# Exit Strategies for Monetary Policy*

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**Abstract**

In response to the financial crisis of 2007/08, all major central banks decreased interest rates to historically low levels and created large excess reserves. Central bankers currently discuss how to raise interest rates in such an environment. The term 'exit strategy' refers to the various policies that allow central banks to achieve this objective. Exit instruments such as paying interest on reserves, term deposits, central bank bills and reverse repos are evaluated with respect to the central bank's ability to control the money market interest rate and their impact on money market trading activity, welfare, inflation and taxes. Each instrument is investigated under two polar coordination regimes: monetary dominance and fiscal dominance.

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*JEL Classification:* E40, E50, D83.

## 1 Introduction

Prior to the financial crisis of 2007/08, all major central banks created an environment in which the banking system was kept short of reserves, a so-called structural liquidity deficit. In such an environment, the central bank provides just enough reserves to ensure that financial intermediaries are able to meet their minimum reserve requirements. Consequently, reserves are scarce and the central bank can achieve the desired interest rate simply by changing the stock of reserves by a small amount via open market operations.

In response to the financial crisis of 2007/08 and the subsequent sovereign debt crisis, all major central banks lowered short-term interest rates to historically low levels and created large excess reserves via asset or foreign currency purchases (quantitative easing, QE). As a result, the

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banking system moved from a structural liquidity deficit to a structural liquidity surplus.[1] In such an environment, traditional monetary policy tools are ineffective in steering the short-term interest rate. For that reason, central bankers and academics are currently discussing how to raise interest rates in an environment with large excess reserves. The term 'exit strategy' in this context refers to the various policies that allow central banks to achieve this objective. The main exit strategies that are discussed are paying interest on reserves, and absorbing reserves via term deposits, central bank bills or reverse repos.

Our goal with this paper is threefold: First, since central banks have little experience with these new policy tools, we construct a dynamic general equilibrium model with a secured money market and use it as a laboratory to study the theoretical properties of these instruments. Second, to assess the quantitative effects of these instruments on the economy, we calibrate the model to the Swiss franc repo market and we evaluate them according to the following criteria: Their capacity to control the money market rate, their impact on the level of trading activity in the money market, as well as on inflation, welfare and taxes. Third, since the future interaction between the fiscal and monetary authorities is uncertain, we assess the effects of these instruments under two polar coordination regimes: Monetary dominance and fiscal dominance.

The following results emerge from our experiments: (i) Irrespective of the coordination regime, all exit instruments allow central banks to achieve the interest rate target, but with different levels of interest rate volatilities. In both regimes, trading activity in the money market under interest on reserves (IOR) is almost inexistent, while trading activity re-emerges for all other instruments and for both regimes. (ii) Under monetary dominance, IOR generates the highest welfare level of all the instruments. Under fiscal dominance, it yields the lowest welfare level. (iii) With an interest rate target, term deposits, central bank bills and reverse repos generate the same real allocation, and hence the same welfare level. (iv) We find that IOR under fiscal dominance generates substantially more inflation than the other three instruments. (v) None of our experiments required a negative real transfer (a tax) to satisfy the consolidated government budget constraint. Nevertheless, all cases involve substantial interest payments from the central bank to financial intermediaries.

The findings of this paper add to the current discussion how to raise interest rates in an environment with large excess reserves and whether monetary policy should be implemented in an excess reserve environment going forward or whether central banks should return to the pre-crisis monetary policy implementation by absorbing reserves.[2] Our results show that the coordination regime is crucial to determining which exit instrument(s) should be applied for exiting the current unconventional monetary policy of historically low interest rates. In particular, the question whether excess reserves should be absorbed via reserve-absorbing instruments (central bank bills, reverse repos or term deposits), or whether the central bank should pay interest on reserves heavily relies on the coordination regime. Furthermore, the choice of instrument also depends on how central bank values criteria such as money market activity or political economy factors such as making large interest payments to a few financial intermediaries. These factors do not directly enter our welfare measure but they are certainly relevant for central banking practice. Against this background, our analysis contributes to the ongoing discussion about exit strategies. For example, the Federal Reserve is currently operating a combination of IOR and reverse repos to control the federal funds effective rate. The SNB used central bank bills and reverse repos in 2010 and 2011 to absorb reserves.

The theoretical model is a dynamic general equilibrium model with a secured money market

[1] The Federal Reserve, the European Central Bank, the Bank of England, the Bank of Japan, and the Swiss National Bank (SNB) are currently in a situation where the banking system is in a structural liquidity surplus. The SNB increased reserves via foreign exchange purchases from CHF 5.62 bn in 2005 to more than CHF 515 bn in 2016.

[2] See, for instance, the Federal Reserve's "Policy Normalization Principles and Plans" (FOMC, September 2014) and the discussions regarding the Federal Reserve's "Long-Run Monetary Policy Implementation Framework" (FOMC, November 2016).

developed in Berentsen et al. (2014a and 2014b). The model is adapted to account for the key characteristics of monetary policy implementation and is based on an explicit microfoundation: Financial intermediaries face liquidity shocks which determine whether they borrow or lend reserves in the money market or at the central bank's standing facilities. Since trading in the money market is secured, we explicitly model the role of collateral.[3] In contrast to a growing body of literature, which models money markets as over-the-counter (OTC) markets that are characterized by search and bargaining frictions, we model the money market as a competitive market. We opted for this modelling strategy after carefully inspecting the institutional details of trading in the Swiss franc repo market. The study and findings also apply to other currency areas, since there is a trend towards shifting money market trading onto transparent (centrally-cleared) electronic trading platforms that reduce informational frictions (see ICMA, 2014).

**Literature.** Our paper is related to Afonso and Lagos (2015) who develop a model of the federal funds market — an unsecured money market for central bank reserves. In their modeling approach, they explicitly take into account the search and bargaining frictions that are key characteristics of this market.[4] They calibrate their model and evaluate the effectiveness of IOR in controlling the overnight money market rate. Armenter and Lester (2016) provide a model that captures the institutional details of the US money market that are relevant for the Federal Reserve's ability to raise the federal funds rate in an environment with large excess reserves. They also calibrate the model and run monetary policy experiments to understand the market reactions when the Federal Reserve hikes rates in a controlled environment. Bech and Monnet (2016) studies the trade dynamics in an unsecured OTC money market. The authors compare different trading protocols and find that a trading arrangement which allows financial intermediaries to direct their search for counterparties replicates the stylized facts of many unsecured OTC money markets best (for an overview of the stylized facts, see Bech and Monnet, 2013).

Related literature on general equilibrium models include Berentsen and Monnet (2008) and Martin and Monnet (2011). The former develops a framework for studying the optimal policy when monetary policy is implemented via a channel, and the latter compares feasible allocations when central banks implement monetary policy via channel or floor systems. Curdia and Woodford (2011) extend a New Keynesian model of monetary policy transmission to analyze monetary policy implementation issues, such as the central bank's balance sheet or IOR as a tool for conducting monetary policy.

This paper is organized as follows: Section 2 develops the theory and Section 3 presents the quantitative analysis. Section 4 analyses exit strategies. Section 5 presents a comparison of all exit instruments when the central bank implements an interest rate target and Section 6 concludes. In the Appendix, the institutional details of the Swiss franc repo market are discussed.

[3] Furthermore, collateral is important for understanding the transmission mechanism of monetary policy, since central banks conduct secured transactions only. For example, the SNB has a target range for the three-month Libor, an unsecured money market rate, and manages the three-month Libor usually via daily repo operations. The European Central Bank does not define a single key policy rate, but, instead, short-term Euro interest rates in general. Presumably, the unsecured overnight money market rate EONIA is monitored and managed via repo operations. For the Federal Reserve, the key policy rate is the Federal Funds Effective Rate, an unsecured overnight interest rate. The Federal Reserve also manages its key policy rate via repo operations and remuneration of reserves.

[4] Other studies of OTC markets include Duffie et al. (2005), Ashcraft and Duffie (2007), Lagos and Rocheteau (2009).

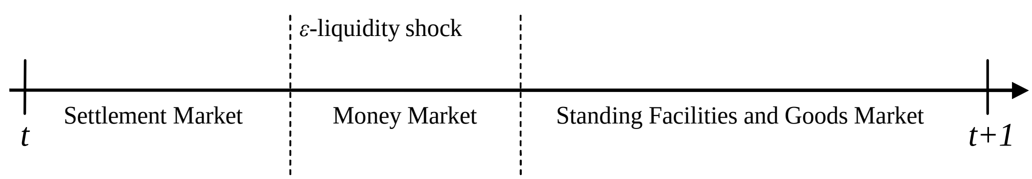
## 2 Theory

The environment is motivated by the elementary features of the Swiss franc repo market, but many other money markets have similar characteristics which are the following:[5] First, at the beginning of the day all outstanding overnight loans are repaid. Second, the Swiss franc repo market operates between 7 am and 4 pm. Third, the SNB controls the stock of reserves by conducting open market operations, typically at 9 am. Fourth, after the money market has closed, the SNB operates its lending facility (discount window) for an additional 15 minutes. This is the last opportunity for financial intermediaries (FIs) to acquire overnight reserves for the same business day in order to settle outstanding short positions in the payment system.

### 2.1 Environment[6]

To reproduce the above sequence it is assumed that in each period three perfectly competitive markets open sequentially (see Figure 1): a *settlement market*, where credit contracts are settled and a generic good is produced and consumed; a *money market*, where borrowing and lending of reserves on a secured basis take place; and a *goods market*, where production and consumption of a specialized good take place.[7] All goods are perfectly divisible and nonstorable, which means that they cannot be carried from one market to the next.

Figure 1: Sequence of markets




There are two types of agents: firms and FIs. Both agent types are infinitely-lived and each of them has the measure 1. The focus of our attention will be on the FIs, since firms play a subordinate role in the model. They are only needed to obtain a first-order condition in the goods market.

Time is discrete and the discount factor across periods for both agent types is $\beta = (1+r)^{-1} < 1$, where $r$ is the time rate of discount. There are two perfectly divisible financial assets: reserves and one-period, nominal discount bonds. One bond pays off one unit of reserves in the settlement market of the following period. Bonds are default-free and book-keeping entries; i.e., no physical object exists.

The three markets are now discussed backwards. In the goods market, the specialized good is produced by firms and consumed by FIs.[8] Firms incur a utility cost $c(q_s) = q_s$ from producing

[5] The Swiss franc repo market is the secured money market for central bank reserves. We model this market because this allows us to benefit from outstanding data quality, featuring detailed information on more than 100,000 overnight transactions. A detailed description of the Swiss franc repo market is provided in the Appendix. The institutional details of the euro area money market and monetary policy implementation by the European Central Bank share the same elements (see Berentsen and Monnet, 2008). For the US, some instutional details differ mainly because it is a segmented market. See Armenter and Lester (2016) for an overview.

[6] The theoretical model presented in Section 2 is adapted from Berentsen et al. (2014a and 2014b).

[7] The Swiss franc repo market is characterized by very few informational frictions and counterparty risks are negligible. See our extensive discussion in the Appendix.

[8] In practice, households consume and hold money on accounts at FIs. The $\varepsilon$-shock can be interpreted as a liquidity shock for FIs which originates from preference or technology shocks experienced by their customers. In order to simplify the model, we abstract from this additional layer, by assuming that our FIs are endowed with the same preferences as potential households.

$q_s$ units and FIs gain utility $\varepsilon u(q)$ from consuming $q$ units, where $u(q) = \log(q)$, and $\varepsilon$ is a preference shock that affects the liquidity needs of FIs. The preference shock has a continuous distribution $F(\varepsilon)$ with support $(0, \infty]$, is i.i.d. across FIs, and is serially uncorrelated.

In order to introduce a microfoundation for the demand for reserves, it is assumed that reserves are the only medium of exchange in the goods market. This is motivated by the assumption that FIs are anonymous in the goods market and that none of them can commit to honor intertemporal promises.[9] Since bonds are intangible objects, only reserves can be used as a medium of exchange in the goods market. Furthermore, claims to bonds cannot be used as a medium of exchange, since agents can perfectly and costlessly counterfeit such claims by assumption (see Lester et al., 2012). In other words, bonds are illiquid in the goods market.

At the beginning of the money market, FIs hold a portfolio of reserves and bonds and then learn the current realization of the liquidity shock. Based on this information, they adjust their reserve holdings by either trading in the money market or at the standing facilities. The central bank is assumed to have a record-keeping technology that keeps track of all trades in the money market.

In the settlement market, a generic good is produced and consumed by firms and FIs. Firms and FIs have a constant-returns-to-scale production technology, where one unit of the good is produced with one unit of labor generating one unit of disutility. Thus, producing $h$ units of goods implies disutility $-h$. Furthermore, the utility of consuming $x$ units of goods is assumed to yield utility $x$. As in Lagos and Wright (2005), these assumptions yield a degenerate distribution of portfolios at the beginning of the money market.

## 2.2 Consolidated government budget constraint

It is assumed that there is a fiscal authority that has the power to levy a lump-sum tax to FIs, with $T$ denoting the nominal lump-sum transfer to each FI in period $t$ ($T < 0$ is a lump-sum tax). The government issues one-period bonds $B_G = \bar{B}_g + B_g$ that are either held by the central bank, $\bar{B}_g$, or the FIs, $B_g$. The government budget constraint at time $t$ satisfies

$$\phi T = \phi \rho B_G^+ - \phi B_G + \phi T_c, \tag{1}$$

where $T_c$ is a nominal transfer from the central bank to the government which can be negative. The price of newly issued bonds is $\rho = 1/(1+i)$, where $i$ denotes the nominal interest rate. Note that throughout the paper, the plus sign is used to denote the next-period variables.

In the settlement market, the central bank controls the stock of reserves and issues one-period bonds denoted $B_c$. Central bank bonds can be used to absorb liquidity and are used as an exit instrument.[10] Government bonds and central bank bonds are both riskless and promise to pay one unit of reserves in the following period. Consequently, they are priced equally, namely, $\rho = 1/(1+i)$.

In the goods market, the central bank operates two standing facilities. First, it offers a lending facility, where the central bank offers nominal loans $\ell$ at an interest rate $i_\ell$. Second, the central bank offers a deposit facility, where it pays interest rate $i_d$ on nominal deposits $d$ with $i_\ell \geq i_d$. An FI that borrows $\ell$ units of reserves at the lending facility in the goods market in period $t$ repays $(1+i_\ell)\,\ell$ units of reserves in the settlement market of the following period. Also, an FI that deposits $d$ units of reserves at the deposit facility in the goods market of period $t$ receives $(1+i_d)\,d$ units of reserves in the settlement market of the following period. Finally, the central bank operates at zero cost.[11]

[9] In practice, households and firms operate in the goods market and the demand for reserves arises because they are anonymous to each other (see also Footnote 8).

[10] The SNB has the legal basis for issuing central bank bills as an instrument to absorb excess reserves. This is not the case for the Federal Reserve.

[11] There is a difference in timing between deposit to and lending from the standing facilities. FIs borrow from

The central bank's budget constraint satisfies

$$\phi T_c = \phi M^+ - \phi M + (\rho\phi B_c^+ - \phi B_c) - (\phi\rho\bar{B}_g^+ - \phi\bar{B}_g) - (1/\rho_d - 1)\,\phi D + (1/\rho_\ell - 1)\,\phi L, \quad (2)$$

where $M$ is the stock of reserves at the beginning of the current-period settlement market, and $\phi$ is the price of reserves in terms of the generic good that is traded in this market. The quantity $B_c$ is the stock of central bank bonds at the beginning of the current-period settlement market, and $B_c^+$ is the stock of bonds at the beginning of the next-period settlement market. Since in the settlement market total loans, $L$, are repaid and total deposits, $D$, are redeemed, the difference $(1/\rho_\ell - 1)\,L - (1/\rho_d - 1)\,D$ is the central bank's revenue from operating the standing facilities.

By combining (1) and (2), the following consolidated government budget constraint is obtained:

$$\phi T = \phi M^+ - \phi M + \phi\rho B^+ - \phi B - (1/\rho_d - 1)\,\phi D + (1/\rho_\ell - 1)\,\phi L, \quad (3)$$

where $B = B_g + B_c$ is the aggregate quantity of bonds held by FIs.

In most monetary models, $T$ passively adjusts to satisfy the consolidated budget constraint. As discussed in Williamson (2016), this effectively means that the interaction between fiscal and monetary policy is neglected. Inspired by Sargent and Wallace (1981), we consider two opposed forms of coordination between the fiscal authority and the monetary authority when we study exit strategies: monetary dominance and fiscal dominance.[12]

**Monetary dominance.** Under this coordination regime, monetary policy is assumed to dominate fiscal policy. According to Sargent and Wallace (1981, p. 1), this implies that "under this coordination scheme, the monetary authority independently sets monetary policy [...]. By doing this, the monetary authority determines the amount of revenue it will supply the fiscal authority through seigniorage. The fiscal authority then faces the constraints imposed by the demand for bonds, since it must set its budgets so that any deficits can be financed by a combination of the seigniorage chosen by the monetary authority and bond sales to the public."

In the context of our model, monetary dominance means that the monetary authority can independently choose the interest rates at the standing facilities, $\rho_d$ and $\rho_\ell$, and the inflation target since the implications for fiscal policy can be neglected. From (2), any combination of these monetary policy instruments determine the real transfer $\phi T_c$. Then, given $\phi T_c$, the fiscal authority needs to adjust its spending or its tax revenues to satisfy (1).[13]

**Fiscal dominance.** Under this coordination regime, fiscal policy is assumed to dominate monetary policy. Under this assumption and according to Sargent and Wallace (1981, p. 2), "the fiscal authority independently sets its budgets, announcing all current and future deficits and surpluses and thus determining the amount of revenue that must be raised through bond sales and seigniorage. Under this second coordination scheme, the monetary authority faces the con-

the lending facility before they trade with firms. And firms and FIs deposit reserves at the deposit facility after the trade.

[12] In several papers, Williamson (2012, 2015, 2016) captures the interaction between the central bank and the fiscal authority by assuming that the central bank faces the constraint that the real value of outstanding government debt remains constant through time. Under fiscal dominance, we impose the constraint that $\phi T$ is constant through time. These two constraints are related, but are not equal.

[13] This is the current practice of the Federal Reserve. Under the Federal Reserve's policy, the earnings of each Federal Reserve Bank are distributed to the US Treasury, after having taken into account the costs of operations, payment of dividends, and other items. For example, the Federal Reserve Banks earned a net income of USD 101.5 bn in 2014. This net income was derived primarily from USD 115.9 bn in interest income on securities acquired through open market operations (US Treasury securities, federal agency and government-sponsored enterprise (GSE) mortgage-backed securities (MBS), and GSE debt securities). The Federal Reserve distributed USD 98.7 bn to the US Treasury.

straints imposed by the demand for government bonds, for it must try to finance with seigniorage any discrepancy between the revenue demanded by the fiscal authority and the amount of bonds that can be sold to the public."

In the context of our model, fiscal dominance means that the fiscal authority fixes the real transfer $\phi T$, and the central bank has to choose a policy that satisfies (3) holding $\phi T$ and the amount of bonds that can be sold to the FIs as given. From (3), it is clear that any change in policy requires that at least one other monetary policy instrument also changes. For example, an increase in the deposit rate $\rho_d$ affects $\phi T$, and so another instrument has to adjust to keep $\phi T$ constant.

## 2.3 Welfare

In the Appendix, it is shown that in a steady state the expected lifetime utility $W$ of an FI satisfies

$$(1-\beta) W = \int \left[\varepsilon u\left(q_{\varepsilon}\right) - q_{\varepsilon}\right] dF\left(\varepsilon\right). \tag{4}$$

It is routine to show that the first-best consumption quantities in the goods market satisfy $q_{\varepsilon}^{*} = \varepsilon$ for all $\varepsilon$. Note that $W$ only depends on the consumption quantities in the goods market. Utilities from consuming and producing goods in the settlement market always add up to zero.

## 2.4 Agents' decisions

In this section, the decision problems of FIs and firms are studied. For this purpose, we let $P$ denote the price of goods in the settlement market and define $\phi \equiv 1/P$. Furthermore, $p$ denotes the price of goods in the goods market.

**Settlement market.** $V_S(m, b, \ell, d, z)$ denotes the expected value of entering the settlement market with $m$ units of reserves, $b$ bonds, $\ell$ loans from the lending facility, $d$ deposits from the deposit facility, and $z$ loans from the money market. Note that $b = b_g + b_c$, where $b_g$ and $b_c$ are, respectively, the government bonds and central bank bonds held by an FI. Since both types of bonds redeem a unit of reserves in the following settlement market, and both can be used as collateral and are riskless, they trade at par. Since FIs are indifferent between the two, they are assumed to hold them all in the same proportion.

$V_M(m, b)$ denotes the expected value from entering the money market with $m$ units of reserves and $b$ units of collateral prior to the realization of the liquidity shock $\varepsilon$. For notational simplicity, the dependence of the value function on the time index $t$ is suppressed. In the settlement market, the problem of an agent is

$$\begin{aligned} V_S(m, b, \ell, d, z) &= \max_{h, x, m\prime, b\prime} x - h + V_M\left(m', b'\right) \\ s.t. \quad x + \phi m' + \phi \rho b' &= h + \phi m + \phi b + \phi d/\rho_d - \phi \ell/\rho_\ell - \phi z/\rho_m + \phi \tau, \end{aligned}$$

where $h$ is hours worked in the settlement market, $x$ is consumption of the generic good, $m'$ ($b'$) is the amount of reserves (bonds) brought into the money market, and $\tau$ is a lump-sum transfer. Using the budget constraint to eliminate $x - h$ in the objective function, one obtains the first-order conditions

$$V_M^{m'} \leq \phi \text{ ( = if } m' > 0 \text{ )} \tag{5}$$

$$V_M^{b'} \leq \phi\rho \text{ ( = if } b' > 0 \text{ ).} \tag{6}$$

$V_M^{m'} \equiv \frac{\partial V_M\left(m', b'\right)}{\partial m'}$ is the marginal value of taking an additional unit of reserves into the money market. Since the marginal disutility of working is one, $-\phi$ is the utility cost of acquiring one unit of reserves in the settlement market. $V_M^{b'} \equiv \frac{\partial V_M(m',b')}{\partial b'}$ is the marginal value of taking additional bonds into the money market. The term $-\phi\rho$ is the utility cost of acquiring one unit of bonds in the settlement market. The implication of (5) and (6) is that all FIs enter the money market with the same amount of reserves and the same quantity of bonds. The same is true for firms, since in equilibrium they will bring no reserves into the money market.

The envelope conditions are

$$V_S^m = V_S^b = \phi; V_S^d = \phi/\rho_d; V_S^\ell = -\phi/\rho_\ell; V_S^z = -\phi/\rho_m, \tag{7}$$

where $V_S^j$ is the partial derivative of $V_S(m, b, \ell, d, z)$ with respect to $j = m, b, \ell, d, z$.

**Money and goods markets.** The money market is perfectly competitive so that the money market interest rate $i_m$ clears the market. Let $\rho_m \equiv 1/(1+i_m)$. All transactions are restricted to overnight transactions. An FI that borrows one unit of reserves in the money market repays $1/\rho_m$ units of reserves in the settlement market of the following period. Also, an FI that lends one unit of reserves receives $1/\rho_m$ units of reserves in the settlement market of the following period.

Firms produce goods in the goods market with linear cost $c(q) = q$ and consume in the settlement market, obtaining linear utility $U(x) = x$. It is straightforward to show that they are indifferent as to how much they sell in the goods market if

$$p\beta\phi^+/\rho_d = 1, \tag{8}$$

where $\phi^+$ is the price of reserves in the next-period settlement market. Since the focus is on a symmetric equilibrium, it is assumed that all firms produce the same amount. With regard to bond holdings, it is straightforward to show that, in equilibrium, firms are indifferent to holding any bonds if the Fisher equation holds, and that they will hold no bonds if the yield on bonds does not compensate them for inflation or time discounting. Thus, for brevity of analysis, it is assumed that firms carry no bonds across periods. Note that firms are allowed to deposit their proceeds from sales at the deposit facility which explains the deposit factor $\rho_d$ in (8).[14] Furthermore, it is also clear that they will never acquire reserves in the settlement market, so that for them, $m' = 0$.

An FI can borrow or lend at the money market rate $i_m$ or use the standing facilities. For an FI with preference shock $\varepsilon$, which enters the money market with $m$ units of reserves and $b$ units of bonds, the indirect utility function $V_M(m, b|\,\varepsilon)$ satisfies

$$\begin{aligned} V_M(m,b|\,\varepsilon) &= \max_{q_\varepsilon, z_\varepsilon, d_\varepsilon, \ell_\varepsilon} \varepsilon u(q_\varepsilon) + \beta V_S(m + \ell_\varepsilon + z_\varepsilon - pq_\varepsilon - d_\varepsilon, b, \ell_\varepsilon, d_\varepsilon, z_\varepsilon) \\ \text{s.t.} \quad & m + z_\varepsilon + \ell_\varepsilon - pq_\varepsilon - d_\varepsilon \geq 0,\ \rho_m\theta b - z_\varepsilon \geq 0,\ \rho_m\theta b - z_\varepsilon - (\rho_m/\rho_\ell)\ell_\varepsilon \geq 0,\ d_\varepsilon \geq 0. \end{aligned}$$

The first inequality is the FI's budget constraint in the goods market. The second inequality is the collateral constraint in the money market, and the third inequality is the collateral constraint at the lending facility where $\theta$ denotes the fraction of bonds that FIs use as collateral in the money market. We introduce $\theta$ here, because it is relevant for the calibration.[15] The last inequality reflects the fact that deposits cannot be negative. Let $\beta\phi^+\lambda_\varepsilon$ denote the Lagrange multiplier for the first inequality, $\beta\phi^+\lambda_z$ denote the Lagrange multiplier for the second inequality, $\beta\phi^+\lambda_\ell$ denote

[14] This assumption reflects the fact that, in practice, firms hold cash from the proceeds of sales on their deposit account at FIs. FIs, in turn, hold these deposits on their reserve account at the central bank.

[15] In practice, only a fraction of the FIs' bonds holdings are used as collateral in the money market. In the case of the Swiss franc repo market, these bonds are earmarked in the securities' account held at the triparty-agent (see Appendix).

the Lagrange multiplier for the third inequality, and $\beta\phi^{+}\lambda_d$ denote the Lagrange multiplier for the last inequality.

FIs use the standing facilities if, and only if, $\rho_\ell = \rho_m$ or $\rho_d = \rho_m$. For brevity of the analysis, in the characterization below, these two cases are ignored by assuming $\rho_d > \rho_m > \rho_\ell$. In this case, $d_\varepsilon = 0$ and $\ell_\varepsilon = 0$. Furthermore, the second and third inequalities are equal and so the third inequality can be ignored without loss in generality.

Using (7), the first-order condition for $z_\varepsilon$ is

$$1 + \lambda_\varepsilon = \lambda_z + \frac{1}{\rho_m}. \tag{9}$$

If $\rho_d > \rho_m > \rho_\ell$, (7) and (8) can be used to write the first-order conditions for $q_\varepsilon$ as follows:

$$\varepsilon u'(q_\varepsilon) - \rho_d/\rho_m = \rho_d \lambda_z. \tag{10}$$

Lemma 1 characterizes the optimal borrowing and lending decisions and the quantity of goods obtained by an $\varepsilon-$FI:

**Lemma 1** *There exist critical values $\varepsilon_1$, $\varepsilon_2$, with $0 \leq \varepsilon_1 \leq \varepsilon_2$, such that the following is true: if $0 \leq \varepsilon \leq \varepsilon_1$, an FI lends reserves in the money market; if $\varepsilon_1 \leq \varepsilon \leq \varepsilon_2$, an FI borrows reserves and the collateral constraint is nonbinding; if $\varepsilon_2 \leq \varepsilon$, an FI borrows reserves and the collateral constraint is binding. The critical values in the money market solve*

$$\varepsilon_1 = \frac{\rho_d}{\rho_m}\frac{m}{p}, \text{ and } \varepsilon_2 = \varepsilon_1\left(1 + \rho_m \frac{\theta b}{m}\right). \tag{11}$$

*Furthermore, the amount of borrowing and lending by an FI with a liquidity shock $\varepsilon$ and the amount of goods purchased by the FI satisfy:*

$$\begin{array}{lll} q_\varepsilon = \varepsilon\rho_m/\rho_d, & z_\varepsilon = p\left(\rho_m/\rho_d\right)\left(\varepsilon - \varepsilon_1\right), & \text{if } 0 \leq \varepsilon \leq \varepsilon_1 \\ q_\varepsilon = \varepsilon\rho_m/\rho_d, & z_\varepsilon = p\left(\rho_m/\rho_d\right)\left(\varepsilon - \varepsilon_1\right), & \text{if } \varepsilon_1 \leq \varepsilon \leq \varepsilon_2, \\ q_\varepsilon = \varepsilon_2\rho_m/\rho_d, & z_\varepsilon = \rho_m \theta b, & \text{if } \varepsilon_2 \leq \varepsilon. \end{array} \tag{12}$$

**Proof of Lemma 1.** See Appendix. ■

Consumption quantities by FIs are increasing in $\varepsilon$ in the interval $\varepsilon \in [0, \varepsilon_2)$ and are flat for $\varepsilon \geq \varepsilon_2$. Note that $\rho_m/\rho_d \leq 1$, which means that the quantities consumed by FIs are always below the first-best quantities, unless $\rho_m = \rho_d$. FIs with a low liquidity shock $\varepsilon$ are lenders. Furthermore, there are two types of borrowers. FIs with an intermediate liquidity shock borrow small amounts of reserves so that the collateral constraint is nonbinding. FIs with a high liquidity shock would like to borrow large amounts of reserves, but their collateral constraint is binding.

## 2.5 Equilibrium

We focus on symmetric stationary equilibria with strictly positive demand for nominal bonds and reserves. Such equilibria meet the following requirements: (i) FIs' and firms' decisions are optimal, given prices; (ii) The decisions are symmetric across all firms and symmetric across all FIs with the same preference shock; (iii) All markets clear; (iv) All real quantities are constant across time; (v) The law of motion for the stock of reserves (2) holds in each period.

Let $\gamma \equiv M^{+}/M$ denote the constant gross reserves growth rate, let $\eta \equiv B^{+}/B$ denote the constant gross bond growth rate, and let $\mathcal{B} \equiv \theta B/M$ denote the bonds-to-reserves ratio, where $\theta$ denotes the fraction of bonds that FIs use as collateral in the money market. It is assumed that there are positive initial stocks of reserves $M_0$ and bonds $B_0$.[16] A stationary equilibrium requires a constant growth rate for the supply of reserves. Furthermore, in any stationary equilibrium the stock of reserves and the stock of bonds must grow at the same rate. In what follows we therefore assume $\gamma = \eta$.

Market clearing in the goods market requires

$$q_s - \int_0^\infty q_\varepsilon dF(\varepsilon) = 0, \tag{13}$$

where $q_s$ is aggregate production by firms in the goods market.

Market clearing in the money market is affected by the presence of the central bank's standing facilities. To understand their role, let $\rho_m^u$ denote the rate that would clear the money market in the absence of the standing facilities. This rate is called the unrestricted money market rate. From Lemma 1, the supply and demand of reserves satisfy

$$\begin{aligned} S(\rho_m^u) &= \int_0^{\varepsilon_1} p(\rho_m^u/\rho_d)(\varepsilon_1 - \varepsilon)\, dF(\varepsilon) \\ D(\rho_m^u) &= \int_{\varepsilon_1}^{\varepsilon_2} p(\rho_m^u/\rho_d)(\varepsilon - \varepsilon_1)\, dF(\varepsilon) + \int_{\varepsilon_2}^{\infty} \rho_m^u b dF(\varepsilon), \end{aligned}$$

respectively, where $\varepsilon_1 = \frac{m}{p}\frac{\rho_d}{\rho_m^u}$ and $\varepsilon_2 = \left(\frac{m}{p}\frac{\rho_d}{\rho_m^u}\right)\left(1 + \rho_m^u \frac{\theta b}{m}\right)$. Money market clearing requires $S(\rho_m^u) = D(\rho_m^u)$, which can be written as follows:

$$\int_0^{\varepsilon_1} (\varepsilon_1 - \varepsilon)\, dF(\varepsilon) = \int_{\varepsilon_1}^{\varepsilon_2} (\varepsilon - \varepsilon_1)\, dF(\varepsilon) + \int_{\varepsilon_2}^{\infty} (\varepsilon_2 - \varepsilon_1)\, dF(\varepsilon). \tag{14}$$

Suppose (14) yields $\rho_m^u > \rho_d$; i.e., the deposit rate is higher than the unrestricted money market rate. In this case, FIs prefer to deposit reserves at the central bank, which reduces the supply of reserves until $\rho_m^u = \rho_d$. Thus, if $S(\rho_d) > D(\rho_d)$, we must have $\rho_m = \rho_d$. Along the same lines, suppose (14) yields $\rho_m^u < \rho_\ell$. In this case, FIs prefer to borrow reserves at the central bank's lending facility, which reduces the demand for reserves until $\rho_m^u = \rho_\ell$. Thus, if $S(\rho_\ell) < D(\rho_\ell)$, we must have $\rho_m = \rho_\ell$. Finally, if $\rho_d > \rho_m^u > \rho_\ell$, FIs prefer to trade in the money market, so $\rho_m = \rho_m^u$.

Accordingly, the market-clearing condition can be formulated as follows:

$$\rho_m = \begin{cases} \rho_d & \text{if} \quad D(\rho_d) < S(\rho_d) \\ \rho_\ell & \text{if} \quad D(\rho_\ell) > S(\rho_\ell) \\ \rho_m^u & \quad\quad\ \text{otherwise.} \end{cases} \tag{15}$$

**Proposition 2** *A symmetric stationary equilibrium with a positive demand for reserves and bonds is a policy $(\rho_d, \rho_\ell)$, with endogenous variables $(\rho, \rho_m, \varepsilon_1, \varepsilon_2)$ satisfying the money market*

[16] Since the assets are nominal objects, the government and the central bank can start the economy off with one-time injections of cash $M_0$ and bonds $B_0$.

*clearing condition (15) and*

$$\rho_d \gamma/\beta = \int_0^{\varepsilon_2} (\rho_d/\rho_m)\, dF(\varepsilon) + \int_{\varepsilon_2}^{\infty} (\rho_d/\rho_m)(\varepsilon/\varepsilon_2)\, dF(\varepsilon) \tag{16}$$

$$\rho\gamma/\beta = \int_0^{\varepsilon_2} dF(\varepsilon) + \int_{\varepsilon_2}^{\infty} (\varepsilon/\varepsilon_2)\, dF(\varepsilon) \tag{17}$$

$$\varepsilon_2 = \varepsilon_1 (1 + \rho_m \mathcal{B}). \tag{18}$$

**Proof of Proposition 2.** See the Appendix. ■

Equation (16) is obtained from the choice of reserves holdings (5). Equation (17) is obtained from (5) and (6); in any equilibrium with a strictly positive demand for reserves and bonds, $\rho V_M^m(m, b) = V_M^b(m, b)$. Then, this arbitrage equation is used to derive (17). Finally, equation (18) is derived from the budget constraints of the FIs. Note that in any equilibrium $\rho_m = \rho$. This result follows from (16) and (17). Note also that once one has derived the endogenous variables $(\rho, \rho_m, \varepsilon_1, \varepsilon_2)$, one can easily solve for all other endogenous variables. For example, the consumption quantities $q_\varepsilon$ and the real value of reserves $m/p$ in the goods market are derived in Lemma 1.

# 3 Quantitative analysis

The model is calibrated to the Swiss franc repo market because of its outstanding data quality. However, our findings apply to the monetary policy implementations of central banks in general. We perform in-sample and out-of-sample tests to assess the fit of the model. For the calibration, the distinction between monetary dominance and fiscal dominance plays no role. Therefore, we discuss this topic in Sections 4 and 5 and only mention it in this section when it is relevant.

The quantitative analysis covers the period from 2005 to 2013 including 107,517 overnight trades. Standard to the literature, month-end data as well as end-of-maintenance period data are excluded (see, for instance, Thornton, 2006). The model is calibrated to the moments of 244 trading days in the sample period which ranges from 3 January 2005 to 15 December 2005 (baseline sample). In the baseline sample, the average overnight rate ($i_m^e$) was 0.63%, the average lending rate ($i_\ell^e$) was 2.61%, and the remuneration of reserves ($i_d^e$) was 0%. The average overnight turnover amounted to CHF 2.77 bn. Finally, the average stock of reserves was CHF 5.62 bn.[17]

## 3.1 Calibration

For the calibration, we choose the model period as one day. The function $u(q)$ is $\log(q)$ and the liquidity shock $\varepsilon$ is log-normally distributed with mean $\mu$ and standard deviation $\sigma$. The parameters to be identified are (i) the preference parameter $\beta$; (ii) the consumer price index (CPI) inflation $\gamma$; (iii) the policy parameters $\rho_\ell$ and $\rho_d$; (iv) the bond-to-reserves ratio $\mathcal{B}$; and (v) the moments $\mu$ and $\sigma$. All data sources are provided in the Appendix. Table 1 reports the identification restrictions and the identified parameter values.

We set $\beta = (1+r^e)^{-1} = 0.99105$ so that the model's real interest rate matches the average real interest rate in the data, $r^e = 0.00188$ which is the difference between one-year Swiss treasury bond yields and CPI inflation. We set $\rho_\ell = (1+i_\ell^e)^{-1} = 0.97454$ and $\rho_d = (1+i_d^e)^{-1} = 1$ in order

[17] During that period, the SNB controlled the stock of reserves via daily repo auctions. The stock was chosen such that FIs were just able to fulfill their minimum reserve requirements. To counter undesired fluctuations in the overnight rate, the SNB conducted fine-tuning operations on an irregular basis. During the baseline sample, the SNB kept its key policy rate constant. For more information, see the Appendix.

to replicate the average lending and deposit rate. In order to match the average CPI inflation, we set $\gamma = \gamma^e = 1.01173$. We normalized $M = 1$. Furthermore, $\mu = 1$, since the numerical analysis shows that $\mu$ is not relevant for our results.

The targets discussed above allow us to calibrate all parameters except the bonds-to-reserves ratio, $\mathcal{B}$, and the standard deviation, $\sigma$. Both are determined by simultaneously matching the average money market rate, $i_m^e$, and the average turnover-to-reserves ratio, $v^e$, by minimizing the weighting function $\min_{\sigma,\mathcal{B}} \omega\left(|i_m - i_m^e|\right) + (1-\omega)\left(|v - v^e|\right)$ with $\omega = 0.5$. We calculate the model's turnover-to-reserves ratio $v$ as follows: Lemma 1 is used to derive $z_\varepsilon/M$ for each $\varepsilon$. We then calculate the integral $\int_{\varepsilon_1}^{\infty} (z_\varepsilon/M)\, dF(\varepsilon)$.

Table 1: Calibration targets[a]

| Parameter | Target description | Parameter value | Target value |
|---|---|---|---|
| $\beta$ | Average real interest rate $r^e$ | 0.99105 | 0.00188 |
| $\gamma$ | Average inflation rate $\gamma^e$ | 1.01173 | 1.01173 |
| $\rho_\ell$ | Average lending rate $i_\ell^e$ | 0.02617 | 0.02617 |
| $\rho_d$ | Average deposit rate $i_d^e$ | 0 | 0 |
| $\mathcal{B}$ | Average money market rate $i_m^e$ | 0.03934 | 0.00631 |
| $\sigma$ | Average turnover-to-reserves ratio $v^e$ | 0.04747 | 0.01548 |
| $\mu$, $M$ | Normalized | 1 | 1 |

[a]Table 1 displays the targets, the parameters and their calibrated values.

Finally, $\mathcal{B} = \theta B/M$ and so we are left to calibrate $\theta$. Recall that the government issues one-period bonds $B_G = \bar{B}_g + B_g$ that are either held by the central bank, $\bar{B}_g$, or the FIs, $B_g$. Accordingly, $B_G/M$ is set to 16.48755 in order to replicate the ratio of outstanding Swiss government bonds to reserves. Furthermore, $\bar{B}_g/M$ is set to 0.51465 to match the SNB's holdings of Swiss government bonds in the baseline calibration period. Then, $B_g/M = B_G/M - \bar{B}_g/M = 15.97290$. Since no central bank bills $B_c$ were outstanding during the baseline calibration period $B = B_g + B_c = B_g$ implying that $B/M = B_g/M = 15.97290$. Hence, from $\mathcal{B} = \theta B/M$, $\theta$ =0.00246. This number indicates that FIs only commit a small quantity of their government bonds holdings as collateral to trade in the money market.

## 3.2 In-sample fit[18]

In order to assess the model's in-sample fit, a finite number $n^t$ liquidity shocks is drawn from a log-normal distribution with the calibrated moments $\mu$ and $\sigma$. Let $\Omega^t$ denote the set of liquidity shocks $\varepsilon$ drawn in period $t$. For each $\varepsilon \in \Omega^t$ Lemma 1 is used to calculate the net borrowing $z_\varepsilon$. Given the various $z_\varepsilon$, the market clearing condition (14) is used to calculate the money market rate $i_m^t$. Since each individual trade that occurs under $\Omega^t$ is known, we can also calculate the turnover-to-reserves ratio $v^t$ from (12) that occurs in period $t$.[19] To generate a sequence of $i_m^t$

[18]For the calibration we assume that all liquidity shocks from the underlying distribution are present. In contrast, when we simulate the model, we draw finite sets of liquidity shocks $\Omega^t$, $t = 1, .., T$, from the underlying distribution. This leads to variability in the money market rate and the turnover-to-reserves ratio across periods. We have chosen this calibration strategy, because it is easy to implement and because there is a long tradition in macroeconomics of calibrating a dynamic stochastic general equilibrium model to the non-stochastic steady state.

[19]The simulated turnover-to-reserves is derived as follows: a finite number $n_t = 4,000$ of liquidity shocks $\varepsilon$ is drawn from the calibrated log-normal distribution, and Lemma 1 is used to calculate $z_\varepsilon/M$ for each $\varepsilon$. Then, we calculate the sum over all strictly positive $z_\varepsilon/M$ and divide the resulting sum by $n_t$. Finally, we repeat this process $T$ times. To map the data to the model, the empirical turnover-to-reserves ratio is calculated as follows. The overnight turnover is divided by the number of active FIs per day. Subsequently, the daily average turnover per active FI is normalized by the stock of reserves.

and $v^t$, the sampling exercise is repeated for $T$ periods. We report the means and the standard deviations of $i_m^t$ and $v^t$ and compare them with the empirical counterparts of the baseline sample. The choice of the sample size $n^t$ affects the standard deviation of $i_m$ and $v$. In particular, the standard deviation converges to zero as the sample size is increased to infinity. To pin down $n^t$, we choose $n^t = 4{,}000$ such that the standard deviation of $i_m$ matches the empirical standard deviation of $i_m^e$. The number $T$ is chosen to fit the number of trading days in the baseline sample.[20]

Table 2: Empirical and simulated moments[a]

| | Empirical | | Simulated | |
|---|---|---|---|---|
| $M = 1$ (in-sample) | Mean | STD | Mean | STD |
| Money market rate $i_m$ | 0.00631 | 0.00064 | 0.00633 | 0.00086 |
| Turnover-to-reserves ratio $v$ | 0.01548 | 0.00512 | 0.01547 | 0.00015 |
| $M = 66$ (out-of-sample) | Mean | STD | Mean | STD |
| Money market rate $i_m$ | 0 | 0.00017 | 0 | 0 |
| Turnover-to-reserves ratio $v$ | 0.00018 | 0.00014 | 0.00024 | 0 |

[a]Table 2 displays the empirical and simulated means and standard deviations of $i_m$ and $v$ for two cases. For $M = 1$, which represents the average stock of reserves of the baseline sample, $n^t = 4{,}000$ and $T = 244$. For $M = 66$, which represents the average stock of reserves in 2013, $n^t = 4{,}000$ and $T = 251$.

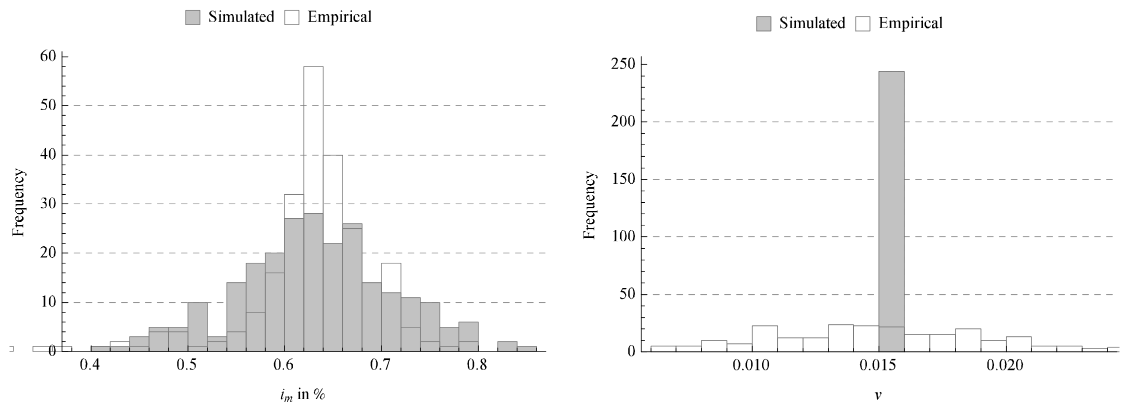
Table 2 displays empirical and simulated means and the standard deviations for $i_m$ and $v$ for two cases: in-sample ($M = 1$) and out-of-sample ($M = 66$, discussed in the following subsection). The in-sample comparison shows that the model fits the average $i_m^e$ and $v^e$ as well as the standard deviation of $i_m^e$ very well. In contrast, the standard deviation of $v$ is too low. The reason is the homogenous collateral constraint: In our model all FI enter the money market with the same collateral and reserves holdings, and so the collateral constraint is binding at the same value. In practice, FIs are heterogeneous with regard to their collateral and reserves holdings and their collateral constraints are binding at different values.

Figure 2 shows the empirical and simulated distributions of $i_m$, $v$ and the borrowing and lending volumes. The left-hand-side panel in the first row shows the histogram of the simulated and the empirical money market rates in the baseline calibration period. The comparison suggests that the model is able to match the empirical distribution of $i_m$ well. In the data, there is a larger concentration of interest rates around the mean than in our simulation. This can be explained by the SNB's fine-tuning operations (see footnote 20).

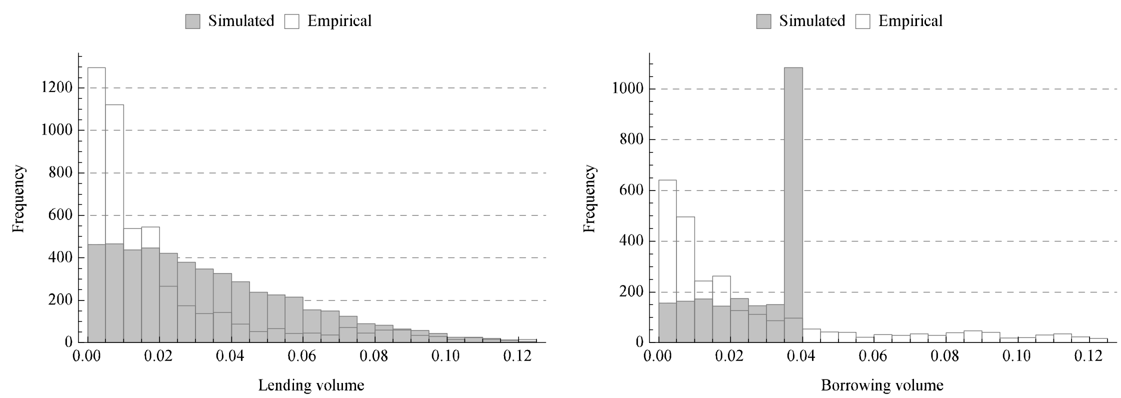
[20]In the model, $n^t$ represents the number of active FIs in the money market at time $t$. This number is much higher than the 32 FIs that were active on an average day. Potential reasons why $n^t$ has to be set higher in order to match the empirical standard deviation of $i_m^e$ are the SNB's fine-tuning operations. Fine-tuning operations were conducted when the money market rate deviated too far from the targeted level and dampened the fluctuation in the money market rate and thus its standard deviation.

Figure 2: In-sample-distribution analysis

*Money market rate and turnover-to-reserves ratio distributions*




*Lending and borrowing volume distributions*




The distributions of the simulated and empirical turnover-to-reserves ratios are displayed in the right-hand-side panel of the first row of Figure 2. There is a large concentration of the simulated turnover-to-reserve ratio at $v = 0.015$. The reason is the collateral constraint as discussed above.

Figure 2 suggests that the model is able to fit the empirical distribution of lending volumes quite well.[21] The frequency is decreasing in size and the model-generated data is able to match this feature. However, the model generates insufficiently small lending volumes compared to the empirical data. As discussed before, there is a large concentration of the simulated borrowing volumes at 0.04, and the reason is again that the collateral constraint binds at this value for all FIs in our model.

## 3.3 Out-of-sample fit

To assess the model's out-of-sample fit, we conduct two experiments. The first experiment considers small reserve supply shocks in a structural liquidity deficit environment. In the second

[21] The borrowing and lending volumes are calculated as follows: a set of liquidity shocks $\varepsilon$ with $n_t = 4,000$ is drawn from the calibrated log-normal distribution. Then, Lemma 1 is used to calculate $z_\varepsilon/M$ for each $\varepsilon$. The lending (borrowing) volume panel displays the distribution of all $z_\varepsilon/M$ with $z_\varepsilon < 0$ ($z_\varepsilon \geqslant 0$).

experiment, the central bank increases the quantity of reserves by a large amount and, thereby, creates a structural liquidity surplus environment. Although we follow the SNB's experience with these two experiments, our findings apply to all major central banks that implemented similar policies and operated in comparable environments. Note that these experiments are tests of how our model performs out-of-sample, as we do not recalibrate the model.

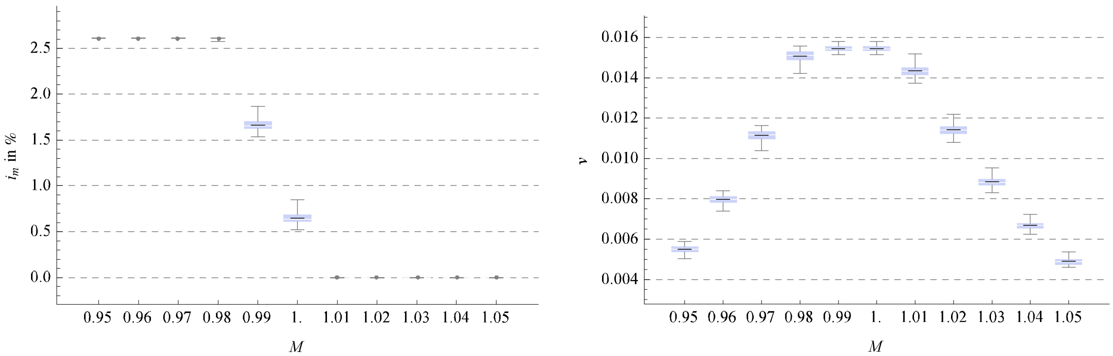
**Structural liquidity deficit: scarcity of reserves.** Prior to the crisis, all major central banks created an environment where the banking system was kept short of reserves, a so-called structural liquidity deficit. In such an environment, the central bank just provides sufficient reserves such that FIs are able to meet their minimum reserve requirements. Consequently, reserves are scarce, and the central bank can achieve the desired interest rate by simply changing the stock of reserves by a small amount. In order to provide the correct amount of reserves, the central bank forecasts FIs' demand for reserves, taking into account exogenous factors such as notes in circulation or the government's reserve balances. When the central bank underestimated (overestimated) the demand for reserves, the money market rate increased above (decreased below) the target rate.

In what follows, we consider a situation in which the central bank has unexpectedly provided either an excess or an insufficient supply of reserves to the banking system. The focus is on the relationship between $M$ and $i_m$, and the experiment is called temporary $M$-shock. Note that a temporary shock does not affect the price of reserves $\phi$ in the settlement market, since $\phi$ is a forward-looking variable: that is, it is determined by future monetary conditions, only. Thus, for a temporary shock, we keep $\phi$ at the calibrated value.

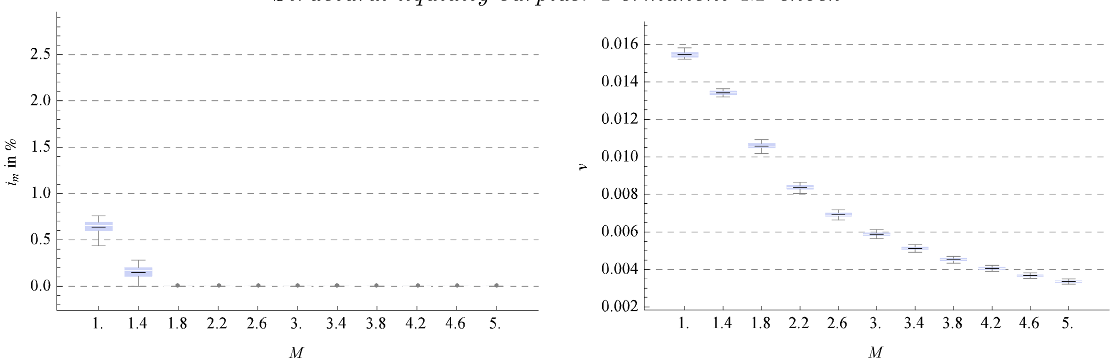
Our simulation method is described in the first paragraph of Section 3.2. We draw $n^t = 4{,}000$ liquidity shocks from the calibrated log-normal distribution and set $T = 40$. A box-plot representation is chosen to illustrate the simulated data. The box-plots displayed in Figure 3 and in all the following figures provide the following information: First, the means of the simulated $i_m^t$ and $v^t$ are indicated by the black horizontal line in the blue area. Second, the width between the 25th and the 75th percentile is represented by the blue area. Third, the minimum and maximum values are indicated by the vertical lines at the extremes of the box-plot.

Figure 3: $M$-shocks

*Structural liquidity deficit: Temporary $M$-shock*




*Structural liquidity surplus: Permanent $M$-shock*




The simulation results of a temporary $M$-shock are shown in the first row of Figure 3. They are based on a variation of $M$ by $+/-5\%$ from the calibrated value $M = 1$.[22] The panel on the left-hand side displays the effect on $i_m$, whereas the panel on the right-hand side displays the effect on $v$. The simulation generates the typical relationship between $M$ and $i_m$: a temporary increase in the stock of reserves $M$ reduces the demand for reserves and increases the supply of reserves in the money market.[23] Consequently, $i_m$ decreases and eventually reaches the deposit rate. In contrast, a decrease in $M$ increases the demand for reserves and decreases the supply of reserves. As a result, $i_m$ increases and ultimately reaches the lending rate.

At the calibrated value $M = 1$, $i_m$ reacts highly elastically to changes in $M$: A change in $M$ of 1% is associated with a change in $i_m$ of 81%. This is in line with empirical studies that estimate elasticities for the demand for reserves. For instance, Kraenzlin and Schlegel (2012) estimate that a change in $M$ of 5% at the end of the minimum reserve requirement period is associated with a change in $i_m$ of up to 60 basis points (applied to our example, this is an interest rate change of approximately 100%). As $M$ moves away from the calibrated value, $i_m$ becomes less elastic. Eventually, due to the standing facilities, the elasticity drops to zero.

The turnover-to-reserves ratio $v$ is increasing in $M$ if $M < 1$ and decreasing if $M \geq 1$. If $M$ is small, there is excess demand for reserves, $i_m$ is at $i_\ell$, and FIs borrow at the lending facility. These borrowed reserves are not included in the calculation of $v$, since the turnover-to-reserves ratio represents the traded volume in the money market, only. The same is true if $M$ is large. In this case, there is an excess supply of reserves, $i_m$ is at $i_d$, and the excess supply of reserves is absorbed by the deposit facility.

[22] For each $M$, we use the same random sample of liquidity shocks.

[23] We provide figures of how the demand and the supply curves of reserves are affected by changes in $M$ in the Appendix.

**Structural liquidity surplus: large excess reserves.** In response to the financial crisis of 2007/08 and the subsequent sovereign debt crisis, all major central banks decreased interest rates to historically low levels and created large excess reserves via asset or foreign currency purchases (QE). In the case of Switzerland, the SNB increased reserves via foreign exchange purchases from CHF 5.62 bn in 2005 to CHF 370 bn in 2013 (a factor of 66). As a result, the banking system is in a structural liquidity surplus with FIs holding large excess reserves, money market interest rates are at $i_d$, and money market activity has collapsed as shown in Figures E.1 and E.2 in the Appendix.

In the following, we study a permanent and large increase in the stock of reserves from $M = 1$ to $M = 66$.[24] In contrast to the temporary $M$-shock, we let the price of reserves $\phi$ adjust to its new equilibrium value.[25] Note that this experiment is conducted under the monetary dominance coordination regime. That is, as $M$ increases, we assume that the real transfer $\phi T$ endogenously adjusts to satisfy the consolidated government budget constraint (3). Note also that in this experiment, we keep the inflation rate constant at the calibrated value.[26] As before, we study the effects on the moments and the distributions of $i_m$ and $v$, as well as the distributions of the borrowing and lending volumes.

Table 2 reports the money market rate and the turnover-to-reserves ratio for $M = 66$. The model predicts a money market rate of zero and a turnover-to-reserves ratio of 0.00024. Both simulated values are very close to the empirical counterparts. The dynamics of a permanent increase of $M$ is also shown in Figure 3. It matches the stylized facts which involve the money market rate at $i_d$ and a subdued money market activity (see Figures E.1 and E.2 in the Appendix).

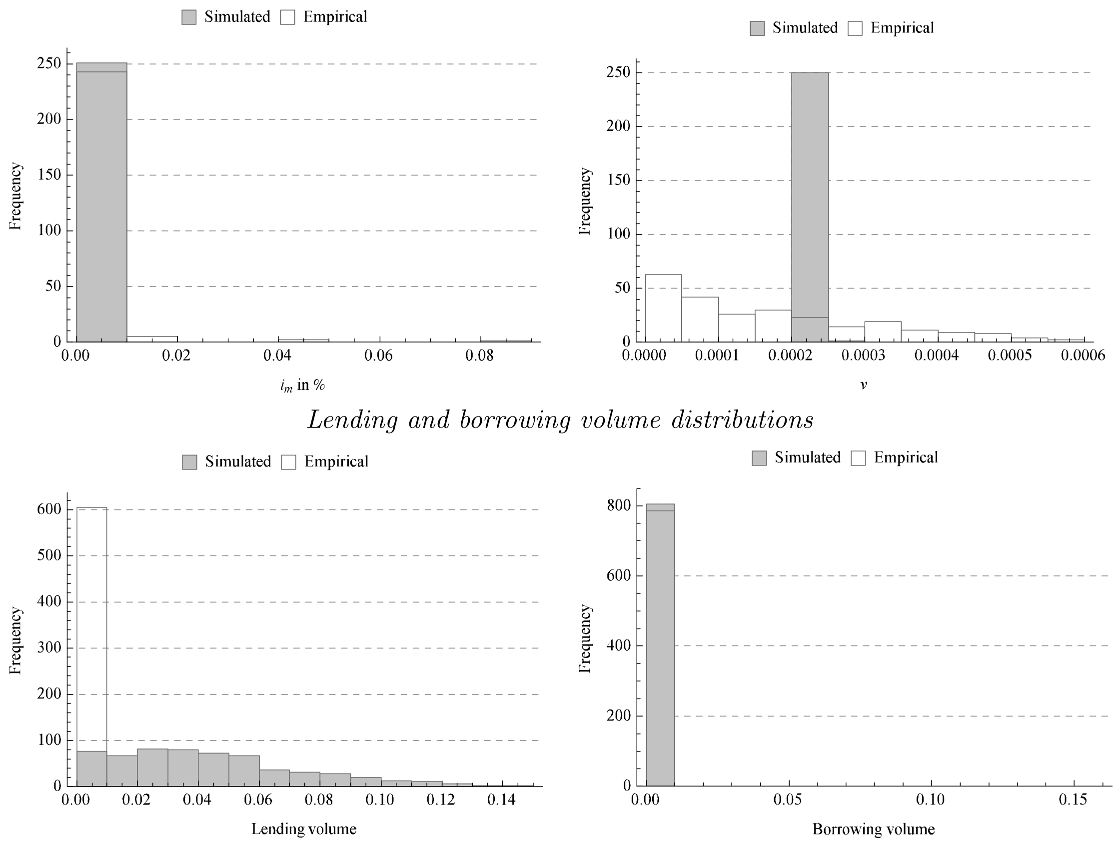
[24] An increase in reserves via QE is a permanent $M$-shock, since the central bank's counterparties are usually non-FIs. Therefore, we study a large and permanent increase in the stock of reserves $M$ holding FIs' stock of collateral $B$ constant (see Benford et al. 2009 for a reference).

[25] Although all prices are fully flexible in our model, a change in $M$ is not neutral. The reason for the non-neutrality is the collateral constraint.

[26] We also conducted the same experiment under the fiscal dominance coordination regime, where $\phi T$ is kept constant and the inflation rate $\gamma$ adjusts to satisfy (3). For this experiment, we find that the inflation rate increases to 8%, which has not been observed in any country that has a major central bank. We, therefore, present this experiment under monetary dominance only.

Figure 4: Out-of-Sample Distribution analysis

*Money market rate and turnover-to-reserves ratio distributions*




The first row of Figure 4 shows the empirical and simulated distributions of $i_m$ and $v$. The left-hand-side panel suggests that the model is able to fit the empirical distribution of $i_m$ well.[27] In contrast, the model again fails to match the empirical distribution of $v$. Again, this is due to the homogeneous collateral constraint. The second row of Figure 4 shows the distributions of lending and borrowing volumes. In the case of the lending volumes, the model simulations predict a less positively skewed distribution, suggesting that the lending volumes generated by the model are more variable than the empirical observations. In the case of the borrowing volumes, the simulated distribution fits the empirical data quite well: FIs are only willing to borrow small volumes because of excess reserves.

# 4 Exit strategies

The current monetary policy environment is characterized by large excess reserves. As a result, the money market rate is at the deposit rate, and the trading activity is close to zero. Central bankers and academics currently discuss how to raise interest rates in such an environment,

[27]Note that a considerable amount of transactions were executed at negative interest rates in 2013. The motivation was to acquire certain types of collateral used in other money market segments. As this motivation is not reflected in our model, negative interest rates are set to zero to make the model's predictions comparable to the empirical observations.

and the term exit strategy is used for various policies that enable this to be achieved.[28] The following four instruments are widely discussed: IOR, term deposits, central bank bills and reverse repos.[29] For each of these instruments, the focus of our attention will be on their effectiveness in controlling the money market rate, how money market trading activity is affected, and its implications for inflation, welfare and transfers. We also calculate the interest payments which would have to be made by the central bank to the FIs in order to implement a certain interest rate target.

The analysis of the exit instruments is conducted under the two coordination regimes of monetary dominance and fiscal dominance discussed in Section 2.2. For that purpose, it is useful to rewrite the consolidated budget constraint (3) as follows (see Appendix):

$$\phi T = \frac{\rho \varepsilon_1}{\beta} \left[ \gamma - 1/\rho_d + (B/M)(\rho\gamma - 1) + (1/\rho_\ell - 1/\rho_d) L/M \right]. \tag{19}$$

Under monetary dominance, we assume that the real transfer to the public $\phi T$ adjusts endogenously to satisfy the consolidated government budget constraint (19) and that the rate of inflation $\gamma$ is kept constant at the calibrated value. For example, when changing $\rho_d$, we take into account the direct effect of $\rho_d$ on $\phi T$ and the general equilibrium effects of $\rho_d$ on $\phi T$ via changes in $\rho$ and $\varepsilon_1$. Under fiscal dominance, we assume that the real transfer $\phi T$ is kept constant at the calibrated value $\overline{\phi T}$, and that $\gamma$ adjusts endogenously. All simulations in this section have the same initial conditions: The initial stock of reserves is $M = 66$, which corresponds to the average stock of reserves in 2013, and the initial inflation rate is at the calibrated value $\gamma = 1.01$. Using theses values, we find that the transfer that is needed to satisfy the consolidated government budget constraint (19) is $\overline{\phi T} = 0.04$.

Recall that $\phi T$ is a lump-sum transfer. Thus, monetary dominance implicitly assumes that any change in policy results in a change of a non-distortionary tax. In contrast, under fiscal dominance, $\phi T$ is kept at the calibrated value, and the inflation rate, which is a distortionary tax, adjusts to a change in policy to satisfy (19).

### 4.1 Interest on reserves

With IOR the central bank remunerates reserves at rate $i_d$, which imposes a floor for the overnight money market rate: No FI would lend to other counterparties at a rate below $i_d$.[30] In an environment with large excess reserves, $i_m$ will be equal to $i_d$. For that reason, this method of implementing monetary policy is referred to as a floor system. IOR is simulated by increasing $i_d$.

**Money market rate and turnover.** As can be seen from the first row of Figure 5, there is no qualitative discrepancy for monetary and fiscal dominance. In both cases, the money market rate satisfies $i_m = i_d$ for all values of $i_d$, and the trading activity in the money market is close to zero. This shows that the central bank can control $i_m$ with perfect precision without changing the stock of reserves in the economy. The model thus replicates what central banks experienced with IOR in an environment with large excess reserves.

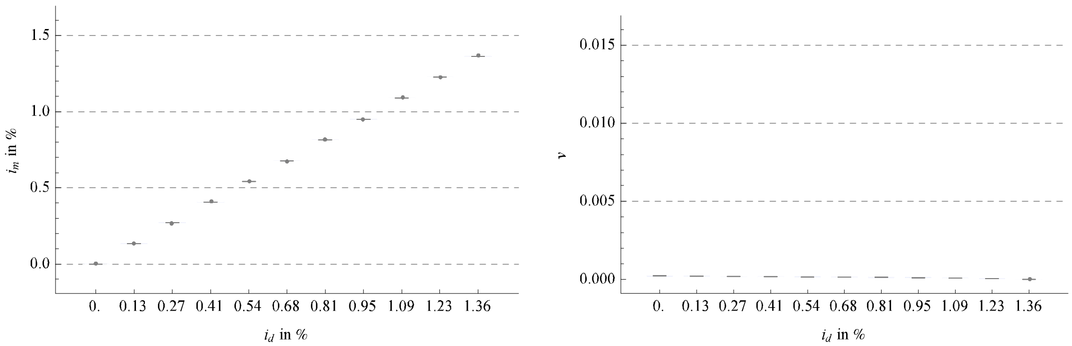
[28] See, for instance, "Policy Normalization Principles and Plans" (FOMC, September 2014).

[29] As alternatives to these exit instruments, central banks could lower aggregate reserves by selling assets in order to reduce their balance sheets to pre-crisis levels, or, they could increase minimum reserve requirements in order to align the demand for reserves with the existing large stock of reserves. For various reasons beyond the scope of our model, central banks refrain from these measures.

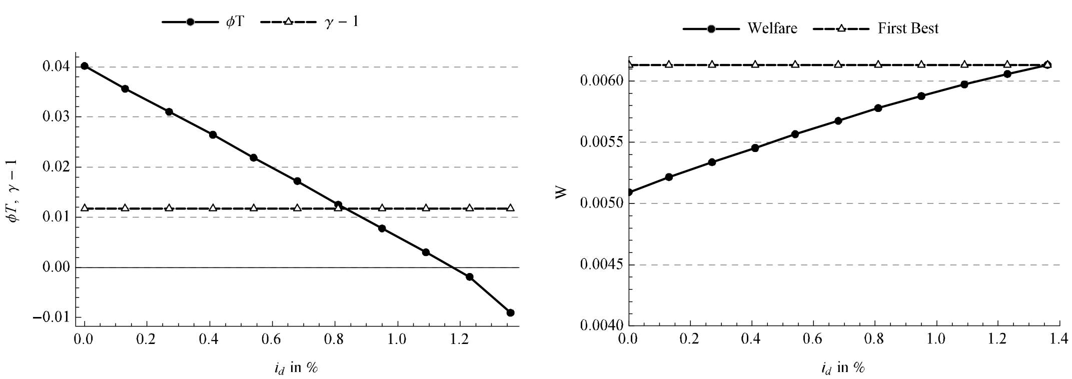
[30] The IOR might represent a binding floor or should at least serve as a magnet for the overnight money market rate. This depends on the degree of segmentation and competition in the money market, as well as on the central bank's access policy to a reserve account, and hence access to earning the IOR. See Bech and Klee (2011) for an analysis of the federal funds market and Jackson and Sim (2013) for a study of the UK case. For an analysis of the impact of central banks' access policies, see Kraenzlin and Nellen (2014).

FIGURE 5: INTEREST ON RESERVES

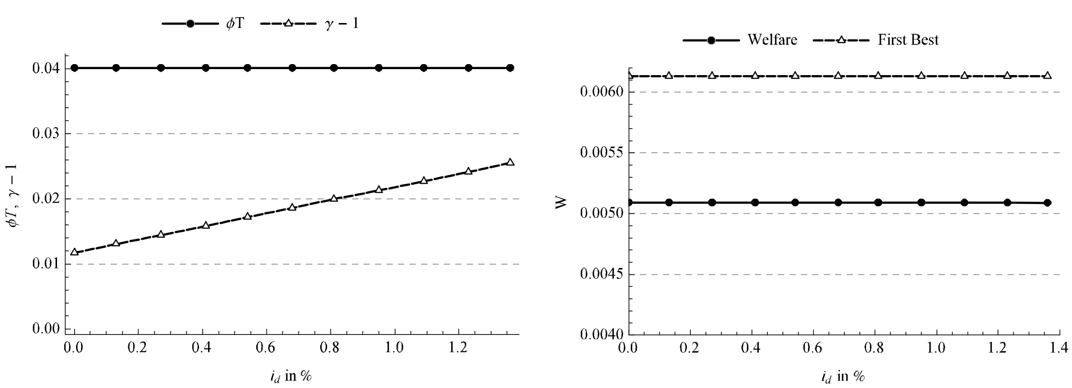
*Fiscal and Monetary dominance*




*Monetary dominance*




*Fiscal dominance*




**Inflation, transfer and welfare.** Under *monetary dominance*, the transfer monotonically decreases from its initial value $\overline{\phi T}$ and eventually becomes negative (a tax). Welfare is increasing and attains the first-best welfare level at $i_d = 1.36\%$. The reason is that the interest payments are financed with a non-distortionary tax and that paying interest on reserves is welfare improving. This finding is related to the Friedman rule which requires that the opportunity cost of holding reserves should be zero. Here, this is achieved by paying interest on reserves.

Under *fiscal dominance*, inflation increases from the calibrated value of 1.17% to 2.56%. The effect on welfare is slightly negative, and it is impossible to attain the first-best welfare level. The intuition is that the interest payments are financed with a distortionary tax. Thus, while paying interest on reserves is welfare improving, the overall effect is negative because of the distortions created by inflation.

**Summary.** Under monetary and fiscal dominance, paying interest on reserves allows the central bank to perfectly control the money market interest rate, but there is no trading activity in the money market. Under monetary dominance, the cost of such a policy is a reduction in transfers $\phi T$. Nevertheless, this policy is welfare-improving, because paying interest on reserves increases efficiency by reducing the opportunity cost of holdings reserves, and the interest payments are financed with a non-distortionary tax instrument. Under fiscal dominance, the consequence of such a policy is a higher inflation. Here, the benefits of paying interest on reserves are reversed, because the interest payments are financed with a distortionary tax instrument.

## 4.2 Term deposits

With a term deposit, the central bank issues an IOU and sells it to FIs against reserves in order to absorb reserves.[31] If sufficient reserves are absorbed, they become scarce and the money market rate increases above the deposit rate. Key characteristics of term deposits are that they cannot be traded by FIs and they cannot be used as collateral. The effects of term deposits are, therefore, simulated by reducing reserves from $M = 66$ to $M = 1$, holding the stock of collateral constant at the calibrated value. Note that in Figure 6 we only show the range between $M = 5$ and $M = 1$.

**Money market rate and turnover.** Under *monetary dominance*, $i_m$ remains at $i_d$ for $M > 1.64$. For $M < 1.64$, $i_m$ increases monotonically until it reaches the calibrated money market rate of 0.63% at $M = 1$. Furthermore, $v$ also increases monotonically and eventually reaches the calibrated value at $M = 1$. The reason is that absorbing liquidity via term deposits is a 'reverse' QE in our model. The effects of QE – the increase in reserves from $M = 1$ to $M = 66$ – are undone.[32]

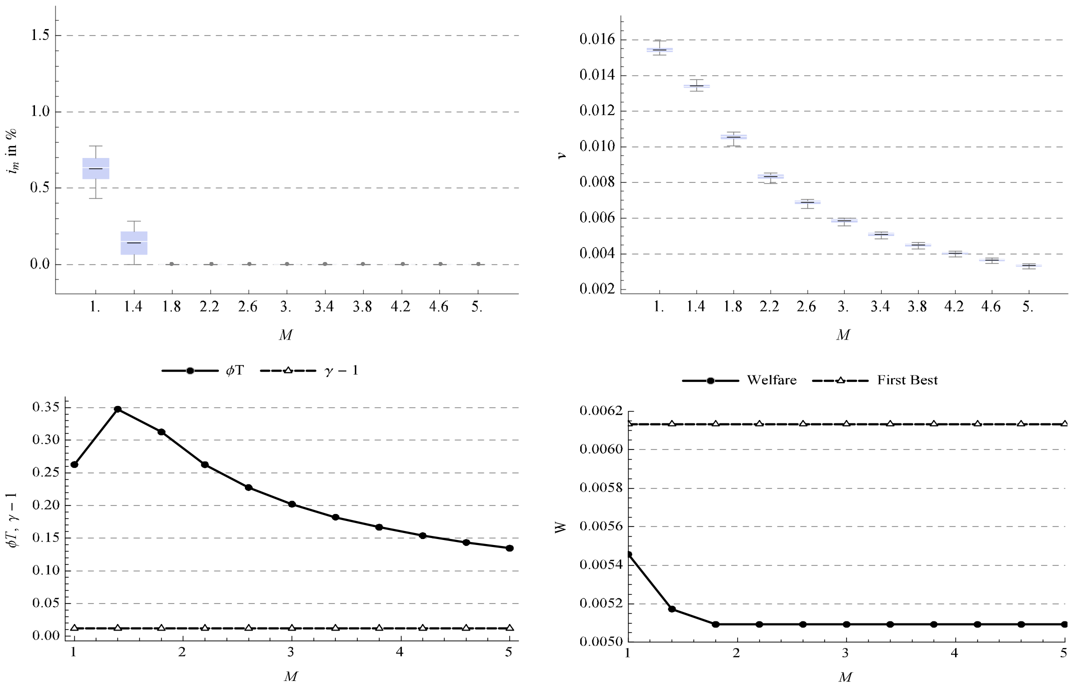
Under *fiscal dominance*, term deposits cannot undo QE. First, as $M$ decreases, $i_m$ stays at $i_d$ until $M < 0.64$. Second, money market activity is lower than under monetary dominance, which can be explained as follows: As inflation, and hence the opportunity cost of holding reserves, decreases, FIs demand more reserves in the settlement market (self-insurance) and rely less on the money market to insure against liquidity shocks. This increases the supply of reserves in the money market and decreases the demand for reserves in the money market, which results in a lower money market rate than under monetary dominance. Hence, the money market rate remains at $i_m = i_d = 0\%$ for values of $M$ where we find a strictly positive rate under monetary dominance. For the same reason, $v$ is lower under fiscal dominance than under monetary dominance.

[31] Counterparties for term deposits are FIs that can participate in the central bank's open market operations. Depending on the central bank's access and remuneration policy, the range of potential counterparties may be broader than in the case of IOR.

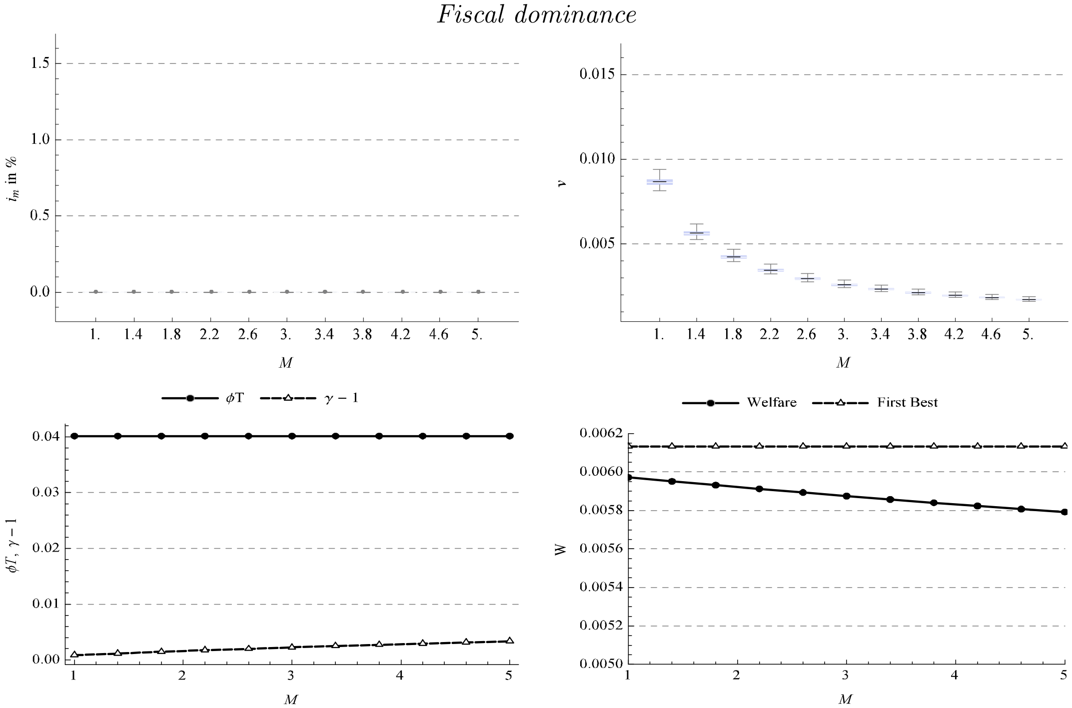
[32] Recall that when we simulated QE, it was under the assumption of monetary dominace, because the increase in inflation that arises under fiscal dominance is not consistent with the data. See our discussion in Section 3.

Figure 6: Term deposits

*Monetary dominance*




*Fiscal dominance*




**Inflation, transfer and welfare.** Under *monetary dominance* and in the region of $M$ where $i_m = i_d = 0$, $\phi T$ increases monotonically when $M$ decreases. In this region, the central bank can absorb reserves at zero costs, and $\phi T$ increases, because the bond-to-reserves ratio $\mathcal{B}$ is increasing. In the region of $M$, where $i_m > i_d$, $\phi T$ can be hump-shaped because now the monetary authority has to pay a strictly positive interest rate to FIs in order to absorb reserves. Our simulations indicate that close to $M = 1$, the interest cost dominates the benefit of increasing $\mathcal{B}$ and so $\phi T$ is decreasing.

With respect to welfare, we find that in the region of $M$ where $i_m = i_d$, welfare is slightly increasing, because of the increasing bonds-to-reserve ratio. In the region of $M$ where $i_m > i_d$, welfare is rapidly increasing, because the money market allows FIs to earn interest on 'idle' reserves. Thus, the existence of such a market is strictly welfare-improving, as has been shown in a different context in Berentsen et al. (2007).

Under *fiscal dominance*, we find that inflation is monotonically decreasing, and welfare is monotonically increasing as $M$ decreases. Welfare is increasing because inflation is decreasing. The mechanism at work can be understood by inspecting the consolidated budget constraint (19): A decrease in $M$ increases the bonds-to-reserve ratio $\mathcal{B}$. Endogenous variables such as $\rho$ and $\varepsilon_1$ do not adjust enough to satisfy $\phi T = \overline{\phi T}$. Accordingly, $\gamma$ has to decrease until $\phi T = \overline{\phi T}$. We find that the welfare level under fiscal dominance is higher than under monetary dominance for any $M \geq 1$. This result is driven by the fact that inflation is lower under fiscal dominance.

**Summary.** Under monetary dominance, term deposits allow the monetary authority to undo QE completely, while under fiscal dominance this is not the case. In both cases, absorbing reserves via term deposits is welfare improving, because it reduces the opportunity cost of holding reserves. Under monetary dominance, the opportunity costs are decreasing because of the increase in $i_m$, and under fiscal dominance, because of the decrease of $\gamma$. Welfare is higher under fiscal dominance than under monetary dominance for any $M$. Compared to IOR, the control of the money market rate under monetary dominance is less precise, as indicated by the box-plots.[33]

### 4.3 Central bank bills and reverse repos

With a central bank bill, the monetary authority issues an IOU and sells it to FIs in order to absorb reserves. In contrast to a term deposit, the central bank creates a tradeable security (the IOU) which can be used as collateral by FIs. With a reverse repo, the central bank borrows reserves against collateral, and FIs collateral holdings increase. In practice, central bank bills and repos can also be purchased by non-FIs. Therefore, we need to take a stand to what extent the collateral holdings of FIs increases. In the following simulations, we assume that $M$ decreases from $M = 66$ to $M = 1$ and that, at the same time, collateral holdings $\theta B$ increase from the calibrated value to $2\theta B$.[34] For expositional simplicity, we only refer to central bank bills, but all results apply to reverse repos as well.

**Money market rate and turnover.** Figure 7 shows that under *monetary dominance*, $i_m$ remains at $i_d = 0$ for $M > 2.6$. For $M < 2.6$, $i_m$ increases monotonically until it reaches the calibrated money market rate of 0.63% at $M = 1.8$. This shows that central bank bills are more effective than term deposits, since less reserve absorption is needed if the goal is to increase the money market rate. The reason for this is that an increase in FIs' collateral holdings relaxes the collateral constraint and hence allows them to borrow more in the money market. Thus, for any

[33] From an operational point of view, a difficulty with term deposits is that the central bank needs to absorb a large quantity of aggregate reserves. Such an absorption operation cannot be done in a short period of time. In contrast, an IOR can be imposed immediately on the entire quantity of reserves.

[34] The SNB used central bank bills and reverse repos in order to absorb reserves in 2010 and 2011. Fuhrer et al. (2016) provide evidence that FIs did not increase their available collateral by the same amount as the SNB absorbed reserves. They find that collateral holdings of FIs doubled, while reserves were decreased by a larger factor. This can be attributed to the fact that SNB Bills were mainly purchased by non-FIs.

value of $M$, the demand for reserves in the money market and the interest rate is higher under a policy using central bank bills than under a policy using term deposits. Applying the same logic, the increase in FIs collateral holdings also leads to more trading activity with central bank bills than with term deposits or IOR.

Under *fiscal dominance*, $i_m$ remains at $i_d$ for $M > 1.12$. For $M < 1.12$, $i_m$ increases rapidly until it reaches the calibrated money market rate of 0.63% at around $M = 1.08$. For any value of $M$, there is slightly less trading activity in the money market under fiscal dominance than under monetary dominance.

**Inflation, transfer and welfare.** Under *monetary dominance*, $\phi T$ increases as $M$ decreases in the region where $i_m = i_d = 0$. In the region where $i_m > i_d$, $\phi T$ decreases because the interest payments are financed by a reduction of the transfer. In the region where $i_m = i_d$, $W$ is flat, and in the region where $i_m > i_d$, $W$ increases because paying interest on reserves – financed in a non-distortionary way – is welfare-improving.

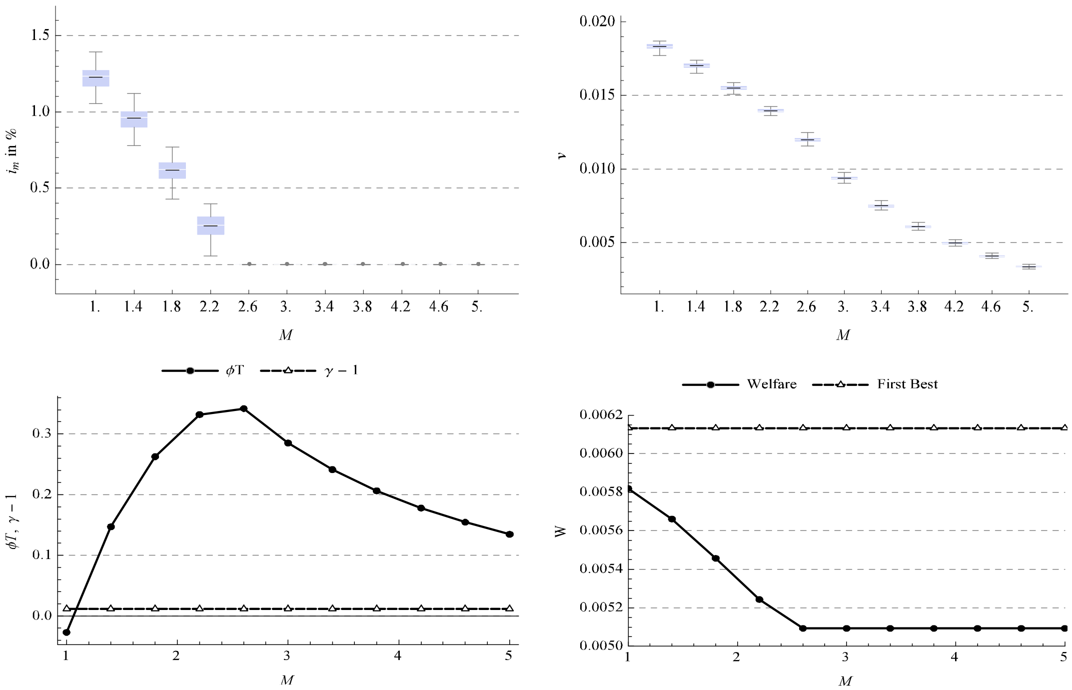
Under *fiscal dominance*, inflation is first decreasing as $M$ decreases and then starts to rapidly increase after $M = 1.12$ . Welfare mimics this result. It is first increasing and then rapidly decreasing. The reason is that the interest rate in the money market moves beyond the optimal value that is described by the Friedman rule.

**Summary.** The simulation suggests that the control of the money market rate with central bank bills and reverse repos is less precise than with IOR, which is indicated by various box-plots.[35] The money market rate increases above the deposit rate earlier, and money market trading emerges more quickly with central bank bills than with term deposits. The reason is that central bank bills increase the collateral holdings of FIs. This relaxes their collateral constraint and increases the demand for reserves. As a result, fewer reserves need to be absorbed in order to achieve a given interest rate target. In general, welfare is increasing if the opportunity cost of holding reserves is decreasing. Under monetary dominance, the increase in the money market rate decreases the opportunity cost of holding reserves, whereas under fiscal dominance, it is the decrease of inflation that decreases the opportunity cost.

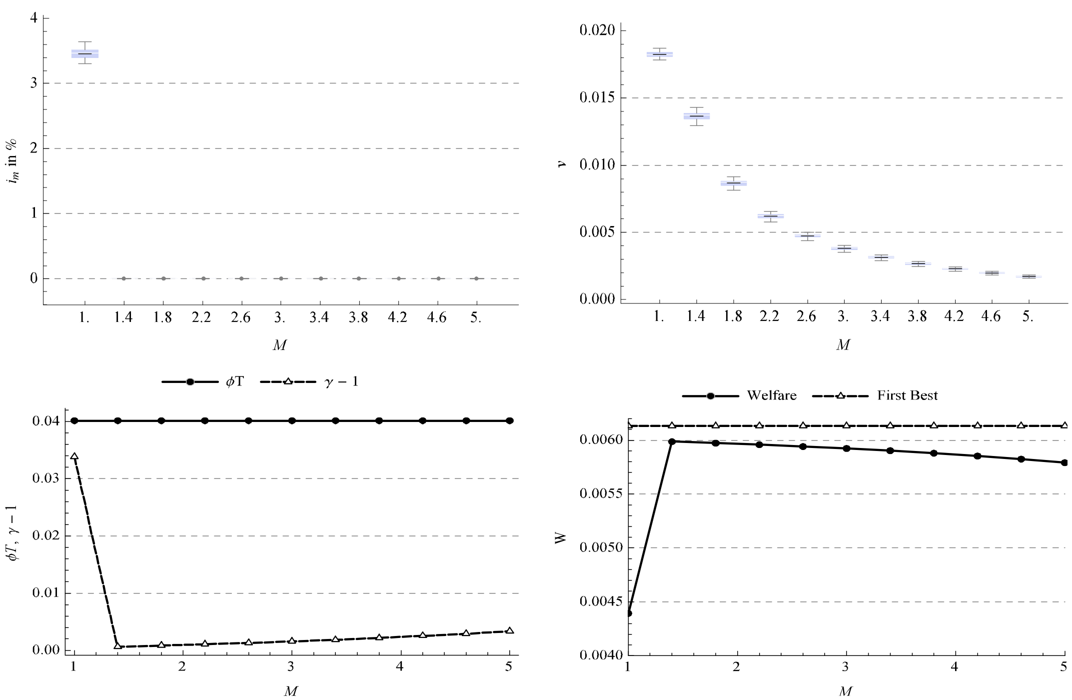
[35] Again, as for term deposits, there are operational issues, since a large amount of reserves has to be absorbed. See our discussion above.

Figure 7: Central bank bills and reverse repos

*Monetary dominance*




*Fiscal dominance*



# 5 Pre-crisis interest rate

After we have investigated the various properties of the exit instruments, we now present our main experiment. We study the implications of returning to the pre-crisis interest rate for all instruments under monetary dominance and fiscal dominance. It is assumed that the central bank has an interest rate target of 0.63%, which is the average interest rate in the baseline calibration period (see Table 1). Table 3 displays our findings for all exit instruments. The first column displays the standard deviation of $i_m$. The second, third and fourth columns show the turnover $v$, the quantity of reserves $M$ at which the money market rate reaches the targeted $i_m$, and the bonds-to-reserves ratio $\mathcal{B}$, respectively. The fifth and sixth columns show the transfer and inflation needed to satisfy the consolidated government budget constraint (19). The seventh column reports the welfare level attained. Finally, the last column reports the yearly interest payment of the central bank to the FIs. They are calculated as follows: The money market interest rate ($i_m = 0.63\%$) is multiplied by the stock of reserves that needs to be remunerated to attain the targeted interest rate.[36]

TABLE 3: TARGET $i_m = 0.63\%$[a]

| *Monetary dom.* | STD $i_m$ | 100*$v$ | $M$ | 100*$\mathcal{B}$ | $\phi T$ | $\gamma$ | 100*$W$ | Payment |
|---|---|---|---|---|---|---|---|---|
| IOR ($i_d = 0.63\%$) | 0.00% | 0.015 | 66 | 0.060 | 0.01878 | 1.173 | 0.564 | 2.331 bn |
| Term deposits | 0.08% | 1.544 | 1 | 3.934 | 0.26266 | 1.173 | 0.546 | 2.296 bn |
| Cb-bills/rev.repo | 0.09% | 1.546 | 1.8 | 3.934 | 0.26266 | 1.173 | 0.546 | 2.267 bn |
| *Fiscal dom.* | STD $i_m$ | 100*$v$ | $M$ | 100*$\mathcal{B}$ | $\phi T$ | $\gamma$ | 100*$W$ | Payments |
| IOR ($i_d = 0.63\%$) | 0.00% | 0.024 | 66 | 0.060 | 0.04016 | 1.813 | 0.509 | 2.331 bn |
| Term deposits | 0.06% | 1.787 | 0.6 | 6.557 | 0.04016 | 0.677 | 0.591 | 2.308 bn |
| Cb-bills/rev.repo | 0.10% | 1.786 | 1.08 | 6.557 | 0.04016 | 0.677 | 0.591 | 2.293 bn |

[a] Table 3 displays the simulation results of the various exit strategies when the central bank targets a money market rate of 0.63%. The following instruments are considered: IOR, term deposits, central bank bills and repos. The instruments are evaluated according to the following criteria: their ability to control the money market rate, their impact on money market trading activity, the real transfer, the inflation rate, welfare, and the yearly interest payments to FIs which is necessary to attain the interest rate target with CHF 370 bn of reserves.

**Inflation and welfare.** The following key results emerge from our analysis. (i) Under monetary dominance, welfare is highest under IOR. (ii) With an interest rate target, term deposits, central bank bills and reverse repos generate the same real allocation and hence the same welfare level. (iii) Under fiscal dominance, these instruments generate the highest welfare level.

To understand our welfare results, it is useful to note that $o \equiv \rho\gamma/\beta$ measures FIs' opportunity cost of holding reserves – see equation (17). A policy that lowers $o$ improves the allocation and increases welfare. Since in equilibrium $\rho = \rho_m$, the interest rate target of 0.63% pins down $\rho$, and so only $\gamma$ affects this cost.

Under *monetary dominance*, the central bank has an inflation target, and hence the opportunity costs of holding reserves are equal for all instruments. Consequently, term deposits, central bank bills and reverse repos attain the same welfare level and the same real allocation, because the bonds-to-reserves ratio $\mathcal{B}$ is the same. Furthermore, IOR generates the highest welfare level, because $\mathcal{B}$ is smaller than for the other exit instruments. Under *fiscal dominance* and IOR,

[36] Recall that for Switzerland $M = 66$, which means that the quantity of reserves is CHF 370 bn. For IOR, the total stock of reserves needs to be remunerated. Thus, the yearly interest payment to FIs is 2.331 bn. For term deposits, central bank bills and reverse repos, the amount of reserves that needs to be absorbed is only $66 - M$, where $M$ is indicated in the third column of Table 3. Due to arbitrage considerations, the interest rate paid in absorbing operations has to be equal to the money market rate.

inflation and hence $o$ is higher than in all other experiments, which results in the lowest welfare level. Here, the three other instruments generate the highest welfare. The reason is that they lead to a lower inflation rate than IOR.

**Standard deviation, turnover and the quantity of reserves.** With all instruments and in both regimes $i_m$ is on target. The standard deviation is zero with IOR and strictly positive with all other instruments. The turnover is close to zero with IOR, because the stock of reserves remains at $M = 66$. In contrast, money market activity is back to the pre-QE levels with all other instruments. Although the turnover is not directly relevant for welfare in our model, many central banks value an active money market, since they can infer information from money market trading activity that can be relevant, for example, for the calculation of transaction-based benchmark rates. From this point of view, IOR can be problematic.

As discussed above, when the central bank has an interest rate target, all instruments except for IOR implement the same real allocation, and hence yield the same welfare level; however, they affect the money market differently. For example, under the central bank bills, the central bank needs to absorb less reserves than under term deposits, and the standard deviations of $i_m$ differ considerably.

**Transfers and interest payments.** None of our experiments displayed in Table 3 yield a negative transfer (a tax). The highest transfers are attained under monetary dominance with term deposits or central bank bills. In all experiments, the interest payments by the central bank to FIs are of similar magnitude. Although, these lump-sum transfers and interest payments are not welfare relevant, they still might affect the public's perception of monetary policy. Large interest payments to FIs could trigger political economy reactions that could have an impact on central bank independence. For this reason, central banks should evaluate whether there are options to minimize these payments without comprising the interest rate target. For example under IOR, one could consider whether it is possible to attain the same real allocation by only remunerating a fraction of reserves. We leave the investigation of this question for future research.

# 6 Conclusion

In response to the financial crisis of 2007/08 and the subsequent sovereign debt crisis, all major central banks decreased interest rates to historically low levels and created large excess reserves. Central bankers and academics currently discuss how to raise interest rates in such an environment. The term 'exit strategy' in this context refers to the various policies that allow central banks to achieve this objective.

This paper studies exit instruments such as paying interest on reserves, term deposits, central bank bills and reverse repos in a dynamic general equilibrium model where financial intermediaries face idiosyncratic liquidity shocks, trade reserves in the secured money market, and have access to the central bank's deposit and borrowing facilities. We calibrate the model to the Swiss franc repo market and perform various exit experiments: In one set of experiments, we absorb reserves to the level observed prior to the financial crisis. In another set of experiments, we increase the short-term rate to the average value that existed prior to the financial crisis.

The exit strategies are evaluated with respect to (i) the central bank's ability to control the money market interest rate and their impact on the money market trading activity; (ii) welfare; (iii) inflation; and (iv) taxes and interest payments to financial intermediaries. Furthermore, for each instrument we investigate two polar coordination regimes: monetary dominance and fiscal dominance.

The following results emerge from our experiments: (i) Irrespective of the coordination regime, all exit instruments allow central banks to achieve the interest rate target, but with different levels of interest rate volatilities. In both regimes, trading activity in the money market under interest on reserves (IOR) is almost inexistent, while trading activity re-emerges for all other instruments and for both regimes. (ii) Under monetary dominance, IOR generates the highest welfare level of all the instruments. Under fiscal dominance, it yields the lowest welfare level. (iii) With an interest rate target, term deposits, central bank bills and reverse repos generate the same real allocation, and hence the same welfare level. (iv) We find that IOR under fiscal dominance generates substantially more inflation than the other three instruments. (v) None of our experiments required a negative real transfer (a tax) to satisfy the consolidated government budget constraint. Nevertheless, all cases involve substantial interest payments from the central bank to financial intermediaries.

Overall, the lesson to be learned is that the effects of these instruments depend to a large extent on the coordination regime that is in place between the fiscal and the monetary authorities. The choice of instrument also depends on how central banks value criteria such as money market activity or political economy factors such as making large interest payments to a few financial intermediaries. These factors do not directly enter our welfare measure, but they are certainly relevant for central banking practice. For example, IOR allows for a perfect control of the money market rate, but money market trading activity is virtually inexistent. This finding is relevant for the current discussions about interest rate benchmark reforms. In order to reduce the potential for manipulation, regulators currently discuss whether references rates should be based on concluded transactions, only (see Financial Stability Board, 2013 and European Central Bank, 2013). If transaction-based reference rates are important, then, central bank bills or reverse repos would become the preferred exit instruments.

The findings of this paper add to the current discussion how to raise interest rates in an environment with large excess reserves and whether monetary policy should be implemented in an excess reserve environment going forward or whether central banks should return to the pre-crisis monetary policy implementation by absorbing reserves (see FOMC, 2014 and FOMC, 2016). For example, the Federal Reserve is currently operating a combination of IOR and reverse repos. Reasons for this particular combination of instruments are the Federal Reserve's access policy and the structure of the US money market. The SNB used central bank bills and reverse repos in 2010 and 2011 to absorb reserves. As predicted by the model, the SNB was able to manage interest rates with these instruments, and trading activity in the money market re-emerged quickly.

# Appendix A: Proofs

In this Appendix, the proof of Lemma 1 and the proof of Proposition 2 is provided.
**Proof of Lemma 1.** For unconstrained FIs, the quantities $q_\varepsilon$ are derived from the first-order condition (10) by setting $\lambda_z = 0$. Since $q_\varepsilon$ is increasing in $\varepsilon$, there exists a critical value $\varepsilon_2$ such that the FI is just constrained. Since in this case, (10) holds as well, we have $q_\varepsilon = \varepsilon \rho_m / \rho_d$ for $\varepsilon \leq \varepsilon_2$.

Next, the cut-off value $\varepsilon_1$ is derived. From (8) and (10), the consumption level of an FI that is unconstrained satisfies

$$q_\varepsilon = \frac{\varepsilon \rho_m}{\rho_d}. \tag{20}$$

The consumption level of an FI, who neither deposits nor borrows is

$$q_0 = \frac{m}{p}. \tag{21}$$

Since (20) is increasing in $\varepsilon$, there exists an $\varepsilon_1$ such that

$$\varepsilon_1 = \frac{\rho_d}{\rho_m} \frac{m}{p}. \tag{22}$$

At $\varepsilon = \varepsilon_1$, the FI is indifferent between depositing or borrowing. The quantity consumed by such an FI is $q_{\varepsilon_1} = \frac{\varepsilon_1 \rho_m}{\rho_d} = \frac{m}{p}$.

We now calculate $\varepsilon_2$. At $\varepsilon = \varepsilon_2$, the collateral constraint is just binding. In this case, we have the following equilibrium conditions: $q_{\varepsilon_2} = \varepsilon_2 \rho_m / \rho_d$ and $p q_{\varepsilon_2} = m + \rho_m \theta b$. Eliminating $q_{\varepsilon_2}$ yields

$$\varepsilon_2 = \varepsilon_1 \left( 1 + \rho_m \frac{\theta b}{m} \right).$$

It is then evident that

$$0 \leq \varepsilon_1 \leq \varepsilon_2.$$

Finally, for $\varepsilon < \varepsilon_2$, the quantities deposited and borrowed are derived from the budget constraint $p q_\varepsilon = m + z_\varepsilon$. Using (20) yields:

$$z_\varepsilon = p \left( \rho_m / \rho_d \right) \left( \varepsilon - \varepsilon_1 \right).$$

For $\varepsilon \geq \varepsilon_2$, we have $z_\varepsilon = \rho_m b$. ■
**Proof of Proposition 2.** The proof involves deriving equations (16) to (18). Equation (18) is derived in the proof of Lemma 1. To derive equation (16), differentiate $V_M(m, b)$ with respect to $m$ to obtain

$$V_M^m(m, b) = \int_0^\infty \left[ \beta V_S^m \left( m + z_\varepsilon + \ell_\varepsilon - p q_\varepsilon - d_\varepsilon, b, \ell_\varepsilon, d_\varepsilon, z_\varepsilon \middle| \varepsilon \right) + \beta \phi^+ \lambda_\varepsilon \right] dF(\varepsilon).$$

Then, use (7) to replace $V_S^m$ and (10) to replace $\beta \phi^+ \lambda_\varepsilon$ to obtain

$$V_M^m(m, b) = \int_0^\infty \frac{\varepsilon u'(q_\varepsilon)}{p} dF(\varepsilon). \tag{23}$$

Use the first-order condition (8) to replace $p$ to obtain

$$V_M^m(m,b) = \left(\beta\phi^+/\rho_d\right)\int_0^\infty \varepsilon u'(q_\varepsilon)\,dF(\varepsilon).$$

Use (5) to replace $V_M^m(m,b)$ and replace $\phi/\phi^+$ by $\gamma$ to obtain

$$\frac{\rho_d\gamma}{\beta} = \int_0^\infty \varepsilon u'(q_\varepsilon)\,dF(\varepsilon).$$

Finally, note that $u'(q) = 1/q$ and replace the quantities $q_\varepsilon$ using Lemma 1 to obtain (16), which is replicated here:

$$\frac{\rho_d\gamma}{\beta} = \int_0^{\varepsilon_2} \frac{\rho_d}{\rho_m}dF(\varepsilon) + \int_{\varepsilon_2}^\infty \frac{\varepsilon}{\varepsilon_2}\frac{\rho_d}{\rho_m}dF(\varepsilon). \tag{24}$$

To derive (17), note that in any equilibrium with a strictly positive demand for reserves and bonds, we must have $\rho V_M^m(m,b) = V_M^b(m,b)$. This arbitrage equation is used to derive (17). $V_M^m(m,b)$ was already derived in (23). To get $V_M^b(m,b)$ differentiate $V_M(m,b)$ with respect to $b$ to obtain

$$V_M^b(m,b) = \int_0^\infty \left[\beta V_S^b(m+\ell_\varepsilon - pq_\varepsilon - d_\varepsilon, b, \ell_\varepsilon, d_\varepsilon|\,\varepsilon) + \rho_m\beta\phi^+\lambda_z\right]dF(\varepsilon).$$

Use (7) to replace $V_S^b$ to obtain

$$V_M^b(m,b) = \beta\phi^+\int_0^\infty (1+\rho_m\lambda_z)\,dF(\varepsilon).$$

Use (10) to replace $\lambda_z$, and rearrange to obtain

$$V_M^b(m,b) = \int_0^{\varepsilon_2}\beta\phi^+dF(\varepsilon) + \beta\phi^+\int_{\varepsilon_2}^\infty(\rho_m/\rho_d)\,\varepsilon u'(q_\varepsilon)\,dF(\varepsilon).$$

Equate $\rho V_M^m(m,b) = V_M^b(m,b)$ and simplify to obtain

$$\rho\int_0^\infty \varepsilon u'(q_\varepsilon)\,dF(\varepsilon) = \int_0^{\varepsilon_2}\rho_d dF(\varepsilon) + \int_{\varepsilon_2}^\infty \rho_m\varepsilon u'(q_\varepsilon)\,dF(\varepsilon).$$

Note that $\int_0^\infty \varepsilon u'(q_\varepsilon)\,dF(\varepsilon) = \rho_d\gamma/\beta$ and rearrange to obtain

$$\frac{\rho\gamma}{\beta} = \int_0^{\varepsilon_2} dF(\varepsilon) + \int_{\varepsilon_2}^\infty(\rho_m/\rho_d)\,\varepsilon u'(q_\varepsilon)\,dF(\varepsilon).$$

Finally, use Lemmas 1 to obtain (17), which is replicated here:

$$\frac{\rho\gamma}{\beta} = \int_0^{\varepsilon_2} dF(\varepsilon) + \int_{\varepsilon_2}^{\infty} (\varepsilon/\varepsilon_2)\, dF(\varepsilon).$$

■

# Appendix B: Consolidated government budget constraint and welfare

In this Appendix, we show how to calculate the real transfers in a steady state, and we derive an expression for welfare. Furthermore, we show in more detail the difference between monetary dominance and fiscal dominance.

**Consolidated government budget constraint in the steady state.** Here, we show how to derive (19) from the consolidated government budget constraint (3) which we replicate here:

$$\phi T = \phi M^{+} - \phi M + \phi\rho B^{+} - \phi B - (1/\rho_d - 1)\,\phi D + (1/\rho_\ell - 1)\,\phi L.$$

In a first step, note that in any equilibrium $D = M + L$. This allows us to write (3) as follows:

$$\phi T = \phi M^{+} - \phi M/\rho_d + \phi\rho B^{+} - \phi B + (1/\rho_\ell - 1/\rho_d)\,\phi L.$$

In a steady state, $\phi M^{+} = \phi M$ and $B^{+}/M^{+} = B/M = \mathcal{B}$. Accordingly, we have

$$\phi T = \phi M\left[\gamma - 1/\rho_d + (B/M)(\rho\gamma - 1) + (1/\rho_\ell - 1/\rho_d)\,L/M\right]. \tag{25}$$

where $\phi M = \frac{\rho\varepsilon_1}{\beta}$. To see this, recall that $M$ is the stock of reserves at the beginning of the current-period settlement market, and $\phi$ is the price of reserves in terms of the generic good that is traded in this market. From Lemma 1, we have $\varepsilon_1 = \frac{\rho_d}{\rho_m}\frac{m}{p}$, where $m = M^{+}$, since the quantity of reserves in the DM of period $t$ is $M^{+}$. Furthermore, from (8), sellers are indifferent as to how much they sell in the goods market if $p\beta\phi^{+}/\rho_d = 1$, where $\phi^{+}$ is the price of reserves in the next-period settlement market. By combining these two equations, we obtain $\varepsilon_1 = \frac{\beta\phi^{+}M^{+}}{\rho_m}$. Finally, in a steady state $\rho = \rho_m$ and $\phi M = \phi^{+}M^{+}$, and so $\phi M = \frac{\rho\varepsilon_1}{\beta}$. Use this expression to rewrite (25) to obtain (19) which we replicate here for ease of reference:

$$\phi T = \frac{\rho\varepsilon_1}{\beta}\left[\gamma - 1/\rho_d + (B/M)(\rho\gamma - 1) + (1/\rho_\ell - 1/\rho_d)\,L/M\right]. \tag{26}$$

How we use this expression depends on whether we study monetary dominance or fiscal dominance.

**Monetary dominance versus fiscal dominance.** Under monetary dominance, we only use (26) to calculate the calibrated value of $\phi T$ which we denote $\overline{\phi T}$. To derive this value, note that in the steady state of the baseline calibration $(1/\rho_\ell - 1/\rho_d)\,L/M = 0$, since $L = 0$. When we report how a change in policy affects $\phi T$, we recalculate the endogenous variables $\rho$ and $\varepsilon_1$ from Proposition (2). For example, if we decrease $\rho_d$, we take into account the direct effect and the indirect effect via $\rho$ and $\varepsilon_1$ in (26).

Under fiscal dominance, we assume that the real transfer is kept constant at the calibrated value $\overline{\phi T}$. Furthermore, in response to any monetary policy change, we assume that the inflation rate adjusts endogenously. To capture this assumption, we solve (26) for $\gamma\left(\overline{\phi T}\right)$ as follows

$$\gamma\left(\overline{\phi T}\right)=\frac{\frac{\overline{\phi T}\beta}{\rho\varepsilon_1}+1/\rho_d+(B/M)-(1/\rho_\ell-1/\rho_d)\,L/M}{1+(B/M)\,\rho}.$$

We then use $\gamma\left(\overline{\phi T}\right)$ to substitute $\gamma$ in Proposition (2). This allows us to calculate how all endogenous variables change in response to a policy change under the assumption that the real transfer $\phi T$ is constant.

**Welfare.** Here it is shown that welfare has the same functional form in the monetary policy dominance and the fiscal policy dominance cases. Welfare, measured at the beginning of the settlement market, satisfies

$$(1-\beta)W=\int\left[\varepsilon\left(q_\varepsilon\right)-q_\varepsilon+\left(x_\varepsilon-h_\varepsilon\right)\right]dF\left(\varepsilon\right).$$

To derive welfare, the integral $\int\left(x_\varepsilon-h_\varepsilon\right)dF\left(\varepsilon\right)$ needs to be identified. In the settlement market, FIs solve the following optimization problem:

$$V_S(m,b,\ell,d,z)=\max_{h,x,m\prime,b\prime}x-h+V_M\left(m',b'\right)$$
$$s.t.\quad x+\phi m'+\phi\rho b'=h+\phi m+\phi b+\phi d/\rho_d-\phi\ell/\rho_\ell-\phi z/\rho_m+\phi\tau M.$$

Accordingly, $\int\left(x_\varepsilon-h_\varepsilon\right)dF\left(\varepsilon\right)$ satisfies

$$\int\left(x_\varepsilon-h_\varepsilon\right)dF\left(\varepsilon\right)=\int\left(\phi m_\varepsilon-\phi m'+\phi b-\phi\rho b'+\phi d_\varepsilon/\rho_d-\phi\ell_\varepsilon/\rho_\ell-\phi z_\varepsilon/\rho_m+\phi\tau M\right)dF\left(\varepsilon\right).$$

Market clearing in the money market implies that $\int\left(\phi z_\varepsilon/\rho_m\right)dF\left(\varepsilon\right)=0$. Note that FIs hold no reserves when they enter the settlement market, since all reserves are deposited at the deposit facility. Accordingly, $m_\varepsilon=0$ and $d_\varepsilon=\tilde{m}_\varepsilon+\ell_\varepsilon$, where $\tilde{m}_\varepsilon$ are reserves deposited at the deposit facility that are not borrowed from the central bank. Accordingly,

$$\int\left(x_\varepsilon-h_\varepsilon\right)dF\left(\varepsilon\right)=\int\left(-\phi m'+\phi b-\phi\rho b'+\phi\left(\tilde{m}_\varepsilon+\ell_\varepsilon\right)/\rho_d-\phi\ell_\varepsilon/\rho_\ell+\phi\tau M\right)dF\left(\varepsilon\right).$$

In a steady state, $m'=M^+, b'=B^+$, $b=B$, and $\int\tilde{m}_\varepsilon dF\left(\varepsilon\right)=M$, $\int\ell_\varepsilon dF\left(\varepsilon\right)=L$. Accordingly, we get

$$\int\left(x_\varepsilon-h_\varepsilon\right)dF\left(\varepsilon\right)=\phi M/\rho_d-\phi M^++\phi B-\phi\rho B^+-\left(1/\rho_\ell-1/\rho_d\right)\phi L+\phi\tau M.$$

Consider, first, the case of monetary dominance. From the consolidated government budget constraint, we have

$$\tau M=M^+-M/\rho_d+\rho B_g^+-B_g+\rho B_c^+-B_c+\left(1/\rho_\ell-1/\rho_d\right)\phi L.$$

This implies that $\int\left(x_\varepsilon-h_\varepsilon\right)dF\left(\varepsilon\right)=0$, since $B=B_c+B_g$. Accordingly, this yields

$$(1-\beta)W=\int\left[\varepsilon\left(q_\varepsilon\right)-q_\varepsilon\right]dF\left(\varepsilon\right).$$

Consider, next, the case of fiscal dominance. From the consolidated government budget constraint, we have

$$\tau\phi M = \overline{\phi T},$$

where $\phi T$ is a constant. That is,

$$\int (x_\varepsilon - h_\varepsilon)\, dF(\varepsilon) = \phi M/\rho_d - \phi M^+ + \phi B - \phi\rho B^+ - (1/\rho_\ell - 1/\rho_d)\,\phi L + \overline{\phi T}.$$

From the consolidated government budget constraint, we have

$$\phi T = \phi M^+ - \phi M/\rho_d + \phi\rho B^+ - \phi B + (1/\rho_\ell - 1/\rho_d)\,\phi L.$$

Furthermore, fiscal dominance requires that in any period $\phi T = \overline{\phi T}$. This implies that $\int (x_\varepsilon - h_\varepsilon)\, dF(\varepsilon) = 0$, since $B = B_c + B_g$. Accordingly, this yields

$$(1-\beta)W = \int \left[\varepsilon(q_\varepsilon) - q_\varepsilon\right] dF(\varepsilon).$$

This clearly shows that the coordination regime choice does not affect the functional form of the welfare function.

# Appendix C: Data

The model is adapted to replicate the elementary features of the Swiss franc repo market and monetary policy implementation by the Swiss National Bank (SNB).[37] The data used for the calibration are described in Table C.1 and are provided by Eurex Ltd., the Swiss Federal Statistical Office (SFSO), the SNB and SIX Ltd.

Table C.1: Data[a]

| Description | Period | Frequency |
|---|---|---|
| SARON | Jan 2005 - Dec 2013 | Daily |
| Overnight SNB Special Rate | Jan 2005 - Dec 2013 | Daily |
| Inflation (year-on-year change) | Jan 2005 - Dec 2013 | Monthly |
| Real interest rate | Q3 2005 - Q4 2013 | Quarterly |
| Money market transaction data | Jan 2005 - Dec 2013 | Daily |
| Central bank reserves | Jan 2005 - Dec 2013 | Daily |

[a]Table C.1 displays the source of the data that we use in the quantitative analysis. The data described in rows one to four are publicly available. The data described in rows five and six are have restricted access.

# Appendix D: Comparative statics

Based on the calibrated parameters, we can explore graphically how the demand and the supply of reserves react to exogenous shocks to $M, \mu, B$, and $\sigma$.[38] For each figure, the money market rate $i_m$ is displayed on the horizontal axis and the turnover-to-reserves ratio $v$ is displayed on

[37]We model the Swiss franc repo market because this allows us to benefit from outstanding data quality, featuring detailed information on more than 100,000 overnight transactions. In contrast to many other studies, there is no need to identify transactions from payment system data applying the Furfine (2000) algorithm which has known caveats (Armantier and Copeland, 2012).

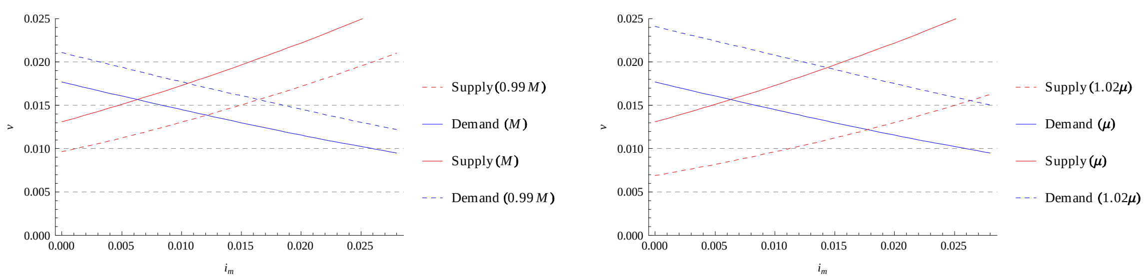
[38]In drawing these figures, we keep the value of reserves $\phi$ constant.

the vertical axis. Demand and supply are shown for the calibrated parameters (solid lines) and for the variation in the parameter under consideration (dashed lines).

The panel on the left-hand side of Figure D.1 displays the effect of a reduction in $M$ of one percent. In this case, the demand for reserves increases (the blue curve shifts upwards) and the supply decreases (the red curve shifts downwards). As a result, $i_m$ unambiguously increases. The effect on $v$ is ambiguous, but in the present case the numerical comparison suggests a slight decrease in $v$.

The effect of an increase in $\mu$ is very similar and is shown in the panel on the right-hand side of Figure D.1. If the average liquidity shock increases, the demand for reserves increases and the supply of reserves decreases. Consequently, $i_m$ unambiguously increases. The effect on $v$ is ambiguous, but in the present case a decrease in $v$ is found.

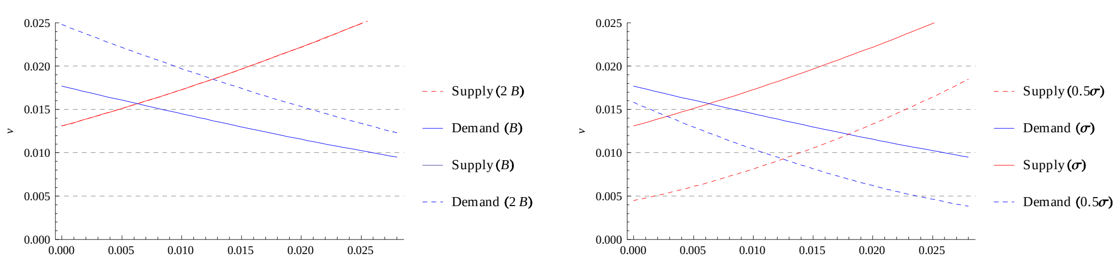
Figure D.1: Comparative statics (I)




The panel on the left-hand side of Figure D.2 displays the effect of doubling $B$. A change in $B$ has no effect on the supply curve. It only increases the demand for reserves, since fewer FIs are collateral-constrained. Here, the comparative statics are unambiguous: both $i_m$ and $v$ increase.

The panel on the right-hand side of Figure D.2 displays the effect of a decrease in $\sigma$ to $0.5\sigma$. If the standard deviation of the liquidity shock decreases, the need for reallocating reserves between FIs decreases. Consequently, the demand for reserves and the supply of reserves decrease. This unambiguously decreases $v$, but the effect on $i_m$ is ambiguous. In the present case, an increase in $i_m$ is found.

Figure D.2: Comparative statics (II)




# Appendix E: The Swiss franc repo market

The Swiss franc repo market (SFRM) is the secured money market for central bank reserves. FIs trade in this market to fulfill minimum reserve requirements and in response to liquidity shocks. Trades are concluded on an electronic trading platform with a direct link to the real-time gross settlement payment system (RGTS) called Swiss Interbank Clearing (SIC) and the central securities depository (CSD) called Swiss Security Services (SIS). Transactions concluded on the platform are settled by SIC and SIS where the latter also serves as the triparty-agent.[39] On the same platform, the SNB conducts its open market operations and offers its standing facilities. The SFRM represents the relevant money market in Swiss francs in terms of volume and participation.[40]

Domestic banks, insurances and federal agencies, as well as banks domiciled abroad, may access the SFRM: currently, 152 FIs have access.[41] Tradable maturities range from overnight to twelve months. In this paper, the focus is on the overnight maturity since approximately two-thirds of the daily turnover is overnight.[42] Approximately 99% of all transactions on the platform are secured by securities that belong to a general collateral (GC) basket, the so-called 'SNB GC' basket. This is the same collateral basket that the SNB accepts in its open market operations and standing facilities. The collateral standard within the SNB GC is homogeneous, because the SNB sets high requirements with respect to the rating and the market liquidity of eligible securities.[43]

The 'Swiss Average Rate Overnight' (SARON) is the money market rate for the overnight maturity, which is calculated as a volume-weighted interest rate based on the overnight trading activity in the SFRM.[44] The 'Overnight SNB Special Rate' is the interest rate in SNB's lending facility and is calculated based on the SARON plus 50 basis points.[45]

Figure E.1 displays the SARON, the Overnight SNB Special Rate, and the 20-day moving average of the overnight turnover for the period from 2005 to 2013. For that period, the average daily overnight turnover was CHF 3.2 bn, and 30 FIs were active on an average day. In total, 107,517 overnight trades were concluded.

[39] The triparty-agent manages the collateral selection, the settlement, the ongoing valuation of the collateral and the initiation of margin calls.

[40] This is especially true since the financial crisis, when the unsecured money market collapsed. See Guggenheim et al. (2011) for a comparison of the two markets. Repos agreed upon bilaterally and outside the platform are rare.

[41] Among these, 150 also have access to the SNB's open market operations and standing facilities. See Kraenzlin and Nellen (2014) for a summary of SNB's access policy.

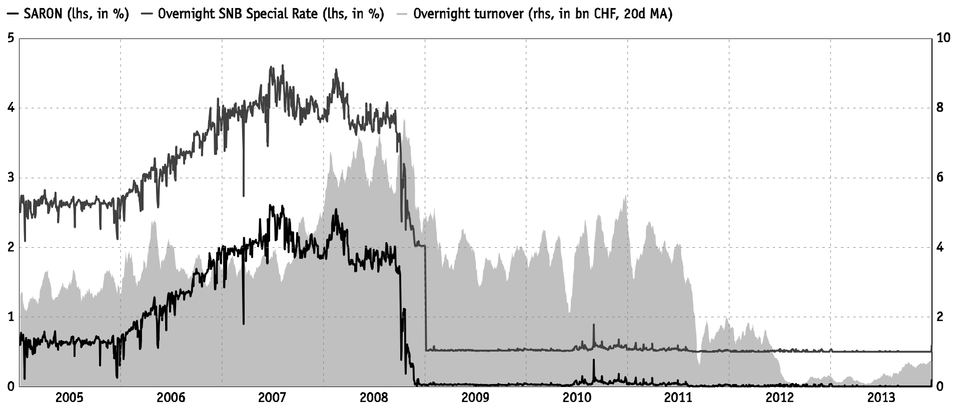
[42] The overnight market is the origin of the term structure of interest rates. It is the most important interest rate for the pricing of many financial products.

[43] For SNB GC eligible securities, see http://www.snb.ch/en/ifor/finmkt/operat/snbgc/id/finmkt_repos_baskets

[44] The SARON is continuously calculated in real time and published every ten minutes. In addition, there is a fixing at 12.00 noon, 4.00 p.m. and at the close of the trading day. Successful trades and quotes are included in the calculation of the SARON. A detailed description of how the SARON is calculated can be found on http://www.six-swiss-exchange.com/downloads/indexinfo/online/swiss_reference_rates/swiss_reference_rates_rules_en.pdf

[45] Until 2009, the Overnight SNB Special Rate was calculated based on the SARON plus 200 basis points.

Figure E.1: Stylized facts




Although, the SNB's key policy rate is not the SARON, but a target range of the Swiss franc three-month Libor, the SARON reflects the SNB's monetary policy stance, since the SNB controls Libor via daily repo auctions in the SFRM. Furthermore, in order to keep track of prevailing monetary conditions, the SNB monitors the intraday development of the SARON and, if needed, conducts fine-tuning operations in the SFRM by placing or accepting overnight quotes.

**Trading protocol.** Trades in the SFRM are initiated by placing or accepting binding offers (so-called quotes) or by sending offers (so-called addressed offers, AOs) to counterparties. Quotes are entries that are placed on the electronic trading platform which indicate the maturity, the interest rate, the trade volume, the collateral basket, and the identity of the FI that has entered the quote. Quotes are collected in an order book which lists bid- and ask quotes for all maturity segments and collateral baskets. A trade upon a quote can be executed by accepting a quote via a click.[46] AOs are price offers that can be sent to selected counterparties and hence are not visible for other FIs. As in the case of quotes, AOs specify the maturity, the interest rate, the trade volume, and the collateral basket. AOs can be negotiated upon by sending a counteroffer to the AO sender.

The terms-of-trades of all past trades (based on quotes and AOs) are viewable on the platform. The platform thus guarantees that all FIs have the same information set. In particular, at any time during the day, they can ascertain the maturities, interest rates, traded volumes, and collateral baskets used in all past trades. Current market conditions are likewise common knowledge thanks to the order book.

**Competitive market.** For several reasons, the SFRM is not an OTC market with search and bargaining frictions. First, an analysis of all overnight trades between 2005 and 2013 reveals that three-quarters of overnight trades are based on quotes, and hence, no bargaining on the terms-of-trades takes place.[47] Second, in an OTC market, traders meet bilaterally and the amount borrowed must be equal to the amount lent in each match. In contrast, in the SFRM, on an average day 13 borrowing and 17 lending FIs are active on the platform. This implies asymmetric trading volumes: the average borrower borrows more than the average lender lends.[48] Third,

[46] Theoretically, financial intermediaries can choose to reveal their quotes only to a restricted group of counterparties. However, this is very rarely done in practice.

[47] A comparison to longer maturities suggests that the relative number of quote based trades is largest in the overnight maturity and decreases the longer the term of the transaction. In the case of the one-week (one-month, six-month) maturity, 65% (50%, 43%) are based on quotes.

[48] One way to capture this stylized fact in an OTC market would be to introduce sequential matching; i.e., financial intermediaries are matched multiple times in one period.

deviations in the interest rates of individual overnight transactions from the SARON are very small — the average daily absolute deviation between 2005 and 2013 is 0.042%.[49] Fourth, for the same period, the average daily bid and ask volume in the order book is CHF 5.5 bn which suggests that an individual FI is not able to affect the overnight rate substantially. Fifth, the access to the platform is open to many FIs. In other words, even though on an average day only 30 banks are active, many FIs continuously monitor the market and are ready to step in if the market conditions provide attractive borrowing and lending opportunities. Sixth, all loans are secured. Consequently, counterparty risk is negligible.

In our view, the six reasons discussed above clearly indicate that the SFRM is best modeled as a competitive market, and not as an OTC market. There are no informational frictions, since all FIs have the same information on past market activities and current market conditions. Furthermore, the large number of market participants and the small price dispersion suggest that no FI has market power. FIs also tend to be indifferent to their choice of trading partners: this is explained by the high collateral standard and the absence of counterparty risk.

**Mapping the SFRM to the theoretical model.** Our theoretical model is motivated by the elementary features of the SFRM and the SNB's monetary policy implementation. First, at the beginning of the day all outstanding overnight loans are settled.[50] Second, the SFRM operates between 7 am and 4 pm.[51] Third, the SNB controls the stock of reserves by conducting open market operations, typically at 9 am.[52] Fourth, after the money market has closed, the SNB offers its lending facility for an additional 15 minutes. This is the last opportunity for FIs to acquire overnight reserves for the same business day in order to settle outstanding short positions in the payment system.[53] The SFRM stays open until 6 pm, but new trades concluded after 4 pm will not be settled on the same day.

**The SFRM in the structural liquidity surplus environment.** In response to the financial crisis of 2007/2008 and the subsequent sovereign debt crisis, the SNB increased reserves via foreign exchange purchases from roughly CHF 5.62 bn in 2005 to CHF 370 bn in 2013 (a factor of 66). As a result, the banking system holds large excess reserves and is in a so-called structural liquidity surplus. Money market interest rates are near zero, and money market activity collapsed as shown in Figures E.1 and E.2.

[49] The comparison to other maturities shows that the deviation is smallest in the overnight maturity and increases the longer the term of the transaction. The respective figure for the one-week (one-month, six-month) maturity is 0.07% (0.1%, 0.27%).

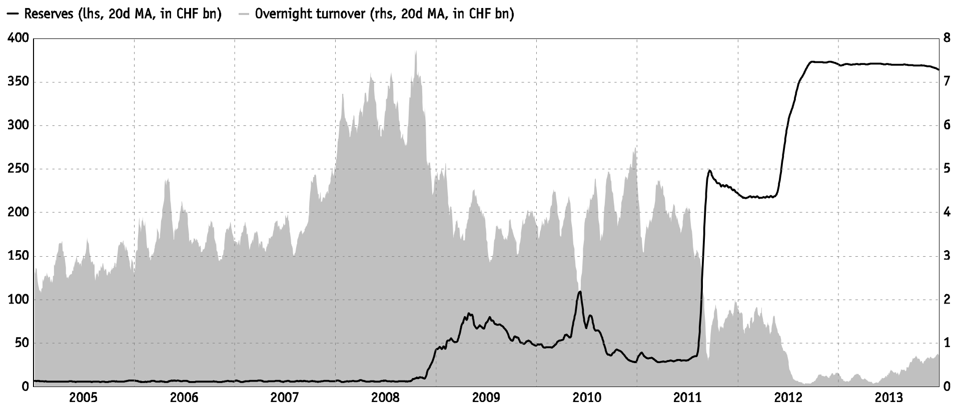
[50] At 7:50 a.m. the repayment of all outstanding overnight transactions is automatically triggered.

[51] Transactions are rarely concluded between 7 am and 8 am (see Kraenzlin and Nellen, 2010).

[52] Usually via fixed rate tender auctions. See Kraenzlin and Schlegel (2012) for an overview.

[53] Short positions remaining at the end of the day must be settled the following business day and are subject to a penalty that is agreed upon bilaterally on the basis of the SARON. The stigma associated with non-settled payments imposes a further penalty which became very pronounced during the financial crisis.

Figure E.2: SNB's response in the crisis



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