposit rates.

In particular, we modify the equation (6) in the baseline model to

$$I_t \leq \frac{\kappa_t B_{t-1}}{R_t^m} + \frac{\kappa_t^L L_t}{R_t^m}, \quad (25)$$

where the variable κ_t^L captures the fraction of loans that the central bank is willing to accept (in the baseline model, $\kappa_t^L = 0$). Furthermore, we assume that these loans are accepted only for liquidity injections in the form of repo agreements, and not for outright purchases, so that the central bank will not hold loans in its balance sheet from one period to the next.⁴⁸

Given this change, the optimality condition from the banks' choice of L_t (the equation (22) discussed before) is now,

$$R_t^L (1 + \kappa_t^L \nu_t) = (1 + \nu_t). \quad (26)$$

Thus, *ceteris paribus*, an increase in κ_t^L will lower the interest rate on loans and, as that rate is part of the firm's marginal costs, it should have an expansionary effect in the economy.⁴⁹

Figure 17 displays the responses to an increase in κ_t^L of five percentage points, relative to a steady state with $\kappa^L = 0$. We report four alternative cases, depending on the duration of the change: the solid blue lines report the case when the increase lasts one period, the solid black lines are those for a four-period increase, the dashed red lines come from a case in which κ_t^L follows an auto-regressive process with a half-life of one quarter, and the dashed magenta lines correspond to a permanent increase in κ_t^L .

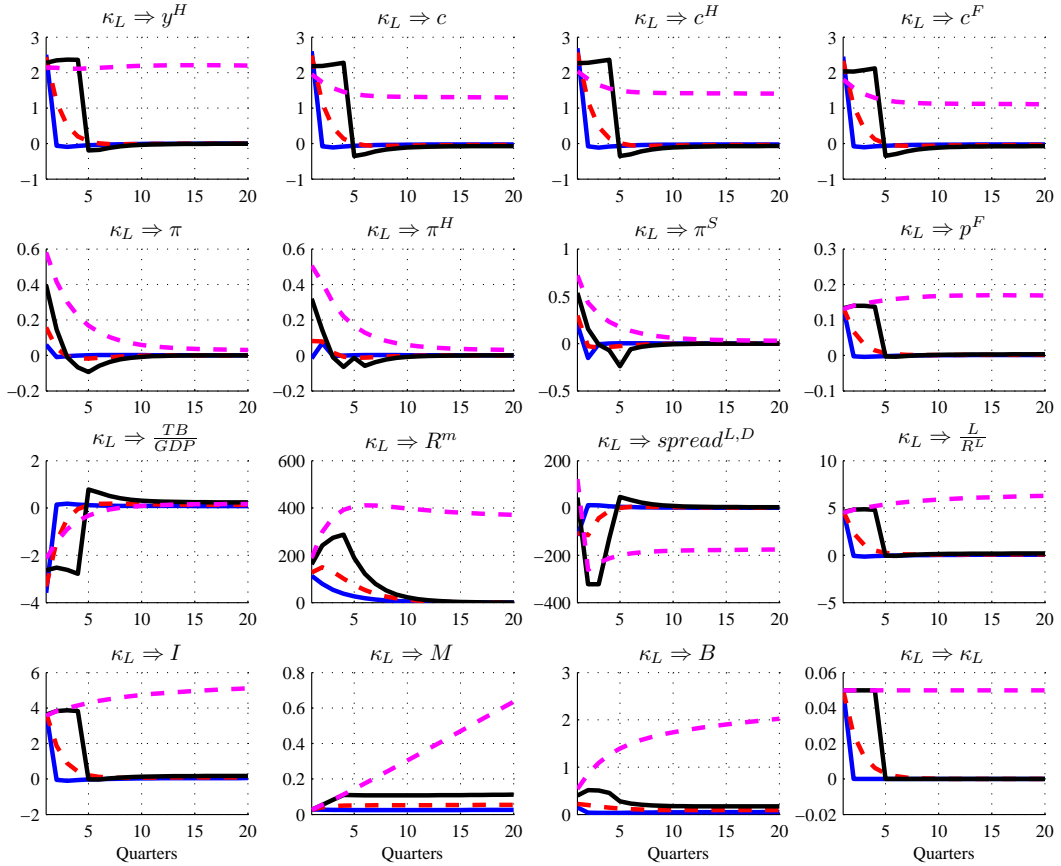
We begin by analyzing the case in which κ_t^L increases permanently. This situation resembles the case of the sterilized intervention, for the permanent increase in κ_t^L produces a permanent rise in liquidity that requires a rise in the price-level path. Thus, as before, this policy will produce a permanent rise in production and consumption, as well as a persistent increase in inflation as well as the nominal and real exchange rates. The spreads also falls and the monetary policy rate increases aggressively. However, as we explained before, the Taylor rule is not enough to undo the change in the price-level path. Overall, although this permanent increase in κ_t^L induces an important expansion, the central bank might not want to implement it if it cares about inflation in the short or medium run.

For all the temporary increases in κ_t^L , the change in the price-level path is not present, so the expansion comes from two channels. First, as mentioned above, accepting loans in the liquidity

⁴⁸ In the model, this has to be the case, as loans are intra-periodic. Nonetheless, this is consistent with the implementation of this policy in Chile, for the central bank is only allowed to use these assets in repo facilities. In other countries, notably the United States, the central bank chooses to keep these additional assets in its balance sheet for an extended period of time. To capture these alternative policy, the model should be extended to include inter-periodic loans.

⁴⁹ With this equation, we can complement the long-run welfare analysis presented in Section 4.8. Notice that the Ramsey allocation can be achieved by setting for $R^M = 1$ and $\kappa^L = 1$, which would in turn imply $R^L = 1$. Thus, when the additional instrument κ^L is available, long-run optimality requires it to be fully used.

Figure 17. Changes in κ_t^L

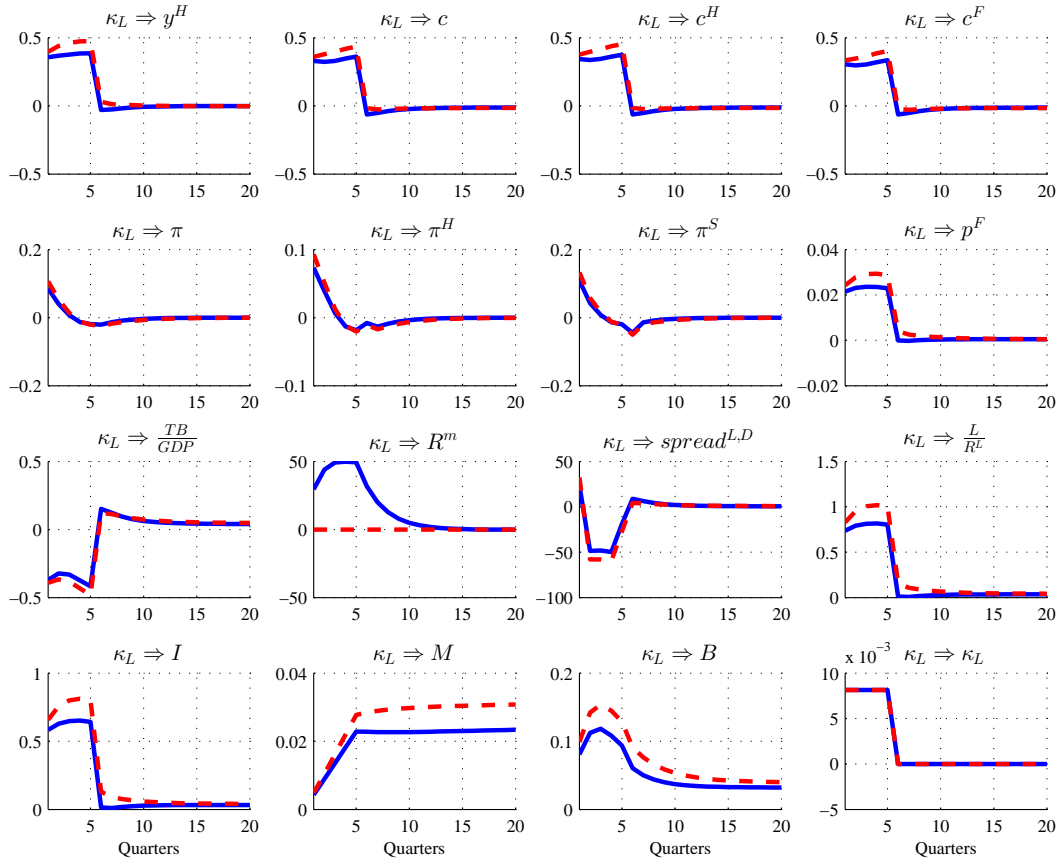


Note: The solid blue lines correspond to an increase in κ_t^L for one period, the solid black lines are for an increase that lasts four periods, the dashed red lines come from the case in which κ_t^L follows an AR(1) process with auto-correlation coefficient of 0.5 (so the half-life of the initial change is one quarter), and the dashed magenta lines correspond to the permanent increase in κ_t^L . In all cases, the initial increase in κ_t^L is 0.5. κ_t^L is measured in levels, in differences with respect to its steady state; for the other variables, see the note in figure 10.

facilities reduces the spread, which expands aggregate supply. Second, the temporary increase in liquidity, coupled with the sluggish adjustment in inflation due to the price rigidities, relaxes the deposit-in-advance constraint, increasing aggregate demand. Compared to the permanent case, the responses of real quantities like output and consumption are somehow larger on impact in the temporary cases but of course less persistent. Inflation and the nominal exchange rate increase by less on impact and the response is also less persistent. Finally, the impact effect on the real exchange rate is similar to the permanent case, but it lasts only for a few periods.

We finish this section with an exercise that tries to assess the effects of the policy implemented by the Central Bank of Chile in 2008 and 2009, when it decided to relax the list of eligible

Figure 18. Change in κ_t^L in line with the Chilean implementation in 2008/2009



Note: The solid blue lines report the case in which R^m moves according to the Taylor rule, while the red broken lines correspond to the case where R^m remains fixed. See description in the text for the description of the policy, and the note in Figure 17 for units of measure.

collaterals required in its liquidity operations. Similar to the sterilized intervention case, the key is to calibrate the path of κ_L . In this case, this is particularly challenging because the policy implemented did not specify the fraction of private banks-related assets that were accepted, which should be the literal interpretation of moving κ_t^L from zero to a positive value in the model. Thus, we proceed as follows. First, we note that the expansion of eligible collaterals implemented in October 2008 was first supposed to last for the rest of 2008, but in early December the measure was extended for the whole year of 2009. Accordingly, we assume that $\kappa_t^L > 0$ for five quarters, a duration that was internalized by agents at the date of the announcement. To specify the value for $\kappa_t^L > 0$ we first notice that after the announcement, and for the last quarter of 2008, the amount of liquidity provided with repo operations averaged Ch\$ 1.1 trillion. Moreover, in its Financial Stability Report of January 2009 the Central Bank of Chile reported that around 50 percent of these

repo operations used private banks-related assets as collateral (Banco Central de Chile, 2009, Table III.3). Finally, we also note that according with the consolidated balance sheet of the banking sector, the stock of credit to the private sector in September 2008 was Ch\$ 67.5 trillion. Therefore, we specify that for a period of five quarters $\kappa_t^L = 0.008 = \frac{0.5 \times 1.1}{67.5}$, and afterwards it returns to $\kappa_t^L = 0$.

As can be seen from the solid blue lines in Figure 18, such a policy has an expansionary effect, brought about by both the drop in the spread of nearly 50 basis points and the relaxation of the liquidity constraint. Output increases by nearly 0.4 percent, inflation rises by almost 0.1 pp. and, with a somehow larger nominal depreciation, the real exchange rate depreciates. The figure also displays in broken red lines the effects of the same policy but coupled with a fixed R_t^m . In that case, the effects on real variables are somehow larger (e.g., the peak effect on output is 0.1 pp. higher), but the response of inflation is not significantly different.

Finally, comparing these predicted responses to the data,⁵⁰ it may be the case that the model is missing some of the dynamics. In particular, the lending spread, which rose by almost 500 bp. from September to November 2008, fell by more than 200 bp. from November 2008 to January 2009. The drop in the spread predicted by our model is clearly smaller (slightly more than 50 bp.), although it is important to keep in mind that ours is a valid exercise in the sense that it allows us to isolate the policy effect, while those changes in the data just described are likely influenced by many other factors. Given the simplicity of our model, we see our prediction as a lower bound for the actual effects of this policy.

7 Conclusions

In this paper we set up a theoretical framework to analyze the role of liquidity management issues in implementing “unconventional” monetary policies. In particular, we analyze two of these types of policies, sterilized interventions and expanding the list of eligible collaterals used in central bank liquidity operations, both of which have been used by the Central Bank of Chile in recent years. We have also presented a detailed account of the events and policies implemented in Chile since the Lehman Brother’s collapse and the beginning of the great recession in 2008. In terms of results, we have found that the effects of sterilized interventions can be large, and their outcomes are mostly determined by how the extra liquidity generated is managed. And regarding the other “unconventional” instrument analyzed, we find that its effect depends on how long the option of using other assets as collaterals is available.

Our focus on liquidity management issues was motivated by their general absence from the related literature which has arisen since the events of 2008. However, it seems intuitive that the

⁵⁰ Unfortunately, as in the case of the 2011 intervention, to the best of our knowledge there are no references to empirical identification exercises that quantify the effects of this policy.

type of policies implemented in recent years require careful management of the liquidity generated. Indeed our results highlight these issues. For instance, we discussed that the way in which exchange rate interventions are sterilized greatly determines the macroeconomic effects of such a policy. This happens because the new bonds issued to finance the purchases of foreign assets can help to relax the constraints on obtaining liquidity from the central bank, which in turn can be a challenge for the implementation of an inflation targeting regime.

Our framework also highlights that, in discussing liquidity, it is not only the stock of money what matters. Many other financial assets are valued, in part, because of the way they facilitate the access to liquidity. While this issue has been emphasized in part of the recent literature (e.g., Gorton, 2009, and Gorton and Metrick, 2012) these issues has not been included in the models developed to analyze the effects of “unconventional” policies. Our model explicitly includes these considerations and, while abstracting from other potentially relevant aspects (such as financial frictions), the results indicate that these issues cannot be taken from granted. Therefore, we see as a necessary line for future research combining the liquidity management considerations that we have considered here with a model in line with the recent developments in the literature analyzing the effects of unconventional policies.

Finally, another limitation of our analysis is the assumption that the different constraints in the model are always binding. Instead, one could argue that many of these constraints are probably not binding during normal times, but they do become a restriction in times of stress. We have chosen this approach for computational simplicity: assuming that constraints are always binding allows us to solve the model using perturbation methods, while solving models with occasionally-binding constraints is computationally more costly. Arguably, the alternative of occasionally binding constraints is most relevant if one want to judge these types of policies from a welfare perspective, as this feature generally produces some type of pecuniary externalities. Thus, another line of future research would be to use alternative solution methods that can handle occasionally binding constraints in order to provide a thorough welfare evaluation of different policy alternatives.

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A Technical Appendix

We first derive the optimality conditions under the assumption that all inequality constraints are binding in equilibrium. Second, we display the stationary-equilibrium conditions. Finally, we show how to compute the non-stochastic steady state.

A.1 Optimality Conditions

HOUSEHOLDS The Lagrangian for the household problem is

$$E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \frac{c_t^{1-\sigma}}{1-\sigma} - \psi \frac{h_t^{1+\varphi}}{1+\varphi} + \lambda_t (1 + \alpha^C \eta_t) \left[\left[\omega^{1/\mu} (c_t^H)^{1-1/\mu} + (1-\omega)^{1/\mu} (c_t^F)^{1-1/\mu} \right]^{\frac{\mu}{\mu-1}} - c_t \right] + \dots \right. \\ \left. \frac{\lambda_t \eta_t}{P_t} [D_{t-1} + W_t h_t - \alpha^C (P_t^H c_t^H + S_t P_t^F c_t^F)] + \dots \right. \\ \left. \frac{\lambda_t}{P_t} \left(W_t h_t + D_{t-1} + \Omega_t + T_t + P_t^{Co} y_t^{Co} - P_t^H c_t^H - S_t P_t^F c_t^F - \frac{D_t}{R_t^D} \right) \right\}$$

Thus, defining $r_{t,t+s} = \beta \frac{\lambda_{t+s}}{\lambda_t} \frac{P_t}{P_{t+s}}$, the first order conditions are the constraints (2), (3) and (23) holding with equality and

$$c_t^{-\sigma} = \lambda_t (1 + \alpha^C \eta_t), \quad \psi h_t^\varphi = \lambda_t \frac{W_t}{P_t} (1 + \eta_t), \\ c_t^H = \omega c_t \left(\frac{P_t^H}{P_t} \right)^{-\mu}, \quad c_t^F = (1 - \omega) c_t \left(\frac{S_t P_t^F}{P_t} \right)^{-\mu}, \\ 1 = R_t^D E_t \{ r_{t,t+1} (1 + \eta_{t+1}) \}.$$

INTERMEDIATE GOODS PRODUCERS Assuming that the borrowing constraint for firms (4) holds with equality, nominal profits for the firm producing variety i are

$$P_t^i a_t (h_t^i)^\gamma (x_t^i)^{1-\gamma} - W_t h_t^i [1 + \alpha_t^L (R_t^L - 1)] - S_t P_t^F x_t^i [1 + \alpha_t^L (R_t^L - 1)].$$

Therefore, the optimality conditions are (4) and

$$P_t^i a_t \gamma (h_t^i)^{\gamma-1} (x_t^i)^{1-\gamma} = W_t [1 + \alpha_t^L (R_t^L - 1)], \quad P_t^i a_t (1 - \gamma) (h_t^i)^\gamma (x_t^i)^{-\gamma} = S_t P_t^F [1 + \alpha_t^L (R_t^L - 1)],$$

RETAILERS AND FINAL GOODS PRODUCERS The retailer j chooses the price P_t^j in order to maximize,

$$E_t \left\{ \sum_{s=0}^{\infty} \theta^s r_{t,t+s} (P_t^j \Gamma_{t,s} - P_{t+s}^i) \left(\frac{P_t^j \Gamma_{t,s}}{P_{t+s}^H} \right)^{-\epsilon} y_{t+s}^H \right\},$$

where $1 - \theta$ is the probability that the firm is able to re-optimize its price at any given period, $\Gamma_{t,s}$ is the indexation variable that satisfies $\Gamma_{t,0} = 1$ and $\Gamma_{t,s} = \pi_{t-1+s} \Gamma_{t,s-1}$ for $s \geq 1$, and $r_{t,t+s}$ is discount factor for nominal flows representing households' preferences defined above.

If \tilde{P}_t^j denotes the optimal choice, it should satisfy the first order condition

$$E_t \left\{ \sum_{s=0}^{\infty} \theta^s r_{t,t+s} \left[\left(\frac{\epsilon - 1}{\epsilon} \right) \frac{\tilde{P}_t^j \Gamma_{t,s}}{P_{t+s}^H} - \frac{P_{t+s}^i}{P_{t+s}^H} \right] \left(\frac{\tilde{P}_t^j \Gamma_{t,s}}{P_{t+s}^H} \right)^{-\epsilon} y_{t+s}^H P_{t+s}^H \right\} = 0,$$

or, alternatively,

$$g_{1,t} = \frac{1}{P_t^H} E_t \left\{ \sum_{s=0}^{\infty} \theta^s r_{t,t+s} \left(\frac{\epsilon - 1}{\epsilon} \right) \left(\frac{\tilde{P}_t^j \Gamma_{t,s}}{P_{t+s}^H} \right)^{1-\epsilon} y_{t+s}^H P_{t+s}^H \right\},$$

$$g_{2,t} = \frac{1}{P_t^H} E_t \left\{ \sum_{s=0}^{\infty} \theta^s r_{t,t+s} \frac{P_{t+s}^i}{P_{t+s}^H} \left(\frac{\tilde{P}_t^j \Gamma_{t,s}}{P_{t+s}^H} \right)^{-\epsilon} y_{t+s}^H P_{t+s}^H \right\},$$

$$g_{1,t} = g_{2,t}.$$

The variables $g_{1,t}$ and $g_{2,t}$ can be written recursively. On one hand,

$$\begin{aligned} g_{1,t} &= \left(\frac{\tilde{P}_t^j}{P_t^H} \right)^{1-\epsilon} y_t^H \left(\frac{\epsilon - 1}{\epsilon} \right) + \frac{1}{P_t^H} E_t \left\{ \sum_{s=1}^{\infty} \theta^s r_{t,t+s} \left(\frac{\epsilon - 1}{\epsilon} \right) \left(\frac{\tilde{P}_t^j \Gamma_{t,s}}{P_{t+s}^H} \right)^{1-\epsilon} y_{t+s}^H P_{t+s}^H \right\} \\ &= \left(\frac{\tilde{P}_t^j}{P_t^H} \right)^{1-\epsilon} y_t^H \left(\frac{\epsilon - 1}{\epsilon} \right) + \frac{1}{P_t^H} E_t \left\{ \sum_{s=0}^{\infty} \theta^{s+1} r_{t,t+s+1} \left(\frac{\epsilon - 1}{\epsilon} \right) \left(\frac{\tilde{P}_t^j \Gamma_{t,s+1}}{P_{t+s+1}^H} \right)^{1-\epsilon} y_{t+s+1}^H P_{t+s+1}^H \right\} \\ &= \left(\frac{\tilde{P}_t^j}{P_t^H} \right)^{1-\epsilon} y_t^H \left(\frac{\epsilon - 1}{\epsilon} \right) + \theta E_t \left\{ \frac{P_{t+1}^H}{P_t^H} r_{t,t+1} \left(\frac{\tilde{P}_t^j \pi_t}{\tilde{P}_{t+1}^j} \right)^{1-\epsilon} \dots \right. \\ &\quad \left. \frac{1}{P_{t+1}^H} \sum_{s=0}^{\infty} \theta^s r_{t+1,t+1+s} \left(\frac{\epsilon - 1}{\epsilon} \right) \left(\frac{\tilde{P}_{t+1}^j \Gamma_{t+1,s}}{P_{t+1+s}^H} \right)^{1-\epsilon} y_{t+1+s}^H P_{t+1+s}^H \right\} \\ &= \left(\frac{\tilde{P}_t^j}{P_t^H} \right)^{1-\epsilon} y_t^H \left(\frac{\epsilon - 1}{\epsilon} \right) + \theta E_t \left\{ r_{t,t+1} \frac{P_{t+1}^H}{P_t^H} \left(\frac{\tilde{P}_t^j \pi_t}{\tilde{P}_{t+1}^j} \right)^{1-\epsilon} g_{1,t+1} \right\}. \end{aligned}$$

On the other hand, with a similar derivation,

$$g_{2,t} = \left(\frac{\tilde{P}_t^j}{P_t^H} \right)^{-\epsilon} y_t^H \frac{P_t^i}{P_t^H} + \theta E_t \left\{ r_{t,t+1} \frac{P_{t+1}^H}{P_t^H} \left(\frac{\tilde{P}_t^j \pi_t}{\tilde{P}_{t+1}^j} \right)^{-\epsilon} g_{2,t+1} \right\}.$$

Finally, given that $(P_t^H)^{1-\epsilon} = \int_0^1 (P_t^j)^{1-\epsilon} dj$, and that all firms able to set prices at t will choose the same price $\tilde{P}_t = \tilde{P}_t^j$ for all j , we can write

$$(P_t^H)^{1-\epsilon} = \theta(P_{t-1}^H \pi_{t-1})^{1-\epsilon} + (1-\theta)(\tilde{P}_t)^{1-\epsilon},$$

or,

$$1 = \theta \left(\frac{P_t^H}{P_{t-1}^H \pi_{t-1}} \right)^{\epsilon-1} + (1-\theta) \left(\frac{\tilde{P}_t}{P_t^H} \right)^{1-\epsilon}.$$

BANKS The Lagrangian of the bank's problem is

$$E_0 \sum_{t=0}^{\infty} r_{0,t} \left\{ S_t \left(\frac{F_t}{R_t^*} - F_{t-1} \right) + B_{t-1} - \frac{B_t}{R_t^B} + \frac{D_t}{R_t^D} - D_{t-1} + L_t \left(1 - \frac{1}{R_t^L} \right) + M_{t-1} - M_t \dots \right. \\ \left. - I_t (R_t^m - 1) + \nu_t (\kappa_t B_{t-1} - I_t R_t^m) + \vartheta_t (M_t - \delta_t D_t) + v_t \left(M_{t-1} - \frac{L_t}{R_t^L} + I_t - D_{t-1} \right) \right\}$$

Thus, the first order conditions are the constraints (6), (7) and (8) holding with equality and, with respect to F_t , B_t , D_t , M_t , I_t , and L_t , respectively,

$$1 = R_t^* E_t \left\{ r_{t,t+1} \frac{S_{t+1}}{S_t} \right\}, \quad 1 = R_t^B E_t \{ r_{t,t+1} (1 + \nu_{t+1} \kappa_{t+1}) \},$$

$$1 - \vartheta_t \delta_t R_t^D = R_t^D E_t \{ r_{t,t+1} (1 + \nu_{t+1}) \}, \quad 1 - \vartheta_t = E_t \{ r_{t,t+1} (1 + \nu_{t+1}) \},$$

$$R_t^m (1 + \nu_t) = 1 + \nu_t, \quad R_t^L = (1 + \nu_t).$$

A.2 Stationary Equilibrium

Given the symmetry imposed by the assumptions related to the intermediate-goods-firms problem, we can drop all superscripts i . We keep, however, the notation P_t^i to denote the (unique) competitive price at which these intermediate goods are sold. Also, these same assumptions and those embedded in the Calvo framework allow us to drop the superscripts j .

As long as inflation and/or the change in the nominal exchange rate in steady state are different from zero, the model as we have described it is non-stationary. To induce stationarity, we divide nominal quantities denominated in pesos dated in period t by P_t and those denominated in dollars by P_t^F . These real quantities are denoted by their lower-case counterpart. In addition, we define the following relative prices and inflations,

$$w_t \equiv \frac{W_t}{P_t}, \quad p_t^H \equiv \frac{P_t^H}{P_t}, \quad p_t^F \equiv \frac{S_t P_t^F}{P_t}, \quad p_t^i \equiv \frac{P_t^i}{P_t}, \quad \tilde{p}_t \equiv \frac{\tilde{P}_t}{P_t^H}, \quad p_t^{Co} \equiv \frac{P_t^{Co}}{P_t^F},$$

$$\pi_t \equiv \frac{P_t}{P_{t-1}}, \quad \pi_t^H \equiv \frac{P_t^H}{P_{t-1}^H}, \quad \pi_t^F \equiv \frac{P_t^F}{P_{t-1}^F}, \quad \pi_t^{Co} \equiv \frac{P_t^{Co}}{P_{t-1}^{Co}}, \quad \pi_t^S \equiv \frac{S_t}{S_{t-1}}.$$

Notice that p_t^F is the real exchange rate in this model. Given these definitions, the following are the equations characterizing the stationary equilibrium of the model

Households (8):

$$\alpha^C (p_t^H c_t^H + p_t^F c_t^F) = \frac{d_{t-1}}{\pi_t} + w_t h_t, \quad (\text{E.1})$$

$$c_t^{-\sigma} = \lambda_t (1 + \alpha^C \eta_t), \quad (\text{E.2})$$

$$r_{t,t+1} = \beta \frac{\lambda_{t+1}}{\lambda_t \pi_{t+1}}, \quad (\text{E.3})$$

$$\psi h_t^\varphi = \lambda_t w_t (1 + \eta_t), \quad (\text{E.4})$$

$$c_t = \left[\omega^{1/\mu} (c_t^H)^{1-1/\mu} + (1-\omega)^{1/\mu} (c_t^F)^{1-1/\mu} \right]^{\frac{\mu}{\mu-1}}, \quad (\text{E.5})$$

$$c_t^H = \omega c_t (p_t^H)^{-\mu}, \quad (\text{E.6})$$

$$c_t^F = (1-\omega) c_t (p_t^F)^{-\mu}, \quad (\text{E.7})$$

$$1 = R_t^D E_t \{ r_{t,t+1} (1 + \eta_{t+1}) \}, \quad (\text{E.8})$$

Firms production (4):

$$y_t^H = a_t (h_t)^\gamma (x_t)^{1-\gamma}, \quad (\text{E.9})$$

$$\alpha^L (w_t h_t + p_t^F x_t) = \frac{l_t}{R_t^L}, \quad (\text{E.10})$$

$$p_t^i a_t \gamma (h_t)^{\gamma-1} (x_t)^{1-\gamma} = w_t [1 + \alpha_t^L (R_t^L - 1)], \quad (\text{E.11})$$

$$p_t^i a_t (1 - \gamma) (h_t)^\gamma (x_t)^{-\gamma} = p_t^F [1 + \alpha_t^L (R_t^L - 1)]. \quad (\text{E.12})$$

Firms pricing (4):

$$g_{1,t} = (\tilde{p}_t)^{1-\epsilon} y_t^H \left(\frac{\epsilon - 1}{\epsilon} \right) + \theta E_t \left\{ r_{t,t+1} (\pi_{t+1}^H)^\epsilon \left(\frac{\tilde{p}_t \pi_t}{\tilde{p}_{t+1}} \right)^{1-\epsilon} g_{1,t+1} \right\}, \quad (\text{E.13})$$

$$g_{2,t} = (\tilde{p}_t)^{-\epsilon} y_t^H \frac{p_t^i}{p_t^H} + \theta E_t \left\{ r_{t,t+1} (\pi_{t+1}^H)^{\epsilon+1} \left(\frac{\tilde{p}_t \pi_t}{\tilde{p}_{t+1}} \right)^{-\epsilon} g_{2,t+1} \right\}, \quad (\text{E.14})$$

$$g_{1,t} = g_{2,t}, \quad (\text{E.15})$$

$$1 = \theta \left(\frac{\pi_t^H}{\pi_{t-1}} \right)^{\epsilon-1} + (1-\theta) (\tilde{p}_t)^{1-\epsilon}. \quad (\text{E.16})$$

Banks (9):

$$i_t = \frac{\kappa_t b_{t-1}}{\pi_t R_t^m}, \quad (\text{E.17})$$

$$\frac{d_{t-1}}{\pi_t} = \frac{m_{t-1}}{\pi_t} - \frac{l_t}{R_t^L} + i_t, \quad (\text{E.18})$$

$$m_t = \delta_t d_t, \quad (\text{E.19})$$

$$1 = R_t^* E_t \{r_{t,t+1} \pi_{t+1}^S\}, \quad (\text{E.20})$$

$$1 = R_t^B E_t \{r_{t,t+1} (1 + \nu_{t+1} \kappa_{t+1})\}, \quad (\text{E.21})$$

$$1 - \vartheta_t \delta_t R_t^D = R_t^D E_t \{r_{t,t+1} (1 + \nu_{t+1})\}, \quad (\text{E.22})$$

$$1 - \vartheta_t = E_t \{r_{t,t+1} (1 + \nu_{t+1})\}, \quad (\text{E.23})$$

$$R_t^m (1 + \nu_t) = 1 + \nu_t, \quad (\text{E.24})$$

$$R_t^L = (1 + \nu_t). \quad (\text{E.25})$$

Central Bank (7):

$$\frac{R_t^m}{R^m} = \left(\frac{R_{t-1}^m}{R^m} \right)^{\rho_R} \left[\left(\frac{\pi_t}{\pi} \right)^{\rho_\pi} \left(\frac{gdp_t}{gdp} \right)^{\rho_y} \right]^{1-\rho_R} \varepsilon_t^{R^m}, \quad (\text{E.26})$$

$$\kappa_t = \kappa, \quad (\text{E.27})$$

$$\delta_t = \delta, \quad (\text{E.28})$$

$$m_t - \frac{m_{t-1}}{\pi_t} + b_t - \frac{b_{t-1}}{\pi_t} = p_t^F z_t - \frac{p_{t-1}^F z_{t-1}}{\pi_t} + b_t^T - b_{t-1}^T / p i_t, \quad (\text{E.29})$$

$$\frac{b_t^T}{b_{t-1}^T} = \frac{\pi}{\pi_t}, \quad (\text{E.30})$$

$$z_t = z_{t-1}, \quad (\text{E.31})$$

$$m_t - \frac{m_{t-1}}{\pi_t} = i_t \Gamma \quad (\text{E.32})$$

Aggregation, market clearing and others (8)

$$y_t^H = c_t^H + c_t^{H*}, \quad (\text{E.33})$$

$$\frac{nfl_t}{R_t^*} + t b_t = \frac{nfl_{t-1}}{\pi_t^F} + \chi p_t^{Co} y_t^{Co}, \quad (\text{E.34})$$

$$nfl_t = f_t - z_t, \quad (\text{E.35})$$

$$tb_t = \frac{p_t^H}{p_t^F} c_t^{H*} + p_t^{Co} y_t^{Co} - (c_t^F + x_t), \quad (\text{E.36})$$

$$gdp_t = y_t^H + y_t^{Co}, \quad (\text{E.37})$$

$$p_t^F = \frac{\pi_t^S \pi_t^F}{\pi_t} p_{t-1}^F, \quad (\text{E.38})$$

$$p_t^H = \frac{\pi_t^H}{\pi_t} p_{t-1}^H, \quad (\text{E.39})$$

$$p_t^{Co} = \frac{\pi_t^{Co}}{\pi_t^F} p_{t-1}^{Co}, \quad (\text{E.40})$$

$$R_t^* = \left(\frac{nfl_t}{n.fl} \right)^\phi R_t^W, \quad (\text{E.41})$$

Overall, there are 41 endogenous variables:

$$\begin{array}{cccccccccc} w_t & p_t^H & p_t^F & p_t^i & \tilde{p}_t & \pi_t & \pi_t^H & \pi_t^S & c_t^H & c_t^F \\ c_t & h_t & d_t & R_t^D & \lambda_t & r_{t,t+1} & \eta_t & y_t^H & x_t & l_t \\ R_t^L & g_{1,t} & g_{2,t} & i_t & m_t & f_t & R_t^* & R_t^B & nfl_t & \nu_t \\ \vartheta_t & \nu_t & tb_t & gdp_t & p_t^{Co} & R_t^m & \kappa_t & b_t & b_t^T & z_t \\ \delta_t & & & & & & & & & \end{array}$$

5 Exogenous Variables:

$$\pi_t^{Co} \quad y_t^{Co} \quad \pi_t^F \quad R_t^W \quad a_t \quad C_t^{H*}$$

A.3 Steady State

The following parameters are calibrated: σ , φ , ω , μ , γ , θ , ϵ and ϕ . The parameters β and ψ are determined endogenously by other restrictions. The following exogenous variables are calibrated y^{Co} , R^W , c^{H*} , while a , π^F and π^{Co} are determined endogenously. The policy-related variables that are calibrated are $\boxed{R^m}$ and $\boxed{\delta}$. The other policy-related variables (κ , i , b , b^T and z) are determined endogenously by other restrictions, as well as the parameter Γ . Finally, the following endogenous variables are also calibrated: \boxed{h} , p^H/p_F , $\boxed{p^{Co}}$, $tby \equiv tb/[(p^H/p_F)y^H + p^{Co}y^{Co}]$, $\boxed{\pi}$, $\boxed{R^D}$, $\boxed{R^L}$, b/m and $p^F z/b^T$.

From (E.41),

$$\boxed{R^* = R^W}.$$

From (E.22)-(E.23).

$$\boxed{\vartheta = \frac{R^D - 1}{R^D - \delta}}.$$

From (E.22),

$$\boxed{v = R_L - 1}.$$

From (E.3) and (E.23),

$$\boxed{r = \frac{1-\vartheta}{1+v}}, \quad \boxed{\beta = r\pi}.$$

From (E.20) and (E.24),

$$\boxed{\pi^S = \frac{1}{R^*r}}, \quad \boxed{\nu = \frac{1+v}{R^m} - 1}.$$

From (E.38)-(E.40),

$$\boxed{\pi^F = \pi/\pi^S}, \quad \boxed{\pi^H = \pi}, \quad \boxed{\pi^{Co} = \pi^F}.$$

From (E.8),

$$\boxed{\eta = \frac{\pi}{R^D\beta} - 1}.$$

From (E.13)-(E.16)

$$\boxed{\tilde{p} = 1}, \quad p^i = \left(\frac{\epsilon - 1}{\epsilon} \right) p^H.$$

From (E.36) and the definition of tby

$$tby[(p^H/p^F)y^H + p^{Co}y^{Co}] = (p^H/p^F)c^{H*} + p^{Co}y^{Co} - (c^F + x). \quad (\text{SS.1})$$

From (E.12),

$$x = \left(\frac{\epsilon - 1}{\epsilon} \right) \frac{(1 - \gamma)(p^H/p^F)}{1 + \alpha^L(R^L - 1)} y^H. \quad (\text{SS.2})$$

From (E.6), (E.7) and (E.33)

$$c^F = \frac{(1 - \omega)}{\omega} (p^H/p^F)^\mu (y^H - c^{H*}), \quad (\text{SS.3})$$

Thus, given the calibrated values, (SS.1)-(SS.3) can be combined to obtain,

$$\boxed{y^H = \frac{[(p^H/p^F) + \frac{(1-\omega)}{\omega}(p^H/p^F)^\mu]c^{H*} + p^{Co}y^{Co}(1-tby)}{tby(p^H/p^F) + \frac{(1-\omega)}{\omega}(p^H/p^F)^\mu + \left(\frac{\epsilon-1}{\epsilon}\right)\frac{(1-\gamma)(p^H/p^F)}{1+\alpha^L(R^L-1)}}}.$$

Then $\boxed{c^F}$ and \boxed{x} follow from (SS.2) and (SS.3).

From (E.9),

$$\boxed{a = \frac{y^H}{(h)^\gamma(x)^{1-\gamma}}}$$

From (E.33),

$$\boxed{c^H = y^H - c^{H*}}$$

From (E.5),

$$c = \left[\omega^{1/\mu} (c^H)^{1-1/\mu} + (1-\omega)^{1/\mu} (c^F)^{1-1/\mu} \right]^{\frac{\mu}{\mu-1}}.$$

From (E.7),

$$p^F = \left[\frac{(1-\omega)c}{c^F} \right]^{1/\mu}, \quad p^H = (p^F/p^H)p^F.$$

From (E.13) and (E.15),

$$p^i = \left(\frac{\epsilon-1}{\epsilon} \right) p^H, \quad g_1 = \frac{y^H \left(\frac{\epsilon-1}{\epsilon} \right)}{1-\theta\beta}, \quad g_2 = g_1.$$

From (E.11),

$$w = p^i \gamma \frac{y^H}{h} [1 + \alpha^L (R^L - 1)]^{-1}.$$

From (E.34)-(E.37),

$$tb = (p^H/p^F)c^{H*} + p^{Co}y^{Co} - (c^F + x), \quad gdp = y^H + y^{Co}, \quad nfl = tb \left(\frac{1}{R^*} - \frac{1}{\pi^S} \right).$$

From (E.2) and (E.4),

$$\lambda = \frac{c^{-\sigma}}{1+\alpha^C\eta}, \quad \psi = \lambda w (1 + \eta) h^{-\varphi}.$$

From (E.1)-(E.2) and (E.4),

$$d = [\alpha^C (p^H c^H + p^F c^F) - wh] \pi.$$

From (E.10)

$$l = \alpha^L (wh + p^F x) R^L.$$

From (E.19)

$$m = \delta \frac{d}{R^D}.$$

From (E.18),

$$i = \frac{d}{\pi} - \frac{m}{\pi} + \frac{l}{R^L}.$$

From (E.32),

$$\Gamma = \left(1 - \frac{1}{\pi} \right) \frac{m}{i}.$$

From (E.29) and given values for b/m and $p^F z/b^T$,

$$b = (b/m)m, \quad b^T = \frac{m+b}{(p^F z/b^T)+1}, \quad z = (p^F z/b^T) \frac{b^T}{p^F}.$$

From (E.17)

$$\kappa = \frac{i\pi R^m}{b}.$$

From (E.21)

$$r^B = \frac{1}{r(1+\nu\kappa)}.$$

From (E.35)

$$f = nfl + z.$$

Overall, we have 47 boxes, corresponding to the steady-state values of the 41 endogenous variables, 3 exogenous variable, and 3 free parameters.