Reverse Speculative Attacks*

Manuel Amador
Minneapolis Fed and University of Minnesota

Javier Bianchi
Minneapolis Fed

Luigi Bocola
Northwestern University

Fabrizio Perri
Minneapolis Fed

May, 2016

Abstract

In January 2015, in the face of sustained capital inflows, the Swiss National Bank abandoned the floor for the Swiss Franc against the Euro, a decision which led to the appreciation of the Swiss Franc. The objective of this paper is to present a simple framework that helps to better understand the timing of this episode, which we label a "reverse speculative attack". We model a central bank which wishes to maintain a peg, and responds to increases in demand for domestic currency by expanding its balance sheet. In contrast to the classic speculative attacks, which are triggered by the depletion of foreign assets, reverse attacks are triggered by the concern of future balance sheet losses. Our key result is that the interaction between the desire to maintain the peg and the concern about future losses, can lead the central bank to first accumulate a large amount of reserves, and then to abandon the peg, just as we have observed in the Swiss case.

Keywords: Fixed Exchange Rates, Currency Crises, Balance Sheet Concerns
JEL classification codes: F31, F32

*Prepared for the Bank of Switzerland International Economic Conference. We thank Mario Crucini for his comments, Alberto Martin and Chris Tonetti for great discussions and seminar participants at Gerzensee, NYU Stern and Michigan for comments. The views expressed herein are those of the authors and not necessarily those of the Federal Reserve Bank of Minneapolis or the Federal Reserve System.

1 Introduction

In January 2015, in the face of sustained capital inflows, the Swiss National Bank (henceforth SNB) decided to abandon the floor for the Swiss Franc against the Euro, a decision which led to a sudden 20% appreciation of the Swiss Franc. Following Cochrane (2015) we name such an event a "Reverse Speculative Attack".[1] This decision by the SNB had a significant effect on financial markets, which seemed to have been surprised by the move. An article in the January 2015 edition of the Economist Magazine suggests that "The doffing of the cap surprised and upset the foreign exchange markets, hobbling several currency brokers," , while Brunnermeier and James (2015) state that "The risks created by the SNB's decision – as transmitted through the financial system – have a fat tail."

The decision by SNB is also surprising when seen through the lenses of standard speculative attack models. It is well known that a Central Bank may be forced to abandon a peg when its foreign currency reserves get depleted, and it no longer has the ability to prevent its currency from depreciating. That is, maintaining the peg can eventually become infeasible.[2] However, the case of Switzerland in January 2015 does not fit this narrative. In principle, it could have been feasible for SNB to increase its domestic liabilities (i.e., currency) while acquiring the foreign currency assets necessary to maintain the peg. The SNB decided to do otherwise.

The goal of the present paper is to develop a simple theoretical and quantitative framework, in order to better understand the timing of the Swiss peg's abandonment, and how changes in fundamentals, such as international interest rates, affected its likelihood.

After reviewing some basic facts about the Swiss experience we trace out a simple theory of the Central Bank's problem. The starting point is the specification of the Central Bank objective. We assume a Central Bank that would like (for reasons we do not model) to maintain a currency peg with a foreign currency.[3] Consistently with the Swiss experience, we also assume that the Central Bank operates in an environment where the demand for its currency is increasing. As a result, if the supply of domestic currency were not to increase

[1]Switzerland is not the only example of this. In May 1971, the Bundesbank decided to abandon the peg against the U.S. dollar, which also led to an appreciation of the German currency (see Brunnermeier and James, 2015).

[2]There exists a very large literature on standard speculative attacks, i.e. when a central bank abandons a peg, and lets its currency depreciate, as its foreign reserves are drained. See, among others, the seminal papers by Krugman (1979) and Flood and Garber (1984), or the very recent survey by Lorenzoni (2014). However, to our knowledge, there is much less analysis on reverse speculative attacks, which are quite different in nature. Exceptions are Grilli (1986) and Amador et al. (2016), which we discuss below.

[3]Although the SNB explicitly targeted a floor on the exchange rate, for simplicity in our theoretical analysis we will focus on the case of a peg, and throughout the rest of the paper we will use the two terms interchangeably.

accordingly, the exchange rate would appreciate. Maintaining the peg involves expanding its reserve holdings and its liabilities. We make two additional key assumptions for our results. First, we assume that there is an exogenous probability that the exchange rate will be below the peg level in the future. This risk is assumed to be outside the control of the Central Bank today, and it makes the holding of reserves (which are denominated in foreign currency) risky, relative to the monetary liabilities issued (denominated in domestic currency). Second, we introduce balance sheet concerns in the following way: we assume that the Central Bank keeps its potential balance sheet losses bounded by a threshold value.

In this set-up, the fear of future losses on its balance sheet may force the Central Bank to abandon a peg. In particular, we show that the Central Bank faces a trade-off when facing an increase in the demand for its liabilities: it can either choose to maintain the peg and accumulate reserves, or it can let the currency appreciate today. The first choice leads to no losses today, but it involves possibly large losses in the future. The latter choice generates some losses today but, by reducing the future appreciation risk, reduces the future losses. When the balance sheet increases significantly, the second choice becomes more attractive, and the Central Bank chooses to abandon the peg.

After describing the model we proceed to solve it numerically, so as to assess whether the economic mechanism we propose can explain the Swiss experience. In particular we introduce shocks to the demand for Swiss currency, shocks to the international interest rates, and we estimate a demand for Swiss currency that is consistent with the patterns of Swiss monetary base and Swiss short term rates before, during and after the peg. Our key result is that increases in money demand and/or a fall in the international interest rates can lead the Central Bank to first accumulate a large amount of reserves and then to abandon the peg. The model's predicted reserve accumulation and the exchange rate appreciation following the abandonment are quantitatively comparable to what is observed in the data.

Our paper is closely related to the work of Grilli (1986), who analyzes speculative attacks assuming the Central Bank has both an (exogenous) upper bound and (exogenous) lower bound on reserves holdings. Our work is different as the bound on reserves arises endogenously from the possibility of future losses to the Central Bank's balance sheet, and as a result, is affected by the Central Bank's exchange rate policy today.[4] This paper is also related to Amador et al. (2016), which develops a general framework to analyze the impact of a given exchange rate policy on asset returns, the balance sheet of the central bank and domestic welfare. Importantly in that paper the foreign demand for domestic currency, which

[4]The implications of a large balance sheet is an issue that is been currently debated in monetary economics given the large increase in the balance sheets of major Central Banks (see, among others, Del Negro and Sims, 2015 and Hall and Reis, 2015). For early contributions on the topic also see Stella (1997,2005).

here we treat as an exogenous shock, is endogenous and depends on the exchange rate policy. Also in the present work we do not consider the implications of a lower bound constraint on interest rates, while Amador et al. (2016) shows that when the economy operates at that lower bound, losses and distortions from exchange rate policies are potentially large.

The paper is organized as follows. In section 2 we present some data that characterize the Swiss experience with the peg to the Euro, section 3 presents the model and section 4 contains our main results. Section 5 discusses sensitivity analysis and section 6 concludes.

2 Evidence on the Swiss experience

In this section we briefly provide some evidence on the experience of the Swiss National Bank with its peg and subsequent abandonment, as these events are the main motivation of our work. The SNB, mentioning overvaluation of the Swiss franc and its negative effect on the Swiss economy, announced in September 2011 a currency floor with the Euro, stating that:

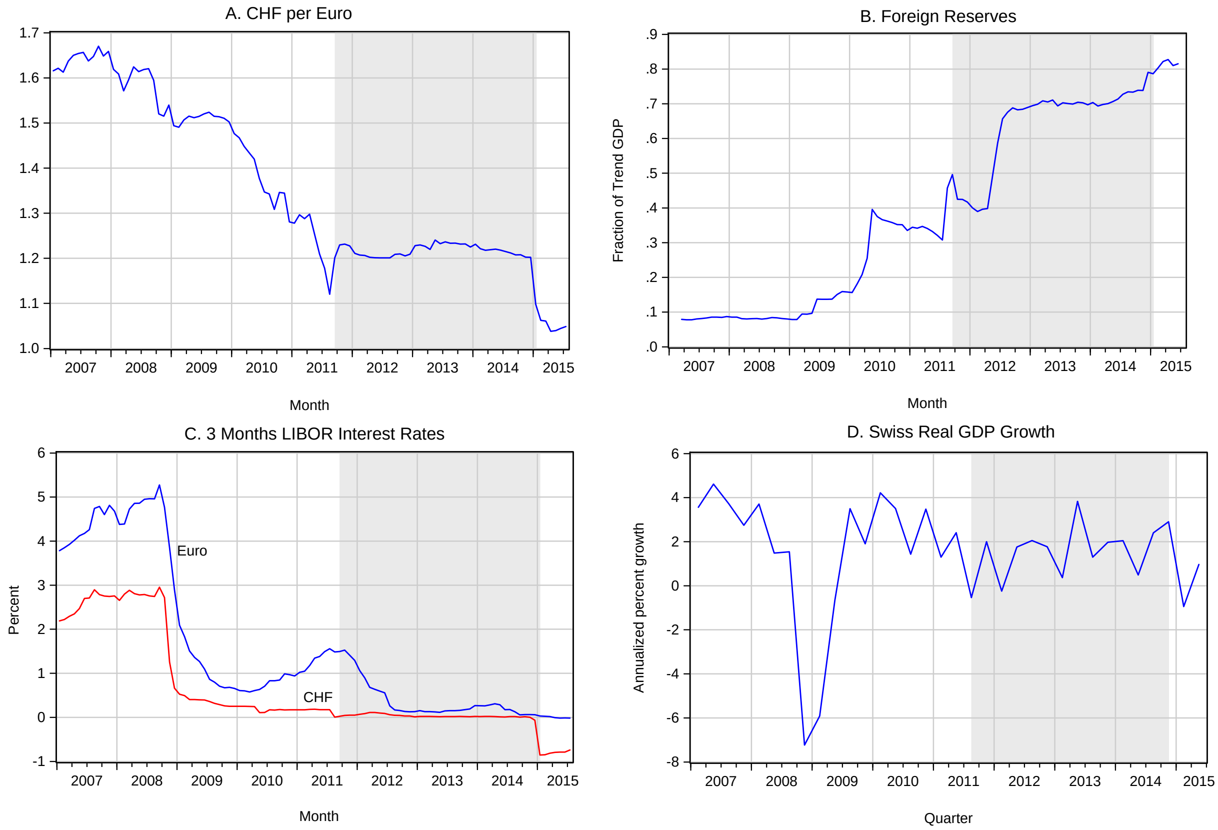
> "With immediate effect, it will no longer tolerate a EUR/CHF exchange rate below the minimum rate of CHF 1.20. The SNB will enforce this minimum rate with the utmost determination and is prepared to buy foreign currency in unlimited quantities."

In January 2015 the SNB abandoned the floor, which resulted in a substantial devaluation of the Euro with respect to the CHF. Panel A of Figure 1 shows the path of the CHF/Euro exchange rate in the years preceding the floor, during the peg (the shaded area) and after the abandonment of the peg. Panel B shows instead the amount of foreign currency reserves held by the SNB (expressed as a fraction of trend GDP).[5]

Notice how in the first part of the sample (pre-floor) the CHF has appreciated quite substantially relative to the Euro, and the SNB has at the same time accumulated foreign reserves. During the floor the CHF has remained stable, while the SNB has continued accumulating reserves at a rapid pace. Panel C plots 3 month LIBOR rates for Swiss Francs and for Euros. Notice how, throughout the whole period, the CHF interest rate has been below the Euro rate, suggesting that, even during the floor, there were expectations that the CHF was going to appreciate against the Euro, i.e. that the floor was not going to last for the indefinite future.[6]

[5] We normalized reserves by trend GDP (as opposed to actual GDP) in order to isolate the fluctuations in reserve holdings. We computed a linear trend using GDP data from 2007Q1 to 2015Q2.

[6] Jermann (2015) uses option prices to back out probabilities of abandonment and found that over the duration of the floor, the probability of abandonment averaged 20%



Note: The shaded areas represent the period in which the SNB maintained a floor for the CHF against the Euro. All data are from the SNB statistics.

Figure 1: The Swiss experience: before, during and after the floor

Finally panel D provides some evidence on the background macroeconomic conditions in which the SNB has been operating. Notice that the peg has been introduced at a time when real GDP growth was slowing down markedly, while the peg has been abandoned at a time in which Swiss growth was mildly accelerating.

3 The model

We consider a world composed of a small open economy (SOE), which uses a local currency (Swiss Francs) and a large trading partner, which has a different currency (Euros). There is a monetary authority in the SOE that starts the period with inherited nominal liabilities (money, M_{t-1}) and foreign reserves denominated in foreign currency (F_{t-1}), and that exits the period with new liabilities M_t and reserves F_t. The Central Bank would like to maintain the exchange rate (number of Swiss Francs needed to buy a Euro), S_t, pegged at a fixed level which we normalize to 1. The net worth of the Central Bank, denominated in local currency, is the difference between the value of its assets minus its liabilities: $NW_t = S_t F_t - M_t$.

We denote by i_t the domestic interest rate and let $i_t^\star$ denote the foreign interest rate. The budget constraint of the Central Bank denominated in local currency is:

$$S_t(F_t - F_{t-1}) = i_{t-1}^\star S_t F_{t-1} + M_t - M_{t-1} - T_t$$

where T_t denotes the transfers from the Central Bank to the treasury.

We define the profits (or losses, if negative) of the Central Bank, Π_t, to be the sum of the earned interest income on reserves, $i_{t-1}^\star S_t F_{t-1}$, plus the changes in valuation in foreign reserves, $(S_t - S_{t-1})F_{t-1}$.

We assume that the Central Bank rebates any profits (or losses) back to the treasury, and as a result, in any equilibrium its net worth will be constant at its initial level NW_0. We will however impose that the Central Bank is committed to avoiding losses exceeding $\bar{\Pi}$. The justification for this assumption is as follows. Since Central Banks are not for profit institutions, it seems reasonable to assume that when they make positive profits those are rebated to the treasury. When profits become losses, then they can significantly impact the net worth of the Central Bank, and that might make it impossible for the Central Bank to buy back (part of) its cash liabilities, and thus to conduct monetary policy. In this case, the Treasury would need to recapitalize the Central Bank. We assume that a recapitalization that is too large would not be politically feasible, justifying a constraint which limits the transfers the Central Bank can receive from the Treasury.[7]

[7] See Benigno and Nisticò (2015) for similar restrictions on the Central Bank transfer policy.

The above discussion then implies that, in equilibrium, the Central Bank makes sure that the following "loss constraint" is always satisfied:

$$((1 + i^{\star}_{t-1})S_t - S_{t-1})F_{t-1} \geq -\bar{\Pi}$$

To finalize the description of the money market, we assume that holders of the SOE's currency behave so to generate a standard money demand equation (in Euros) which we denote by

$$L(i_t) = B_t l(i_t) \tag{1}$$

where B_t is an exogenous stochastic shock to money demand and $l(.)$ is a decreasing function reflecting that as the nominal interest rate increases the real demand for cash balances falls.

The foreign interest rate i^*_t is assumed to be stochastic. We also assume that B_t and i^*_t can take values within a finite set. And finally, at any period there is a constant probability that the exchange rate takes a value of $\bar{S}$. We let A_t index whether the exchange rate shock has occurred this period, taken a value of 1 if so, and zero otherwise. This shock captures, in a reduced form way, the possibility that in some future state there is a change in fundamentals (i.e., a large depreciation of the Euro vis-a-vis a third currency) that will make the abandonment of the peg and an appreciation of the exchange rate necessary. As we will show, this last shock is critical in generating risk in the balance sheet, which the Central Bank will try to manage.

We are now in a position of defining a *competitive equilibrium* which is a collection of processes for S_t, M_t, i_t and F_t such that the following four equations are satisfied:

$$S_t F_t - M_t = NW_0 \tag{2}$$

$$M_t = S_t L(i_t) \tag{3}$$

$$1 + i_t = (1 + i^{\star}_t)\mathbb{E}_t \left\{ \frac{S_{t+1}}{S_t} \right\} \tag{4}$$

$$((1 + i^{\star}_t)S_{t+1} - S_t)F_t \geq -\bar{\Pi} \tag{5}$$

where S_t takes the value of $\bar{S}$ whenever the exchange rate shock hits.

Equation 2 guarantees that in any equilibrium the net worth of the Central Bank is constant. Equation 3 reflects the equilibrium in the money market, i.e., money demand equals money supply. Equation 4 is the uncovered interest rate parity condition. And equation 5 is the loss constraint of the Central Bank, which we previously discussed.

There are potentially many possible competitive equilibria. For example, it is immediate to verify that there exists an equilibrium in which $S_t = \bar{S}$ for all t. To select among different equilibria, we specify an objective function for the Central Bank. In addition to avoiding losses, the Central Bank would like to keep the exchange rate as close as possible to its preferred level of 1. In particular, the objective function of the Central Bank is given by:

$$v_t = -(S_t - 1)^2 + \beta \mathbb{E}_t [v_{t+1}] \tag{6}$$

where $\beta < 1$ denotes the monetary authority discount factor.[8]

We restrict attention to Markov equilibria, where the states are given by the level of money demand, the foreign interest rate, and whether or not the exchange rate shock has taken place:

Definition 1. *A* Markov equilibrium *is a collection of processes for the exchange rate, S_t, the domestic interest rate, i_t, money demand M_t, and foreign reserves F_t measurable with respect to the money demand shock, B_t; the foreign interest rate shock, $i_t^\star$; and exchange rate shock A_t; such that, as long as $A_t = 0$, equations (2), (3), (4), (5) are satisfied; and S_t maximizes the objective of the Central Bank, taking as given the future equilibrium process for S_{t+j} for $j \geq 1$.*

Note that it is possible to describe a competitive equilibrium by just describing the behavior of the exchange rate. That is, given a process for the exchange rate, the domestic interest rate, the amount of money, and the foreign reserves are determined. In a Markov equilibrium, the Central Bank today takes as given the future choices for the exchange rate and chooses a level of the exchange rate such that (i) the loss constraint is satisfied (given the implied interest rate) and (ii) the level of the exchange rate is as close as possible to 1.

In general, a Markov equilibrium will display states in which the Central Bank pegs the exchange rate at 1 (its preferred outcome) and states where it abandons the parity and lets the exchange rate appreciate to a value lower than 1. The dynamics of exchange rate in these states are what we label "reverse speculative attacks." It should be clear that in our framework a reverse speculative attack happens if and only if the loss constraint is binding. After specifying numerical values for the parameters, we can characterize Markov equilibria numerically, which we proceed to do next.

4 A Numerical Analysis

In order to characterize the dynamics surrounding the reverse speculative attack, we first impose more structure on the states of the economy and their evolution, as well as specify

[8] As we will see below, the precise value of β will be irrelevant.

numerical values for the parameters of the model. We then numerically solve for Markov equilibria and finally characterize the patterns of key variables. We would like to stress that, given the highly stylized model we are using, the goal of this exercise is just to provide the reader with some simple qualitative and quantitative insights on reverse speculative attacks; we will surely not provide a comprehensive quantitative evaluation of the issue.

4.1 States of the economy

As we discussed previously, our economy is going to be subject to three exogenous disturbances.

For the exchange rate shock, we assume that the economy starts initially at $A_0 = 0$, and we let λ denote the probability that $A_t = 1$ next period if $A_t = 0$ today. The state $A_t = 1$ is assumed to be absorbing.

We assume that the level of money demand (B_t in equation 1) obeys the following process. At any t,

$$B_t = e^{g \times b_t} \tag{7}$$

where $b_t \in \{0, 1, ..., N\}$ and represents possible shocks to money demand. The parameter $g > 0$ is fixed and determines by how much money demand increases when a money demand shock hits. We assume that the state $b_t = N$ is absorbing, i.e. that money demand shocks are bounded, and that once the money demand shock reaches its maximum level, it will stay there. For all $b_t < N$, b_{t+1} will stay constant at b_t with probability $1 - \gamma > 0$ or increase by 1 with probability $\gamma > 0$. In words, γ represents the probability that the economy is hit by a shock that increases money demand by $g\%$. This probability is assumed to be independent from other events in the economy.

The third and final source of uncertainty in the economy regards the foreign interest rates. Our modeling of the foreign interest rates is loosely motivated by panel C in figure 1, where we observe that, during the period of the Swiss peg, Euro interest rates fell initially (in late 2011), and did not move much subsequently. As a consequence, we assume that the foreign interest rate can take two possible states: high (i_h) or low (i_l), with $i_h > i_l$. The probability of transiting from the high to the low interest rate state is denoted by θ_{hl}; and from the low to the high, θ_{lh}. As with the previous shocks, we assume that these transition probabilities are independent from the realization of the other shocks.

To sum up, figure 2 shows possible paths for the three sources of uncertainty. The value $\hat{T}$ on the x axis represents the time in which the economy switches from $A_t = 0$ to $A_t = 1$. After $\hat{T}$ our model economy is not interesting, as by assumption the exchange rate will be constant at $\bar{S} < 1$. Before $\hat{T}$ the economy faces a period of stochastically increasing demand

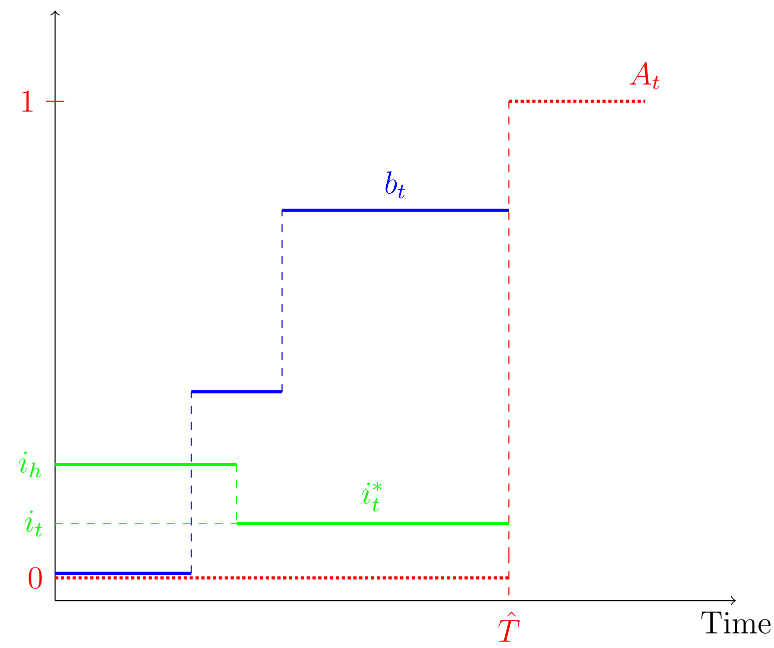


Figure 2: Possible paths for the exogenous stochastic variables

for its own currency (due for example to global increased risk aversion, or fears of inflation in the trading partner) represented by the line labelled b_t and/or stochastic international rates, represented by the line labelled i_t^*. Our goal in the reminder of the paper is to analyze the Central Bank behavior, and to analyze its decision whether to keep a peg (i.e. keep $S_t = 1$) or not, when $t < \hat{T}$.

4.2 Functional forms and parameter values

Our baseline parameter values are reported in Table 2 below. We now briefly describe how we pick those values. We start with the estimation of the money demand elasticity and money demand shocks. In order to do so we first construct a measure of money demand. The measure that is more consistent with our stylized model is the monetary base, which is a measure of the monetary liabilities of the Central Bank. We construct this by adding currency in circulation plus deposits of domestic and foreign banks at the Central Bank (as reported in the balance sheet of the SNB) all converted into Euros.[9] Panel A in figure 3 plots the log of the monetary base along with the Swiss Franc 3 month LIBOR rate. The panel shows an overall negative correlation between the two series, but also suggests that it is difficult to separately identify the impact of interest rate changes from the impact of

[9]This measure is narrower than more traditional measures of money demand such as M1 or M2, but is highly correlated with those.

exogenous (positive) shocks to the demand for Swiss francs, that are also correlated with reductions in the Swiss rates (the shocks in the figure are marked by the solid vertical lines). To see this consider the Euro crisis of 2011. Panel A of the figure shows that during the crisis there was, at the same time, a large increase in the demand for Swiss currency and a small reduction in the Swiss interest rates. If one estimated a money demand without shocks, one would attribute the whole increase in money demand to the reduction in interest rates, and would come up with a very large estimated elasticity. In reality a large fraction of the increase in money demand came from exogenous reasons (i.e. a sharp recession in the Euro area) that at the same time increased the demand for Swiss francs and induced the SNB to lower its rate.

Our (admittedly simplistic) attempt to separately identify the impact of shocks from the impact of interest rates on money demand is to specify the log money demand as the following linear function:

$$\begin{aligned} \log L(i) &= \sum_{j=1}^{S} D_j \phi_j - l(i) \\ &= \sum_{j=1}^{S} D_j \phi_j - \psi i \end{aligned} \tag{8}$$

where S is the number of permanent shocks to money demand (to be specified below), D_j is a dummy variable that takes the value of 0 for all the months before shock j hits, and 1 for the month in which the shock hits and for all subsequent months. There are two set of parameters to be estimated in equation 8. The first includes the ϕ_j, which represent the percentage increase in money demand caused by shock j, and pin down the parameter g in equation (7). The second includes the constant $\psi > 0$, which pins down the elasticity of money demand to the interest rate. Note that our specification of the functional form of the interest elastic portion of money demand is the commonly used Cagan specification.[10]

Guided by the evidence from panel A, we consider 5 possible specifications of the shocks in equation (8).

[10] See R. (2000) for different specifications.

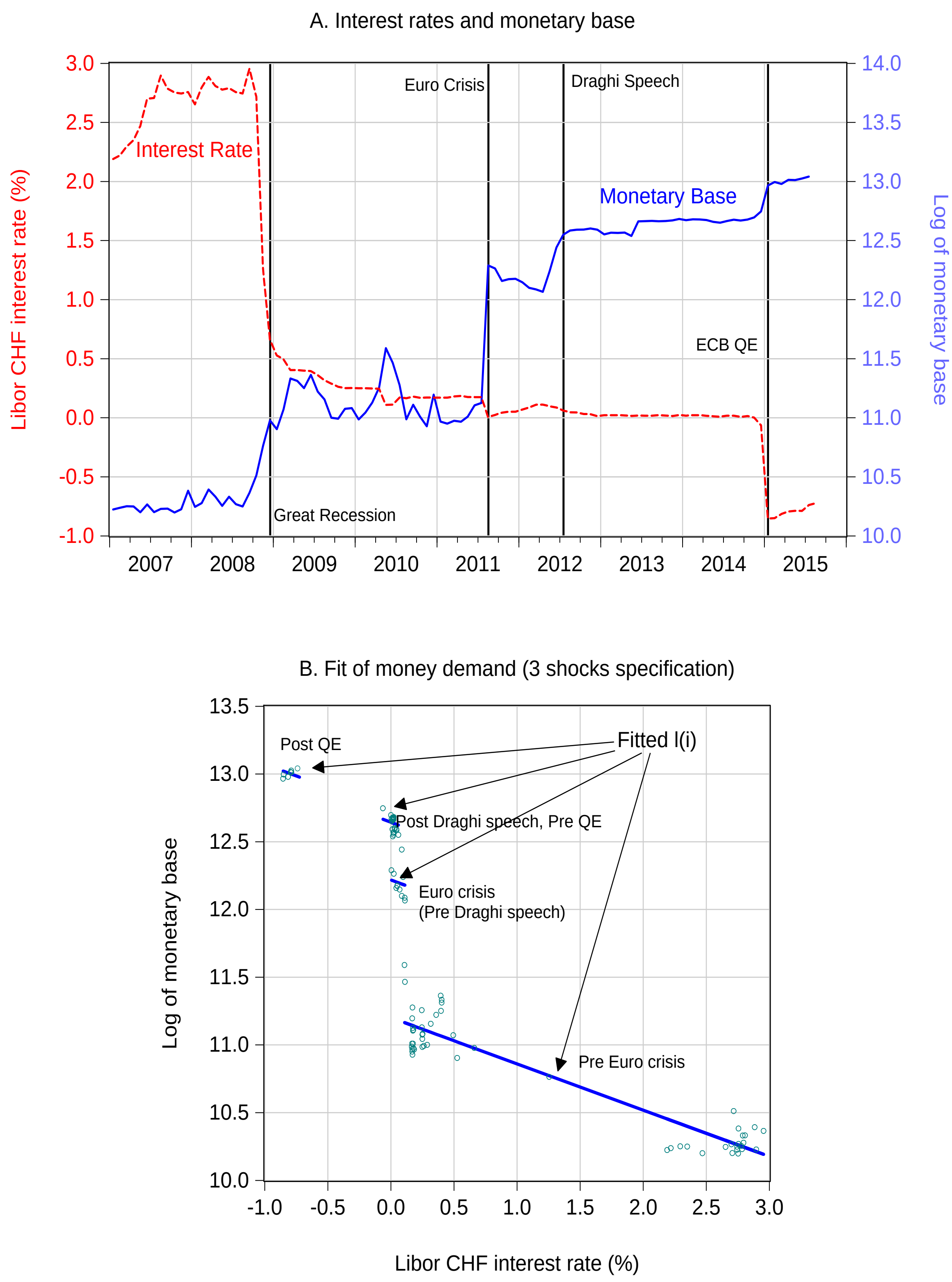


Figure 3: Money Demand in Switzerland: 2007-2015

Table 1. Estimation of Swiss Money Demand, 2007-2015

	No Shocks	1 shock	2 Shocks	3 Shocks	4 Shocks
ψ	0.72 (0.05)	0.36 (0.02)	0.35 (0.02)	0.34 (0.02)	0.17 (0.06)
ϕ_1, Euro Crisis		1.33 (0.04)	1.00 (0.04)	1.01 (0.04)	1.04 (0.04)
ϕ_2, Draghi Speech			0.44 (0.04)	0.43 (0.04)	0.43 (0.04)
ϕ_3, ECB QE				0.09 (0.05)	0.22 (0.04)
ϕ_4, Great Recession					0.41 (0.04)
Avg. ϕ	-	1.33	0.72	0.51	0.53
Adj. R^2	0.66	0.97	0.98	0.98	0.99
Obs.	103	103	103	103	103

The first one includes no shock, the second one includes one shock (the onset of the Euro crisis dated August 2011), the third one includes two shocks (the Euro crisis plus the Draghi "Whatever it takes" Speech, dated July 2012), the fourth one includes three shocks (the Euro crisis, the Draghi Speech, and the announcement of ECB QE, dated January 2015) and the final one includes 4 shocks (the Euro crisis, the Draghi Speech, the ECB QE and the Great Recession, dated December 2008). Table 1 reports the estimate of the interest elasticity for these 5 specifications along with estimates of the impact of each shock on Swiss money demand.

Note that as we include more and more shocks the estimated interest elasticity ϕ falls, reflecting the potential bias in the estimated interest elasticity of money demand when such shifts in the money demand function are not included in the specification. As our baseline specification we use the three shocks case, and the fit of that specification is visualized in panel B of figure 3. The thick lines in the figure all have slope equal to ψ (the estimated interest elasticity) while the difference in the intercept of the lines represents the shock. The specification implies an interest elasticity (ψ) of 0.34 and an average shock size (g) of 51%. Since the elasticity of money demand is an important parameter, in section 5 we analyze how our results change when we vary it.

In order to specify the probability of a shock to money demand we note that in our baseline specification we observe 3 such shocks in a period of seven years, so we set the monthly probability of such a shock equal to 3.5% which implies, on average, one shock every 28 months.[11]

We move next to the values for the foreign interest rates. Figure 1 shows how in the early phase of the peg, Euro rates moved from 1.5% to about 0%. For this reason we set $i_h = 1.5\%$ and $i_l = 0\%$. To specify the transition probabilities for interest rates we think of transitions from high to low as standard transitions associated with changes in monetary policy over the business cycle, so we set the monthly transition probability $\theta_{hl} = 1\%$, which translates into an expected duration of a high interest rate period (expansion phase) of 8 years and the probability $\theta_{lh} = 1.7\%$, which roughly translates to a duration of the low interest rate period of six years. The latter is consistent with the data, if we project that Euro interest rates will stay at 0 throughout 2016.

The next parameters are related to the appreciation risk (i.e. the A shock), which are the value of the currency in case of appreciation $\bar{S}$ and the probability of such an appreciation λ. Note that these two parameters jointly determine the minimum expected appreciation of the domestic currency during the peg, but are very hard to pin down as such an event is not observed in our sample. We set the probability of appreciation to 0.4%, which implies that this event is rare (one every 20 years), and we set the value of the currency in case of appreciation to 0.7, which implies a minimum expected annual appreciation during the peg of about 1%. In section 5 we explore how our results change when we change these parameters.

[11] Obviously we are making inferences about this probability using a short sample that might be quite special. We experimented with alternative values for this probability, and our qualitative results were not affected.

Table 2. Parameter Values

	Symbol	Name	Value
Money Demand	ψ	Interest Elasticity of Money Demand	0.34
	g	Size of jump in money demand	0.51
	γ	Probability of a jump (monthly)	3.5%
Interest rate	i_h	High foreign interest rate	1.5%
	i_l	Low foreign interest rate	0%
	θ_{hl}	Prob. from high to low	1%
	θ_{lh}	Prob. from low to high	1.7%
Appreciation Risk	$\bar{S}$	Appreciated exchange rate	0.7
	λ	Probability of Appreciation	0.04%
Balance sheet[a]	NW_0	Net Worth of Central Bank	0.2
	Π	Maximum Loss	1.6

[a] NW_0 and Π are expressed as ratio to monetary base at the start of the peg

The final set of parameters concerns the balance sheet of the Central Bank. Figure 4 plots the monetary base and it shows that in September 2011 (the month in which the peg was introduced) the difference between foreign reserves and the monetary base (which in our model corresponds to net worth) was about 20% of the monetary base. So we set the value of the initial net worth, NW_0, so that the model matches that ratio in the first period of the simulation, i.e. when the peg starts. Note from the figure that net worth of the central SNB stays fairly constant, despite large fluctuations in the monetary base and in reserves. This pattern is consistent with our modelling of the transfer policy of the Central Bank, that implies a constant net worth.

Finally we set the maximum value of losses that can be sustained by the Central Bank (Π) equal to 1.6 the value of the monetary base at the start of the peg. This value is chosen so that the expected duration of the peg, under a constant high foreign interest rate, is approximately 7 years. Again the exact value of the parameter is hard to pin down, as it is hard to quantify exactly what is the maximum size of balance sheet losses a central bank is willing to take. In section 5 we assess how our results change with different values for Π.

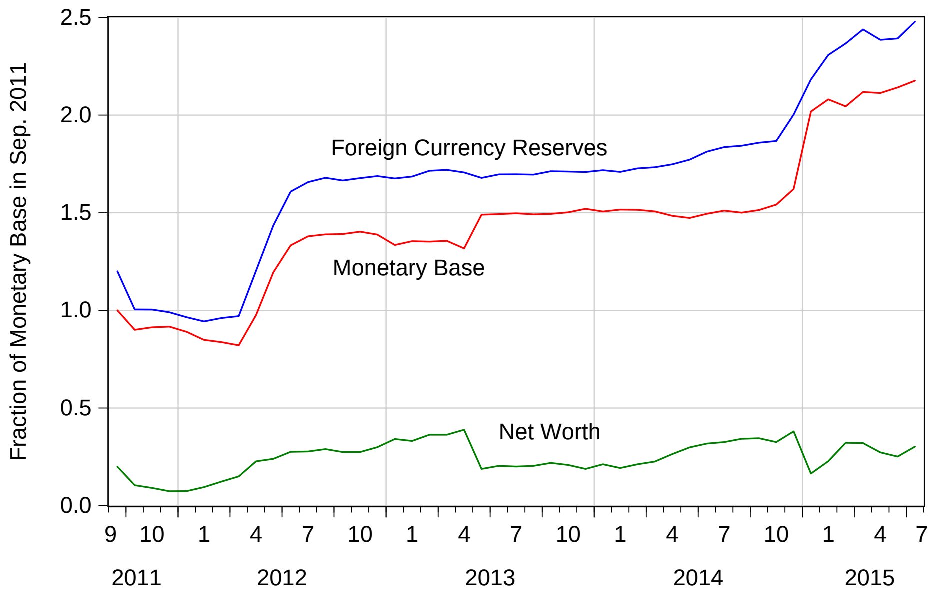


Figure 4: The Balance Sheet of the SNB during the Peg

4.3 Results

Given these parameter values, we can numerically solve for the Markov equilibria in the following way. We guess an initial exchange rate function, $S_0(.)$. Given this, for every state, we compute the exchange rate that is closest to 1 and that guarantees that the loss constraint tomorrow is satisfied in every possible state, while assuming that $S_0(.)$ is the equilibrium exchange rate policy the following periods. This generates a new equilibrium conjecture $S_1(.)$ for every state. We keep iterating this procedure until the $S_i(.)$ converges. We found that this procedure converges to a unique exchange rate function, for a very large set of the initial guesses.

Once we have a numerical solution we can characterize the periods that feature reverse speculative attacks, i.e. abandonment of the peg. In particular, we focus on two types of abandonments: those driven by shocks to money demand, and those driven by a reduction in the foreign interest rates.

Figure 5 displays the key variables of the economy in all possible states. In each panel, the x-axis represents the increasing permanent shocks to money demand, while the different lines represent different states for the foreign interest rates. For example, the right-most square on the top line in panel A represents the equilibrium exchange rate that will prevail when the money demand shock is in the fourth largest state value and the foreign interest rate is high.

To understand the first type of abandonment, consider an economy that moves along the lines represented by the square markers, i.e. an economy that is facing a high foreign interest rate and experiencing a sequence of increases in money demand. Panel A shows how, for the first two money demand shocks, the Central Bank keeps the exchange rate at 1. In those states the loss constraint is not binding, and thus the Central Bank can maintain the exchange rate pegged at parity, its preferred outcome. Panel C shows that maintaining the peg, while facing an increasing money demand, involves accumulating reserves. The jump in money demand that takes place when shock 2 hits can possibly capture the experience of the SNB during the second half of 2012, where the peg was maintained through a large accumulation of foreign reserves.

Note however that, as reserves grow, so does the size of the losses of the Central Bank in case of an exogenous appreciation (i.e., the A shock), and that makes the loss constraint more likely to bind. Indeed, the money demand state 2 is the largest state for which the Central Bank can maintain the peg. Panel A shows that when the next money demand shock (state 3) hits, the Central Bank will abandon the peg and the exchange rate will appreciate by about 7%. When this appreciation happens, the Central Bank experiences losses, while setting an exchange rate away from its preferred target. The benefit of doing so is that the current appreciation prevents a larger appreciation in the future, that would have led to much larger losses.

Panel B plots the domestic interest rates. The top line shows that appreciation in state 3 is anticipated by investors, and that it induces a decline in the domestic interest rate in state 2 (a result that follows directly from the UIP condition, equation 4). The fall in interest rates causes a further increase in money demand (over and above the increase caused directly by the shock) that forces an even larger increase in reserves just before the peg is abandoned (see the steep increase between states 1 and 2 in the bottom line in panel C). It is interesting that before the attack, the model displays patterns that resemble a defense against an attack. That is, as abandonment of the parity becomes more likely (the economy moves to state 2), reserves increase, while domestic interest rates fall.

Note that quantitatively the increase in reserves implied by the model is too large relative to the Swiss data: in the model, reserves during the peg increase 4 times, while in the data (see figure 1) reserves roughly doubled. Also domestic interest rates fall to a much lower level (-3%) than what is observed in the data. We conjecture that these discrepancies are due to the fact that we do not explicitly model a lower bound on interest rates, and the patterns of money demand and capital flows around that bound.[12]

[12]See Rognlie (2016) for some recent work on the money demand when interest rates are close to their lower bound and Amador et al. (2016) for an analysis of reverse speculative attacks with an explicit bound on interest rates.

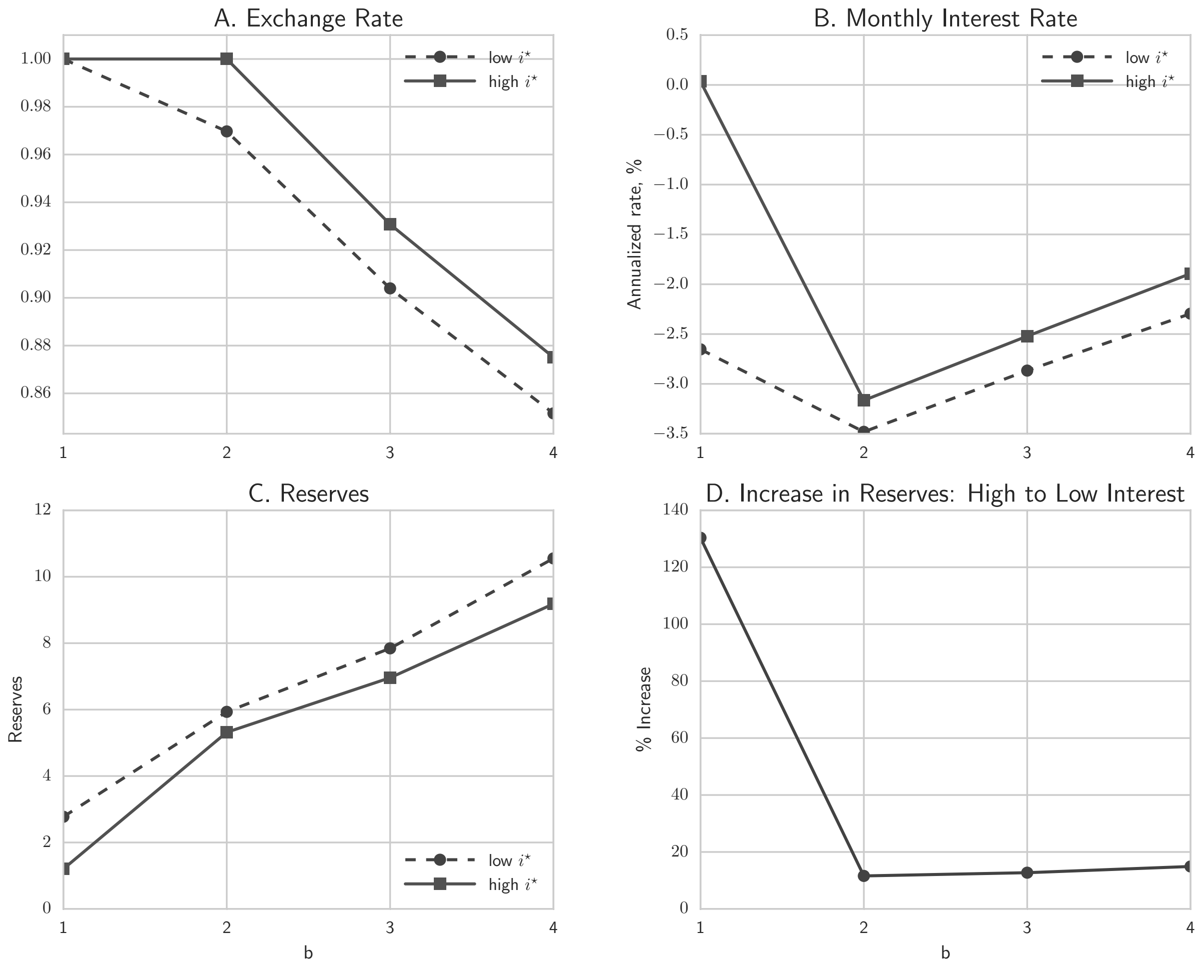


Figure 5: Markov Equilibria

Figure 5 also suggests another possible trigger of the abandonment of the parity. Suppose, for example, that the economy is at state 2 in panel A. Consider now a change in the foreign rate from high to low. In this situation, the Central Bank abandons the parity while the exchange rate appreciates by about 3%. The logic behind this result is similar to the one described above: the fall in the foreign interest rate causes (should the Central Bank maintain the parity) a fall in the domestic rate, and this induces an increase in demand for local currency, accompanied by a similar increase in reserves. Panel D shows the increase in reserves that takes place when the economy moves from the high to the low foreign interest rate. The increase in reserves might, in some state, cause the loss constraint to bind, and hence in that state maintaining the parity is no longer feasible for the Central Bank.

To sum up, we have highlighted two possible causes of an abandonment of the peg. In both of them, the Central Bank abandons the peg because maintaining the exchange rate at parity involves a large reserve accumulation, which coupled with the appreciation risk may lead to losses in the Central Bank's balance sheet that are large, and by assumption, not sustainable by the Central Bank. By letting the currency appreciate early on, the Central Bank realizes some of these losses when reserves are still low, and in this way, reduces the size of future losses.

5 Sensitivity Analysis

The objective of this section is to illustrate how the dynamics of reverse speculative attacks change as we change some of the fundamental parameters of the model economy. Figure 6 displays the patterns of exchange rates, while figure 7 displays the pattern of reserves for Markov equilibria under different parameter specifications.

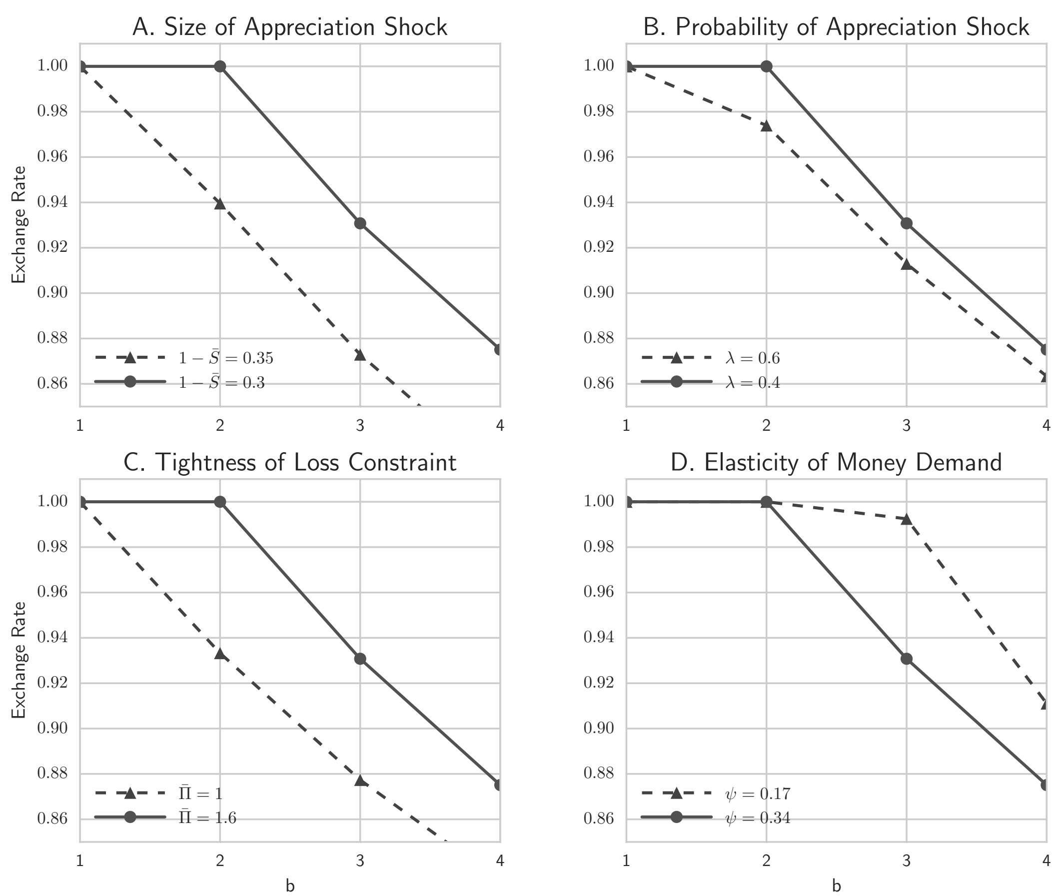


Figure 6: Sensitivity analysis: Exchange Rates

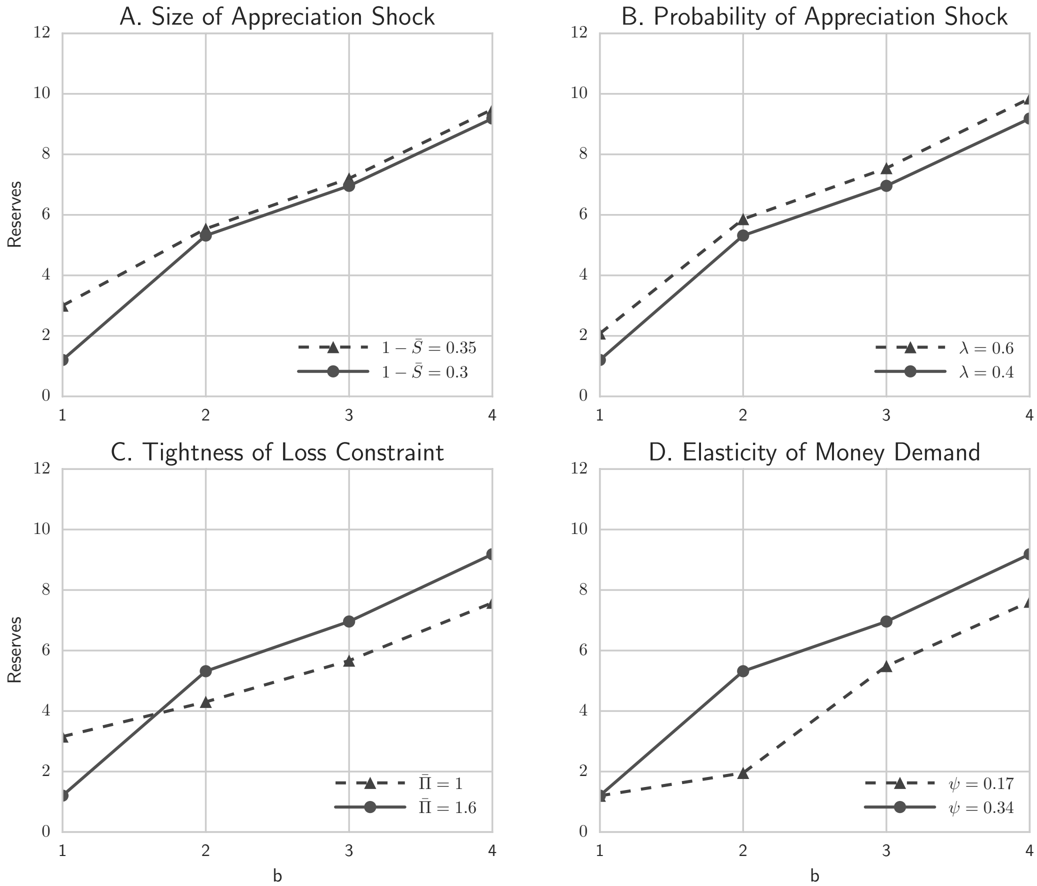


Figure 7: Sensitivity analysis: Reserves

Panel A in both figures shows how the patterns of speculative attack depend on the expected size of the appreciation shock $1-\bar{S}$. When the size of the appreciation shock is larger (the dashed lines) the expected losses of the Central Bank, in case of appreciation, are larger, and the Central Bank is less willing to accumulate reserves; this implies that the peg will be abandoned earlier. Note that the higher probability of abandonment causes a higher expected appreciation of the exchange rate in every state, and thus (through the UIP equation) a lower interest rate. This implies an increase in reserves even in the first state where the Central Bank can maintain the peg (see panel A in figure 7). Panel B in both figures shows the impact of a higher probability of the appreciation shock (the dashed lines). Notice that, because the the way we have specified the loss constraint of the Central Bank (equation 5), a higher likelihood of the appreciation shock does not make the loss constraint directly more binding. Yet, a higher probability of appreciation induces an earlier abandonment. The logic is again that a more likely appreciation induces a current lower domestic interest rate, higher money demand and thus more reserves, which make the loss constraint more likely to bind, and thus induce earlier abandonment. Going back to figure 1, we noticed how the attack that caused the collapse of the Swiss exchange rate floor happened after the Swiss economy experienced two quarters of positive economic growth. The positive news about growth could be interpreted, through the lens of our set-up, as news that the appreciation shock is more likely to happen, and thus could help explain the abandonment of the floor, even before the shock actually happens.

Panel C in figures 6 and 7 shows the impact of having a tighter loss constraint on the Central Bank (a lower $\bar{\Pi}$). Not surprisingly a tighter loss constraint leads to earlier abandonment. Comparing Panels A and C we notice that, in the first state, the effect of a tighter constraint is very similar to the effect of a larger depreciation shock. However, in subsequent states the tighter loss constraint has a milder impact on exchange rates and reserves, than the larger appreciation shock. The reason is that the larger appreciation shock also causes a lower interest rate (through the UIP, i.e. equation 4), higher demand for money and higher reserves. The tighter loss constraint does not have this additional channel, as it does not directly affect the expected exchange rate.

Finally panel D explores the impact of a different elasticity for the demand for money. The dashed lines in panel D in figures 6 and 7 depicts the case when the elasticity is lower ($\psi = 0.17$, corresponding to the 4 shocks specification in table 1). Notice that with a lower elasticity of money demand the Central Bank accumulates less reserves as money demand shock become larger (the dashed line in panel D in figure 7 is below the solid line). As a consequence, its loss constraint is less likely to bind, and the bank can keep the exchange rate closer to the peg than in the benchmark case (see panel D in figure 6). To understand why this is the case, recall that when money demand increases and domestic appreciation becomes more likely, the UIP equation implies that the domestic interest rates fall. When domestic interest rates fall, demand for domestic currency increases further, making reserves grow faster, making the loss constraint more likely to bind and appreciation more likely. With lower elasticity this additional increase in money demand is muted, and thus the Central Bank accumulates less reserves, and can delay appreciation. Another consequence of the lower elasticity is that the exchange rate is less sensitive to foreign interest rate shocks. As we discussed earlier, a reduction in the foreign interest rate lowers domestic rates and increases domestic money demand, which forces the Central Bank to appreciate the currency. With a lower elasticity, the increase in money demand stemming from a reduction in the foreign rate is lower and hence, the appreciation of the exchange rate is also lower. Indeed we find that when the foreign interest rates falls in state 2 and the elasticity is high ($\psi = 0.34$, the benchmark case) the Central Bank appreciates the exchange rate by 3% (see panel A, figure 5). If instead the elasticity is low ($\psi = 0.17$) we find that the Central Bank can maintain the parity in state 2, even when the foreign interest rate falls to its low level.

6 Conclusions

This paper has presented a stylized framework to analyze the abandonment of the peg and subsequent appreciation experienced by the Swiss National Bank in January 2015. We consider a framework in which maintaining a peg involves accumulation of risky foreign reserves, and the Central Bank might abandon the peg in order to limit its exposure to this risk. We have shown that, in this framework shocks to the demand for local currency, and/or to the foreign interest rates can lead to dynamics of reserves and exchange rates that resemble those observed in Switzerland.

The framework used here is highly stylized in several dimensions. We have assumed that the risk associated with the accumulation of foreign reserves is exogenous, that uncovered interest rate parity holds at all states, and we have ignored the presence of a lower bound of the nominal interest rates. In reality the risk and the inflows of foreign reserves are affected by actions of the Central Bank, and are likely to depend on current and future economic conditions as well as on monetary policy objectives. Moreover, in international financial markets, we routinely observe significant deviations from uncovered interest parity. In addition, in low interest rate environments, the presence of a lower bound on nominal rates constrains the actions of the monetary authority.

For all these reasons we think more work on reverse speculative attacks is useful and relevant, not only to better understand these episodes, but also because it sheds light on the limits of monetary policy in highly integrated economies operating at very low interest rates.[13]

[13] For recent work on this see, for example, Acharya and Bengui (2015), Amador et al. (2016) and Caballero et al. (2015)

References

Acharya and J. Bengui (2015), "Liquidity traps, capital flows." CIREQ Working Paper 14.

Amador, Manuel, Javier Bianchi, Luigi Bocola, and Fabrizio Perri (2016), "Exchange rates and the central bank balance sheet." Working paper, Federal Reserve Bank of Minneapolis.

Benigno, P. and S. Nisticò (2015), "Non-neutrality of open-market operations." CEPR Discussion Paper 10594.

Brunnermeier, M. and H. James (2015), "Making sense of the swiss shock." Project syndicate.

Caballero, R. J., E. Farhi, and P. Gourinchas (2015), "Global imbalances and currency wars at the zlb." NBER Working Paper 21670.

Cochrane, J. (2015), "Snb, chf, ecb, and qe." The Grumpy Economist Blog.

Del Negro, M. and C. Sims (2015), "When does a central bank's balance sheet require fiscal support?" *Journal of Monetary Economics*, 73, 1–19.

Flood, R. and P. Garber (1984), "Collapsing exchange-rate regimes: some linear examples." *Journal of international Economics*, 17, 1–13.

Grilli, V. (1986), "Buying and selling attacks on fixed exchange rate systems." *Journal of International Economics*, 20, 143 – 156.

Hall, R. and R. Reis (2015), "Maintaining central-bank financial stability under new-style central banking." NBER Working Paper 21173.

Jermann, U. (2015), "Financial markets' views about the euro-swiss franc floor." Working paper, Wharton School.

Krugman, P. (1979), "A model of balance-of-payments crises." *Journal of money, credit and banking*, 311–325.

Lorenzoni, G. (2014), "International financial crises." *Handbook of International Economics*, 4, 647–87.

R., Lucas Jr. (2000), "Inflation and welfare." *Econometrica*, 68, 247–274.

Rognlie, Matthew (2016), "What lower bound? monetary policy with negative interest rates." Working paper, MIT.

Stella, Peter (1997), "Do central banks need capital?" IMF Working Paper 97/83.

Stella, Peter (2005), "Central bank financial strength, transparency, and policy credibility." *IMF Staff Papers*, 335–365.