Capital controls on inflows, exchange rate volatility and external vulnerability

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ABSTRACT

We use high frequency data and a new econometric approach to evaluate the effectiveness of controls on capital inflows. We focus on Chile's experience during the 1990s, and investigate whether controls on capital inflows reduced Chile's vulnerability to external shocks. We recognize that changes in the controls will affect the way in which different macro variables relate to each other. In particular, we consider the case where controls co-exist with an exchange rate band aimed at managing the nominal exchange rate. We develop a methodology to deal explicitly with the interaction between these two policies. The main findings may be summarized as follows: (a) a tightening of capital controls on inflows depreciates the exchange rate and (b), we find that a tightening of capital controls increases the unconditional volatility of the exchange rate, but makes it less sensitive to external shocks.

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1. Introduction

During the last few years the economics profession has made important progress in understanding the determinants of currency crises. This research has helped reshape the way in which monetary and fiscal policies are conducted in emerging and transition nations. Scholars and policy makers, however, continue to disagree on some important aspects of macroeconomic policy. One of the key topics of debate refers to the role of capital controls and the adequate degree of financial integration of emerging markets to the rest of the world.[1] According to some authors, limiting the extent of financial integration reduces speculation, and helps countries withstand external shocks and avoid extreme exchange rate fluctuations (Bhagwati, 1998; Krugman, 1999; Stiglitz, 2000, 2002; Rodrik, 2006).[2] Authors that support restricting capital mobility have mentioned Chile's experience with market-based controls on capital inflows between 1991 and 1998 as an example worthwhile emulating.[3] In late 2006 Thailand's economic authorities justified the imposition of controls on short term capital inflows, by

referring to Chile's experience during the 1990s.[4] In 2007, Colombia imposed hort term capital inflows in an effort to reduce the extent of (nominal) exchange rate appreciation; in rationalizing this policy the authorities also referred to Chile's experience with controls on inflows.[5]

Authors such as Stiglitz (2002), Eichengreen (2000), Eichengreen and Hausmann (1999), Stallings (2007) and Williamson (2003) have argued that Chile-style controls on inflows have three important effects: (a) they reduce the degree of vulnerability to external shocks; (b) they result in lower exchange rate volatility; and (c) they help avoid the extent of currency appreciation during episodes of capital inflows. According to these authors, controlling short term inflows were one of the keys to Chile's economic success during the 1990s.

Calvo and Mendoza (1999), however, have argued that Chile's success during the 1990s was mostly the result of favorable external conditions, including very positive terms of trade. In their view, macroeconomic policies — including the controls on inflows — had little to do with "the notable accomplishments of the Chilean economy."[6] The empirical literature on Chile's controls has tended to support Calvo and Mendoza (1999); most works on the subject have found that Chile's controls had limited macroeconomic effects. De Gregorio et al. (2000), for example,

[1] See, for example, the papers collected in Edwards (2007).
[2] The IMF seems to support a very gradual lifting of restrictions to capital mobility in emerging economies. See, for example Prasad et al. (2003).
[3] For a detailed discussion of Chile's experience with capital controls on inflows see Cowan and De Gregorio (2007).

[4] On Thailand's 2006 imposition of controls on inflows, see http://www.imf.org/external/np/sec/pn/2007/pn0739.htm.
[5] On Colombia's 2007 controls on inflows, see, http://www.rgemonitor.com/blog/economonitor/196421.
[6] In a different paper Calvo and Mendoza (2000) point out that capital controls on inflows *may* be justified if the costs of contagion are high. See also Edwards (2007).

found that during the 1990s controls on inflows altered the composition of capital flows, with short term flows declining and longer term flows increasing. Controls, however, failed to stop currency appreciation or to increase the Central Bank's ability to control monetary aggregates over the medium or long run. Similar results were found by Edwards (1999) and Valdes-Prieto and Soto (1998). Forbes (2003, 2005) uses firm-level data to investigate whether Chile's controls had microeconomics effects. Her results indicate that by restricting access to external funding, the controls increased the cost of capital to small and mid size firms (see, also, Ulan, 2000).

Although the results reported by these early papers are useful, they are subject to some limitations and potential econometric problems. In particular, these works have ignored the fact that controls on capital inflows were only one component of Chile's external macroeconomic policy, and of the authorities' efforts to avoid "excessive" nominal exchange rate fluctuations and, in particular, currency appreciation. A second key element of this policy was a band of varying width that constrained the movement of the nominal exchange rate. Ignoring this exchange rate band can introduce an important bias in the estimation of equations that attempt to assess the effects of the controls on key macroeconomic data, such as the exchange rate (nominal or real). The reason for this is that the controls themselves affected the width and realignment of the band, and the existence of the band affected the behavior of macroeconomic variables such as interest rates and the exchange rate.

The purpose of this paper is to develop a new methodology that allows us to evaluate the effects of capital controls on inflows in countries that intervene in the foreign exchange market. In particular, this new approach allows us to investigate whether restricting capital inflows will reduce nominal exchange rate changes and volatility. We do this by using a two-step estimation technique that incorporates the concept of shadow or equilibrium exchange rate developed by Bertola and Caballero (1992). In the first step, we use data on exchange rate fundamentals and on the nature of the foreign exchange rate intervention policy (or, if appropriate, the exchange rate band) to estimate the shadow exchange rate.[7] In the second step, we use an augmented GARCH approach to evaluate whether changes in the restrictiveness of capital controls affected the level and volatility of the nominal exchange rate. In the empirical section we use high frequency daily data for Chile for 1991–1998; in some of the estimates, and in order to investigate the robustness of our estimates, we use monthly data.

The methodology and results presented in this paper go beyond the historical interpretation of Chile's economic performance, and are useful to evaluate future initiatives aimed at restricting capital mobility in countries that pursue an active exchange rate management policy. This exchange rate intervention policy may take place through an explicit band, as in Chile, or through implicit feedback rules that rely on more implicit intervention thresholds. As pointed out above, both Thailand and Colombia recently imposed controls on inflows as a way to avoid nominal exchange rate appreciation.

Our analysis differs from previous work on the subject in, at least, four respects: First, we use high frequency (daily) data to analyze the effects of controls on capital inflows on the nominal exchange rate. Previous work, in contrast, has used relatively low frequency data (monthly or quarterly) to analyze real exchange rate behavior. Second, we explicitly take into account the fact that an active exchange rate policy affects the evaluation of capital controls. All previous papers on the subject that we are aware of ignored this important fact. Indeed, one of the key objectives of introducing capital controls is to allow the monetary authority to exercise some control over exchange rates. As we explain in detail in Section 3, we do this by estimating a shadow exchange rate, which captures the response of the exchange rate to changes in fundamentals in the absence of the exchange rate band.

Third, we focus on the effects of the controls on the level and volatility of the nominal exchange rate. In contrast, most previous research deals with the impact of controls on the level of the exchange rate only. And fourth, we use a two-step augmented ARCH and GARCH, while most previous analyses have relied on VARs and/or standard regressions.

It is also important to clarify at the outset what our paper doesn't do: we don't provide a complete cost–benefit analysis of Chilean style capital controls. In particular, we don't deal with the potential efficiency (and other) costs of restricting capital mobility. Also, this paper doesn't deal with the effects of capital controls on the probability of a currency crisis, or their effects on interest rates and foreign debt maturities. These are important issues, but they are beyond the scope of the present paper.[8]

The main findings from our analysis may be summarized as follows. First, a tightening of capital controls results in a depreciation of the domestic currency. This level effect on the nominal exchange rate should have been expected, given that tighter capital controls reduce capital inflows, and cause a deterioration in the balance of payments.[9] To return to equilibrium, then, an improvement in the current account is required, and hence a real exchange rate depreciation should take place; this real exchange rate change takes mostly place through changes in the nominal exchange rate. Surprisingly, most of the papers that have studied the Chilean experience have not found significant effects of the controls on the real exchange rate.[10] We believe that this is because early studies on the subject ignored the endogenous response of the exchange rate to monetary policy. Second, we find that the "vulnerability" of the nominal exchange rate to external factors decreases with a tightening of the capital controls. More specifically, we find that Chile's controls on capital inflows were effective in (partially) isolating the nominal exchange rate from external shocks to import and export prices and international interest rates. Third, we find that a tightening of capital controls increases the unconditional volatility of the exchange rate. This effect can be explained by the fact that tighter controls are likely to have segmented the Chilean foreign exchange market further. On the other hand, isolating the foreign exchange market contemporaneously means that, in the end, exchange rate volatility is larger in the following periods. Capital controls introduce a tradeoff stabilizing contemporaneous exchange rates (in terms of external shocks), but destabilizing future nominal rates.

The rest of the paper is organized as follows: In Section 2 we discuss the functioning of Chile's controls on inflows, and we review the empirical literature on the subject. Section 3 is the core of the paper: we present our model, and we discuss a two-stage strategy for estimating the effects of controls on inflows on the level and volatility of the exchange rate. In this Section we compare the results obtained using a shadow exchange rate and the observed exchange rate. Additionally, we present some robustness tests and we discuss issues for future research. Finally, Section 4 is the conclusions.

2. Controls on capital inflows: Chile's experience during the 1990s

2.1. The mechanisms for controlling capital inflows into Chile

Chile introduced market-based controls on capital inflows in June 1991.[11] Originally all portfolio inflows were subject to a 20% reserve

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[7] See Kearns and Rigobon (2005) for a discussion on identification and estimation of central bank exchange rate intervention rules.

[8] For an analysis of (some of) the costs of Chile's experience with controls on inflows, see Forbes (2003, 2005). Edwards (2007) addresses the effects of controls on the probability of a crisis; De Gregorio et al. (2000) analyze the effects on interest rates and debt maturity.

[9] Most emerging markets that have undertaken modernizing reforms have been subject to massive capital inflows that have generated forces toward currency appreciation. See, for example, Calvo et al. (1993).

[10] See, for example, De Gregorio et al. (2000).

[11] For a detailed discussion on the administrative details of Chile's controls on inflows, see Ulan (2000), and Cowan and De Gregorio (2007). Chile also implemented controls on inflows during the 1980s. That earlier episode is discussed in Edwards (1998).

deposit that earned no interest. If the inflow had a maturity of less than a year, the deposit applied for the entire duration of the inflow. For longer maturities, the reserve deposit was for one year. In July 1992 the rate of the reserve requirement was raised to 30%, and its holding period was set at one year, independently of the length of the maturity of the inflow. Also, at that time trade credits and loans related to foreign direct investment became subject to the unremunerated reserve requirement (URR). New changes to this policy were introduced in 1995, when the reserve requirement coverage was extended to include Chilean stocks traded in the New York Stock Exchange (ADRs), "financial" foreign direct investment (FDI), and bond issues. In June of 1998, and as a result of the sudden slowdown of capital inflows associated with the East Asian currency crises, the rate of the reserve requirement was lowered to 10%, and in September of that year the deposit rate was reduced to zero. Throughout this period Chile also regulated foreign direct investment: until 1992, FDI was subject to a three years minimum stay in the country; at that time the minimum stay was reduced to one year. There were no restrictions on the repatriation of profits from FDI.

In 1991, when capital controls on inflows were introduced, the authorities had four goals in mind:[12] First, to slow down the volume of capital flowing into the country, and to tilt its composition towards longer maturities; second, to reduce the degree of nominal (and real) exchange rate volatility; third, to reduce (or, at least, delay) the real exchange rate appreciation that stemmed from these inflows; and fourth, to allow the Central Bank to implement an independent monetary policy, and to maintain high domestic (real) interest rates (De Gregorio et al., 2000; Massad, 1998).

Chile's system of unremunerated reserve requirements was equivalent to a tax on capital inflows. What made this policy particularly interesting was that the rate of the tax was not constant; in fact, it varied constantly. This was because the rate of the tax depended both on the period of time during which the funds stayed in the country, as well as on the opportunity cost of these funds (i.e. "the" world rate of interest). As shown by Valdés-Prieto and Soto (1998) and De Gregorio et al. (2000), the tax equivalent for funds that stayed in the country for k months, is given by the following expression:

$$\tau(k) = \frac{r^* \lambda}{1 - \lambda} \frac{\rho}{k}, \tag{1}$$

where r^* is an international interest rate that captures the opportunity cost of the reserve requirement, λ is the proportion of the funds that has to be deposited at the Central Bank, and ρ is the period of time (measured in months) that the deposit has to be kept in the Central Bank.

Fig. 1 contains the estimates of this tax-equivalent for three values of k: six months, one year and three years. Three aspects of this figure are particularly interesting: first, the rate of the tax is inversely related to the length of stay of the funds in the country. This was exactly the intent of the policy, as the authorities wanted to discourage short-term inflows. Second, the rate of the tax is quite high even for a three year period. During 1997, for example, the average tax for 3 year-funds was 80 basis points. And third, the tax equivalent varied through time, both because the rate of the required deposit was altered and because the opportunity cost of the unremunerated deposits changed.

Between 1988 and 1998 shorter-term flows into Chile — that is, flows with less than a one year maturity — declined steeply relative to longer term capital. Liabilities in hands of foreigners maturing within a year also declined in the period following the imposition of controls (De Gregorio et al., 2000). By late 1996 Chile had a lower percentage of short-term debt (relative to total debt) to G-10 banks than any of the East Asian countries, with the exception of Malaysia (Edwards, 1998).
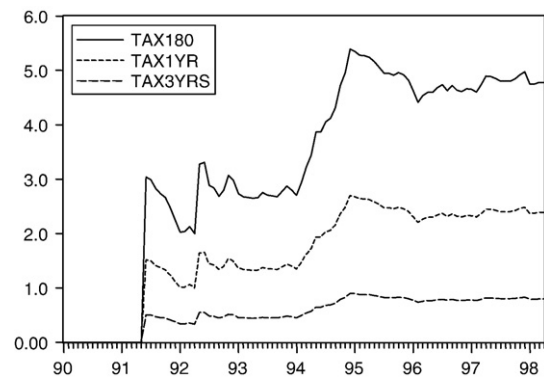

Fig. 1. Tax Equivalent of Capital Controls: stay of 180 days, 1 year and 3 years (vertical axis: percentage points).

A traditional shortcoming of capital controls (either on outflows or inflows) is that it is relatively easy for investors to avoid them. Valdés-Prieto and Soto (1998), for example, have argued that in spite of the authorities' efforts to close loopholes, Chile's controls were subject to considerable evasion. Cowan and De Gregorio (1998) acknowledged this fact, and constructed an index of the "power" of the controls. This index takes a value of one if there is no (or very little) evasion, and takes a value of zero if there is complete evasion. According to them this index reached its lowest value during the second quarter of 1995.

2.2. A selective review of the empirical literature

Most previous works on the macroeconomic effects of Chile's controls on capital inflows have relied on two alternative empirical methodologies: single equation estimation or vector auto regressions (VARs). In addition, a few papers used GARCH techniques to investigate the effect of controls on the second moments of key macroeconomic data. The vast majority of these works have focused on real exchange rates, interest rates and the maturities of flows. As far as we know, however, none of them has dealt with the effects of controls on the nominal exchange rate. In addition no study has incorporated the existence of an active exchange rate management policy.

Some of the single regression works include Valdes-Prieto and Soto (1998, 2000), who concluded that, although the controls changed the composition of capital inflows, they did not affect the exchange rate level. Eyzaguirre and Schmidt-Hebbel (1997) found that the URR increased the central bank's ability to engage in independent monetary policy, and had a small and temporary effect on the exchange rate. After estimating a series of rolling regressions on interest rate differentials, Edwards (1998) concluded that the capital controls increased the degree of monetary policy effectiveness in the short run. Cardoso and Laurens (1998) also estimated interest rate differential equations, and found that the controls had no significant effects on the macroeconomic variables of interest. Larrain et al. (2000) used a nonlinear switching regimes model for capital flows of different maturities. They found that while short term flows declined after the URR was adopted, long term flows were not affected. Gallego et al. (2002) estimated a series of nonlinear equations and error correction models, and concluded that during the URR period the central bank had a somewhat greater ability to pursue independent monetary policy objectives. However, the capital controls did not affect the exchange rate level.[13]

A number of authors have tried to account for the simultaneous determination of different macroeconomic variables by estimating vector auto regressions. Soto (1997) and Edwards (1999) concluded that the controls on inflows were effective in helping avoid an appreciation of the currency in the short run. Edwards (2000) used multi-country

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[12] Magud and Reinhart (2007) refer to these four objectives as the four macroeconomic "fears" of emerging and transition economies.

[13] These results are consistent with Montiel and Reinhart (1999).

systems VARs to analyze whether the capital controls were able to isolate Chile from contagion stemming from aboard. He concluded that contagion was not reduced by the controls. De Gregorio et al. (2000) estimated a series of VARs using monthly data and found that their effects on interest rates and the exchange rate were (very) short lived. The effects on the composition of capital inflows, on the other hand, were longer. Magud and Reinhart (2007) provide an in depth review of some of these studies, and compares them to studies for other countries.

These studies have provided some light on the functioning of capital controls on inflows, and have helped evaluate the effectiveness of this policy. None of these works, however, have taken explicitly into account the existence of an exchange rate band that restricted nominal exchange rate movements. As we show in Section 3 of this paper, ignoring this band will introduce serious biases in the estimation. In Section 3 we also propose a specific methodology for evaluating the effects of capital controls on inflows in countries that pursue an active exchange rate management policy.

3. Estimating the effects of capital controls on the nominal exchange rate

A serious difficulty in evaluating whether Chile's policy on capital controls was successful in reducing macroeconomic volatility — and in particular, in reducing exchange rate volatility — is that it was implemented at the same time as the country had a (credible) target-zone exchange rate regime. The co-existence of these two policies — controls on inflows and a target zone — make it difficult to determine if changes in exchange rate volatility are the result of the controls, or if they respond to the fact that throughout most of the period the actual exchange rate was very close to one of the bands. This results in an identification problem from the monetary policy choice to the observed exchange rate.

There also exists an effect that goes from capital controls to the way a target zone works. As it is well known, a credible target zone regime implies a mapping from a fundamental exchange rate to an observed exchange rate that depends on the stochastic process of such fundamentals. Therefore, if the capital controls are effective, when the controls are tightened, they should reduce the volatility of the fundamentals that drive the exchange rate. That is, effective controls alter the mapping from the fundamentals to the observed exchange rate. From the policy point of view, it is not surprising that there is a link between nominal exchange rates' management and capital controls. Indeed, most countries implement capital restrictions because they are hoping to have some control over the nominal exchange rate.

In this paper we develop a methodology to disentangle these effects. We take seriously the exchange rate bands announced by the Chilean Central Bank, and we estimate the implied "fundamentals" determining the observed exchange rate — this is equivalent to estimating a shadow exchange rate that would have prevailed in the absence of the intervention implied by the target-zone exchange rate regime. Once the shadow exchange rate has been computed in the first stage of the analysis, we can then evaluate the effectiveness of the capital controls by measuring the pass through from external shocks to the shadow exchange rate, under alternative intensities of capital controls. We carry out this second stage by estimating a series of GARCH regressions on the conditional variance of the shadow exchange rate.

3.1. Data

The data are daily and are taken from Datastream and the Central Bank of Chile. Exchange rate data correspond to the daily exchange rate, the central parity and the target-zone bands. We also use daily data on domestic peso denominated interest rates on 30-day deposits, and on the equivalent tax rate implied by the controls — computed according to equation (1). Finally, we used alternative sources of external shocks — changes in U.S. interest rates (30-day deposit rates),

and the JP Morgan EMBI+ index that excludes Chile. We also collected the price of oil and copper (Chile's main imports and exports, respectively) for the same period.[14] The sample corresponds to the period in which the target zone regime was in place — starting in January 1991 until September 2nd, 1999. (Daily domestic interest rates were only available from January 1st 1994, however.)

3.2. Estimation: model and methodology

In order to estimate the shadow exchange rate — or exchange rate that would have prevailed in the absence of intervention (target zone) — we assume that the announcement of the target zone regime is credible while in place; however, we allow for the possibility of a bands' realignment —, something that indeed happened in Chile during this period.

Conditional on modeling the Central Bank actions, the mapping from the shadow exchange rate to the observed nominal exchange rate is uniquely determined by the bands and by the stochastic properties of the exchange rate process. We assume that the mean of the shadow exchange rate is constant across time; the variance, on the other hand, is assumed to be time dependent.[15] This means that at each instant, the mapping from the shadow to the observed exchange rate will shift. This assumption is required because our purpose is to evaluate how capital controls have changed the stochastic properties of the fundamentals determining the exchange rate. Therefore, given that the degree of tightness of the capital controls changes through time — recall Eq. (1) —, and that the shocks are characterized by conditional heteroskedasticity, we should also expect the shadow exchange rate to have conditional heteroskedasticity.

To derive the shadow exchange rate as a function of the observed exchange rate we follow Bertola and Caballero (1992) closely, where the possibility of realignment is exogenously specified.[16] It is important to recognize that our methodology does not assume a connection between the capital controls and possible sources of crises. For instance, assume that capital controls allow the fiscal authority to raise its fiscal deficit (by lowering the domestic cost of financing) and ultimately cause an exchange rate crisis. This connection between the capital controls and the exchange rate is missing in our methodology — we concentrate exclusively on the endogeneity that exists between monetary policy management and capital controls and abstract from all other feedback effects.

As in the standard target zone model, assume that money demand in each country is given by (where standard notation has been used):

$$m_t^* - p_t^* = -\alpha i_t^*$$
$$m_t - p_t = -\alpha i_t \tag{2}$$

Assume further that both purchasing power parity (PPP) and uncovered interest parity (UIP) hold. This implies that the exchange rate is:

$$e_t = m_t - m_t^* + \alpha \frac{E[de_t]}{dt}, \tag{3}$$

where we have substituted the money demands in the PPP equation and use the fact that the interest rate differential is equal to the expected exchange rate depreciation. In this equation the changes in

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[14] Ideally we would have used indexes for the price of imports and exports, or the terms of trade. These data, however, are not available at daily intervals. This is the reason why, as suggested by one of the referees, we concentrate on the prices of copper and oil (Chile's main import).

[15] We can allow the mean to change and makes no difference in the estimation. Means, however, are very badly estimated when the process follows a random walk. We faced the exact same estimation issues in our procedure. Nevertheless, we were encouraged by the fact that allowing the trend to vary or to force it to be the same produced (qualitatively) very similar results.

[16] See Garber and Svensson (1995) for a detailed survey of the literature.
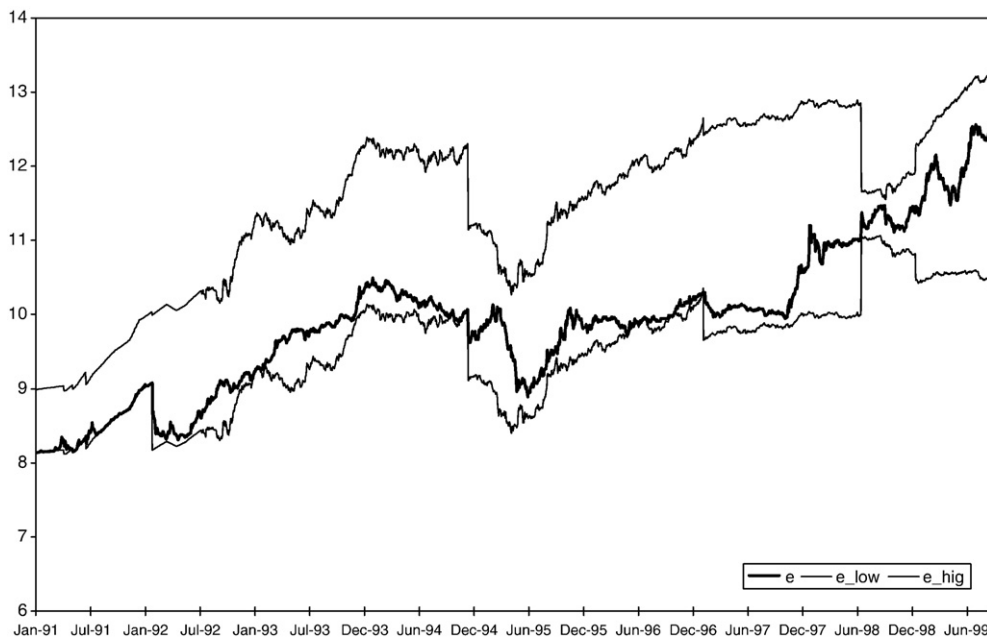
Fig. 2. Exchange rate and exchange rate bands. All exchange rates measured in logs.

money supplies are the "fundamentals" or shadow exchange rate that govern the exchange rate dynamics. We assume that the fundamentals are given by:

$$f_t = \mu dt + \sigma_t dz_t \tag{4}$$

where the mean is constant and the variance is time shifting. Using Ito's lemma it is easy to show that the exchange rate satisfies the following differential equation:

$$e_t = f_t + \alpha \left[\mu \frac{\partial e_t}{\partial f_t} + \frac{1}{2} \sigma_t \frac{\partial^2 e_t}{\partial f_t^2} \right].$$

The solution to the differential equation is:

$$e_t(f_t) = \alpha\mu + f_t + A_t exp(\lambda_{1t} f_t) + B_t exp(\lambda_{2t} f_t), \tag{5}$$

where λ_{1t} and λ_{2t} satisfy

$$\lambda_t = -\frac{\mu}{\sigma_t^2} \pm \sqrt{\left(\frac{\mu}{\sigma_t}\right)^2 + \frac{2}{\alpha \sigma_t^2}}. \tag{6}$$

To pin-down the coefficients in the homogeneous solution to the differential equation we require boundary conditions. These are specified by the bands of the target zone and the credibility of the exchange rate regime.

The exchange rate bands in Chile moved frequently — see Fig. 2. In this figure we present the nominal exchange rate (the thick line in) and the upper and lower bands (the thinner lines). A sizeable proportion of this movement is predictable in the sense that it depended on how the central parity is computed. Throughout the period under consideration the Central Bank set the central parity as a weighted average of past realizations — which means that the bands can be computed according to the information available at time t.[17] Indeed, during our sample there are only 5 band alignments (see Fig. 2): (a) On January 2nd 1991 the bands are set to $+/-5\%$ of the central parity; (b) On January 23rd 1992 the bands are expanded to $+/-10\%$; (c) On January 21st 1997 the bands

are further expanded to $+/-12.5\%$ of the central parity; (d) On June 26th 1998 the bands are heavily tightened to an upper band of only 2% and a lower band of 3.5%; and (e) On September 17th 1998 both bands are set to $+/-3.5\%$, and the bands are progressively increased every day until they become almost 12% in September 2nd 1999 when the regime was abandoned.

It is reasonable to assume that the probability that the bands are realigned increases when the exchange rate is close to the band. The realignment model of Bertola and Caballero needs an estimate of this probability or realignment — which is usually assumed to be fixed or exogenous. In our estimation, we computed the probability of realignment as the number of realignments that occurred in the sample divided by the number of observations in which the exchange rate was closer than 0.5% of the band.[18] At each point in time we have the following boundary conditions:

$$f_t \in \left\lfloor \underline{f_t}, \overline{f_t} \right\rfloor$$
$$\underline{e_t} = \alpha\mu + \underline{f_t} + A_t exp\left(\lambda_{1t} \underline{f_t}\right) + B_t exp(\lambda_{2t} \underline{f_t}) \tag{7}$$
$$\overline{e_t} = \alpha\mu + \overline{f_{t_t}} + A_t exp\left(\lambda_{1t} \overline{f_t}\right) + B_t exp\left(\lambda_{2t} \overline{f_t}\right),$$

where $\underline{f}$ and $\overline{f_t}$ represent the lower and upper implied shadow exchange rate bands. These boundary conditions are known as the value matching conditions. The smooth pasting conditions take into account the fact that the bands are time varying and incorporate the probability of realignment, as well as the predicted changes in the central parity. As may be seen in Fig. 2, most of the changes in the central parity and the width of the band are relatively small and follow the predictable process described above. We compute the expected

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[17] For details on exchange rate policy during this period see, for example, Cowan and De Gregorio (2007).

[18] The methodology only deals with exogenous realignments, and therefore, we decided to allow for a relatively large probability of realignment. In fact, the larger this probability is, the closer the shadow and the actual exchange rates are going to be. In other words, if the probability of realignment is one, the target zone regime is irrelevant and the shadow and actual exchange rates are identical. When we performed the estimation we tried with different probabilities of realignment and the results remain unchanged. Indeed, the results setting the probability equal to zero are almost identical to the ones we present.
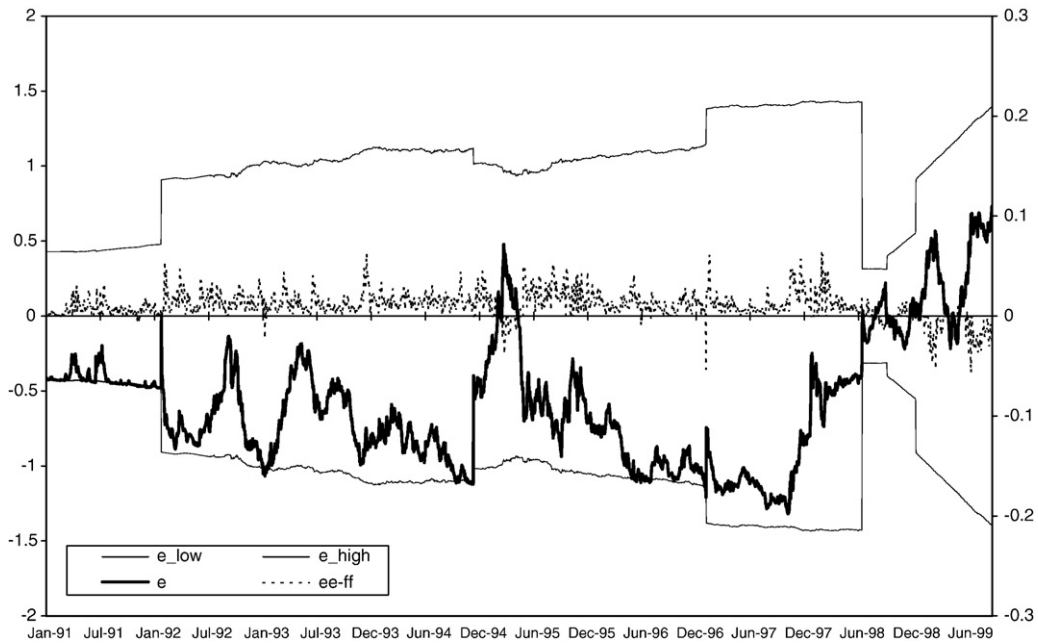
Fig. 3. Exchange rate, bands, and the difference between the nominal exchange rate and the shadow exchange rate. Exchange rates measured on the left axis in logs and as differences with respect to central parity. The difference between exchange rate and shadow exchange rate is measured on the right axis (also in logs).

change in each of the bands, and write the smooth pasting conditions as follows:

$$\underline{\hat{e}}_t = 1 + A_t\lambda_{1t}exp\left(\lambda_{1t}\underline{f_t}\right) + B_t\lambda_{2t}exp\left(\lambda_{2t}\underline{f_t}\right) \quad\quad (8)$$

$$\overline{\hat{e}}_t = 1 + A_t\lambda_{1t}exp\left(\lambda_{1t}\overline{f_t}\right) + B_t\lambda_{2t}exp\left(\lambda_{2t}\overline{f_t}\right)$$

Our data set includes the following information: the actual (observed) exchange rate (e_t), the bands ($\underline{e_t}$ and $\overline{e}_t$), and the probability of realignment (reflected in the fact that the smooth pasting conditions are not equated to zero). We also have knowledged on the backward looking rule used by the central bank to determine the central parity.

Our objective is to estimate the shadow exchange rate (f_t), the bands $\lfloor \underline{f_t}, \overline{f_t} \rfloor$, the coefficients A_t and B_t, and the time varying moments describing the fundamentals' process: μ and σ_t.

This is a highly complex non-linear problem: there are as many stochastic differential equations as observations. The mapping from the fundamental or the shadow exchange rate to observed exchange rate changes with the conditional mean and variance. If capital controls are effective and change the volatility of the fundamentals, or the pass through from external shocks to the fundamentals, the mapping between the shadow and the observed will change as well. We take into account these changes in our estimation.

3.3. Computing the shadow exchange rate

We assume that the variance of the shadow exchange rate moves smoothly — and that it can be approximated by a moving average. This assumption is required for identification reasons. We have a limited number of moments at each point in time, and smoothness allows us to estimate conditional variances on the actual exchange rates, and use them in the estimation.[19] Under this assumption, the conditional

variance at some time t is given by the variance of the previous n observations. This method allows us a very flexible specification, where we do not have to commit to a particular parametrization of the variance process — we only need that the variance process is approximated relatively well by a moving average. We did some sensitivity analysis on these assumptions that is discussed below.

The procedure of estimation is by iteration, and involves the following steps:

a) Initialize the shadow exchange rate equal to the observed exchange rate: $f_t^0 = e_t$. This is the first iteration.
b) At iteration i we have an initial guess denoted as f_t^i.
c) Compute the mean return in the fundamentals (we are assuming that the mean return is constant throughout the whole sample) and the rolling variance of the fundamentals ($\sigma_t = var(f_{t-n}^i : f_{t-1}^i)$). For some n that represents a reasonable window (we used 5, 10, 20 and 60 days and the results are very similar. All the results we show are those from the 5 days).
d) Using the mean return and the rolling variance, compute the series of λ_{1t} and λ_{2t} that prevails at each time t.[20]
e) Using the observed bands $\lfloor \underline{e_t}, \overline{e_t} \rfloor$, the λ_{1t} and λ_{2t} previously computed, and the expected changes in the bands $[\underline{\hat{e}}_t, \overline{\hat{e}}_t]$ we compute $(A_t, B_t, \underline{f_t}, \overline{f_t})$ using Eqs. (7) and (8). Note that at each time t, Eqs. (7) and (8) form a system of four equations in four unknowns — hence, for each observation we solve the system of equations.
f) Using Eqs. (5) and (6) we solve for the implied fundamental that explains the exchange rate. This provides an estimate of the shadow exchange rate f_t^{i+1} for every time.
g) We compare the estimated fundamental (f_t^{i+1}) with the initial guess (f_t^i).
h) Jump to step (c) and continue iterating until convergence has been achieved in the shadow exchange rate.

Because the mapping is unique, continuous and differentiable between $[\underline{f_t}, \overline{f_t}]$, the iteration has a fixed point. In the end, we estimate the shadow exchange rate, the implied shadow exchange rate's bands,

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[19] If the variances where to be completely random with no pattern whatsoever, we cannot estimate the model. The reason is that there are far too many unknowns at every point in time: the fundamental, the bands, and the volatility. The smoothness on the variance implies that the volatility of the shadow exchange rate is explained by a process that can be approximated (reasonably well) by a moving average. For instance, a GARCH or ARCH model.

[20] In fact, all the variations in these variables are due to the change in the volatility.
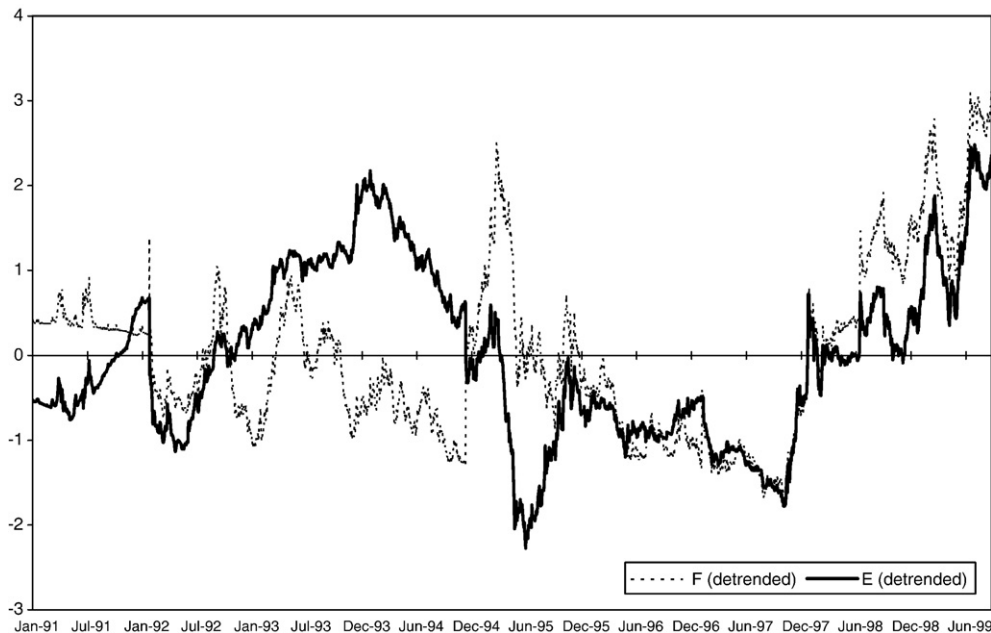
Fig. 4. Exchange rate, bands, and rolling window variance (5 days) of the shadow exchange rate. All variables are measured in logs.

and the conditional variance of the shadow exchange rate that is consistent with the observed exchange rate and the bands.

Notice that in developing this procedure we have made several important assumptions: First, we have assumed that the mean returns are constant. This is mainly for convenience. It is well known that mean returns are poorly estimated when the time horizon is short. In our case, the (daily) data runs from the beginning of the 90's to the end of the 90's. If we were to estimate a yearly mean return we would introduce a noisy estimate in the procedure. However, when we allowed the trend to change, the shadow exchange rate was almost identical to the one we estimated forcing the trend to be constant. Thus, we view this restriction as innocuous.

Second, we have assumed that the central bank only intervenes when the exchange rate is close to the band, following precisely what a target zone exchange rate regime implies. We made this assumption because there are no data on daily interventions for the period under study.[21] We were only able to compile monthly interventions; when we re-estimate the estimate at this lower frequency, the results are quite similar to those obtained under our assumption that intervention only takes place in the neighborhood of the bands, but the standard errors became large. Finally, although we allow for exchange rate bands realignments we assume that the exchange rate regime as a whole is credible. In other words, it is fully credible up to the realignment. For instance, assume that a drop in the price of copper might imply a lower credibility in the target zone. This connection is missing in our estimates given that the probability of realignment has been fixed.

The results from the estimation of the shadow exchange rate are shown in Fig. 3, where in order to avoid clutter we have not shown the central parity. The thick line corresponds to the estimated fundamental, the top and bottom lines are the estimated bands, and the dashed line is the difference between the fundamental and the actual exchange rate. The bands and the fundamentals are measured on the left axis, while the difference is measured on the right hand side axis. Notice that when the central parity shifts are removed, the bands are much stable than those shown in Fig. 2. Indeed, this is the case just in the raw data. This is not a feature from the estimation.

Second, as may be seen in Fig. 3, the shadow and actual exchange rates are fairly close to each other. The differences are, however, in line

with what we would have expected. From the theory we know that when the exchange rate is below the central parity the observed exchange rate is larger than the shadow exchange rate. The opposite occurs when the exchange rate is above the central parity.[22] Notice that indeed this is the relationship between the exchange rate and the shadow exchange rate. At the beginning of the sample the exchange rate is usually below the parity and the difference to the shadow one are always negative. The opposite happens when the exchange rate is positive. Furthermore, the theory also implies that the closer the exchange rate is to the band, the larger the deviations should be (ceteris paribus). Our shadow exchange rate follows exactly such prescription.

Third, in order to highlight the differences even further, in Fig. 4 we present the demeaned and de-trended actual and shadow exchange rates. The thick line is the actual exchange rate, and the dashed line is the shadow exchange rate (or fundamental). Notice that the differences can be appreciated much better in this case; the differences are more meaningful at the beginning of the sample than at the end. This is indeed a characteristic of the Chilean exchange rate regime that prevailed at the time. The credibility of the exchange rate regime started to be severely affected at the end of the sample, and this is shown by the fact that the shadow and the actual exchange rates are almost identical.

3.4. External vulnerability and capital controls

After the shadow exchange rate has been computed, the second step is to estimate a GARCH model to evaluate the importance (and role) of capital controls in the propagation of external shocks. As mentioned earlier, we measure the degree of capital control tightness by the tax equivalent pressure. We have three measures depending on the horizon, and because they are multicollinear, we decided to use the shorter maturity (180 days).[23]

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[21] We thank Rodrigo Valdes from the Central Bank of Chile for confirming this to us.

[22] This is a standard result in the target zone literature. In our setup, the slope of the mapping at the central parity is one and it goes to zero when the exchange rate approaches the bands.
[23] The results are virtually identical (except for normalization) if we use any of the other measures of capital controls. If the implied taxes were much different than the ones we have, a weighted estimator would have proven very useful. In our case, because the measures are identical, such estimator makes very little difference.
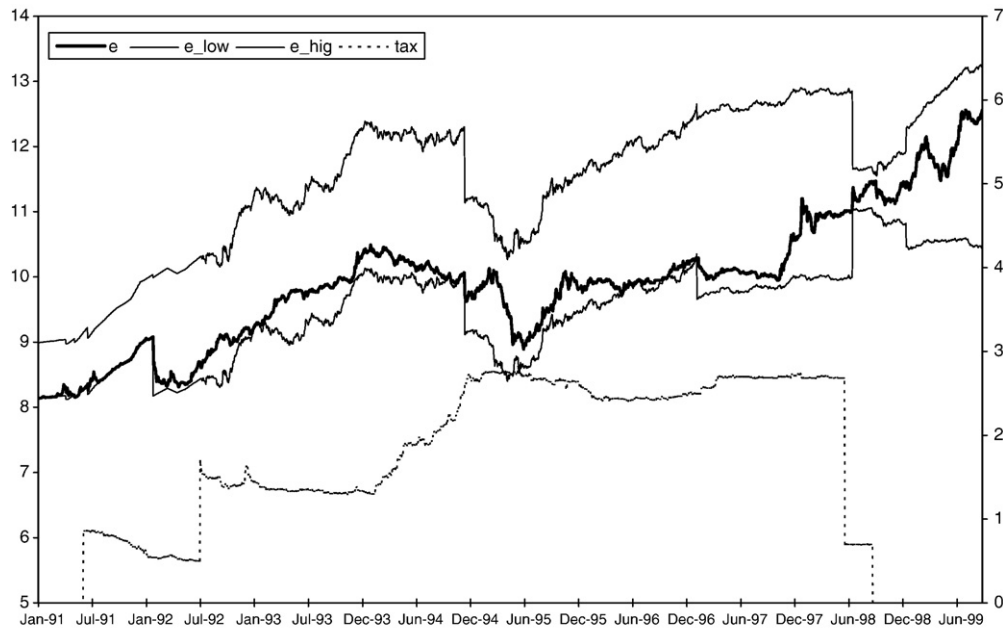
Fig. 5. Exchange rate, bands, and the equivalent tax rate implied by the capital controls. Exchange rates are measured in logs, and taxes are measured in percentages.

In Fig. 5 we present the actual exchange rate, together with the bands and the equivalent tax from the controls. We assume that changes in the extent of the controls are exogenous to the exchange rate. This is a reasonable assumption, since changes in the tax equivalence of capital controls tax rate are not associated with realignments in the band, but with changes in the international interest rate. Indeed, these two variables are only related when the controls are abandoned in 1998 and the band is widened. We estimate the following GARCH specification:

$$f_t = c_0 + \beta_0 x_t + \beta_1 \tau_t + \beta_2 x_t \cdot \tau_t + \varepsilon_t$$
$$\varepsilon_t \sim N(0, h_t) \qquad\qquad\qquad\qquad\qquad (9)$$
$$h_t = \eta_0 + \eta_1 h_{t-1} + \eta_2 \varepsilon_{t-1}^2 + \eta_3 x_t + \eta_4 \tau_t + \eta_5 x_t \cdot \tau_t$$

where f_t is the shadow exchange rate computed in the first step, x_t is the vector of external shocks, τ_t is the equivalent tax rate on capital inflows, $x_t \cdot \tau_t$ is a term that interacts the external shocks and the tax rate implied by the capital controls, and ε_t is the heteroskedastic residual. All variables have been demeaned and normalized by their standard deviations. We present the results in differences and in levels.

In Eq. (9), x_t is a vector of external shocks. We introduced a measure of the terms of trade (the price of copper minus the price of oil), and the EMBI+ (excluding Chile); this last variable is computed as the change in JP Morgan's EMBI+ spread for Latin America, excluding Chile. Our main interest is to understand how the external shock affects the shadow exchange rate and its conditional variance, for different levels of the tax equivalence of the capital controls. We estimate the model with no lags, and with one lag; and we also estimated only the ARCH model. We also introduced the US interest rate, but because it was insignificant and the estimates of the other coefficients were invariant to its introduction we decided not to present then in the results.

All the results are presented in Tables 1 and 2. We estimated the same regression for the actual and the shadow exchange rates. This will allow us to analyze the way in which the results are affected when the shadow exchange rate is used in the analysis. Table 1 presents the results of the level's regression, while Table 2 shows the results for the regressions in first differences. The model is estimated by maximum likelihood. Several

estimations are presented in Table 1. The first column represents our preferred specification; a ARCH (1,1). The second are the GARCH (1,1) results. The first two columns are the estimates for the shadow exchange rate, while the estimates in the second set of columns are the results for the spot exchange rate. Table 2 is organized in the same way and we present the estimates for the first differences.

For each estimate the first coefficient indicates the point estimate, and the T-stats are presented next.[24] For the exogenous variables, EMBI is the EMBI Latin America excluding Chile; TOT is the daily price of copper in international markets relative to the daily WTI price of oil. This is a rough measure of the terms of trade affecting Chile. TAX is the measure of capital controls used assuming a length of stay of 180 days.[25] The interactions should be clearly understood by their labels.

3.4.1. The mean equation

In discussing the results, we first concentrate on the estimation of the shadow exchange rate and compare them to the estimation using nominal (observed) exchange rates. The purpose of this comparison is to highlight the differences that arise due to our estimation procedure, rather than repeating the results that are common to both specifications. We start with the regressions in levels. We discuss the results for the in-differences specification in the next sub-section.

The direct effects of the exogenous variables on the shadow exchange rate are in line with economic intuition: an increase in the emerging market risk premium (EMBI), and a deterioration of the terms of trade (TOT) produce a depreciation of the shadow exchange rate. These coefficients are all statistically significant. All variables were normalized by their standard deviations; hence, the interpretation is as follows: a one standard deviation increase in the EMBI depreciates the exchange rate by 0.5374 of its standard deviation. While the improvement in the terms of trade by one standard deviation appreciates the exchange rate by 0.57% of its standard deviation. As can be seen in column 2, these results are robust to the

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[24] Just to clarify purposes, when the exchange rate moves up, it is a depreciation; this is because the exchange rate in Chile is measured as number of pesos for one dollar.
[25] When other maturity lengths were used, or a weighted average of maturities was used, the results were very similar.

Table 1
Regressions in levels.

	Shadow exchange rate				Spot exchange rate			
	Arch(1,1)		Garch (1,1)		Arch(1,1)		Garch (1,1)	
Mean equation								
C	− 1.2356	− 34.6	− 1.3804	− 15.0	− 1.0456	− 6.9	− 1.1341	− 10.6
EMBI	0.5374	58.5	0.5759	22.8	0.5065	12.9	0.5292	20.9
TOT	− 0.4639	− 33.8	− 0.4248	− 13.3	− 0.0181	− 0.3	− 0.0198	− 0.5
TAX	0.5684	33.1	0.4956	10.0	0.7553	8.9	0.7957	15.2
EMBITAX	− 0.3274	− 79.3	− 0.2698	− 20.0	− 0.3945	− 16.2	− 0.3898	− 30.0
TOTTAX	0.2262	41.2	0.2580	19.2	− 0.0320	− 1.4	0.0182	1.1
Variance equation								
C	0.0178	7.3	0.3167	2.9	0.5521	2.5	0.3805	3.3
RESID(−1)^2	1.0404	14.6	0.8196	7.8	0.6375	3.3	0.9625	6.0
GARCH(−1)			− 0.1705	− 7.1			− 0.2523	− 6.6
EMBI	0.0084	7.3	− 0.0176	− 0.6	− 0.0248	− 0.5	− 0.0292	− 1.0
TOT	0.0133	9.9	0.0198	0.5	0.0423	0.6	0.0300	2.2
TAX	− 0.0040	− 2.6	− 0.0232	− 0.5	− 0.0307	− 0.3	− 0.0519	− 1.1
EMBITAX	− 0.0036	− 7.4	− 0.0058	− 0.6	− 0.0077	− 0.3	− 0.0039	− 0.3
TOTTAX	− 0.0051	− 9.8	0.0062	0.4	0.0121	0.4	− 0.0012	− 0.2

GARCH specification. The message is the same, and the estimated coefficients are very similar.

We now focus on the capital controls variable TAX. As may be seen, an increase in the extent of capital controls depreciates the shadow exchange rate. The effect is statistically significant and has the expected sign. A higher tax equivalence of the controls makes domestic securities less attractive, and results in a decline in the volume of capital flowing into the country. Hence, to return to equilibrium an improvement in the current account is needed − which requires a depreciation of the exchange rate.

It is instructive, at this time, to compare the results with the estimates using the observed or actual nominal exchange rate, as opposed to the shadow exchange rate. First, the direct effects are all consistent with the ones estimated using the shadow exchange rate − consistent in terms of their signs and sometimes significances. The point estimates, however, change. If we take the estimates from the shadow as the correct ones, the regression using (observed) nominal rates exacerbates the importance of TAX and underestimates the importance of the TOT. When thinking about monetary policy, these results make sense. The Central Bank is more likely to intervene when pressures in the market are forcing it to move the capital controls. In fact, as shown below, most of the capital control changes occurred when the exchange rate was closed to the bands − This is the time when expected Central Bank interventions is at its highest, and indeed the differences between shadow and spot are the biggest. In other words, there is an automatic response of the central bank to the shocks that is "cleaned out" in the estimation of the shadow exchange rate.

Let us turn our attention now to the interaction terms, both in the shadow and nominal exchange rate specifications. As can be seen, all the interaction terms have the opposite sign to the direct effects, and they are all statistically significant. This means that the capital controls are effectively reducing the impact of foreign shocks to the shadow exchange rate. Importantly, this is a measure of the effectiveness of the controls. The estimated coefficients of the variables interacted with TAX run from a minimum of 0 to a maximum of 0.2, which means that the economic effect for some of them is small. For instance, in the case of the TOT, the total effect goes from − 0.46 to − 0.40 when the tax equivalent of the controls is increased from the minimum to the maximum. The effect of the EMBI, on the other hand, declines from 0.54 to 0.45. Moving to the estimates that use the (observed) nominal exchange rate it can be seen that the stabilizing effect of the capital controls is also present for the EMBI, but not for the TOT.

In summary, the mean equations have two important messages. An increase in the equivalent tax rate of the capital controls depreciates the exchange rate, and makes the fundamental exchange rate less sensitive to external shocks. Although the first result could have been inferred from estimating the regression on the observed exchange rate, the second one is mostly found when the proper (shadow) exchange rate is used.

Table 2
Regressions in first differences.

|	Shadow exchange rate				Spot exchange rate			
	Arch(1,1)		Garch (1,1)		Arch(1,1)		Garch (1,1)	
Mean equation								
C	− 0.0008	− 0.3	0.0032	0.6	− 0.0004	− 0.2	− 0.0006	− 0.2
D(EMBI)	0.2911	3.6	0.3978	2.4	− 0.2193	− 4.0	− 0.2253	− 1.9
D(TOT)	− 0.0166	− 4.5	− 0.0127	− 0.2	0.0026	0.1	0.0108	0.2
D(TAX)	− 0.0059	0.0	0.0755	0.3	− 0.0982	− 1.0	− 0.1011	− 0.5
D(EMBITAX)	− 0.0004	0.0	0.0251	0.3	0.0183	0.6	0.0186	0.3
D(TOTTAX)	0.0049	1.1	0.0227	0.8	− 0.0068	− 0.6	− 0.0093	− 0.4
Variance equation								
C	0.0090	60.8	0.0099	3.5	0.0045	81.5	0.0043	3.3
RESID(−1)^2	0.2827	12.1	0.0060	3.7	0.2303	11.9	0.0850	4.8
GARCH(−1)			0.5504	4.2			0.5416	4.0
D(EMBI)	− 0.0036	− 0.6	− 0.0196	− 1.3	− 0.0010	− 0.3	− 0.0095	− 1.2
D(TOT)	0.0081	8.2	0.0147	6.4	− 0.0012	− 14.3	0.0021	0.6
D(TAX)	0.0020	0.2	0.0055	0.2	0.0020	0.3	0.0033	0.6
D(EMBITAX)	0.0010	0.3	0.0013	0.2	0.0003	0.2	0.0006	1.6
D(TOTTAX)	0.0010	2.4	0.0014	6.2	0.0007	2.1	0.0008	0.5
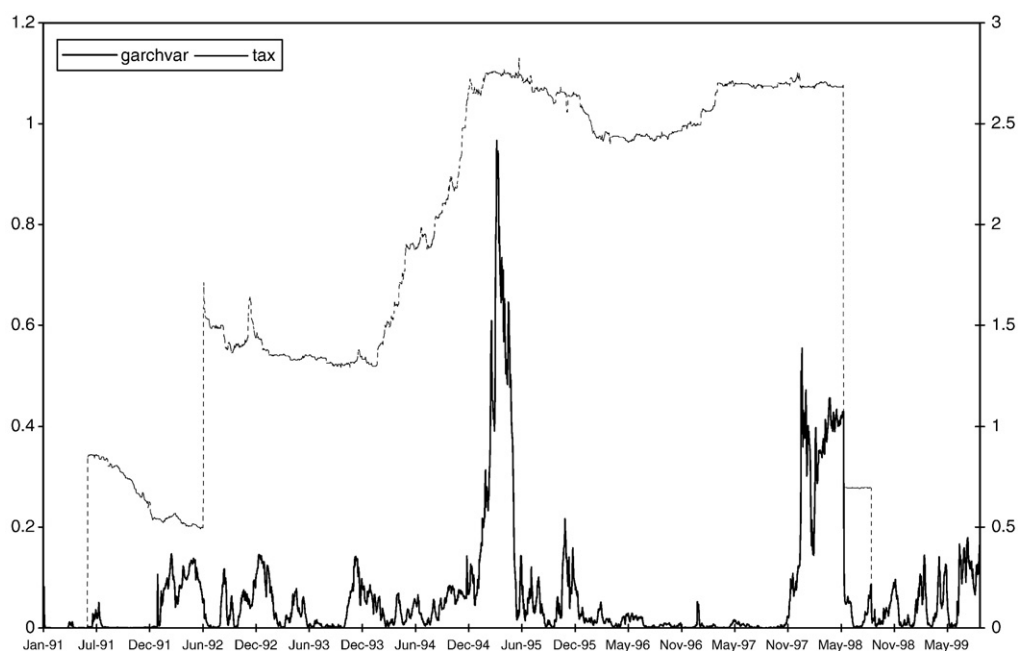
Fig. 6. Conditional volatility and tax rate implied by the capital control. Capital controls are measured in percentage points, and the conditional standard deviation is measured in logs.

3.4.2. The variance equation

We now turn our attention to the variance equation, which we present in the lower panels. As may be seen, when the tax rate equivalent of the capital controls increases, the exchange rate conditional volatility decreases. In all specifications the coefficients are negative, although they are only statistically significant when the shadow exchange rate is used and the ARCH model is estimated. This result should be expected because usually the capital controls in Chile where changed when the nominal exchange rate was close to a band. That means that the observed exchange rate had very little variance, while the shadow exchange rate might be more volatile. Hence, the reduction in variance is more likely to be observed in the shadow than in the nominal exchange rate. Movements in the terms of trade and EMBI increase the conditional volatility of the shadow exchange rate. All these results are very strong in the ARCH estimation, but are weakened when the GARCH model is estimated. In fact, the effects become statistically insignificant. Interestingly, the results for the spot exchange rate reflect no patterns whatsoever even in the estimation of the ARCH.

One point we have made repeatedly in this discussion has been related to the timing of the capital controls changes. In Fig. 6 we present the relationship between the predicted variance of the shadow exchange rate and the tax rate. The tax rate is measured on the right hand axis and the variance is measured on the left-hand side. Note that in the earlier periods in the sample — that is before 1996 — increases in the equivalent tax rate were associated with significant reductions in the conditional volatility; which is in line with the regression results we have shown. This implies that the effectiveness of the capital controls is not the same along the whole sample. After 1997, changes in the tax rate seem to have no effect on the variance of the shadow exchange rate. This indicates that capital controls experienced a reduction in their degree of effectiveness after mid-1997, a period when capital flows to all emerging markets plunged severely. Not surprisingly, then, in the absence of capital inflows, market-based capital controls on the inflows, by construction, should be ineffective. Our evidence suggests that indeed the changes in the policy were unable to affect the stability of the exchange rate in the later part of the sample; they were effective, however, during the earlier period.

3.5. Sensitivity analysis and future research

We performed several sensitivity analyses in order to determine the robustness of our findings. In this Section we present the main results, and we discuss some open issues that, in our opinion, should be addressed by future research. We first, checked the estimation of the shadow exchange rate by changing the rolling window used to compute the variance. The results presented above are for a 5-day window; in the robustness analysis we tested 10, 20 and 60-day windows. The results are qualitatively very similar. The only difference is the magnitude of the coefficients in the second step (ARCH/GARCH), but not their significance, nor their signs. In general, the longer the window is, the larger the coefficients in the regression. We also allowed the trend to shift through time. The resulting shadow exchange rate is almost identical to the one used in the regressions reported in the preceding sections. Additionally, we estimated the model assuming that no exchange rate realignment was possible, i.e. that the bands were fully credible. Once again, the shadow exchange rate computed was almost identical to the one in our preferred specification.

As a second step in our robustness analysis, we evaluated the sensitivity of the results in the ARCH/GARCH specification. We tried specifications in first differences, and with more lags. The results for the first differences are shown in Table 2.[26] As can be seen, the estimates in the second stage are somewhat weakened when the regression is estimated in first differences (for all variables). For the ARCH specification using the Shadow Exchange Rate, still an increase in the EMBI and a deterioration of the terms of trade generate an exchange rate depreciation. These effects are statistically significant and have the correct signs. The GARCH specification conserves the EMBI effect, while the TOT one becomes insignificant. Notice that the regression using the spot exchange rate have almost no significant coefficients, and the ones that are significant have the incorrect sign. Having pointed out to the direct effects, the interaction terms are all insignificant. The variance equation exhibits a similar pattern. The TOT effect is positive and its interaction term has the same sign as the level equation. The impact of taxes and the EMBI are insignificant, though.

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[26] We thank the editor and the referee for pointing out to us the importance of these results.

The regression on the spot exchange rate has either the wrong sign or coefficients are insignificant. Taking the results in the level equation and the first differences together implies that we should moderate somewhat of our previous claims. Clearly there seems to be a benefit of estimating the regressions on the shadow exchange rate, but the results that were significantly clean in the levels equation are weakened in the in-differences specification.

An important caveat is that the model assumes that interventions only occurred close to the bands. This was not always the case for Chile. Unfortunately we did not have information about daily interventions. For the period under consideration we were only able to collect bi-weekly intervention data. As a way of dealing with this issue we re-estimated the model using bi-weekly data. However, the amount of information lost is tremendous, and in the end most estimates were not statistically different from zero (except for the level effects in the mean and the variance equation).

Three additional issues are worth mentioning. First, we have obviated the issue of evasion and assumed that capital controls were effective. However, there is evidence that this was not the case in Chile. Taking evasion into account should make our results stronger — not weaker.[27] Second, we have assumed that other policies are not endogenous to capital controls — such as fiscal policy and foreign borrowing. Future research should incorporate these issues in order to understand fully the consequences of capital controls on macroeconomic vulnerability. Third, we have taken the central bank announcements with respect to the exchange rate system to be fully credible. We have assumed that the managed exchange rate announcement is indeed implemented, and that it is believed by the market, even though in our sample the central bank realigned the bands five times. As in the case of evasion, if the monetary policy is not credible the distance between the shadow and the actual exchange rate should be smaller. In fact, a non-credible target zone implies that the shadow and the observed exchange rates are identical. Therefore, not including the lack of credibility of the managed exchange rate should reduce our coefficients. Nevertheless, if the capital controls have an impact on the degree of credibility of the exchange rate regime, then our results will be affected. Unfortunately we do not have information to deal with this issue.

Before concluding we highlight what we have done, and what is left for future research. We have concluded that capital controls in Chile were effective in reducing the effects of shocks on the nominal exchange rate. This is a first step to a full welfare analysis. However, if the controls are not effective at all, the discussion about the desirability of capital controls is futile. In this sense, there are two important dimensions for future research: first, there is the comparison between capital controls and other forms of intervention; second, there is the cost–benefit analysis of the controls by themselves, weighing the microeconomic costs with the "isolation" benefits. Both questions are very important for policy design in emerging countries around the world; nevertheless, they are beyond the scope of the present paper.

Even though we have tried to take into account the endogenous response of monetary policy to changes in the stochastic process of the fundamentals, we have done it using a two step estimation which is model intensive in the first step, and model free in the second step. We do this for simplicity.[28] A more efficient method would be to incorporate the ARCH/GARCH model into the estimation of the shadow exchange rate and estimate the complete model simultaneously — or to estimate a full structural model where restrictions on the evolution of the fundamentals come from first principles. This, however, is a highly intractable procedure. Also, we believe that one advantage of our procedure is that

the fundamentals are a sufficient statistic to the exchange rate — indeed, in any model of exchange rate that would be true. Hence, the impact of the macro economic variables — i.e. the EMBI+ or the capital controls — will have an effect on the exchange rate only through their impact on the stochastic properties of the fundamentals.

4. Conclusions and policy implications

An important policy objective of restrictions on capital inflows has been to avoid — or at least control — nominal exchange rate changes, and to allow the central bank to have (some) policy independence. This was, for instance, a stated policy objective of Chile's renowned controls on inflows during most of the 1990s. More recently, Thailand (2006) and Colombia (2007) have put in place restrictions on inflows as a way of slowing down the appreciation of their currencies.

When there is an active exchange rate management policy, it is not possible to evaluate the effectiveness of capital controls by analyzing the co-movement between the observed exchange rate and external shocks. In this case, simple estimates are likely to capture the combination of both the controls and the active exchange rate policies. Without a clear model of how exchange rate (or monetary) policy is conducted, this exercise cannot be solved, and it is likely to produce biased results and misleading policy analyses. Furthermore, it is not enough to specify a parsimonious monetary policy reaction function, because one of the purposes of capital controls is to change the stochastic properties of the fundamentals driving the exchange rate (mean, variances, vulnerabilities, and so on). Therefore, the monetary reaction function is also likely to change when controls are imposed, or when the extent of controls changes.

In this paper we have attempted to disentangle the role played by capital controls from the management of the exchange rate. In doing so, we specify how monetary policy is conducted — which in the case of Chile between 1991 and 1999 is described by a target zone model based on the contribution by Bertola and Caballero (1992). This is equivalent to estimate a structural model, where the monetary policy reaction function is specified.

The contributions of this paper are twofold. First, to estimate a shadow exchange rate that "cleans" the observed exchange rate by the endogenous monetary policy reaction function. This procedure takes into account that the mapping between the two changes through time, and is an explicit function of the stochastic properties of the fundamentals. Second, using the shadow exchange rate estimated in step one we are able to evaluate how the capital controls have affected the exchange rate. As we pointed out in Sections 1 and 2, our results are quite different from those in the previous literature. More specifically, we find that a tightening of the controls on capital inflows is associated with: (a) a depreciation of the nominal exchange rate; (b) an increase in the unconditional variance of the nominal exchange rate; and (c) a reduction in the vulnerability of the nominal exchange rate to external shocks (mainly in the mean equation).

Our results are important because using standard techniques it is not possible to evaluate properly if controls have been effective (see the discussion in Section 3). Our results indicate that capital controls on inflows have been — at least in Chile — more effective than what previous studies had suggested, in the sense of helping reduce the impact of external shocks on the nominal exchange rate. This, however, does not mean that capital controls on inflows played a central role in Chile's economic success during the 1990s. Indeed, we are persuaded by Calvo and Mendoza's (1999) comprehensive analysis of Chile's performance in the 1985–1998 period, and by their conclusion that macroeconomic policy played a relatively minor role.

It is also important to point out, once again, what we haven't done in this paper: we have not provided a complete cost–benefit analysis of Chilean style capital controls on inflows. In particular, we have not dealt with the potential efficiency (and other) costs of restricting capital mobility. A complete policy evaluation of the controls would

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[27] In other words, the evasion implies that the effects of the capital controls on the exchange rate are smaller in practice than the theoretical ones. Hence, our estimates should reflect the coefficients assuming evasion which means that all the true effects are larger than the ones shown here.

[28] Our first step is actually estimating a fixed point computing almost 2000 stochastic differential equations. This procedure needs some reasonable assumptions to be able to find a solution. We thought the two steps are reasonable enough.

consider both the macroeconomic and microeconomic aspects of the policy, including their effects on the probability of crises, interest rates and debt maturities. These are important issues, but they are beyond the scope of the present paper.[29]

Acknowledgement

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[29] See the references in footnote 8.