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Central Bank Liquidity Management and “Unconventional” Monetary Policies

Central banks that work under an inflation-targeting regime generally use an interest rate as the main instrument to implement monetary policy. The latter can be denominated conventional monetary policy. Central banks often deviate from this practice, however, and engage in other policies to deal with particular situations. As these alternatives depart from the usual practice, they are generally labeled “unconventional” policies.

During the recent global financial crisis and recession of 2008–09, central banks around the world and in Latin America, in particular, responded to external shocks in a variety of ways. Canales-Kriljenko and others provide a precise description of how different Latin American central banks reacted to the U.S. financial crisis shock in 2008, with an emphasis on the heterogeneity in the use of unconventional monetary policy instruments.¹ For example, while Colombia and Peru lowered reserve requirements in their banking systems, the Central Bank of Chile relaxed the collateral requirements for repurchase (repo) transactions.² Also, Chile and Peru extended the repayment period in repo transactions. These examples illustrate not only the heterogeneity in responses, but also the prevalent use of unconventional instruments. Ishi, Stone, and Yehoue note that

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The views and conclusions presented in this paper are exclusively those of the authors and do not necessarily reflect the position of the Central Bank of Chile or its board members.

1. Canales-Kriljenko and others (2010).

2. The Central Bank of Peru lowered the marginal reserve requirement on foreign currency from 49 percent in October 2008 to 30 percent in December 2009 (Jara, Moreno, and Tovar, 2009).

the central bank interest rate increased rather than decreased in many emerging countries in the months immediately following the fall of Lehman Brothers.³

Deviations from conventional policies were observed in Latin America even before the recent global financial crisis (and before the central banks implemented inflation-targeting frameworks). Most notably, central banks have often engaged in sterilized exchange rate interventions to smooth the effects of capital inflows (due in part to commodity price booms) and the resulting nominal exchange rate appreciation. Some countries, like Peru, have used these interventions quite frequently, whereas others have implemented these policies only after extreme movements in the nominal exchange rate (for instance, in Chile), even after the inflation-targeting policies were already in place.

In this regard, one important policy discussion is the relationship between inflation-targeting regimes and liquidity management responses.⁴ In particular, it is not obvious whether the application of such liquidity management policies implied some type of threat to the “good implementation” of the inflation-targeting framework. Ishi, Stone, and Yehoue highlight the difficulties of using econometric time-series techniques to evaluate the impact of liquidity management policies implemented in an inflation-targeting framework, because it requires disentangling the impact of each type of policy, as well as the impact of the external shocks that presumably triggered the implementation of such policies.⁵ The fact that such policies were usually in place for just a few quarters further complicates the application of the time-series-based impact evaluation.

This paper contributes to the evaluation of such policies by constructing, solving, and simulating a dynamic stochastic general equilibrium (DSGE) model that explicitly includes the central bank’s balance sheet as a key modeling input. The model can explicitly predict the impact of selected unconventional monetary policies on the major macroeconomic variables, including gross

3. Ishi, Stone, and Yehoue (2009).

4. The growing international literature on unconventional monetary policies that emerged after the crisis focuses on the central banks in member countries of the Organization for Economic Cooperation and Development (OECD), as described in the next section of the paper. Svensson (2010), who is one of the leading researchers on inflation targeting, distinguishes between two possible policies for the central bank: monetary policy, whose main objective is a combination of inflation stability and output stability, and financial stability policy. Although Svensson recognizes possible interaction between the two, he emphasizes that, in principle, they should be analyzed from completely separate perspectives. However, in emerging economies such as those in Latin America, it is doubtful that these 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 the overall liquidity and solvency conditions of the banking system, as a standard bank-lending channel argument may state.

5. Ishi, Stone, and Yehoue (2009).

domestic product (GDP), consumer price index (CPI) inflation, and the real exchange rate, and it pays special attention to the role played by the specific facilities used by the central bank to manage market liquidity. This paper uses Chile as the main case for the application of the model, 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 then analyze the effects of some of the policies implemented.

The theoretical framework is an extension of a New Keynesian model of a small open economy with banks that take deposits from households (which is the only way for the latter to finance consumption, extending the more traditional cash-in-advance assumption), borrow abroad, lend to productive firms, and hold bonds issued by the central bank. A key ingredient of the model is that it explicitly includes 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 bonds), and these operations can take two forms: outright purchases and repo agreements. This feature, in turn, allows us to consider alternative types of monetary policies. First, as the central bank's balance sheet becomes relevant to describe the dynamics of the economy, we can use the model's predictions to evaluate policies like sterilized exchange rate interventions. Second, the central bank may temporarily accept other assets (in particular, bank loans) as collateral in the repo operations.⁶

The main results of the paper are as follows. With regard to sterilized interventions, the model predicts that while they can have potentially large expansionary effects, their use poses an important challenge for the implementation of an inflation-targeting regime. Because the purchase of foreign assets is financed with bonds that can later be used in the central bank's liquidity facilities, the sterilization relaxes the liquidity constraint faced by banks. This has large expansionary and inflationary effects due to the sluggish adjustment of prices and the deposit-in-advance constraint. In other words, while the intervention in the model is sterilized, it has effects akin to those of nonsterilized interventions in more standard frameworks that neglect liquidity management issues. Given this result, the next step is to analyze how the central bank can adjust its other policy tools to regulate the additional liquidity brought about by the intervention. The paper calibrates the policy intervention according to the actual

6. Given the focus of the paper, we do not include quantitative exercises on conventional (that is, Taylor-rule-based) monetary policies. The working paper version (García-Cicco and Kawamura, 2014) provides a detailed analysis of these policies.

foreign asset purchase program implemented by the Central Bank of Chile in 2011, specifying both the size of the purchases and the liquidity management. Our analysis suggests that the policy had only a mild effect on the economy.

The impact of the sterilized interventions operates through increased bank liquidity, which allows banks to lower their interest rates, thereby reducing the cost of borrowing for firms and, with price rigidities, generating a short-run positive impact on output. However, as time passes and more firms are allowed to adjust nominal prices, this increase in activity (and demand) would translate into higher prices, even though the policy interest rate may react to the incipient rise in inflation. Depending on whether the sterilized foreign reserve purchase is permanent or transitory, the increased inflation may also be persistent. This is the origin for the threat that sterilized interventions may pose for fulfilling the inflation target.

This transmission channel for sterilized interventions is different from the channels described in the literature. The portfolio balance channel refers to the presence of some friction that makes bonds and foreign assets imperfect substitutes, which raises the cost of adjusting portfolio positions, such that a change in the relative stock of these assets can modify their relative prices.⁷ The signaling channel is based on the fact that the central bank's intervention sends information about exchange rate fundamentals to uninformed investors, generating a real effect that would be absent with perfect information.⁸ However, none of these strands of literature explore a liquidity-based channel, which is the focus of this model.

In terms of the acceptance of loans as additional collateral for obtaining liquidity from the central bank, the model predicts that such a policy can also have expansionary effects depending on how long it is in place. These effects appear because the lending-deposit spread narrows, given the extra liquidity generated (which fosters activity due to sticky prices and the deposit-in-advance constraint). The exercise described in the paper captures the collateral-expansion policy implemented by the Central Bank of Chile in response to the Lehman Brothers collapse, and the results indicate that the policy had nontrivial expansionary effects. In light of the methodological problems discussed by Ishi, Stone, and Yehoue, this paper contributes to policy evaluation by isolating the implementation of liquidity policy from other shocks and thus allowing for an explicit quantification of the potential (short- and medium-run) impact of such policies on GDP and inflation without mixing them with foreign

7. See, for example, Dominguez and Frankel (1993).

8. For example, Sarno and Taylor (2001).

shocks.⁹ A more complete evaluation of policies that were actually implemented in response to external shocks may also be performed in the model. However, simultaneously calibrating such policies together with the real magnitude of those shocks is indeed problematic, given that the data do not identify each of the shocks (given that usually more than one foreign shock occurred).

The rest of the paper is organized as follows: The next section reviews the related literature, and the paper then documents the Chilean case. We subsequently describe the model used for the analysis, discuss its calibration, and analyze the different unconventional policies we consider: namely, sterilized exchange rate interventions and the expansion of the list of eligible collateral for operations with the central bank. A final section concludes.

Background Literature

The global financial crisis spurred a line of research attempting to introduce the role of financial intermediation into the core model used in precrisis central banking (namely, 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. Moreover, this new literature focuses mainly on closed economy models, while advances in a small open economy framework (which is the relevant one for Latin America) are less frequent. This section briefly reviews this line of research.

In the precrisis models incorporating financial frictions, the information asymmetries that generate the friction are between households and the owners of productive technologies (entrepreneurs), but the role of financial intermediaries is quite limited.¹⁰ A number of recent studies add financial intermediaries that are exposed to financial risk in closed economy models, which seems a sensible description of recent events, particularly in the United States.¹¹ These are generally real models, however, and thus while they are appropriate for assessing the role of a variety of credit policies, the interaction with the usual monetary policy tools is not clear. In contrast, Adrian and Shin consider the interaction between more conventional monetary tools and credit policies, but they use

9. Ishi, Stone, and Yehoue (2009).

10. The main reference of this literature is the financial accelerator framework in Bernanke, Gertler, and Gilchrist (1999). For a recent example, see Christiano, Motto, and Rostagno (2013). For an application to small open economies, see Céspedes, Chang, and Velasco (2004) and Elekdag and Tchakarov (2007).

11. Examples include Gertler and Karadi (2011) and Gertler and Kiyotaki (2011).

a simplified framework that is silent about the macroeconomic consequences of these interactions.¹²

Another branch of literature uses the reallocation-shock monetary banking model of Champ, Smith, and Williamson to analyze the role of monetary policy conducted through open market operations.¹³ For example, Antinolfi, Huybens, and Keister introduce a central bank that issues new domestic currency and lends it to banks to cover their liquidity needs.¹⁴ They show that this central bank behavior can lead to multiple equilibria: one that implements the Pareto-efficient allocation and a continuum of others, which they call hyperinflationary, that lead to the nonmonetary steady state. Antinolfi and Kawamura expand the model to include a solvency-risk dimension and transactions in incomplete financial security markets, showing that the Pareto-efficient allocation can only be achieved with banks, securities markets, and a central bank that lends money to banks for liquidity needs.¹⁵ 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 model are not suitable for quantitative analysis, since they all assume an overlapping-generations structure.

Most of the analysis described above focuses on closed economy models, which clearly limits their applicability to small open economies like those in Latin America. There are, however, a few exceptions. García-Cicco uses a New Keynesian small open economy model with financial wedges that takes into account the policies associated with changes in the central bank balance sheet, such as exchange rate interventions (both sterilized and nonsterilized) and changes in the maturity structure of public debt.¹⁶ In that framework, however, financial frictions are ad hoc, there is no role for financial intermediaries, and the lower bound on the policy rate is binding. Another example is the work by Alp and Elekdag, who estimate a New Keynesian model with 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.¹⁷

12. Adrian and Shin (2010). Cúrdia and Woodford (2010) introduce credit spreads into a New Keynesian framework, but their model does not feature financial intermediaries.

13. Champ, Smith, and Williamson (1996).

14. Antinolfi, Huybens, and Keister (2001).

15. Antinolfi and Kawamura (2008).

16. García-Cicco (2011).

17. Alp and Elekdag (2011).

Céspedes, Chang, and García-Cicco present a model in which banks are included as in Edwards and Végh, with two additional features: bank lending is constrained by bank capital; and banks face reserve requirements imposed by the government.¹⁸ They use this model to analyze the virtues of a policy that reduces reserve requirements when the borrowing-lending spread increases, showing that this type of policy may be useful to smooth the effects of a shock to bank costs. Finally, Céspedes, Chang, and Velasco present a simple small open economy model in which financial intermediation is occasionally subject to collateral constraints.¹⁹ They find that policies such as credit facilities and exchange rate interventions can indeed be useful when the financial intermediaries are facing binding constraints. While these last two papers move in the desired direction, they focus on the role of unconventional policies in isolation, in the sense that the model simplifications prevent the analysis of these tools in tandem with the more usual role of monetary policy under an inflation target.²⁰

The Chilean Experience with Unconventional Policies

Since the central bank became independent of the executive power in 1989, Chile has become one of the main emerging economies to adopt an inflation-targeting regime. Until 2006, this regime evolved from a version with strong capital controls and real-interest-rate targets to one with a freely floating nominal exchange rate and a nominal interest rate target. The paper focuses on events related to the 2007–08 U.S. financial crisis, so the relevant window for the study starts in 2006, two years before the crisis, and continues through 2012. Thus, a detailed description of the evolution of the earlier inflation-targeting regime is out of the scope of the paper, but there are many excellent references explaining various aspects of the different stages in the implementation of this regime.²¹

The Chilean Reaction to the 2007 U.S. Financial Crisis: Unconventional Policies

In 2007 the U.S. financial markets were hit with the worst crisis in several decades, after the burst of the real estate bubble that formed during the recovery

18. Céspedes, Chang, and García-Cicco (2011); Edwards and Végh (1997).

19. Céspedes, Chang, and Velasco (2012a).

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

21. See, for example, Corbo (1998); De Gregorio and Tokman (2004); Fuentes and others (2003); Gallego, Hernández, and Schmidt-Hebbel (1999); Morandé (2002); Morandé and Tapia (2002); Tapia and Tokman (2004); Valdés (2007).

from the 2001 recession. The crisis moved through several phases. The first started around the second quarter of 2007 and developed through the fall of Lehman Brothers in September 2008. During that period, international food and oil prices continued increasing, following the upward trend that began in 2002.²² This surge in prices, together with a sudden drop in the supply of energy from Argentina to Chile, put further inflationary pressures on the Chilean Central Bank (see figure 1), which reacted by raising the monetary policy rate from 5 percent in the second quarter of 2007 to 5.79 percent in the fourth quarter. The rate hikes continued throughout 2008, peaking at 8.25 percent in the fourth quarter (figure 2).

The central bank kept increasing its rate even after the global economy had entered the second phase of the crisis. One of the reasons outlined in the central bank's policy papers is the persistence of inflationary pressures from the evolution of international oil prices that year.²³ At the same time, the central bank also purchased foreign currency to avoid further appreciation of the exchange rate, with daily purchases of US\$50 million between 14 April and 29 September 2008, for a total of US\$5.75 billion.²⁴ Several economists later deemed this amount "sufficient" to work as a "buffer" for liquidity provision in foreign currency.²⁵

The second phase of the crisis began in October 2008, when the news about the fall of Lehman Brothers triggered an international liquidity crunch that induced various central banks to implement different policy measures to cope with the shock.²⁶ In the case of Chile, the first reaction was the interruption of foreign currency accumulation, followed by a widening of collateral requirements in the repo programs and an extension of swap operations. In terms of collateral, bank deposits were accepted starting in October 2008, followed by government bonds and time deposits in January 2009.

Figure 3 shows the Central Bank of Chile's repo operations in 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 of four days), and the total (nominal) amount of overnight

22. See, for example, De Gregorio (2009a); Céspedes, Chang, and Velasco (2012b).

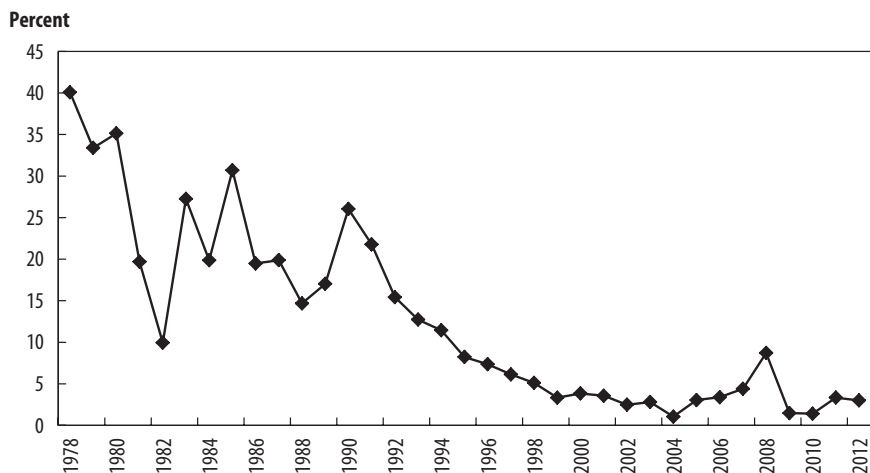
23. See De Gregorio (2009b).

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

25. See De Gregorio (2009a, p. 8).

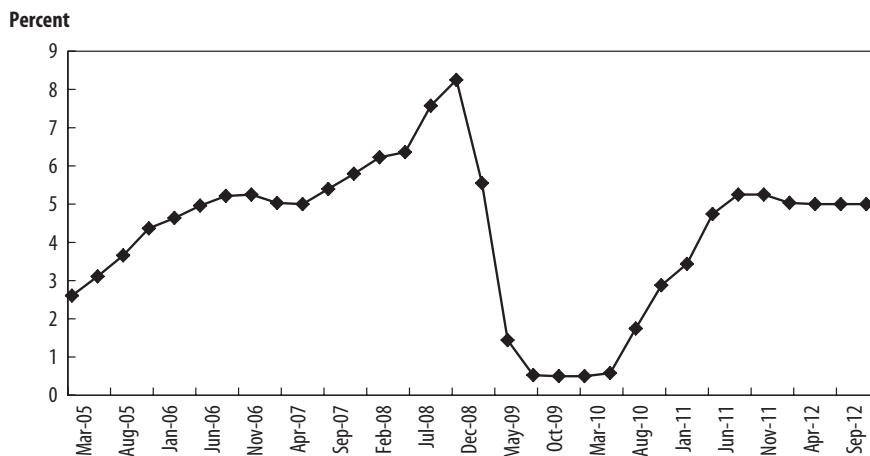
26. See Céspedes, Chang, and García-Cicco (2011).

FIGURE 1. Annual CPI-Based Inflation Rate in Chile, 1978–2012



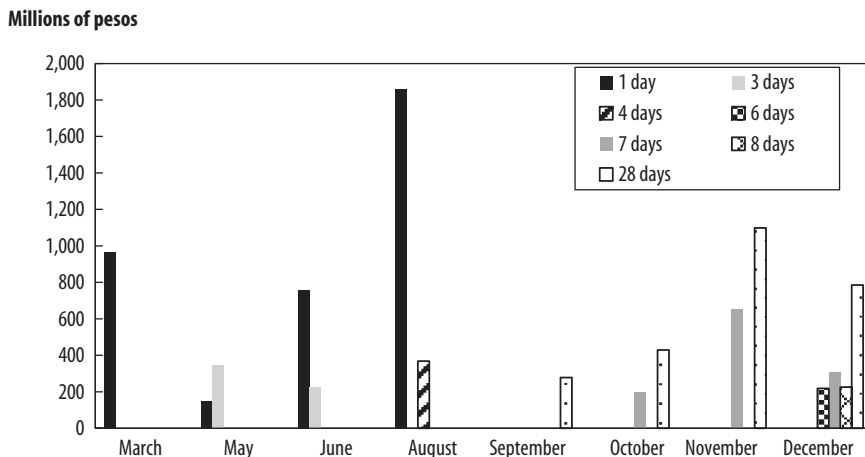
Source: Central Bank of Chile.

FIGURE 2. Quarterly Monetary Policy Rate of the Central Bank of Chile, 2005:1 to 2012:4



Source: Central Bank of Chile.

FIGURE 3 . Monthly Repo Purchases by the Central Bank of Chile in 2008, by Maturity



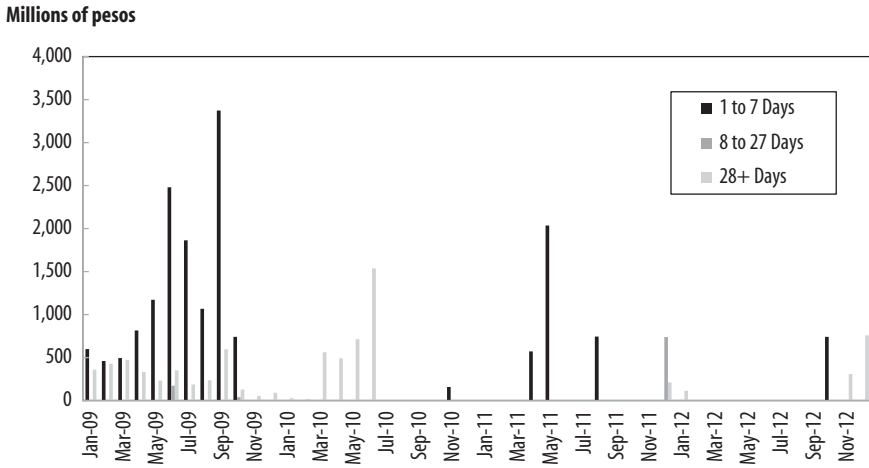
Source: Central Bank of Chile.

repo purchases was Ch\$3.7 billion. In contrast, there were no overnight repo operations between October and December 2008, when the majority of the purchases were 28-day repos. Also, the minimum maturity length after October 2008 went from 24 hours to seven days. This maturity extension served to ease domestic liquidity conditions in response to the international illiquidity conditions. It continued through June 2010, as shown in figure 4.

As a complement to repos, the central bank implemented a swap purchase program from September 2008 to December 2009. There is no official report on this kind of operation by the central bank in 2010.

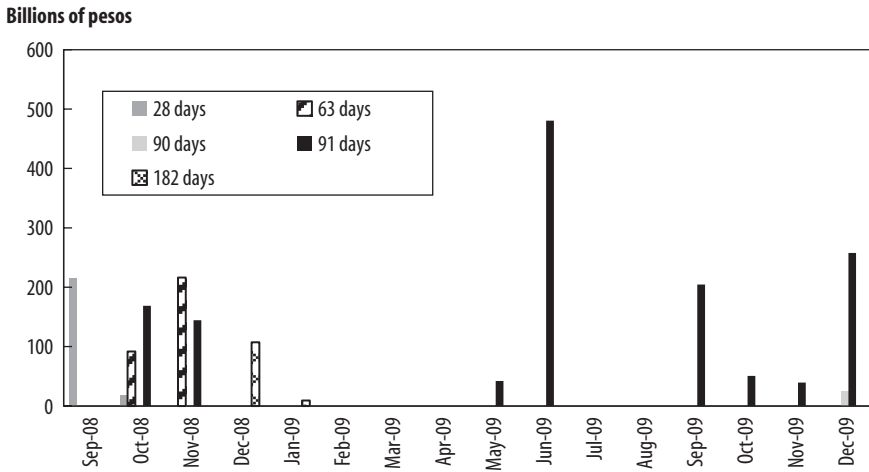
Figure 5 illustrates the central bank’s swap purchases during this period. These operations added up to Ch\$2.07 billion (nominal). Of this total, about 67 percent corresponded to swap purchases with a maturity of 91 days, while only 11.21 percent corresponded to 28-day swap purchases, the shortest term negotiated in this program. The two main 28-day swap operations occurred in the first two months of the program. Most of the 91-day swap purchases were registered during 2009. This difference could reflect a learning process by the central bank. By September and October 2008, the collapse of Lehman Brothers had caused uncertainty to spike in the international markets, but that uncertainty may have included how long the illiquidity would last. In this context, the central bank would ease liquidity for very short periods, waiting

FIGURE 4. Repo Purchases by the Central Bank of Chile at Different Maturities, January 2009 to December 2012

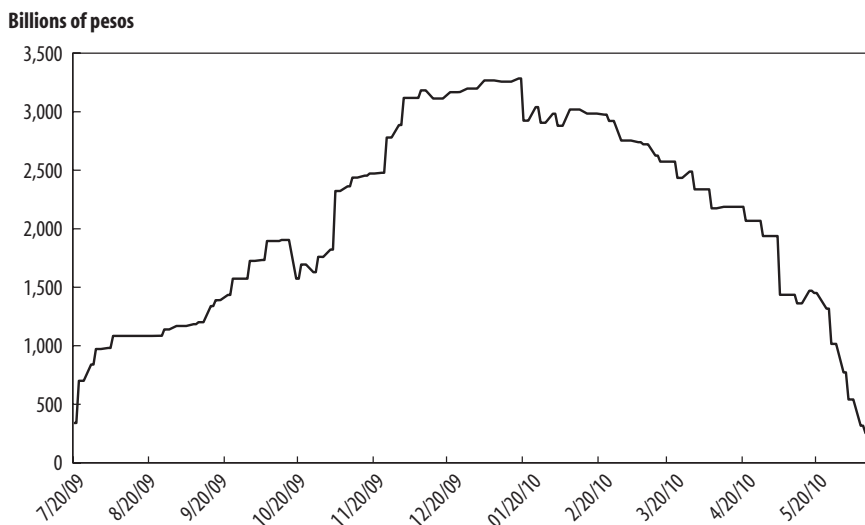


Source: Central Bank of Chile.

FIGURE 5. Swap Purchases by the Central Bank of Chile, by Maturity



Source: Central Bank of Chile.

FIGURE 6 . Daily Use of the FLAP

Source: Central Bank of Chile.

for more news to either confirm or reverse the negative scenario. Thus, when there was a certain consensus that the illiquidity stemming from the 2008 shocks would remain for most of the following year, the central bank decided to increase the maturity of the swaps. This may explain the pattern of both swaps and repos in the period.

Another central bank strategy for easing domestic liquidity conditions was the implementation of a short-term liquidity facility (known locally by its Spanish acronym, FLAP), which was in place between July 2009 and June 2010. This program consisted in a direct short-term (90-day and 180-day) lending program to banks at the prevailing monetary policy rate, which complemented other existing programs (such as repos).²⁷ The other goal behind the FLAP was related to the fact that the policy rate had reached its lower bound. The FLAP helped signal the central bank's commitment to keeping the policy rate at its lower bound for a prolonged period of time.

Figure 6 shows the evolution of the use of the FLAP on a daily basis. The stock peaked in January 2010 and then rapidly decreased to zero by June of that year. This pattern is consistent with the idea of a short-lived program that

27. Céspedes, García-Cicco, and Saravia (2013).

complemented others that were considered more permanent. In terms of its effectiveness, Céspedes, García-Cicco, and Saravia perform an econometric exercise to evaluate the impact of the program on asset prices and bank lending.²⁸ According to their results, the program allowed a drop in the three-month yield of about 50 basis points, while the one-year yield fell on the order of 30 basis points. Corporate spreads also decreased by about 10 basis points. In terms of bank lending behavior, the authors find that the ratio of loans to total assets was four percentage points higher for banks that participated in the program than for banks that did not. Thus, although the program was short-lived, it seems to have been effective in increasing liquidity.

Monetary Policy and Exchange Rate Issues in Chile after the U.S. Financial Crisis

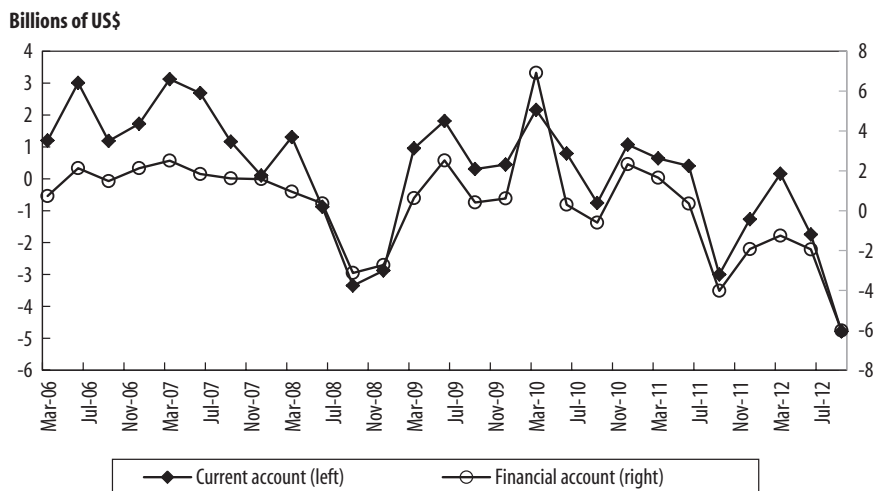
As shown earlier in figure 4, the central bank gradually raised the monetary policy rate from 0.50 percent in the second quarter of 2010 to 5.25 percent in the third quarter of 2011, where it stayed until the last quarter of 2012. This central bank behavior is consistent with the abandonment of the (extraordinary) liquidity programs implemented during the peak of the U.S. crisis. Note, however, that the central bank did not raise the rate to its precrisis levels. This 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.

The Chilean economy faced new challenges as the international financial markets began to recover (at least until the European crisis appeared). As early as 2009 and through the third quarter of 2011 (when the European crisis began), the financial account presented a surplus (with the exception of the third quarter of 2010). The financial account then turned sharply negative until the third quarter of 2012, and the whole balance of payments was in deficit in the first and third quarters of 2012. These facts are summarized in figure 7.

This evolution of the capital flows confirmed the argument of the main central bank economists toward the end of the U.S. crisis: the problem in the world recovery phase was the higher volatility of capital flows, and the challenge was to reduce its consequences on the domestic economy without substantially changing the inflation-targeting framework.²⁹ One of the central bank's reactions when the financial account was still in surplus was to intervene with a foreign currency purchase program, which was implemented through preannounced daily purchases of US\$50 million each. These purchases were all sterilized by the issue of letters and bonds by the central bank, to ensure the

28. Céspedes, García-Cicco, and Saravia (2013).

29. See the discussion in two policy papers by De Gregorio (2010a, 2010b).

FIGURE 7. Current Account and Financial Account of Chile, 2006:1 to 2012:3

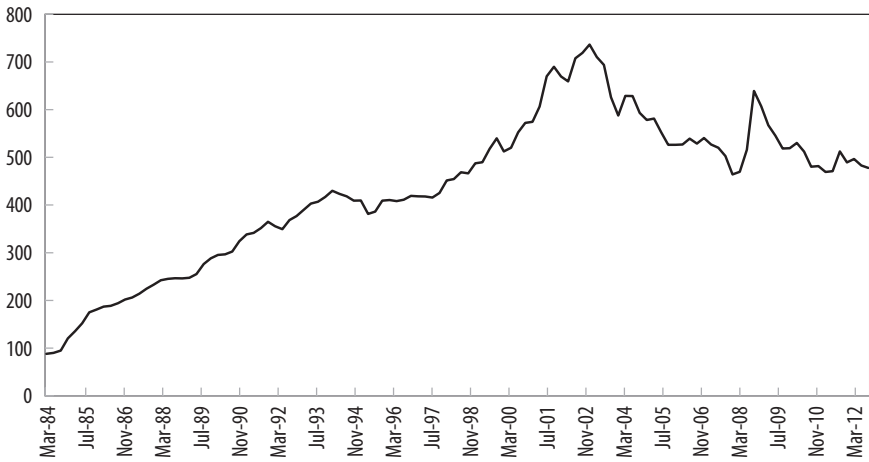
Source: Central Bank of Chile.

achievement of the inflation target that year. Total foreign currency purchases added up to US\$12 billion for the year. This foreign reserves accumulation was part of a macroprudential regulation policy for managing the high volatility of capital flows.³⁰ In late 2012, the pressure grew for a new intervention as both the nominal and the real exchange rate appreciated further (figure 8).

Noticeably, most of these interventions were sterilized. Figure 9 shows the evolution of the monetary base vis-à-vis the stock of nonmonetary liabilities (which are related to monetary policy decisions). The stock of nonmonetary debt presented a sudden increase of 47.9 percent in 2011, versus a 24 percent increase in the monetary base. Even when such foreign reserve purchases were sterilized, the expansion in the stock of central bank debt can have similar effects on liquidity as an expansion in the monetary base, since open market operations by the central bank are often guaranteed using central bank bonds as collateral. In the case of Chile, this is how sterilizations are done because the central bank has a legal constraint that prevents it from arbitrarily changing its holding of government debt, in particular to implement a sterilized exchange rate intervention. Our model-based analysis below emphasizes the

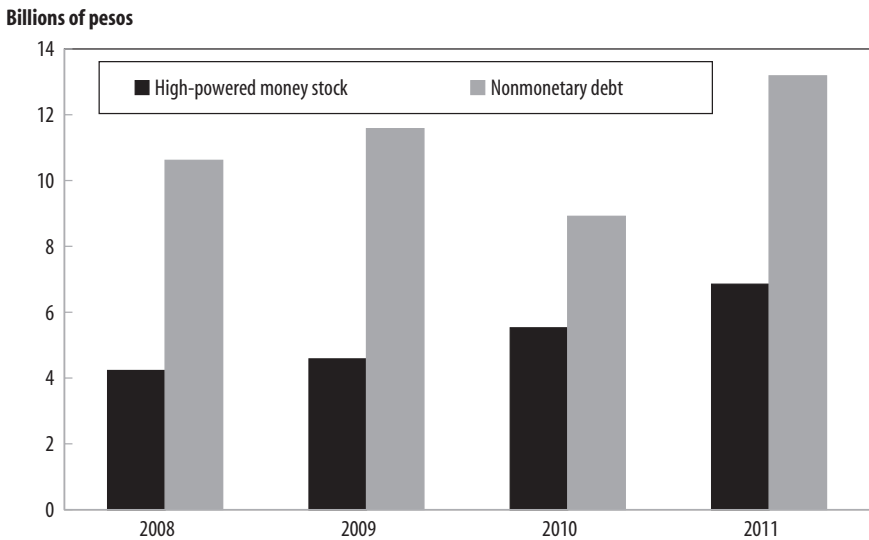
30. For a general discussion on foreign currency reserves hoarding, see De Gregorio (2011a). For the 2011 program, see De Gregorio (2011b).

FIGURE 8 . Quarterly Real Exchange Rate Index for Chile, 1984:1 to 2012:4



Source: Central Bank of Chile.

FIGURE 9 . Central Bank’s Monetary Base and Nonmonetary Debt



Source: Central Bank of Chile.

role that an appropriate management of this newly issued central bank debt, vis-à-vis the control of liquidity, has in implementing this type of intervention in an inflation-targeting framework.

Baseline Model

For the model-based analysis, we start by describing the baseline model, which contains all the features of the banking system plus a setup for monetary policy that captures inflation targeting in normal times (that is, conventional policies). In the next section, we then extend the model to consider two unconventional policies that go beyond the use of the policy rate: sterilized exchange rate interventions and the expansion of the list of eligible collateral accepted for operations with the central bank.³¹

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 intermediated goods, each of them produced by 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 commodities are determined abroad.

In each period t , the timing of events is as follows:

- The input markets open (labor and imported inputs). Firms pay their input costs in advance (that is, before the goods market opens) and thus need to borrow a fraction of these costs from banks.

- 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, only central bank bonds are accepted), under two alternative arrangements: outright purchases or repo agreements.

- The goods market opens (domestic production and imports). Households face a deposits-in-advance constraint by which their purchases have to be paid for using deposits and the cash received as wage payments. Deposits are with-

31. The working paper version (García-Cicco and Kawamura, 2014) contains a section describing the dynamics implied by the baseline model in response to foreign shocks (interest rate and commodity prices), as well as to monetary policy shocks, under conventional monetary policies. Moreover, we compare the results of our model with those obtained with specifications in the New Keynesian tradition. The working paper version also includes a technical appendix with the full derivation of the equilibrium conditions, as well as the computation of the steady state.

drawn from banks, so they need to have enough cash to cover these withdrawals. In addition, commodities are exported.

—Dividends are paid, and 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.

The rest of this section describes each part of the model and presents the calibration of the parameters.

Households

Household preferences are represented by

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

where c_t^H and c_t^F denote consumption of home and foreign goods, respectively, and h_t represents labor.³² 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

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

where S_t denotes the nominal exchange rate (pesos to the dollar), P_t^H and P_t^F are the prices of domestic goods (in pesos) and foreign goods (in dollars), and $\alpha^C > 0$. This is a relaxation of the typical Lucas cash-in-advance framework.³³ Since a major point of the paper is to analyze the aggregate effects of the central bank's liquidity management, we need an assumption that gives a role to both cash and other bank-related assets (such as deposits). In the absence of such an assumption, there is no way to generate a meaningful policy exercise that would imply a change in the composition of the central bank assets or liabilities. Using a deposit-in-advance constraint instead of a cash-in-advance constraint could lead to an extension of the notion of liquidity. In particular,

32. We use the notational convention that lowercase letters are real variables, while uppercase are nominal variables. In addition, variables without a time subscript represent steady-state values.

33. Lucas (1982). See also Edwards and Végh (1997).

liquidity expands not only from an increase in hard money, but also from the expansion of any item that would allow banks to increase the assets that are used to back deposits (such as central bank bonds). This is key for understanding the consequences of sterilized interventions, one of the two major unconventional monetary policy measures analyzed within this model.

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

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

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

Firms

The model incorporates three types of firms: intermediate firms, retailers, and final goods producers.

INTERMEDIATE FIRMS. 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 models with liquidity, the assumption is that to produce in period t firms need to pay workers and purchase foreign inputs in advance at the beginning of that period.³⁴ In particular, we assume that firms face the following borrowing constraint:

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

34. For similar models, see Fuerst (1992); Schlagenhaut and Wrase (1995).

The parameter α^L can be interpreted as a measure of the 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

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

Given that credit is completely intraperiodic, the intermediate firm i solves the problem of maximizing equation 5 subject to equation 4 every period.

RETAILERS AND FINAL DOMESTIC GOODS PRODUCERS. There is a continuum of retailers who buy intermediate good i at price P_t^i (taking the price as given), repackage these goods into retail goods y_t^j , and sell them in a monopolistically competitive market to final domestic goods producers. The latter bundles all these varieties into the home good according to the constant-elasticity-of-substitution (CES) production function:

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

Therefore, the demand faced by retailers is given by $y_t^j = (P_t^j/P_t^H)^{-\varepsilon} y_t^H$, with $(P_t^H)^{1-\varepsilon} = \int_0^1 (P_t^j)^{1-\varepsilon} dj$. 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, with full indexation to past inflation.³⁵

Banks

As mentioned above, the model assumes the presence of financial institutions, called banks, that are owned by households. They extend loans to firms, hold bonds issued by the central bank, and also hold reserves, obtaining funds from households' deposits and from foreigners. Banks face a number of constraints. First, to obtain liquidity from the central bank, they need to participate in open market operations, so they need to take into account that the central bank may decide to accept certain types of asset and not others for these operations (in the baseline model, only central bank bonds can be used).

35. Calvo (1983). Under this assumption, the distortion introduced by price dispersion is irrelevant up to first order.

Second, banks need enough cash to cover the withdrawals made by households when they enter the goods market. Finally, the central bank imposes minimum reserve requirements.

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 liability side, they have obligations given by deposits D_{t-1} , and foreign debt F_{t-1} denominated in dollars. In the first subperiod, loans are extended to firms (in cash) for the amount L_t/R_t^L and therefore money holdings shrink to $M_{t-1} - (L_t/R_t^L)$.

In the second subperiod, the money market opens. Money is traded in this market with the central bank in exchange for a selected list of assets (in this baseline case, bonds).³⁶ 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:

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

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

In the next subperiod, the goods market opens, and households withdraw D_{t-1} . Banks need to have enough cash on hand to cover these needs. In other words, they face the constraint

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

After these withdrawals, banks' holdings of money become $M_{t-1} - (L_t/R_t^L) + I_t - D_{t-1}$.

36. As in Reynard and Schabert (2009), Schabert (2010), and Hörmann and Schabert (2010). This discount window is very different from the island model literature, such as Antinolfi, Huybens, and Keister (2001) and Antinolfi and Kawamura (2008), which consider direct lending by the central bank without any explicit collateral requirement and with an implicit perfect enforcement assumption. Given that one of the policies we analyze is the relaxation of collateral requirements by central banks, the inclusion of this mechanism, although more complex, can better capture how such relaxation implies liquidity provision.

In the last subperiod, 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 bond holdings after this subperiod are

$$\begin{aligned}\tilde{M}_t &\equiv M_{t-1} + I_t - \frac{L_t}{R_t^L} - D_{t-1} - B_t^R + \frac{D_t}{R_t^D} \quad \text{and} \\ \tilde{B}_t &\equiv B_{t-1} - I_t R_t^m + B_t^R.\end{aligned}$$

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

$$(8) \quad \begin{aligned}\Omega_t^b &= S_t \left(\frac{F_t}{R_t^*} - F_{t-1} \right) + B_{t-1} - \frac{B_t}{R_t^B} + \frac{D_t}{R_t^D} - D_{t-1} \\ &\quad + L_t \left(1 - \frac{1}{R_t^L} \right) + M_{t-1} - M_t - I_t (R_t^m - 1).\end{aligned}$$

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. This term 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 $r_{t,t+s}$, that is,

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

Banks maximize this objective function subject to the money market constraint (equation 6), the withdrawals restriction (equation 7), and an additional

constraint: the central bank imposes a minimum reserve requirement, with δ being the fraction of deposits that needs to be backed up with reserves. In other words,

$$(9) \quad M_t \geq \delta D_t.$$

This constraint is similar to that in Edwards and Végh or Céspedes, Chang, and García-Cicco.³⁷

Central Bank

The central bank injects money through open market operations, creates its own bonds, holds foreign reserves and Treasury bonds (B_t^T , with interest rate R_t^T), and transfers resources to households.³⁸ The central bank enters the period with holdings of Treasury bonds 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 stock of these last three instruments before the last subperiod (asset market) 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 subperiod is

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

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

$$(10) \quad S_t Z_{t-1} + B_{t-1}^T + M_t + \frac{B_t}{R_t^B} + I_t (R_t^m - 1) = S_t \frac{Z_t}{R_t^*} + \frac{B_t^T}{R_t^T} + M_{t-1} + B_{t-1} + T_t.$$

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), the supply of bonds (B_t), and the money injections (I_t).³⁹ The central bank also sets the reserve requirements (δ) and decides the transfers to households (T_t). Not all these variables are policy instruments, because there are many equilibrium conditions that impose constraints on the behavior of some, but are conditional on others. In what follows, we describe

37. Edwards and Végh (1997); Céspedes, Chang, and García-Cicco (2011).

38. The role of Treasury bonds is clarified below.

39. The difference between I_t and $M_t - M_{t-1}$ equals the money supplied under repos.

how we model the implementation of monetary policy, which is meant to capture policy in normal times (that is, conventional policy).

We assume that the central bank sets the policy rate R_t^m according to a Taylor-rule:⁴⁰

$$(11) \quad \frac{R_t^m}{R^m} = \left(\frac{R_{t-1}^m}{R^m} \right)^{\rho_R} \left[\left(\frac{\pi_t}{\pi} \right)^{\rho_\pi} \left(\frac{y_t^H}{y^H} \right)^{\rho_y} \right]^{1-\rho_R} \varepsilon_t^{R^m}.$$

The parameter κ_i 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 $(M_t - M_{t-1})/I_t = \Gamma$, with $\Gamma \in [0,1]$. Since the choice of bank reserves (M_t) is determined by the reserve requirement (equation 9), under reasonable calibrations of the model, if all injections are outright, then banks may not be able to satisfy the withdrawal constraint (equation 7) if the reserve requirement holds with equality.⁴¹ Therefore, the central bank injects more liquidity in every period than is needed to constitute required reserves, so that the withdrawal constraint can be satisfied. Because these extra injections take the form of intraperiodic repurchase agreements, the extra liquidity returns to the central bank by the end of the period, and the stock of money held outright (M_t) changes only according to the reserve requirement.⁴²

We assume that the treasury collects lump-sum taxes from households, which are simply used to maintain a stock of Treasury bonds that grows at

40. 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.

41. Later we show that without the reserve requirement, banks will choose not to hold any reserves.

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

a constant rate. These Treasury bonds are held only by the central bank.⁴³ In addition, we specify that the central bank uses transfers to give households a rebate for profits/losses from money market operations and from changes in the valuation of bonds, Treasury bonds and foreign reserves.⁴⁴ These assumptions imply that the constraint of equation 10 yields

$$(12) \quad S_t Z_t - S_{t-1} Z_{t-1} + B_t^T - B_{t-1}^T = M_t - M_{t-1} + B_t - B_{t-1}.$$

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 show up in equilibrium, the stock of central bank bonds and asset holdings will not appear in other equilibrium conditions. Thus, whenever monetary policy is implemented as an interest rate rule, the evolution of the money stock is pinned down by other equilibrium conditions, and an equation like equation 12 will be irrelevant for the dynamics of other variables. The assumption behind this result is that either money is dropped from a helicopter or open market operations have no cost. This is not the case in this model, however, 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 matters as long as the money market constraint (equation 6) holds. In turn, this provides the space 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, extended here to a model with banks in a small open economy framework.⁴⁵

Second, consider the case in which the left-hand side of equation 12 is zero (that is, the peso value of assets is constant). The equation would then state

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

44. This follows García-Cicco (2011) and Schabert (2010).

45. Reynard and Schabert (2009).

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. This cannot be the case in a world with positive steady-state inflation, however, because nominal variables have to grow at this positive inflation rate in the long run; but if the right-hand side of equation 12 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 plays 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.⁴⁶ To satisfy this requirement, we assume that Treasury bonds grow at the long-run inflation rate ($B_t^T/B_{t-1}^T = \pi$) and that the dollar value of foreign reserves is adjusted by the (exogenous) rate of foreign inflation, $(Z_t/Z_{t-1}) = (P_t^F/P_{t-1}^F)$.⁴⁷ The first of these two assumptions reflects actual constraints that the Central Bank of Chile faces when performing open market operations, as we already described, due to the regulatory framework in place. Therefore, even if the demand for bank reserves (M_t) does not change in a particular period, the stock of central bank bonds will still change to compensate for the change in Treasury bonds 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 allow us to consider the effects of sterilized interventions in this model.

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 $L_t = \int_0^1 L_t^i di$. Given the linear homogeneity of the production function, $y_t^h = F(h_t, x_t)$.⁴⁸ 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

$$(13) \quad TB_t \equiv \frac{P_t^H}{S_t} c_t^{H*} + P_t^{Co} y_t^{Co} - P_t^F (c_t^F + x_t),$$

46. 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 since this type of fiscal dominance does not seem to be relevant for the Chilean case.

47. In the long run, since the real exchange rate is constant in the model, the value in pesos of foreign reserves will grow at the long-run inflation rate.

48. And given the absence of price-dispersion distortions due to full indexation, as described earlier.

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

$$(14) \quad gdp_t \equiv \frac{P_t^H}{P_t} y_t^H + \frac{S_t}{P_t} P_t^{Co} y_t^{Co}.$$

Finally, combining the household budget constraint (equation 3) with profits from firms (equation 5) and banks (equation 8), 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 (equation 10), we obtain the balance-of-payments equation:

$$(15) \quad \frac{NFL_t}{R_t^*} + TB_t = NFL_{t-1} + \chi P_t^{Co} y_t^{Co},$$

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

The Rest of the World

The foreign interest rate is

$$(16) \quad R_t^* = \left(\frac{NFL_t}{P_t^F nfl} \right)^\phi R_t^W,$$

where R_t^W is an exogenous process, the term $(NFL_t/P_t^F nfl)^\phi$ is a debt-elastic country premium that serves as a closing device, and nfl is a parameter describing the value of (real) net foreign liabilities in steady state.⁴⁹ 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 cointegrates in the long run with P_t^F , which is also exogenous.

49. On the closing device, see Schmitt-Grohe and Uribe (2003).

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, $\pi_t^F \equiv (P_t^F/P_{t-1}^F)$, follows an independent first-order autoregressive, or 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 e_t^m which is independent and identically distributed (i.i.d.).

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. Whenever the constraints are binding, there will be spreads between the different interest rates in the model. In this subsection, we provide some intuition regarding the conditions under which these constraints bind and how this is related to the differences between interest rates.

The equilibrium conditions, under the assumption that all the constraints are binding, include the following:⁵⁰

$$(17) \quad 1 = R_t^D E_t \{ r_{t,t+1} (1 + \eta_{t+1}) \},$$

$$(18) \quad 1 = R_t^* E_t \{ r_{t,t+1} \pi_{t+1}^S \},$$

$$(19) \quad 1 = R_t^B E_t \{ r_{t,t+1} (1 + \nu_{t+1} \kappa_{t+1}) \},$$

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

$$(21) \quad 1 - \vartheta_t = E_t \{ r_{t,t+1} (1 + \nu_{t+1}) \},$$

$$(22) \quad R_t^m (1 + \nu_t) = 1 + \nu_t; \text{ and}$$

$$(23) \quad R_t^L = (1 + \nu_t),$$

50. The complete characterization of the equilibrium is presented in the appendix of the working paper version.

where $\pi_t^s = (S_t/S_{t-1})$. As mentioned before, $r_{t,t+1}$ denotes the stochastic discount factor for nominal flows coming from the households' optimization problem. The variable η_t is the Lagrange multipliers associated with the deposit-in-advance constraints (equation 2) faced by households. In terms of the banks' problem, the multiplier ν_t corresponds to the money market constraint (equation 6), υ_t is related to the withdrawal constraint (equation 7), and ϑ_t is related to the reserve requirement (equation 9).⁵¹

Equation 17 is the optimal demand for deposits by households. It relates the gross nominal interest rates on deposits to the fact that the deposit-in-advance constraints may or may not be binding, as is usual in the cash-in-advance literature. Thus, one way that monetary policy may affect the deposit rate is through consumers' liquidity constraints. Moreover, in steady state, equation 2 will hold as long as $\beta^{-1} > (R^D/\pi)$ or, equivalently, if the real rate consistent with intertemporal preferences (β^{-1}) exceeds the real rate offered by deposits (R^D/π), compensating for the fact that holding deposits satisfies the constraint.

Equations 18 through 23 correspond to the characterization of optimal decisions by private banks. Equation 18 characterizes the optimal decision on foreign debt F_t , equation 19 characterizes the choice of bond holdings B_t , equation 20 is the decision on deposits D_t , equation 21 represents the choice of reserves M_t , equation 22 is related to money injections I_t , and equation 23 characterizes 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 equation 23, the multiplier on the withdrawal constraint (equation 7), υ_t , will be positive as long as the lending rate R_t^l is larger than one (that is, 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 the increased liquidity needed 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 (that is, $\upsilon_t > 0$), which will thus hold with equality.

Equation 23 also highlights a limitation of our model. The lending rate will only move according to changes in the multiplier υ_t . Therefore, any change in the model that tightens the withdrawal constraint will increase the multiplier

51. Here we have omitted the equation characterizing the choice of loans for firms, which equation reads $R_t^l = 1 + \varphi_t$, where φ_t is the multiplier associated with the borrowing constraint (equation 4). From equation 23, we have $\varphi_t = \upsilon_t$.

and the lending rate, while any shock that relaxes the constraint will reduce it.⁵² This is not the only channel affecting the lending rate in reality, and the model could be extended to account for other relevant channels.⁵³ We leave this extension for future research, focusing here on analyzing the role played by the incorporation of the central bank's liquidity facilities.

Combining equations 20 and 21 shows 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 does not need to hold 100 percent reserves, then $\vartheta_t > 0$, and the bank will choose to keep only required reserves. Moreover, these two equations also show that if the central bank does not need to hold required reserves (that is, $\vartheta_t = 0$), banks will decide not to hold any reserves as long as $R_t^D > 1$.⁵⁴ This is so because banks can always use the facilities offered by the central bank (I_t) to obtain the required liquidity to satisfy the withdrawal constraint.

In terms of v_t , combining equations 22 and 23 shows that it will be positive as long as the lending rate is larger than the money market rate. In other words, banks will choose to take as much as they can from the liquidity facilities based on their bond holdings B_{t-1} , the share of bonds accepted in these facilities κ_t , and the policy rate R_t^M , as indicated by equation 6.

Overall, whether or not the constraints bind in the neighborhood of the steady state will depend on the calibration of the interest rates used. In the Chilean data, on average, $R^M < R^D < R^L$. We thus assign the steady-state values of the multipliers to replicate these interest rates. As it turns out, all the multipliers are positive under our calibration.

When equation 19 is combined with equation 23, we get $R^L = R^B(1 + v\kappa)(1 - \vartheta)$ in steady state. Suppose for the moment that that reserve requirements were irrelevant (that is, $\vartheta = 0$). In that case, $R^L > R^B$, reflecting the fact that

52. 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 the withdrawal constraint, as it will force banks to accumulate more reserves.

53. For instance, financial frictions could be included, either in the relationship between banks and borrowers (as in Bernanke and others, 1999) or between banks and depositors (as in Gertler and Karadi, 2011).

54. In that case, equation 21 will not hold with equality, implying that the implicit constraint $M_t \geq 0$ will hold with equality.

because only bonds can be used to obtain liquidity from the central bank's facilities, loans will pay an illiquidity premium in equilibrium. This leaves the door open for an expansionary effect of a policy that allows banks to use other assets (loans in this case) as collateral in these liquidity facilities, by lowering this liquidity premium in the assets that become eligible.⁵⁵ 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 will 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 .

Functional Forms and Calibration

In terms of the instantaneous utility function, we assume

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

with

$$(24) \quad c_t = \left[\omega^{1/\mu} (c_t^H)^{1-1/\mu} + (1-\omega)^{1/\mu} (c_t^F)^{1-1/\mu} \right]^{\frac{\mu}{\mu-1}}.$$

For the production function, we use

$$(25) \quad F(h_t^i, x_t^i) = (h_t^i)^\gamma (x_t^i)^{1-\gamma}.$$

The time unit is set to a quarter. Table 1 presents the values of the parameters. Since the model features a number of parameters that are also present in New Keynesian models, we borrow from previous studies that have estimated them using Chilean data. In particular, Medina and Soto estimate a medium-scale DSGE model for the Chilean economy, which is the core of the DSGE model used by the Central Bank of Chile for the forecast published in its Monetary Policy Report.⁵⁶

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

56. Medina and Soto (2007). The only difference between our parametrization and Medina and Soto's is that we choose a value of 0.0001 for the elasticity of the country premium, 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.

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 disutility	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
<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^0	S.S. value of R_t^0	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)

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.

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 the Chilean data. These parameters are those indicated as endogenous in table 1.⁵⁷ The moments that we choose from the data are the following. We set the steady-state inflation rate to an annual 3 percent, which corresponds to the target for inflation in Chile since 2001. We set the steady-state values of R^* , R^M , R^D , and R^L to 3.42 percent, 3.96 percent, 4.2 percent, and 7.88 percent, respectively, which are the average values for 2001–12. Our steady-state ratio of deposits to GDP is 0.4, and the ratio of loans to GDP is 1.5, both of which are the average for 2003–12. Because deposits in the model mature in one quarter, we contrast the model with data on short-term peso deposits (up to three months). Also, given that in the model loans are taken by firms, we complement the data with information on commercial loans.⁵⁸

For the trade balance, we use a GDP share of 7 percent. For copper production, the GDP share in the model is 10 percent, while the ratio of copper exports to other exports is 1.01. All of these values correspond to the average in 2001–12. The ratio of foreign reserves to treasury holdings by the central bank is set at 3, which matches 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 0.3.⁵⁹ The solution of the model is approximated using a (log-linearization) first-order perturbation approach around the nonstochastic steady state, assuming that all the constraints are binding in the neighborhood of the steady state.

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 the expansion of the list of eligible collateral

57. 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.

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

59. The working paper includes a calibration of the driving forces, which is relevant for understanding how these shocks are propagated in different versions of the model under a conventional policy setup. We do not discuss that part of the calibration here, however, since it is omitted from the analysis in this version. The working paper also analyzes the model's ability to match several stylized facts from the Chilean economy.

in operations with the central bank, both of which have been implemented in Chile in the past. While these policies generate no effect in equilibrium in standard models, such as the New Keynesian framework, our baseline model can be modified to evaluate these alternatives.

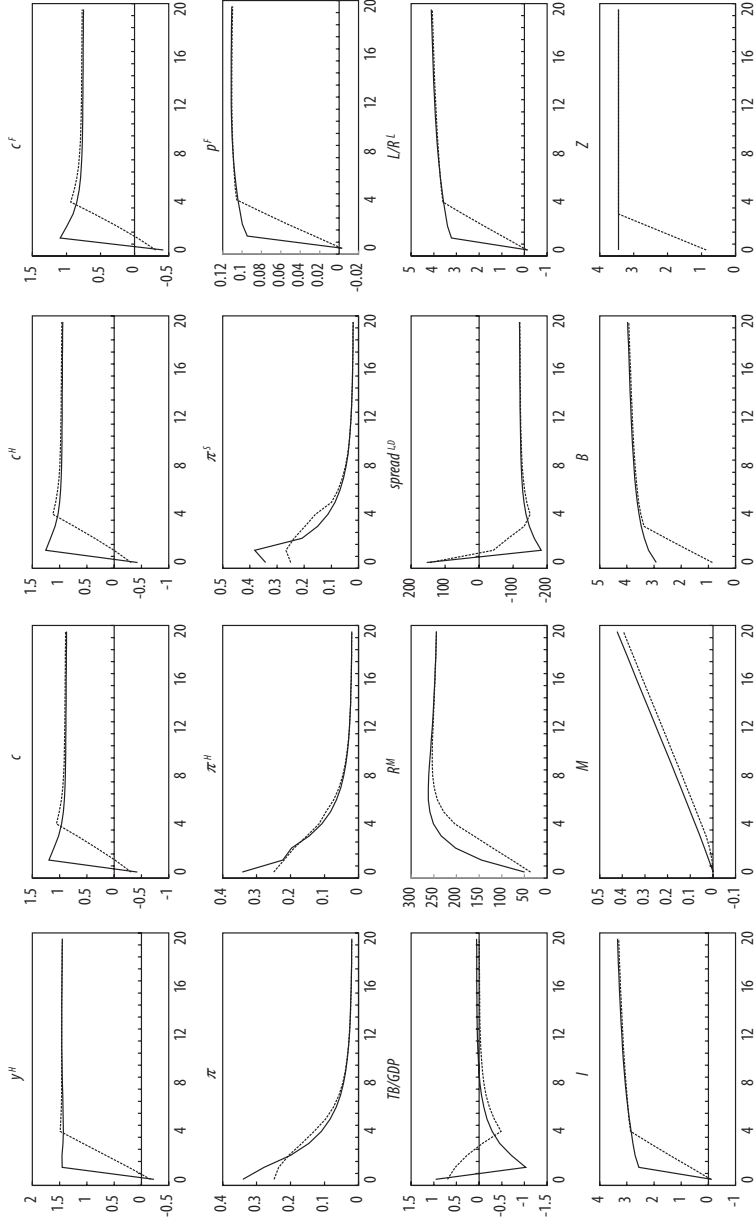
Sterilized Interventions

In the baseline model, we assume that the stock of foreign reserves held by the central bank (Z_t) grows at a rate equal to the (exogenous) rate of foreign inflation. This condition, when combined with our assumption about B_t^f , is sufficient to guarantee that the inflation target will be met in the long run. In the short run, however, we can consider temporary deviations. Moreover, because the stock of money (M_t) that appears on the central bank balance sheet is determined by the reserve requirement δ , changes in Z_t have to be financed by changes in either the central bank's debt B_t or its treasury holdings B_t^f . Given the assumptions of the model (in particular, that Treasury bonds cannot be used in obtaining liquidity), changes in Z_t that are offset by changes in B_t^f will have no effect in equilibrium. In contrast, if the change in Z_t is financed by additional central bank bonds, then the intervention will have an effect in equilibrium. This representation is in line with the Chilean regulatory framework: the central bank cannot freely decide on its treasury holdings, so the sterilization is done by modifying the stock of central bank bonds.

Figure 10 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 thus will move endogenously as inflation and output change in equilibrium). We consider two different implementations of this operation: first, the change in Z_t is implemented fully in the period in which it is announced (the solid lines in the figure); second, the central bank announces in the first period that the intervention will be done in four equal parts, starting from the announcement period (dotted lines). This second alternative is in line with the way the intervention was implemented in Chile in January 2011. In both cases, we normalize the shock so that the cumulative increase in Z_t is equivalent to a 5 percent of the dollar value of nominal GDP in steady state, which is the size of the intervention implemented in 2011.

As the figure shows, the intervention generates an almost permanent change in activity, a persistent increase in both inflation and the rate of nominal exchange rate depreciation, and an almost permanent real depreciation. The monetary policy rate increases aggressively as dictated by the Taylor rule, and the spread experiences an almost permanent reduction (after increasing on

FIGURE 10. Permanent Increase in Z^a



a. Solid lines: all the intervention is done in the first period; dotted lines: the intervention is spread evenly over four periods. In both cases, the cumulative increase in Z is equivalent to 5 percent of nominal GDP in steady state. The responses are deviations from steady state with the following units of measure: y^H , c^H , c^F , I , M , and B are in percentage deviations; π^H , π^F , and (TB/GDP) are in percentage point deviations; R^M and $spread^{L,B}$ are in annualized basis point deviations; $spread^{L,B}$ is in basis point deviations; and κ is in level deviations.

impact). Moreover, the stock of bonds B_t not only rises on impact (in response to the increase in Z_t), but records a permanent change thereafter.

What is the intuition behind this result? While the intervention is sterilized (in the sense that the purchase of dollars is not paid for by printing money), the permanent increase in the stock of bonds will generate a permanent increase in liquidity due to the binding money market constraint (equation 6) (*ceteris paribus*, in particular keeping κ_t unchanged). This, in turn, requires a permanent increase in the price-level path, at least in the long run.⁶⁰ 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 intertemporal consumption decisions is significantly reduced, increasing consumption demand.⁶¹ 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, so aggregate supply also rises. Finally, since purchasing power parity is assumed to hold in the long run, the nominal exchange rate is also expected to depreciate in the long run, which raises its value today. Such reactions strongly suggest that sterilized interventions can play a countercyclical role in preventing exchange rate appreciations.

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.⁶² 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; therefore, a change in the relative stock of these assets can modify their relative price. The latter is based on the idea that the central bank, by intervening, is sending information on exchange rate fundamentals, which generates an effect under the assumption of imperfect information.

The mechanism present in our model, however, raises a challenge for the implementation of inflation targeting. In the long run, the jump in the price-level path does not prevent the economy from meeting the inflation target, but

60. Inflation rises initially and then converges to the steady state from above. Thus, the integral of this response (that is, the change in the price-level path) is positive.

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

62. See, for instance, Dominguez and Frankel (1993); Sarno and Taylor (2001).

the process will be slower.⁶³ Therefore, if the central bank also cares about inflation in the short or medium run, its ability to reach that goal might be compromised—even if the central bank is aggressively raising the policy rate, as dictated by the Taylor rule. Temporary changes in the policy rate cannot be used to deal with the permanent increase in liquidity created by the permanent increase in the stock of bonds.

A more effective tool for dealing with the problem of unwanted additional liquidity is to decrease the share of bonds that are accepted in the liquidity facilities, κ . According to the money market constraint (equation 6), after the intervention the central bank can set this share to counteract 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 . This is not an efficient policy because it hinders the achievement of the goal of the intervention (that is, to affect the nominal exchange rate). Thus, the central bank would probably prefer to undo the change in B_t with gradual changes in κ_t .⁶⁴

This is actually not a bad description of the implementation of monetary policy in Chile. The central bank has tended to drain liquidity from the system. This is precisely because the Central Bank of Chile has a significantly higher stock of debt than other central banks, due in part to historic events

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

64. If Treasury bonds were also held by the private sector but not accepted in liquidity facilities, a policy analogous to changing κ after the intervention would be for the central bank to implement the sterilization through a combination of issuing new central bank debt and selling some of its Treasury bonds. Although equivalent, and to some extent easier to understand, we do not follow this alternative here because the Central Bank of Chile cannot freely decide on its Treasury holdings, which implies that the sterilization cannot be effected by selling Treasury bonds. Alternatively, and closer to the real world, one could consider central bank debt of different maturities (such as letters and bonds), where certain maturities are used for open market operations while others are not. In this setup, a policy analogous to changes in κ would be to sterilize with a combination of the two types of debt. We do not use this alternative so as to keep the analysis as simple as possible. Regardless of the assumption used, what is relevant is how the sterilization is split between instruments that can be used in liquidity facilities and others that cannot. In reality, central banks are careful about these issues, but most of the theory omits them. Our model shows that such a distinction is key.

(such as the rescue of the banking system in the 1980s and the exchange rate interventions of the 1990s) and in part to more recent interventions.⁶⁵ Given the legal restrictions on how the Central Bank of Chile uses its holdings of government debt, the bank instead manages its different liquidity facilities to compensate for the effects of its past decisions. In our model, this can be represented with changes in κ_t .

To assess the effects of the intervention implemented by the Central Bank of Chile in January 2011, we calibrate the size of the sterilized intervention and the change in κ_t to replicate that policy (see figure 11). As mentioned, the size of the announced intervention (US\$12 billion) was close to 5 percent of nominal GDP, and the purchases of foreign currency were evenly distributed over the course of the year (this scheme was described at the announcement, so we assume that agents perfectly anticipated it). Our calibration of Z_t captures this pattern. With regard to the evolution of κ_t , on the day following the announcement of the intervention, the Central Bank of Chile communicated how the sterilization was programmed: of the US\$12 billion, US\$2 billion would be financed with the issue of short-term letters and liquidity facilities (repo operations), while the rest would be financed with long-term bonds (with a maturity of over two years). In the first month, only short-term letters and liquidity facilities were used, and the issue of longer-term bonds started in the second month. Accordingly, we calibrate the evolution of κ_t so that in the first quarter, 25 percent of the new bonds issued to finance the intervention can be used in the liquidity facilities, decreasing gradually to 17 percent ($\approx 2/12$) after one year. Thereafter, the remaining extra liquidity generated is gradually eliminated in three years.⁶⁶ The resulting path for κ_t , which is perfectly anticipated by economic agents, is displayed in the bottom-right graph in figure 11.⁶⁷

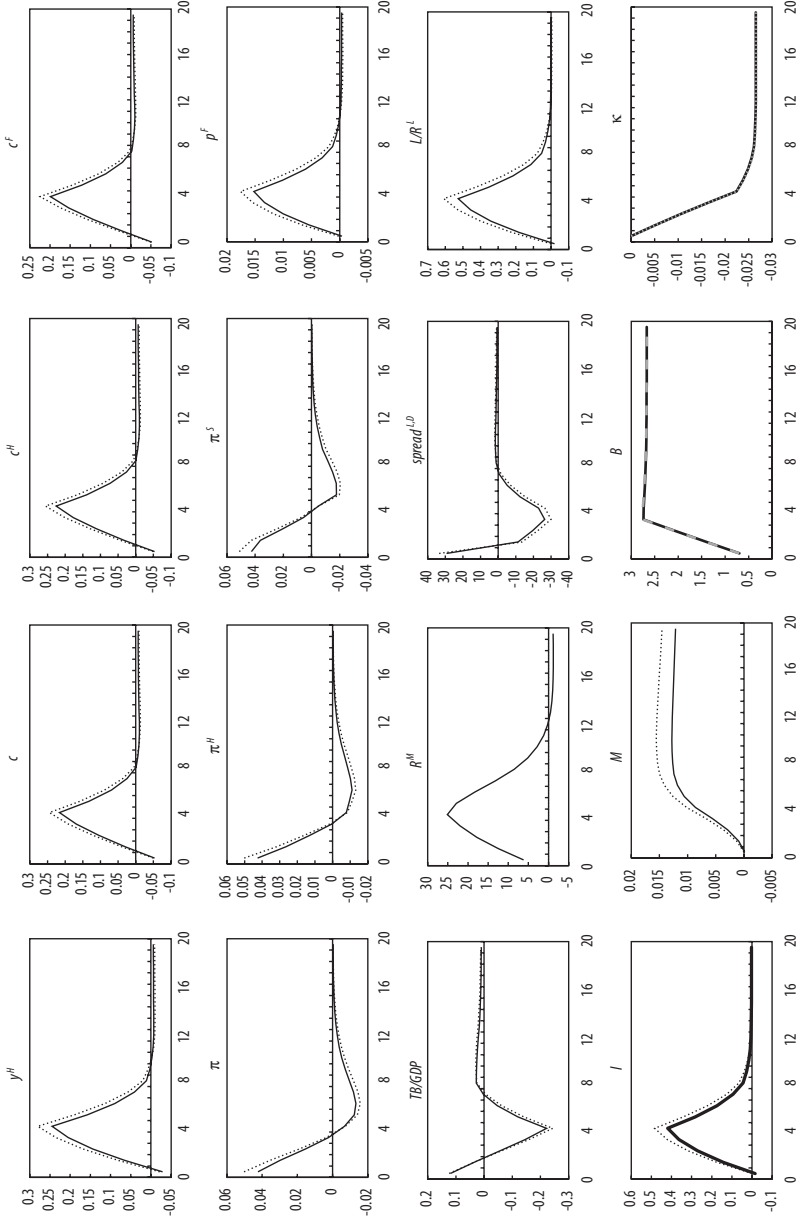
The solid lines in the figure report the policy described above. The model predicts a mild effect on the nominal exchange rate, which only rises about 0.05 percent in the quarter of the announcement and then maintains a positive depreciation rate in the following quarters (with a peak cumulative effect—that is, the maximum effect on the exchange rate level—of around 0.1 percent), followed by an appreciation. The effect on the other variables is limited, as

65. See Central Bank of Chile (2012).

66. We assume that this extra liquidity is eventually eliminated because otherwise the remaining liquidity would make the long-run price level jump. Again, this assumption is in line with the fact that the Central Bank of Chile tends to drain liquidity from the system.

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

FIGURE 11 . Permanent Increase in Z in Four Periods, with a Decrease in κ in Line with the Chilean Implementation in 2011^a



a. Solid lines: R^M moves according to the Taylor rule; dotted lines: R^M remains fixed. See the text for the description of the policy and the note to figure 10 for units of measure.

well. For instance, the maximum effect on GDP is close to 0.25 percent, and inflation rises by less than 0.05 percent percentage points.

As a complementary exercise, we show the effects of the same intervention policy coupled with a fixed monetary policy rate (instead of being determined by the Taylor rule as in the baseline case) (the dotted lines in the figure).⁶⁸ As expected, the effects are more expansionary, but quantitatively the difference is almost nil. For 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, quantitatively it does not seem to be important. The aspect of monetary policy that is indeed relevant is the liquidity management that follows the intervention.

Finally, we compare our results with the behavior of Chilean variables after the intervention in 2011. A first glance at the evolution of the nominal exchange rate hints that the intervention probably had only minor effects: in the days following the intervention, the exchange rate depreciated by more than 6 percent, but after one month it was only 2.5 percent higher than its initial level, and after a quarter it was less than 1.0 percent higher than its initial level. While this simple look at the data is not an identification exercise, it seems reasonable to conclude that the policy had a very limited effect on the exchange rate, in line with the prediction of our model. Similarly, Pincheira analyzes the effect on inflation expectations of several interventions carried out by the Central Bank of Chile, finding that 2011 episode had insignificant effects on this variable, which is also in line with the predictions of our model.⁶⁹

Expansion of the List of Eligible Collateral

Another policy alternative that can be evaluated with our model is the addition of assets to the list of eligible collateral that can be used in liquidity facilities offered by the central bank. This policy was implemented by the Central Bank of Chile at the onset of the Lehman Brothers' collapse. In the model, the central bank may want to include loans as eligible collateral, thereby reducing the spread between lending and deposit rates.

68. 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 (for example, Woodford, 2003).

69. Pincheira (2013).

In particular, we modify equation 6 in the baseline model as follows:

$$(26) \quad I_t \leq \frac{\kappa_t^L B_{t-1}}{R_t^m} + \frac{\kappa_t^L L_t}{R_t^m},$$

where κ_t^L captures the share 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.⁷⁰

Given this change, the optimality condition from the banks' choice of L_t (equation 23) is now

$$(27) \quad R_t^L (1 + \kappa_t^L \nu_t) = (1 + \nu_t).$$

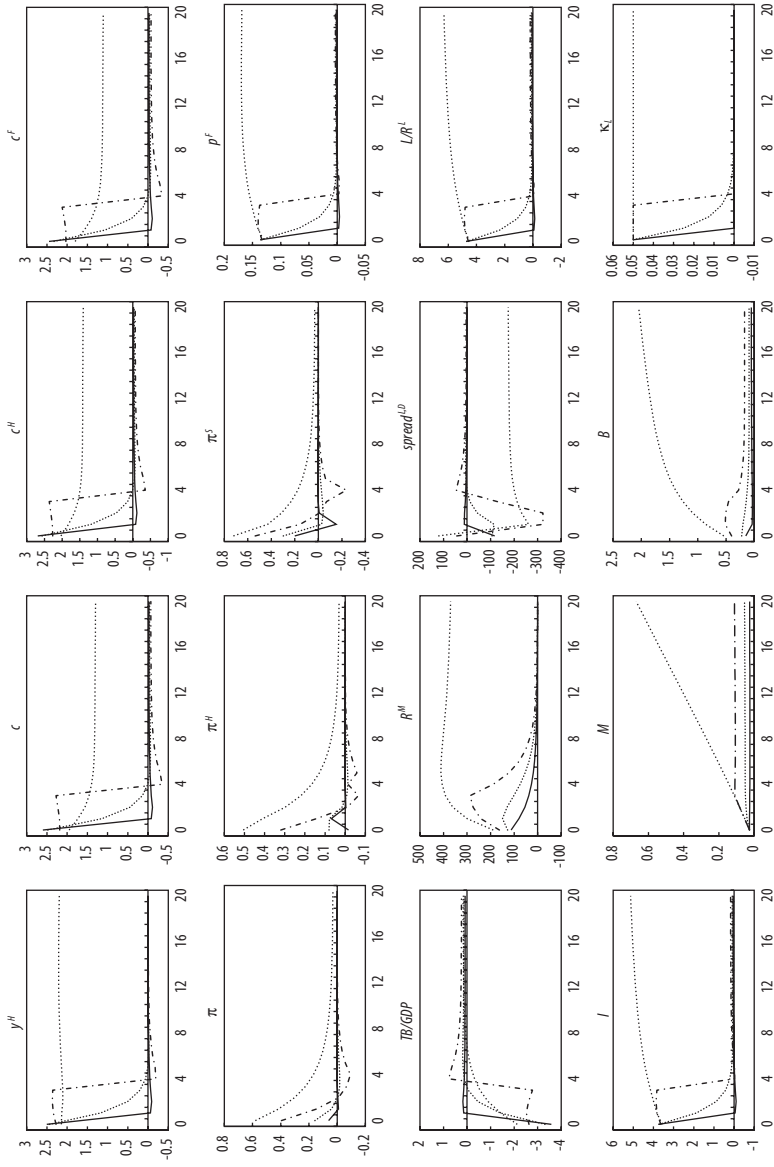
Thus, *ceteris paribus*, an increase in κ_t^L will lower the interest rate on loans, which should have an expansionary effect in the economy since that rate figures into the firm's marginal costs.

Figure 12 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 increase in κ_t^L lasts one period (solid lines), the increase in κ_t^L lasts four periods (dashed-and-dotted lines), κ_t^L follows an autoregressive process with a half-life of one quarter (dotted lines), and the increase in κ_t^L is permanent (dashed lines).

We begin by analyzing the case in which κ_t^L increases permanently. This situation resembles the sterilized intervention, for the permanent increase in κ_t^L produces a permanent increase in liquidity that requires the price-level path to shift upward. Thus, as before, this policy will produce a permanent rise in production and consumption, as well as a persistent increase in inflation and the nominal and real exchange rates. The spreads also fall, and the monetary policy rate increases aggressively. However, the Taylor rule alone cannot offset 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.

70. In the model, this has to be the case, since loans are intraperiodic. Nonetheless, it is consistent with the implementation of this policy in Chile, where the Central Bank only allowed these assets to be used in repo facilities. In other countries, notably the United States, the central bank chose to keep these additional assets on its balance sheet for an extended period of time. To capture this alternative policy, the model should be extended to include interperiodic loans.

FIGURE 12. Changes in $\kappa_t^{L^a}$



a. Solid lines: the increase in $\kappa_t^{L^a}$ lasts one period; dashed-and-dotted lines: the increase in $\kappa_t^{L^a}$ lasts four periods; dotted lines: $\kappa_t^{L^a}$ follows an AR(1) process with an autocorrelation coefficient of 0.5 (so the half-life of the initial change is one quarter); and dashed lines: the increase in $\kappa_t^{L^a}$ is permanent. In all cases, the initial increase in $\kappa_t^{L^a}$ is 0.5. Finally, $\kappa_t^{L^a}$ is measured in levels, in differences with respect to its steady state; for the other variables, see the note to figure 10.

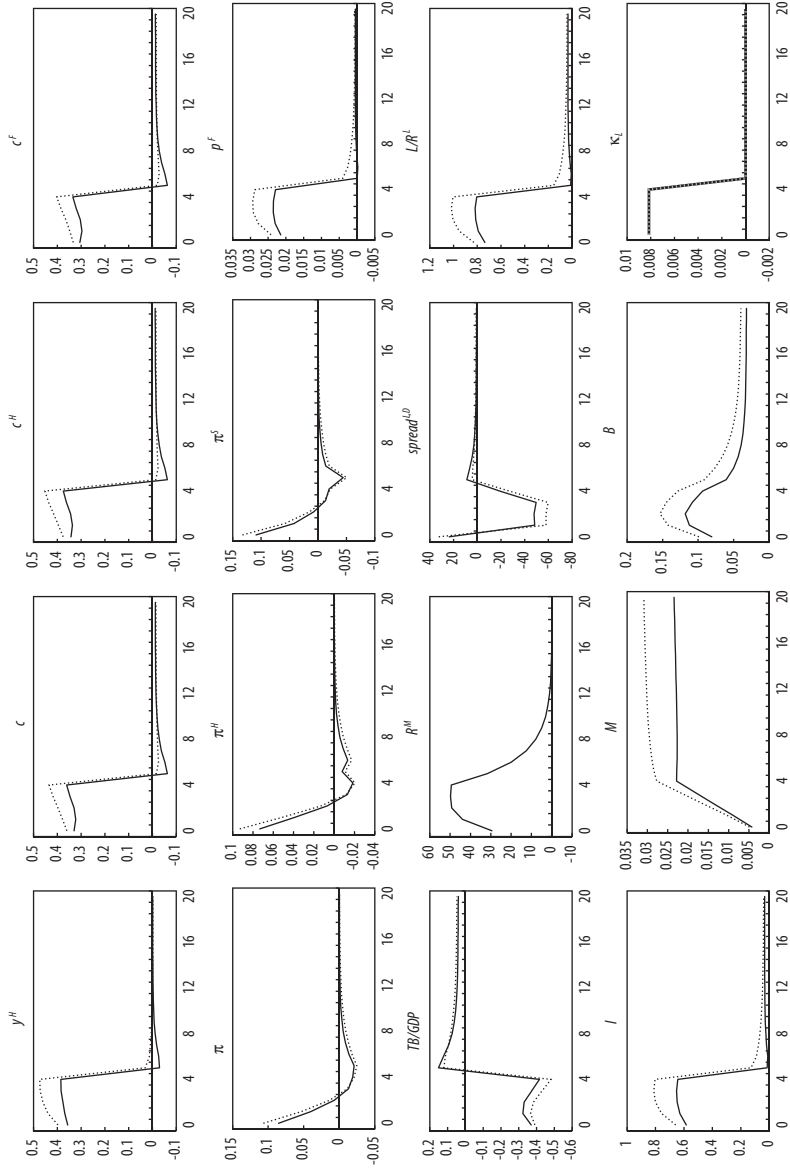
For all the temporary increases in κ_t^L , the price-level path does not change, so the expansion comes from two other channels. First, accepting loans in the liquidity facilities reduces the spread, which expands aggregate supply. Second, the temporary increase in liquidity, coupled with the sluggish adjustment in inflation due to price rigidities, relaxes the deposit-in-advance constraint, which increases aggregate demand. Compared with the permanent case, the responses of real quantities like output and consumption are somewhat larger on impact in the temporary cases, but they are 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 only lasts for a few periods.

Finally, we assess the effects of a policy implemented by the Central Bank of Chile in 2008 and 2009, when it decided to relax the list of eligible collateral for its liquidity operations. As with the sterilized intervention analyzed above, the key is to calibrate the path of κ_t^L . In this case, this is particularly challenging because the policy implemented did not specify the share of private bank 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 collateral implemented in October 2008 was initially supposed to last until year-end 2008, but in early December the measure was extended through the end 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. Second, to specify the value for $\kappa_t^L > 0$, we note that the amount of liquidity provided with repo operations averaged Ch\$1.1 trillion in the last quarter of 2008. Moreover, in its Financial Stability Report for January 2009, the Central Bank of Chile reported that around 50 percent of these repo operations used private bank assets as collateral.⁷¹ According to 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 $\kappa_t^L = (0.5 \cdot 1.1)/67.5 = 0.008$ after which it returns to $\kappa_t^L = 0$.

As illustrated in figure 13 (solid lines), this 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 almost 0.4 percent, inflation rises by almost 0.1 percentage point, and the real exchange

71. Central Bank of Chile (2009, table III.3).

FIGURE 13. Change in κ_t^i in Line with the Chilean Implementation in 2008–09



a. Solid lines: R^m moves according to the Taylor rule; dotted lines: R^m remains fixed. See the text for the description of the policy and the note to figure 10 for units of measure.

rate depreciates, with a somewhat larger nominal depreciation. When the same policy is coupled with a fixed R_t^m (figure 13, dotted lines), the effects on real variables are somewhat larger (for example, the peak effect on output is 0.1 percentage point higher), but the response of inflation is not significantly different.

Finally, a comparison of these predicted responses with the data suggests that the model is missing some of the dynamics.⁷² In particular, in the data the lending spread rose by almost 500 basis points from September to November 2008 and then fell by more than 200 basis points from November 2008 to January 2009. The drop in the spread predicted by our model is clearly smaller, at slightly more than 50 basis points. Such differences do not invalidate the exercise, however, which aims to isolate the policy effect, whereas the changes in the data are most 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.

Conclusions

This paper has developed a theoretical, quantitative model to analyze the macroeconomic impact of unconventional monetary policies, with a focus on sterilized interventions and the expansion of the list of eligible collateral used in a central bank's discount window operations. These two policies were used, in particular, by the Central Bank of Chile between 2008 and 2011. Our main findings are that, first, the effects of sterilized interventions on both output and inflation can be large, although the outcomes depend on how the central bank manages the additional liquidity generated by the sterilized foreign reserve purchase. Second, the magnitude of the macroeconomic effects of relaxing collateral requirements in open market operations depends on how long the option of using other assets as collateral is available. Some of our results, however, suggest that the final impact of the policies also depends on how the central bank combines different unconventional monetary policy tools to manage aggregate liquidity. For example, the macroeconomic effects of sterilized foreign reserve interventions in the model depend on whether the central bank changes collateral requirements to absorb part of the liquidity expansion. This happens because the new bonds issued to finance the pur-

72. Unfortunately, there are no references of empirical identification exercises that quantify the effects of this policy.

chases 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.

A major policy conclusion arises from the two expansionary policy exercises calibrated to the Chilean data (one for sterilized interventions and the other for a collateral relaxation in discount window operations). Given the transitory nature of both policy interventions (less than a year and a half), the impulse responses showed a relatively short period of inflationary expansion, returning to the steady-state level in a year, while output and consumption stayed above the steady-state level for almost two years. These results indicate that the Central Bank of Chile's use of a combination of unconventional monetary policy tools to expand liquidity may not have constituted any serious threat toward the consistency of the (flexible-form) inflation-targeting framework (as some analysts feared), but rather helped mitigate the economic consequences of negative external shocks such as the Lehman Brothers crisis in 2008. Other results also show the importance of using more than one unconventional monetary policy tool to achieve the dual goals of maintaining inflation close to the target and acting countercyclically to support economic activity, given that some of the exercises using only one unconventional expansionary measure complemented with the Taylor rule do lead to more persistent inflationary expansions.

Our discussion of liquidity also highlights that the money stock is not the only thing that matters. Many other financial assets are valued, in part, because they facilitate access to liquidity. While this issue has been emphasized in the recent literature, it has not been included in models developed to analyze the effects of unconventional policies.⁷³ Our model explicitly includes these considerations, and the results indicate that these issues cannot be taken for granted, although aspects such as financial frictions are also potentially relevant. Future research should combine the liquidity management considerations considered here 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. Many of these constraints are probably not binding in normal times, but they 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, whereas solving models with occasionally

73. See, for example, Gorton (2009); Gorton and Metrick (2012).

binding constraints is computationally more costly. Arguably, the alternative of occasionally binding constraints is most relevant if one wants to judge these types of policy from a welfare perspective, as this feature generally produces some 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 the different policy alternatives.

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