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Overnight rate and signalling effects of central bank bills

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ABSTRACT

We analyse the impact of interest-bearing central bank bills on financial market variables in Switzerland. The unique institutional setting allows us to identify the causal effects of two orthogonal shocks occurring on days with central bank bill auctions through heteroscedasticity: an overnight interest rate shock and a signalling shock. The first shock raises the overnight interest rate and modestly appreciates the exchange rate. The signalling shock appreciates the exchange rate more strongly. In addition, it lowers stock prices, long-term interest rates, as well as inflation expectations, and it raises corporate bond spreads. The signalling shock is economically more important for forward-looking variables than the overnight rate shock. The results suggest that liquidity-absorbing operations between official monetary policy decisions affect financial market variables by revealing information about the central bank's future policy actions.

1. Introduction

How does monetary policy affect financial markets? Many studies answer this question by analysing official monetary policy decisions (see, e.g., Kuttner, 2001; Romer and Romer, 2004; Nakamura and Steinsson, 2010). In between these decisions, however, central banks conduct a variety of liquidity-providing and -absorbing operations. In fact, all of the 15 central banks listed in a compendium of the Bank for International Settlements (BIS) have the possibility to either conduct (reverse) repo operations and/or issue central bank bills (see BIS, 2019b). Despite their widespread use, and their growing importance since the financial crisis, little is known about the impact of liquidity-absorbing operations. This paper provides such evidence by empirically identifying the causal effect of issuing central bank bills on financial market variables.

From 2008–2011, the Swiss National Bank issued central bank bills (SNB Bills) to drain reserves created during the global financial and euro area debt crises (see SNB, 2008, 2011).[1] Canetg and Kaufmann (2019) show theoretically that, in an environment with large excess reserve balances, central bank bills can be used to drain enough reserves to raise short-term interest rates. Issuing a sufficiently large volume of central bank bills is therefore one way to return to an environment with scarce reserves. Because the SNB revealed the volume of SNB Bills allotted on an auction day, it may have provided information on its intent to raise short-term

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[1] Similar programs were in place in a variety of countries, such as the United Kingdom, Sweden, and Singapore (see BIS, 2019a). In addition, policy makers considered other tools to steer interest rates in an environment with excess reserve balances, such as interest on reserves, reverse repurchase agreements, and term deposits (see SNB, 2009b, 2011; Hamilton, 2019; Federal Reserve Board, 2019b,a; BIS, 2019a).

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interest rates in the future. We therefore ask whether SNB Bill auctions had a signalling effect on forward-looking financial market variables in addition to an effect on the overnight interest rate.

When estimating the impact of this program on financial markets, we face two identification problems. First, financial market participants form expectations about the SNB's actions before it auctions SNB Bills. These expectations impact financial market variables immediately, that is before the actual auction. Therefore, anticipated changes in the SNB Bills program may have little impact on financial market variables on an auction day. Second, changes of financial market variables on auction days are contaminated by other events that occur at the same time. Indeed, SNB Bills were issued during the global financial and euro area debt crises, which were both associated with substantial 'safe haven' pressures on the Swiss franc and rising risk premia on money markets.

To address these identification problems, one may consider a high-frequency identification scheme along the lines of Kuttner (2001). In this case, this approach is infeasible because we lack the exact time of the auctions. Also, information about the auction results was likely revealed gradually during the day.[2] Therefore, we opt for identification through heteroscedasticity (see Rigobon, 2003; Rigobon and Sack, 2004; Nakamura and Steinsson, 2018a). This allows us to estimate the causal impact of unexpected changes in the SNB Bills program on auction days ('SNB Bill shocks'). We can recover the impact of SNB Bill shocks because they change the variance–covariance of financial market variables relative to the variance–covariance on similar days without an auction. The key identifying assumption is that the timing of the auctions was pre-determined; an endogenous timing in response to economic developments would imply that auction days systematically differ for other reasons than the SNB Bills program. We show that the auctions were indeed announced in advance and occurred on specific days of the week. We additionally impose variance and zero restrictions to disentangle two orthogonal dimensions of SNB Bill shocks. First, we impose that an overnight rate shock raises the variance of the overnight interest rate, in line with most of the literature using high-frequency identification schemes (see, e.g., Gürkaynak et al., 2005). Second, we impose that a signalling shock does not affect the overnight rate but raises the variance of stock prices.[3] A signal about a more contractionary future policy stance may increase the expected riskless interest rate, lower future nominal cash flows, and potentially increase future expected risk premia. All three factors would lead to a decline in stock prices.[4] The zero restriction on the overnight rate follows a growing literature imposing similar restrictions to identify non-conventional policy shocks in high-frequency identification schemes (see, e.g., Swanson, 2021; Altavilla et al., 2019).

We find that SNB Bill auctions affect financial markets through a signalling dimension, which is more important than the direct effect on the overnight rate. A one standard deviation overnight rate shock leads to a 0.02 pp increase in the overnight interest rate and a 0.03% appreciation of the Swiss franc. The forecast-error variance decomposition shows that the overnight rate shock explains only 3% of the variation in the exchange rate but 75% of the variation in the overnight rate. Therefore, the overnight rate shock only modestly affects forward-looking variables. By contrast, a one standard deviation signalling shock causes a 0.3% appreciation of the Swiss franc, a 0.9% decline in stock prices, a 0.03 pp decline in long-term interest rates, a 0.02 pp increase in corporate bond spreads, and a 0.02 pp decline in inflation expectations. Signalling explains 53% of exchange rate fluctuations, 44% of stock price fluctuations, 54% of long-term interest rate fluctuations, and 70% of corporate bond spread fluctuations. Our results imply that issuing bills allows the central bank to control the short-term interest rate. However, these bills affect forward-looking variables through changing financial market participants' expectations.

Our paper makes three contributions to the literature. First, we empirically estimate the causal impact of central bank bills on financial market variables, exploiting daily data on central bank operations. Most papers measuring the impact of monetary policy surprises focus on the information released on days with official monetary policy decisions (e.g. Kuttner, 2001; Gürkaynak et al., 2005, 2020). Our findings for the overnight rate shock resonate well with existing evidence on 'target' surprises (see Kuttner, 2001; Rigobon and Sack, 2004; Gürkaynak et al., 2005). However, it is well-known that financial market variables are at least as strongly affected by signalling, or 'path' surprises associated with official monetary policy decisions and large-scale asset purchases (see, e.g., Gürkaynak et al., 2005, 2020; Woodford, 2012; Bauer and Rudebusch, 2014). We show that daily central bank operations in between these official decisions comprise an important signalling dimension, too, despite the fact that these operations are not accompanied with a public press release.

Second, we disentangle an overnight rate shock and a signalling shock, combining a heteroscedasticity-based identification scheme with zero restrictions. This approach is particularly useful if we know only the day, but not the exact time of central bank operations. Most other papers use high-frequency identification to identify multiple dimensions of monetary policy decisions. Jarociński and Karadi (2020) impose sign restrictions on the co-movement of interest rates and stock prices to isolate an information dimension of monetary policy surprises. Gürkaynak et al. (2020), Swanson (2021), and Altavilla et al. (2019) combine high-frequency identification with a factor model to disentangle target, path, and large-scale asset purchase surprises, also imposing a zero restriction on short-term interest rates. We show how to impose similar restrictions in a heteroscedasticity-based identification scheme.

Third, we estimate dynamic effects, combining a heteroscedasticity-based identification scheme with local projections (Jordà, 2005). Wright (2012) identifies monetary policy surprises through heteroscedasticity in a vector-autoregression (VAR). Swanson

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[2] For example, when the auction started; when bids were entered; when the marginal yield was announced; when the overall results were communicated; when this information transmitted to financial market participants not involved in the auction.

[3] Our signalling shock is therefore different from a contractionary large-scale asset sale shock that would lead to an increase in the term premium. We do not restrict the term premium because a contractionary signalling shock may lead to a compression of the yield curve, as long-term interest rates decline due to lower expected economic activity and inflation. A contractionary monetary policy may therefore well be associated with lower long-term interest rates (see Friedman, 1968).

[4] By contrast, the impact on long-term interest rates is ambiguous. Lower economic activity and inflation expectations push long-term rates down. Expectations about a higher future policy rate push long-term rates up.

(2021) uses local projections to estimate dynamic effects, but the shocks are identified with high-frequency monetary policy surprises.

The remainder of this paper is structured as follows. Section 2 provides an overview of the related literature. Section 3 describes the SNB Bills program providing relevant information for our empirical approach. Section 4 presents the identification and estimation strategy. The findings are discussed in Section 5, before Section 6 concludes.

2. Related literature

Central bank bills have, until recently, mostly been used in emerging economies (see, e.g., Yi, 2014). Issuing central bank bills in domestic currency drains reserves and reduces the monetary base. Therefore, central bank bills can be used to sterilize foreign exchange interventions (see, e.g., Nyawata, 2013). In addition, they may help to develop domestic bond markets. Most studies focus on conceptual and operational issues (see e.g. Dziobek and Dalton, 2005; Nyawata, 2013; Gray and Pongsaparn, 2015). They discuss eligibility of central bank bills as collateral in repurchase operations, treatment for capital requirements, liquidity of marketable central bank bills, coordination of debt management and monetary operations, possible threats to balance sheets of central banks (losses and recapitalization), and coordination of emissions with the treasury.

More recently, central bank bills and other reserve-absorbing operations have been used in developed economies. In the wake of the global financial crisis, central banks increased their balance sheets through large-scale asset purchases, liquidity provisions to interbank markets, and foreign exchange interventions. To sterilize these interventions, or even tighten monetary policy without shrinking the balance sheet through outright sales of assets, policy makers considered tools closely related to central bank bills: interest on reserves, reverse repurchase agreements, and term deposits (see e.g. SNB, 2009b, 2011; Hamilton, 2019; Federal Reserve Board, 2019b,a). Such tools have been summarized under the term ‘exit strategies’.[5]

Most papers on exit strategies focus on interest on reserves and the institutional setting in the US, however. For example, Goodfriend (2002) and Keister et al. (2008) suggest that paying interest on reserves establishes an interest rate floor for the short-term interest rate. Therefore, an interest on reserves policy allows the central bank to control the short-term interest rate independently of the money supply. Moreover, Armenter and Lester (2017) discuss how a reverse repo facility supports the short-term interest rate in an environment with interest on reserves and limited access to reserve accounts. Few papers analyse the impact of central bank bills. Berentsen et al. (2018) investigate the welfare implications of central bank bills relative to other reserve-absorbing operations and interest on reserves. In addition, Berentsen et al. (2018) show theoretically that central banks can use bills to implement an interest rate floor to raise short-term interest rates even with large excess reserve balances. Canetg and Kaufmann (2019) show in a static money market model that central bank bills with a fixed interest rate are equivalent to paying interest on a fraction of reserves.

Empirical evidence on the impact of reserve-absorbing monetary policy operations is scarce. Most papers estimate the causal effects of conventional and unconventional monetary policy decisions (see Gürkaynak and Wright, 2013; Nakamura and Steinsson, 2018b, for surveys on event studies and other approaches). They focus on unexpected changes in interest rates in a narrow time window around monetary policy decisions (see e.g. Kuttner, 2001; Gürkaynak et al., 2005; Gertler and Karadi, 2015; Cieslak and Schrimpf, 2019); therefore, they measure the impact of a new interest rate target, as well as the information released, independently of the tools used to implement the target. These unexpected interest rate changes therefore largely reflect liquidity or communication effects. More recent studies showed that these unexpected changes are also affected by unconventional monetary policy measures, as well as information about the state of the economy (Nakamura and Steinsson, 2018a; Gürkaynak et al., 2020; Jarociński and Karadi, 2020; Altavilla et al., 2019).

3. The SNB bills program

This section provides background information on the SNB Bills program and motivates the empirical modelling choices.[6]

We find two distinct reasons why the SNB issued its own bills.[7] First, in late 2008 and early 2009 the Swiss National Bank had an interest rate target well above 0%. Like other central banks it provided substantial liquidity to reduce risk premia on money markets in the wake of the financial crisis. The liquidity provisions increased the monetary base and pushed short-term interest rates down. To prevent the short-term interest rate from falling below target, the SNB issued central bank bills. In a press release the SNB (2008) explained that these bills “[. . .] will serve to absorb liquidity, thereby neutralizing the monetary policy impact of measures to inject liquidity”. The Bank of England, the Riksbank, and the Monetary Authority of Singapore also issued central bank bills during this

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[5] Some central banks obtain liquidity issuing bills denominated in foreign currency (see e.g. Rule, 2011; SNB, 2009a). For example, the Bank of England issues central bank bills to finance its foreign exchange reserves. The central banks of Malaysia and Switzerland issued central bank bills to finance subsidiaries which supported troubled commercial banks during the Asian crisis and the 2008 financial crisis, respectively (see Rule, 2011; SNB, 2009a). Importantly, because these central bank bills are denominated in foreign currency, they do not drain reserves in domestic currency.

[6] We provide more operational details in Online Appendix B.

[7] At first sight, issuing central bank bills resembles issuing treasury bills. In fact, the SNB regularly issues treasury bills and bonds on behalf of the Swiss Confederation. From our perspective, the most important difference between the two operations is that central bank bills absorb reserves. Meanwhile, if the central bank issues securities for the treasury, the operation will not drain reserves because the central bank offsets the impact on the monetary base. See also Nyawata (2013) for a discussion of conceptual considerations on the difference between central bank bills and treasury bills.

period (BIS, 2019a).[8] Similarly, the ECB sterilized its purchases under the Securities Markets Program (see, for example, Eser and Schwaab, 2016).

Second, in 2010 the SNB aimed to reduce the monetary base amid growing concerns of rising inflation. Especially during the euro area debt crisis, the SNB intervened in the foreign exchange market to curb appreciation pressures on the Swiss franc. For example, in the monetary policy assessment of March 2010, the SNB (2010b) stated that "It will act decisively to prevent an excessive appreciation of the Swiss franc against the euro". As a consequence, between December 2009 and June 2010 foreign currency investments rose from CHF 95 billion to CHF 225 billion.[9] In the first half of 2010, the foreign exchange interventions led to a sharp increase in reserves of domestic counterparties, and thus the monetary base (see Fig. 1, panel a). In June 2010, the SNB considerably changed its policy stance. Its inflation forecast, conditional on an interest rate target of 0.25%, amounted to 3.1% for the first quarter of 2013. This was well above the SNB's price stability range of 0%–2%. The SNB (2010a) explained that "[. . .] the deflationary risk in Switzerland has largely disappeared" and that "the current expansionary monetary policy cannot be maintained over the entire forecast horizon without compromising medium and long-term price stability". Also, the reference to foreign exchange interventions disappeared. Therefore, we believe that the SNB intended to increase the short-term interest rate in the near future. Against the backdrop of growing fear of inflation, the SNB issued SNB Bills to drain reserves with the intent to sterilize its foreign exchange interventions.[10]

The frequency and volume of the SNB Bills program was large. From October 2008 to July 2011, the SNB issued 232 SNB Bills on 167 auction days (see Fig. 1, panel b). Most securities had a short time to maturity, from 7 days to one year, and were denominated in Swiss francs (CHF). At the peak in 2011, outstanding CHF SNB Bills accounted for more than 45% of total SNB liabilities, more than 17% of Swiss nominal GDP, and 20% of the Swiss bond market capitalization.[11] CHF SNB Bills were issued in exchange for reserves from the SNB's counterparties (see Online Appendix B, for more details). The large volume therefore led to a relevant decline in reserves and the monetary base (see Fig. 1, panel a). Although the SNB also drained reserves with reverse repo operations, the outstanding volume of reverse repos was much smaller (less than 10% of total liabilities).

SNB Bills were allotted in auctions in the early afternoon. The results were published later in the afternoon. Several days before an auction, the SNB announced the auction day, a price range for valid bids, the term to maturity, and the settlement date.[12] The day of the auction was therefore pre-determined. That the auction day was largely expected is also in line with the fact that, in the first half of the sample, most auctions occurred on Tuesdays and, in the second half of the sample, they occurred on Thursdays (see Fig. 1, panel b).[13] In the first half of the sample, we sometimes observe two auctions per week. No auctions took place in the last week of the years 2009 and 2010.

We conclude this section with descriptive evidence showing that the volume and yield of SNB Bills were related to short-term interest rates. Fig. 2 shows the monthly average marginal yield jointly with the share of bills in the SNB's balance sheet. The volume and the marginal yield were relatively high in 2008, when the SNB sterilized its liquidity provisions in the money market. In addition, the marginal yield increased from about 0% to more than 0.25% in 2010. At the same time, the volume of bills relative to the SNB's balance sheet increased from 20% to 75%. Periods with a high volume of and high marginal yields on SNB Bills were associated with a relatively high SARON, a secured overnight money market rate. This suggests that SNB Bills pushed up short-term interest rates. In addition, the three-month interest rate increased somewhat more than the overnight rate, suggesting that the operations may have triggered expectations about future interest rate hikes. Finally, when the volume of and marginal yield on SNB Bills were high, the Swiss franc strengthened: It appreciated in trade-weighted terms by 6% and 11% in 2008 and 2010, respectively.[14] Of course, these co-movements cannot be interpreted in a causal fashion. The next section explains how we empirically identify the causal effects of surprise changes in the SNB Bills program.

4. Empirical strategy

We identify the causal impact of surprise changes in the SNB Bills program through heteroscedasticity (see Rigobon, 2003; Rigobon and Sack, 2004; Wright, 2012; Nakamura and Steinsson, 2018a). In contrast to the existing literature, we impose additional restrictions to recover two orthogonal dimensions through which SNB Bills affect financial markets: an overnight rate shock and a signalling shock. In what follows, we focus on a baseline specification without dynamics to explain the identification scheme.[15]

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[8] The Federal Reserve sterilized its liquidity injections by selling treasury securities. When it ran out of treasuries to sell it introduced interest on reserves (see Bernanke, 2015, p. 325–326).

[9] See data.snb.ch/en/topics/snb#!/cube/snbbipo (accessed on 6 October 2019).

[10] At the time the SNB viewed the reserve-absorbing operations as irrelevant as long as reserves were ample: "From a monetary policy perspective, liquidity draining operations are negligible, as long as commercial banks hold excess liquidity and interest rates are close to zero". (SNB, 2011). This view is also mirrored in Federal Reserve Board (2012), who argued that paying (a moderate) interest on reserves as irrelevant: "We have looked at the possibility of not paying that 25 bps [. . .] the stimulative effect, the effect on interest rates generally of eliminating that, or the effect on credit extension would be quite small".

[11] Bond market capitalization data stem from the SIX Exchange (see Online Appendix A for all data sources).

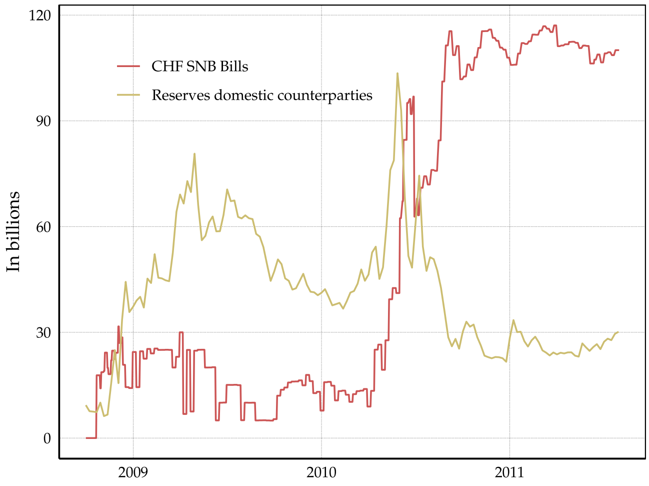
[12] This information stems from a small number of announcement forms stored on a web archive. Unfortunately, we were not able to obtain these announcement forms from the SNB or from commercial banks.

[13] One motivation to change the auction day may have been to highlight the difference between treasury bill auctions and SNB Bill auctions, which were both held on Tuesday in the first half of the sample. Rule (2011) discusses general guidelines for issuing central bank bills suggesting that "[...] clear and precise announcements mean that market participants have a clear knowledge as to the size and regularity of central bank operations which they can separate from the government's issuance".

[14] The trade-weighted exchange rate stems from the SNB (Müller, 2017).

[15] Online Appendix C discusses conditions for identification, shows how to identify dynamic responses with local projections, estimate cumulative responses, compute a variance decomposition, and presents a simulation exercise.

(a) Outstanding SNB Bills and reserves



(b) Allotted SNB Bill volume by weekday

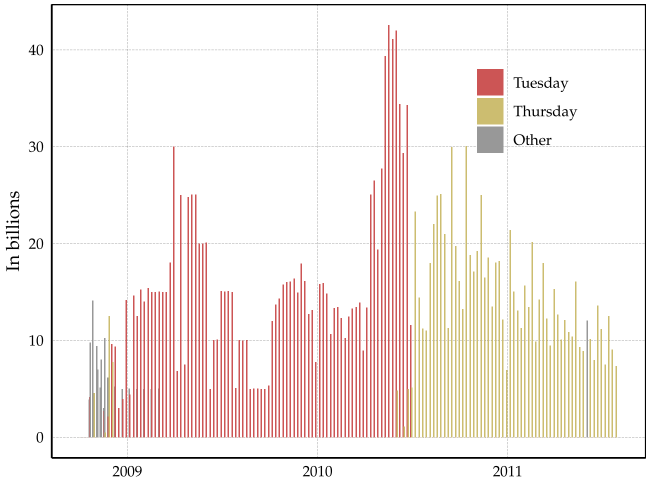


Fig. 1. Timing and volume of the SNB Bills program. Notes: Panel (a): Daily volume of outstanding CHF SNB Bills and average weekly reserves of domestic counterparties. Panel (b): Allotted CHF SNB Bill volume by day of the week.

4.1. Model

Assume that changes in stock prices (Δs_t), the overnight interest rate (Δr_t), and the exchange rate (Δx_t) are driven by a vector of exogenous factors, z_t, and a vector of serially uncorrelated structural shocks, e_t:

$$y_t = \alpha + \beta z_t + \Psi e_t \ , \tag{1}$$

where $y_t = [\Delta r_t \ \Delta s_t \ \Delta x_t]'$, α is a vector of constant terms, z_t is a vector of exogenous control variables, $e_t = [e_{1t} \ \ e_{2t} \ \ e_{3t}]'$ is a vector of i.i.d. structural shocks with a variance normalized to unity ($V[e_{1t}] = V[e_{2t}] = V[e_{3t}] = 1$), and Ψ is a (3×3) matrix measuring the immediate impact of the structural shocks.

Let us assume that shocks 1 and 2 occur only on pre-determined auction days, whereas shock 3 occurs on all days. Shocks 1 and 2 represent two orthogonal dimensions of the SNB Bill shocks. Meanwhile, shock 3 may be a linear combination of various other orthogonal shocks that occur on all days. Because shocks 1 and 2 occur only on auction days, the variance–covariance matrix of the one-step-ahead forecast error ($\varepsilon_{t|t-1} = \Psi e_t$) is heteroscedastic. Let $\Omega_{t\in A}$ ($\Omega_{t\notin A}$) denote the variance–covariance of $\varepsilon_{t|t-1}$ during

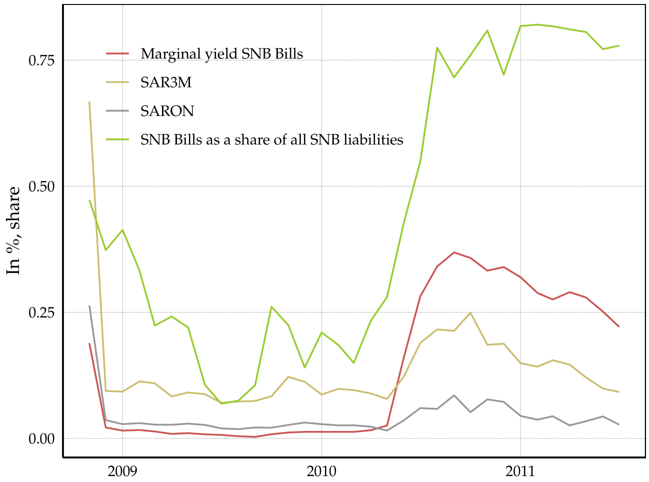


Fig. 2. CHF SNB Bill volume, marginal yield, and short-term interest rates. Notes: The marginal yield on CHF SNB Bills is an average over all SNB Bills issued on a particular auction day (monthly average). The overnight (SARON) and three-month (SAR3M) interest rates are Swiss Average Rates (SAR), that is interest rates based on actual repo transactions and binding quotes (monthly average). The share of outstanding CHF SNB Bills as a share of all SNB liabilities is based on end of month values and does not take into account potential repurchases of SNB Bills.

auction days (other days), and ψ_{ij} the impact of variable $i \in \{r, s, x\}$ to shock $j \in \{1, 2, 3\}$. It follows that:

$$\Omega_{t\in A} = \begin{bmatrix} \psi_{r1}^2 + \psi_{r2}^2 + \psi_{r3}^2 & \psi_{r1}\psi_{s1} + \psi_{r2}\psi_{s2} + \psi_{r3}\psi_{s3} & \psi_{r1}\psi_{x1} + \psi_{r2}\psi_{x2} + \psi_{r3}\psi_{x3} \\ & \psi_{s1}^2 + \psi_{s2}^2 + \psi_{s3}^2 & \psi_{s1}\psi_{x1} + \psi_{s2}\psi_{x2} + \psi_{s3}\psi_{x3} \\ & & \psi_{x1}^2 + \psi_{x2}^2 + \psi_{x3}^2 \end{bmatrix} \tag{2}$$

$$\Omega_{t\notin A} = \begin{bmatrix} \psi_{r3}^2 & \psi_{r3}\psi_{s3} & \psi_{r3}\psi_{x3} \\ & \psi_{s3}^2 & \psi_{s3}\psi_{x3} \\ & & \psi_{x3}^2 \end{bmatrix} .$$

The diagonal of the difference between the variance–covariance matrices on auction days and other days ($\tilde{\Omega} = \Omega_{t\in A} - \Omega_{t\notin A}$) comprises the sum of the squared impact coefficients of shock 1 and 2:

$$\tilde{\Omega} = \Omega_{t\in A} - \Omega_{t\notin A} = \begin{bmatrix} \psi_{r1}^2 + \psi_{r2}^2 & \psi_{r1}\psi_{s1} + \psi_{r2}\psi_{s2} & \psi_{r1}\psi_{x1} + \psi_{r2}\psi_{x2} \\ & \psi_{s1}^2 + \psi_{s2}^2 & \psi_{s1}\psi_{x1} + \psi_{s2}\psi_{x2} \\ & & \psi_{x1}^2 + \psi_{x2}^2 \end{bmatrix} . \tag{3}$$

Therefore, comparing the variance–covariance of financial market variables on auction days to the one on other days allows us to remove the impact of other shocks that occur on all days (shock 3). Next, we discuss our identifying assumptions to recover the impact coefficients of shock 1 and 2.

4.2. Identification

The key assumption of the identification scheme, which we cannot formally test, is that SNB Bill auctions occurred on predetermined days.[16] That the auction days were announced in advance and occurred almost always on the same day of the week supports this assumption (see Section 3).

To further decompose the overall impact into an overnight rate shock and a signalling shock, we need to impose additional restrictions. First, we impose that a contractionary overnight rate shock (shock 1) increases the overnight interest rate ($\psi_{r1} > 0$). Second, we impose that a contractionary signalling shock (shock 2) causes a decline in stock prices, but no change in the overnight interest rate ($\psi_{r2} = 0, \psi_{s2} < 0$). By imposing these restrictions we can use the first two rows of $\tilde{\Omega}$ to recursively compute the impact of the two shocks on the interest rate, stock prices, and the exchange rate[17]:

$$\begin{aligned} \psi_{r1} &= \sqrt{\tilde{\Omega}_{11}} \\ \psi_{s1} &= \tilde{\Omega}_{12}/\psi_{r1} \\ \psi_{x1} &= \tilde{\Omega}_{13}/\psi_{r1} \end{aligned} \tag{4}$$

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[16] For example, if the SNB would systematically decide to auction bills on days with a strong depreciation, the variance of the exchange rate would be higher on auction days for reasons unrelated to the SNB Bills program (e.g. foreign monetary policy).

[17] We can identify multiple shocks either by using more rows of $\tilde{\Omega}$, imposing additional restrictions, or both (see Online Appendix C).

$$
\begin{aligned}
\psi_{r2} &= 0 \\
\psi_{s2} &= -\sqrt{\tilde{\Omega}_{22} - \psi_{s1}^2} \\
\psi_{x2} &= (\tilde{\Omega}_{23} - \psi_{s1}\psi_{x1})/\psi_{s2} \ ,
\end{aligned}
$$

where $\tilde{\Omega}_{ij}$ denotes the ith row and jth column of $\tilde{\Omega}$.

Four comments are in order. First, we use stock prices to disentangle a contractionary signalling shock from other orthogonal shocks.[18] A signal about a more contractionary monetary policy will increase the riskless interest rate, lower future nominal cash flows, and potentially increase risk premia. All three factors would lead to a decline in stock prices. Our signalling shock therefore differs from a contractionary large-scale asset sale shock that would lead to an increase in the term premium.

Second, we impose that there is indeed an effect on the interest rate and an additional effect on stock prices (i.e. $\tilde{\Omega}_{11} > 0$ and $\tilde{\Omega}_{22} - \psi_{s1}^2 > 0$).[19] That is, we assume that the variance of the one-step-ahead forecast error increases on auction days and that there are two orthogonal shocks. Whether the variance changes, and whether there is more than one orthogonal shock occurring on an auction day, can be tested empirically (see Wright, 2012).[20] We estimate the responses using a bootstrap algorithm (see next section). This algorithm provides us with a distribution for $\tilde{\Omega}_{11}$, $\tilde{\Omega}_{22}$, and ψ_{s1}. Based on these distributions we can compute the probability that the variance of the one-step-ahead forecast error for the overnight rate is indeed higher on auction days ($\tilde{\Omega}_{11} > 0$). Similarly, we can compute the probability of whether, besides the indirect effect via the overnight interest rate, there is an additional increase of the variance of stock prices ($\tilde{\Omega}_{22} - \psi_{s1}^2 > 0$). Therefore, we can verify whether these assumptions are supported by the data.[21]

Third, we could add more variables to the system and exploit more rows of $\tilde{\Omega}$. For this model, we could use a GMM estimator, as well as, test the overidentifying restrictions (see Rigobon and Sack, 2004; Nakamura and Steinsson, 2018a).[22] The advantage of GMM is that we exploit more information and obtain more efficient estimates. This implies that some of our estimates may be less precisely estimated than if we would use GMM.

Fourth, our approach imposing a zero restriction allows us to identify two orthogonal shocks with a structural interpretation through which SNB Bill auctions affect financial market variables.[23] Such restrictions are common in high-frequency identification schemes (see Swanson, 2021; Altavilla et al., 2019). We apply a similar idea to identification via heteroscedasticity, which is particularly useful if it is not possible to construct high-frequency shocks. The first shock works through the overnight rate, as in Nakamura and Steinsson (2018a). It therefore resembles what Gürkaynak et al. (2005) and Altavilla et al. (2019) call target surprises.[24] The second shock is associated with forward-looking stock prices, which we interpret as a signalling shock. The reason is that stock prices hardly respond to overnight interest rates, but rather, to changes in expectations about the future path of overnight interest rates. The signalling shock therefore resembles what Gürkaynak et al. (2005) call path surprises. But also, it is related to the so-called signalling channel of large-scale asset purchases. These purchases may be expansionary because they change expectations about the path of future overnight rates (see e.g. Woodford, 2012; Bauer and Rudebusch, 2014). Similarly, by issuing bills the central bank may reveal information about its future policy actions.[25]

4.3. Data and estimation

In the baseline specification y_t includes a Swiss nominal effective exchange rate, a Swiss stock price index, as well as overnight and a long-term interest rates.[26] The effective exchange rate comprises the CHF/EUR, CHF/USD, and CHF/JPY, weighted by 2008 trade weights from the SNB. We construct our own index in order to know the exact time when the bilateral exchange rates are recorded (18.00 CET). We express the effective exchange rate as one unit of a basket of foreign currencies in terms of Swiss francs. Therefore, a decline in the exchange rate is an effective appreciation of the Swiss franc. The stock price index (Swiss Market Index, SMI) comprises 20 companies with the largest market capitalization on the SIX Exchange. We use close values recorded at 17.30 CET. As an overnight interest rate, we use the Swiss Average Rate Overnight (SARON), a secured money market rate. The close fixings are recorded at 18.00 CET. As a long-term interest rate we use yields of 8Y government bond yields from SIX exchange.[27] The Swiss bond market closes at 17.00 CET.

We transform all interest rates to first differences and the remaining variables to log-changes multiplied by 100. Then, we estimate the one-step-ahead forecast errors by regressing each variable on a constant and exogenous international factors (see Eq. (1)). The

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[18] Similarly, Jarociński and Karadi (2020) exploit stock price movements to disentangle a contractionary monetary policy shock from an information shock.

[19] The sign serves only to normalize the shocks to be contractionary.

[20] However, Wright (2012) tests whether the entire variance–covariance matrix changes. In addition, he constructs a test whether there is more than one shock on a day with a monetary policy decision. Because we impose additional structure to identify our shocks, we can test the identifying assumptions with a subset of $\tilde{\Omega}$.

[21] This underlines that the key identifying assumption, which we cannot formally test, is that SNB auction occurred on pre-determined days.

[22] See Rigobon (2003) and Wright (2012) for a discussion of the conditions for identification with heteroscedasticity.

[23] Compared to GMM, we can therefore obtain a clearer interpretation of the structural shock. See Online Appendix C for a general discussion.

[24] This label, however, is inappropriate in our application because there is no interest rate target change associated with an SNB Bill auction.

[25] It differs, however, from a large-scale asset purchase shock as we do not restrict corporate risk or term premia.

[26] We remove all weekends because some financial market variables are missing. If there are missing values, for example in stock price data when markets are closed on holidays, we replace these with the last available observation. See Online Appendix A for all data sources.

[27] The SIX exchange actually provides yields in maturity buckets. For brevity, we label their 7Y-10Y bucket as an 8Y maturity, and 1Y-3Y bucket as a 2Y maturity.

international factors include the USD/EUR exchange rate, the federal funds rate, a US 8Y zero coupon yield, and the S&P 500. Because US markets close after Swiss markets, we lag them by one day. The estimation sample covers the SNB Bills program starting with the first auction on 20 October 2008 and ending at the end of July 2011.[28]

In some specifications and robustness tests, we extend the model with inflation expectations, yields of corporate bonds, and term spreads. We approximate inflation expectations by yields of high-quality CHF bonds issued by foreign entities on the SIX exchange. The real bond yield of foreign issuers should not be affected by changes in domestic monetary policy as Switzerland is a small open economy. But the nominal yield is affected by Swiss inflation expectations because they are denominated in CHF. Therefore, the change in foreign CHF bond yields on an SNB Bill auction day mainly reflects a change in inflation expectations. Of course, this is only an approximation of Swiss inflation expectations and only valid in the context of a Swiss monetary policy shock. Using this argument, we then compute the real long-term interest rate by the difference of Swiss 8Y government bond yields and foreign CHF bond yields of the same maturity. In addition, we compute a corporate bond risk premium as the difference between 8Y corporate bond yields and 8Y government bond yields.[29] We also examine two term spreads. The 8Y-2Y spread uses government bond yields; the 8Y-3M spread uses the CHF 3M LIBOR as a short-term interest rate. The 3M LIBOR is recorded at 12:55 CET.[30]

We exclude various other operations and events when estimating the variance–covariances of the forecast errors. These include monetary policy decisions (by the SNB and the ECB), repo operations (in CHF and USD), foreign exchange swaps, USD SNB Bill auctions, and auctions of government bonds and treasury bills on behalf of the Swiss Confederation. To control for these events, we remove them from the estimation of the variance–covariances. There is one exception. Reverse repo operations in CHF sometimes took place in the morning of an SNB Bill auction. We therefore exclude those operations only when no SNB Bill auction took place.[31]

For inference, we use 8000 samples from a moving block bootstrap as described in ch. 8 by Efron and Tibshirani (1993), with a block size of 5 business days. We varied the block size from one to 20 business days and obtained similar results.

5. Empirical results

Table 1 shows the results. Before discussing the responses, it is worth noting that the data support the identifying assumptions; Lewis (2020) explains that if these assumptions are not met, standard inference methods fail because of a 'weak-instruments' problem.[32] Therefore, we interpret our results only in the case where the data support the identifying assumptions. The share of identified responses for the overnight rate shock, that is bootstrap replications fulfilling $\tilde{\Omega}_{11} > 0$, is equal to unity. Moreover, the share of identified responses for the signalling shock, that is bootstrap replications fulfilling $\tilde{\Omega}_{22} - \psi_{s1}^2 > 0$, amounts to 0.95. The first test implies that SNB Bill shocks indeed affect the overnight interest rate. The second test implies that there is a second shock affecting stock prices beyond the impact of the overnight rate shock.

The shocks yield qualitatively and quantitatively different responses. A signalling shock appreciates the Swiss franc (−0.3%) and lowers stock prices (−0.9%). Both responses are statistically significant. In addition, long-term interest rates decline. The overnight rate shock raises the overnight interest rate and long-term interest rates. Although the response of the latter is imprecisely estimated. The point estimates for stock prices and the exchange rate are negative, but not statistically significantly different from zero. The impact of an overnight rate shock is qualitatively in line with conventional monetary policy target surprises (see e.g. Gürkaynak et al., 2005).

To assess the relative importance of the shocks, we provide a forecast-error variance decomposition. The signalling shock is more important for forward-looking variables; it explains 54% of long-term interest rate, 53% of exchange rate, and 44% of stock price fluctuations. The overnight rate shock explains 75% of the variation of the overnight interest rate, but less than 30% of forward-looking variables. The last column shows that, overall, the two SNB Bill shocks account for between 46% and 85% of the forecast-error variance on an auction day. This share appears large to what is documented in studies for the United States (see, e.g., Wright, 2012). Recall, however, that we control for international factors that may capture a large share of financial variables' fluctuations. In addition, these shares are quite imprecisely estimated.

Most studies associate expansionary large-scale asset purchases with lower long-term interest rates (see, e.g., Gagnon et al., 2011). We find, however, that lower long-term interest rates are associated with a contractionary signalling shock. One possible explanation of this finding is that a contractionary signalling shock leads to a compression of the yield curve, as expectations about future economic activity and inflation expectations decline.

To shed more light on this finding, we extend the model with the long-term riskless real interest rate, corporate bond risk premia, and inflation expectations. We approximate these measures using eight-year zero coupon yields of bonds from Swiss corporations, the Swiss Confederation, as well as foreign companies issuing bonds in Swiss franc. We compute a proxy for corporate risk premia as the spread between eight-year corporate and government bond yields. Then, we assume that foreign real interest rates are not affected by an SNB Bill shock. This allows us to interpret the response of CHF denominated bond yields of foreign issuers as the

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[28] Changing the estimation sample for a few days does not affect the results. We discuss results on subsamples in a robustness section.

[29] The rating of the bonds covers BBB up to AAA. In a robustness test, we examine risk premia using other ratings.

[30] Alternatively, we may use the 3M SAR, which is recorded at the same time as the SARON. The 3M SAR is based on few transactions and more often missing than the SARON, however. We also examined interest rates based on swaps. The results were similar.

[31] In addition, we collected information on speeches by SNB representatives and important data releases (Swiss CPI, PPI, and GDP) and control for these days in a robustness test.

[32] We provide IV estimates, a special case of the model we use in the baseline, and the corresponding F-test for weak instruments as a robustness test. For the IV special case, the F-statistic indicates rejection of the null hypothesis of weak instruments.

Table 1
Impact of SNB Bills shocks.

	Effects of orthogonalized shocks		Variance share explained by		
	Signalling	Overnight rate	Signalling	Overnight rate	Total
ON interest rate (in pp)	0.000 [0.000, 0.000] (0.000, 0.000)	0.019 [0.013, 0.025] (0.012, 0.026)	0.00 [0.00, 0.00] (0.00, 0.00)	0.75 [0.55, 0.91] (0.49, 0.92)	0.75 [0.55, 0.91] (0.49, 0.92)
8Y interest rate (in pp)	−0.033 [−0.052, −0.012] (−0.057, −0.008)	0.026 [0.002, 0.053] (−0.001, 0.057)	0.54 [0.11, 0.92] (0.06, 1.19)	0.30 [0.01, 0.69] (0.00, 0.76)	0.85 [0.21, 1.28] (0.14, 1.50)
Stock prices (in %)	−0.907 [−1.326, −0.394] (−1.393, −0.289)	−0.004 [−0.359, 0.332] (−0.439, 0.403)	0.44 [0.13, 0.65] (0.07, 0.68)	0.03 [0.00, 0.10] (0.00, 0.14)	0.46 [0.17, 0.66] (0.11, 0.69)
Exchange rate (in %)	−0.320 [−0.653, −0.082] (−0.824, −0.045)	−0.026 [−0.191, 0.148] (−0.223, 0.189)	0.53 [0.02, 1.04] (0.01, 1.66)	0.03 [0.00, 0.12] (0.00, 0.15)	0.56 [0.05, 1.08] (0.03, 1.69)
Share identified	0.95	1.00			
N overall	725	725			
N auctions	52	52			
N without auctions	207	207			

Notes: Impact of one standard deviation SNB Bill shocks identified with sign and zero restrictions. We assume that a signalling shock leads to a decline in stock prices but no change in the overnight interest rate. The overnight rate shock leads to an increase in the overnight interest rate. The right panel gives a variance decomposition. 90% and 95% confidence intervals are shown in brackets and parentheses, respectively. Inference is based on 8000 draws from a block bootstrap algorithm. We also report the share of bootstrap replications for which $\tilde{\Omega}_{11} > 0$ or $\tilde{\Omega}_{22} - \psi_{s1}^2 > 0$ (share identified), the overall number of observations to estimate the parameters (N overall), the number of observations to estimate $\Omega_{t\in A}$ (N auctions), and $\Omega_{t\notin A}$ (N without auctions). Note that N overall = N auctions + N without auctions + N other events. We remove N other events from the computation of the variance–covariance matrices.

Table 2
Impact of SNB Bill shocks on corporate bond yields.

	Effects of orthogonalized shocks		Variance share explained by		
	Signalling	Overnight rate	Signalling	Overnight rate	Total
8Y real rate (in pp)	−0.014 [−0.029, 0.004] (−0.032, 0.009)	0.008 [−0.008, 0.024] (−0.010, 0.027)	0.50 [0.01, 0.86] (0.00, 1.11)	0.18 [0.00, 0.57] (0.00, 0.71)	0.67 [0.05, 1.18] (0.03, 1.47)
8Y risk premium BBB-AAA (in pp)	0.015 [0.002, 0.027] (−0.001, 0.030)	−0.006 [−0.015, 0.005] (−0.017, 0.006)	0.70 [0.03, 1.15] (0.01, 1.59)	0.13 [0.00, 0.40] (0.00, 0.49)	0.83 [0.10, 1.32] (0.05, 1.72)
8Y inflation expectations (in pp)	−0.018 [−0.032, −0.004] (−0.037, −0.001)	0.018 [0.003, 0.032] (0.000, 0.034)	0.35 [0.02, 0.75] (0.01, 1.07)	0.26 [0.02, 0.54] (0.01, 0.59)	0.62 [0.16, 0.99] (0.11, 1.27)
Share identified	0.95	1.00			
N overall	725	725			
N auctions	52	52			
N without auctions	207	207			

Notes: Responses of 8Y bond yields to one standard deviation SNB Bill shocks identified with heteroscedasticity and zero restrictions. We decompose the nominal corporate bond yield into the riskless real interest rate (government bond yield–inflation expectations), a risk premium (corporate bond yield–government bond yield), and inflation expectations (foreign corporate bond yields denominated in CHF). We assume that a signalling shock leads to a decline in stock prices but no change in the overnight interest rate. The overnight rate shock leads to an increase in the overnight interest rate. The right panel gives a variance decomposition. 90% and 95% confidence intervals are shown in brackets and parentheses, respectively. Inference is based on 8000 draws from a block bootstrap algorithm. We also report the share of bootstrap replications for which $\tilde{\Omega}_{11} > 0$ or $\tilde{\Omega}_{22} - \psi_{s1}^2 > 0$ (share identified), the overall number of observations to estimate the parameters (N overall), the number of observations to estimate $\Omega_{t\in A}$ (N auctions), and $\Omega_{t\notin A}$ (N without auctions). Note that N overall = N auctions + N without auctions + N other events. We remove N other events from the computation of the variance–covariance matrices.

response of inflation expectations. Finally, we approximate the riskless long-term real interest rate as the difference of government bond yields and inflation expectations.

Table 2 shows that a signalling shock lowers the long-term real interest rate (−0.01 pp). But the coefficient is not statistically significant. In addition, we observe an increase of corporate bond spreads (0.02 pp) and a decline in inflation expectations (−0.2 pp). Meanwhile, the overnight shock leads to an increase in inflation expectations. This counter-intuitive result may be due to an information effect, as documented by Nakamura and Steinsson (2018a) for official monetary policy announcements, implying that if the SNB raises the overnight rate, it communicates to the markets that the economy is improving. The variance decomposition shows that the signalling shock is more important than the overnight rate shock. It explains 50% of the variance in the real interest rate, as well as 70% of corporate bond spreads.

Our finding that a contractionary signalling shock raises risk premia is in line with studies finding that expansionary large-scale asset purchases lower risk premia of long-term interest rates. However, we also find that the riskless long-term real rate and

Table 3
Impact of settlement day shocks.

	Effects of orthogonalized shocks		Variance share explained by		
	Signalling	Overnight rate	Signalling	Overnight rate	Total
ON interest rate (in pp)	0.000 [0.000, 0.000] (0.000, 0.000)	0.020 [0.013, 0.027] (0.011, 0.029)	0.00 [0.00, 0.00] (0.00, 0.00)	0.84 [0.62, 0.95] (0.53, 0.95)	0.84 [0.62, 0.95] (0.53, 0.95)
8Y interest rate (in pp)	0.005 [−0.024, 0.045] (−0.038, 0.065)	−0.005 [−0.014, 0.003] (−0.016, 0.004)	1.12 [0.00, 2.47] (0.00, 6.73)	0.05 [0.00, 0.16] (0.00, 0.19)	1.17 [0.02, 2.52] (0.01, 6.76)
Stock prices (in %)	−0.263 [−0.480, −0.059] (−0.522, −0.045)	−0.130 [−0.336, 0.072] (−0.382, 0.102)	0.09 [0.00, 0.22] (0.00, 0.26)	0.04 [0.00, 0.14] (0.00, 0.18)	0.11 [0.02, 0.26] (0.01, 0.30)
Exchange rate (in %)	0.009 [−0.492, 0.559] (−0.684, 0.887)	−0.111 [−0.185, −0.032] (−0.200, −0.011)	1.59 [0.00, 2.90] (0.00, 7.97)	0.07 [0.01, 0.16] (0.00, 0.18)	1.66 [0.04, 2.93] (0.03, 8.05)
Share identified	0.07	1.00			
N overall	725	725			
N settlement days	114	114			
N without settlement days	148	148			

Notes: Impact of one standard deviation settlement day shocks identified with sign and zero restrictions. We assume that a signalling shock leads to a decline in stock prices but no change in the overnight interest rate. The overnight rate shock leads to an increase in the overnight interest rate. The right panel gives a variance decomposition. 90% and 95% confidence intervals are shown in brackets and parentheses, respectively. Inference is based on 8000 draws from a block bootstrap algorithm. We also report the share of bootstrap replications for which $\tilde{\Omega}_{11} > 0$ or $\tilde{\Omega}_{22} - \psi_{s1}^2 > 0$ (share identified), the overall number of observations to estimate the parameters (N overall), the number of observations to estimate $\Omega_{t\in A}$ (N settlement days), and $\Omega_{t\notin A}$ (N without settlement). Note that N overall = N settlement days + N without settlement + N other events. We remove N other events from the computation of the variance–covariance matrices.

inflation expectations fall. Thus, riskless nominal long-term interest rates decline in response to a contractionary signalling shock. Our preferred interpretation of this results is that the signalling shock reduces future expected economic activity, which reduces the future expected real interest rate as well as inflation expectations, and increases risk premia on corporate bonds.

Besides the auction itself, there at least two other days on which the SNB Bills program may impact financial market variables: the announcement day and the settlement day. The announcements provided information about the maturity of SNB Bills and price ranges for valid bids. If the SNB intended to raise short-term interest rates in the near future, it may have started to issue SNB Bills of a longer maturity and a higher yield (lower price). Therefore, the announcements may have provided information about future monetary policy actions.[33] On the auction day the SNB revealed the volume of SNB Bills allotted, as well as the marginal SNB Bill yield. Auction days may also provide information on whether the SNB intended to raise short-term interest rates because it needs to issue more SNB Bills to return to an environment with scarce reserves. Finally, on the settlement day no new information was released. But SNB Bills were exchanged for reserves and therefore the settlement may have affected the overnight interest rate. Unfortunately, we were not able to determine the days when the announcements took place. However, we can apply our method to settlement days.

Table 3 shows the results for a settlement day shock. The signalling shock is not well identified. The share identified responses, that is bootstrap replications fulfilling $\tilde{\Omega}_{22} - \psi_{s1}^2 > 0$, amounts to 7%. In line with what we would expect, the results therefore suggest that there was no signalling dimension on the settlement day. As explained before, we should therefore refrain from interpreting the estimates of the signalling shock response and variance decomposition, because the shock is not well identified.[34] Meanwhile, the overnight rate shock is well identified and explains a large share of the overnight interest rate variance. This is in line with the idea that the settlement does not reveal new information but still affects the overnight interest rate because it drains reserves.

Next, we analyse whether the responses depend on the maturity of SNB Bills. On the one hand, short-term SNB Bills may have little effect because they absorb reserves only for a brief period. On the other hand, the impact of short-term SNB Bills depends on financial market participants' expectations. If financial market participants expect the SNB to roll over a short-term SNB Bill after maturity, the effect would be identical to issuing a long-term SNB Bill in a market without frictions and without uncertainty.[35]

We define short-term SNB Bills as having a maturity of three months or less. Long-term SNB Bills have a maturity of more than three months up to one year. When estimating the effect of long-term SNB Bills, we only exclude short-term auctions when they do not coincide with long-term auctions. Otherwise, the number of observations would be too small. By contrast, we exclude all long-term auctions when estimating the effects of short-term SNB Bills.

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[33] Figure B.2, panel (b), in Online Appendix B shows that the SNB indeed started to issue longer maturities at a higher yield after it turned to a more hawkish communication in June 2010.

[34] The implausibly high variance share explained by the signalling shock is likely an artefact of poor identification. We should refrain from interpreting it. First, if the variance of the variables does not change much on a settlement day, a very small coefficient will explain almost all of the variance. Second, although the confidence intervals are very wide, they are not reliable as standard inference techniques fail because of the 'weak instruments problem' (see Lewis, 2020).

[35] Note, however, that in practice short-term SNB Bills expose the investor to more interest rate risk, as they have to be rolled over more frequently.

Table 4
Short- and long-term SNB Bill auctions.

	Signalling shock	
	Long-term Bills	Short-term Bills
ON interest rate (in pp)	0.000 [0.000, 0.000] (0.000, 0.000)	0.000 [0.000, 0.000] (0.000, 0.000)
8Y interest rate (in pp)	−0.016 [−0.057, 0.019] (−0.072, 0.034)	−0.041 [−0.062, −0.017] (−0.067, −0.012)
Stock prices (in %)	−0.315 [−0.562, −0.079] (−0.592, −0.050)	−1.304 [−1.834, −0.627] (−1.918, −0.479)
Exchange rate (in %)	−2.747 [−6.187, −1.083] (−10.980, −1.004)	−0.087 [−0.330, 0.158] (−0.393, 0.240)
Share identified	0.07	0.97
N overall	725	725
N auctions	24	28
N without auctions	207	207

Notes: Impact of one standard deviation signalling shocks identified with heteroscedasticity according to maturity of SNB Bills. Short-term Bills include all maturities up to three months. Long-term Bills include maturities longer than three months. Note that in the second half of the sample auctions of long-term SNB Bills always coincided with short-term SNB Bills. We therefore exclude long-term auctions when estimating the short-term auction effects, but not vice versa. We assume that a signalling shock leads to a decline in stock prices but no change in the overnight interest rate. 90% and 95% confidence intervals are shown in brackets and parentheses, respectively. Inference is based on 8000 draws from a block bootstrap algorithm. We also report the share of bootstrap replications for which $\tilde{\Omega}_{11} > 0$ or $\tilde{\Omega}_{22} - \psi_{s1}^2 > 0$ (share identified), the overall number of observations to estimate the parameters (N overall), the number of observations to estimate $\Omega_{t\in A}$ (N auctions), and $\Omega_{t\notin A}$ (N without auctions). Note that N overall = N auctions + N without auctions + N other events. We remove N other events from the computation of the variance–covariance matrices.

Table 4 shows the effect of short-term and long-term SNB Bill auctions. For brevity, we only report the signalling shock. We find that our results are driven by short-term SNB Bill auctions. Indeed, the signalling shock is not well identified for long-term bill auctions. By contrast, the shock is well identified for short-term auctions. We therefore find no evidence in favour of the hypothesis that long-term auctions had a stronger signalling effect due to their longer maturity. One possible reason for this result is that the maturity of SNB Bills was already revealed on the announcement sheets. Therefore, the signalling effect of longer maturities may have affected financial market variables on the announcement day rather than on the auction day.

There are at least two reasons why we are interested in estimating dynamic effects. First, studies on US large-scale asset purchases do not agree whether they had a persistent effect (Wright, 2012; Swanson, 2021). Second, monetary policy shocks identified with VARs sometimes affect the exchange rate with some delay (see, e.g., Kim et al., 2017).

Our approach allows to estimate dynamic effects using the forecast errors at various forecast horizons.[36] Fig. 3 shows the results for the signalling shock. We observe an immediate and relatively persistent effect on all variables. There is no evidence of a delayed response of the exchange rate. Two comments are in order. First, the dynamic effects are less precisely estimated at longer horizons. Second, we impose the identifying restriction at every horizon. Therefore, the share of bootstrap replications that fulfil the identifying assumptions (share identified) falls over time. After a few days, it falls below 0.9. However, in a robustness test we obtain similar estimates with a more efficient VAR approach that does not suffer from weak identification.

The responses to the overnight rate shock are shown in Fig. 4. We find that an overnight rate shock has no significant impact on forward-looking variables at any horizon. The only exception are long-term interest rates and inflation expectations that increase briefly. But even for these variables, the responses are only barely significant. Meanwhile, the share identified is close to unity at every horizon. This suggests that there is indeed a shock that affects the overnight interest rate. However, quantitatively it is much less important for forward-looking financial market variables than the signalling shock.

5.1. Placebo and robustness tests

We performed various placebo and robustness tests to challenge our identification scheme and main results. In what follows, we provide an overview and discuss the most important caveats. A detailed discussion is given in Online Appendix D.

We performed three placebo tests. We estimated the model with placebo auction days before the SNB Bills program was in place (2005–2008). Then, we examined placebo auction days during the SNB Bills program, excluding actual auctions. Finally, we

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[36] Specifically, we use local projections to estimate the forecast errors (Jordà, 2005). See Online Appendix C for a technical discussion.

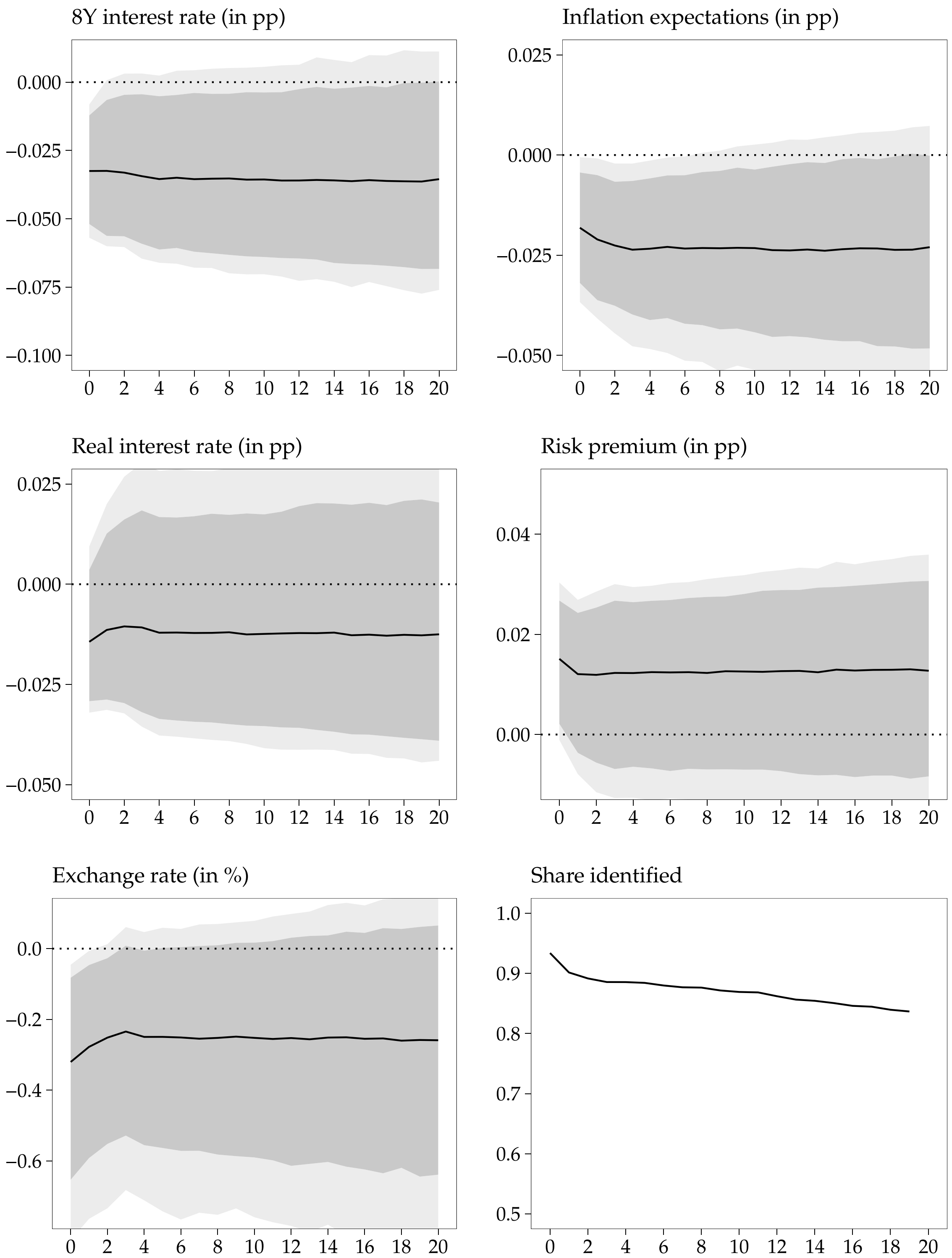

Fig. 3. Dynamic impact of a signalling shock. Notes: Dynamic daily impact of a one standard deviation signalling shock identified with sign and zero restrictions. We assume that a signalling shock leads to a decline in stock prices but no change in the overnight interest rate. Shaded areas give 90% and 95% confidence intervals. Inference is based on 8000 draws from a block bootstrap algorithm. We also report the share of bootstrap replications for which $\tilde{\Omega}_{22} - \psi_{s1}^2 > 0$ (share identified).

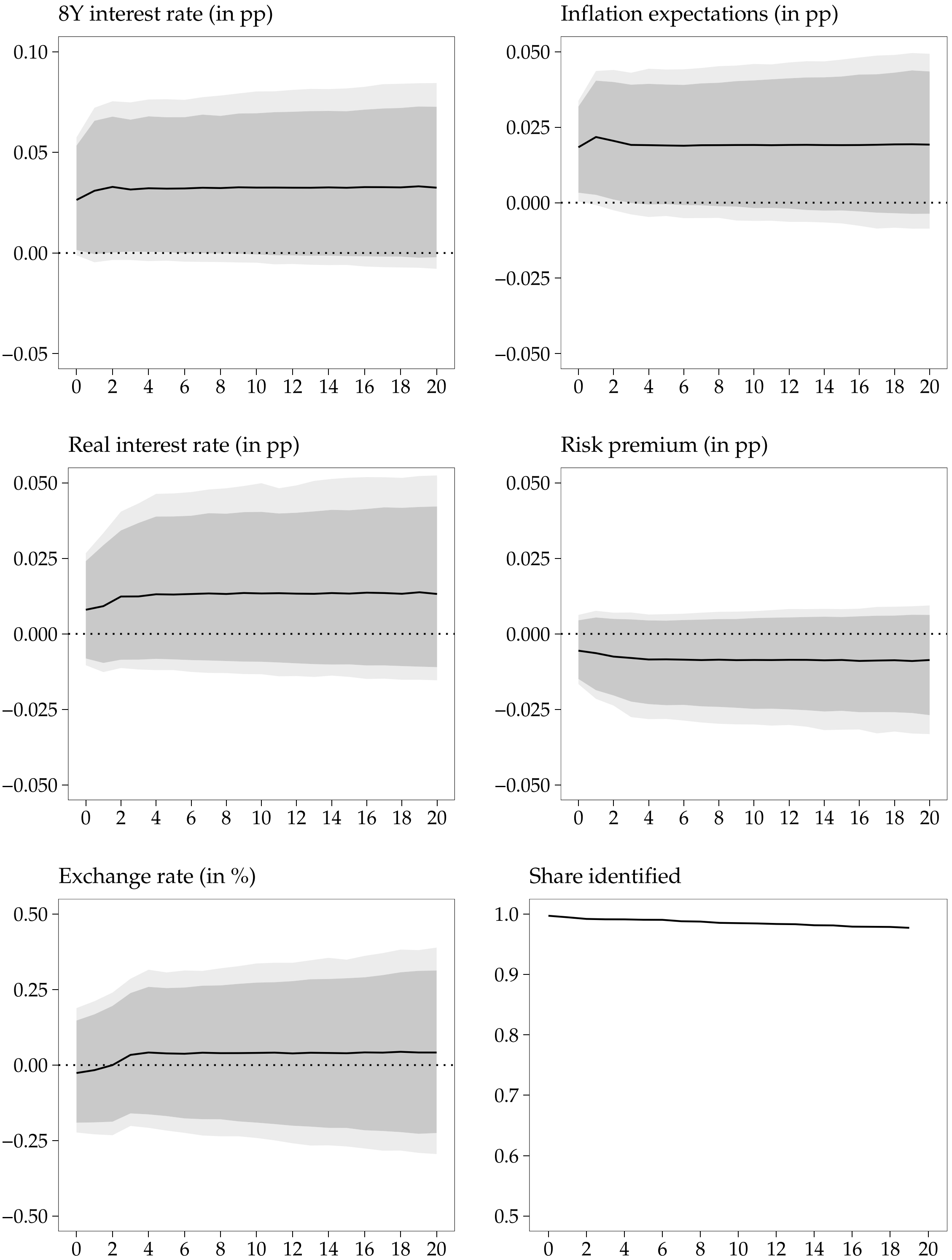

Fig. 4. Dynamic impact of an overnight rate shock. Notes: Dynamic daily impact of a one standard deviation overnight rate shock identified with heteroscedasticity. We assume that an overnight shock leads to an increase in the overnight interest rate. Shaded areas give 90% and 95% confidence intervals. Inference is based on 8000 draws from a block bootstrap algorithm. We also report the share of bootstrap replications for which $\tilde{\Omega}_{11} > 0$ (share identified).

estimated the effect of treasury bill auctions, USD SNB Bill auctions and reverse repo auctions. Treasury bills should have no impact as they are issued on behalf of the Swiss government, that is, without the intention to drain reserves. Similarly, USD SNB Bills do not drain CHF reserves. Although reverse repo operations do drain reserves, their volume and term to maturity was much smaller than for SNB Bills (see Online Appendix B). In all cases, the identifying assumption is not satisfied, suggesting that there is no signalling dimension associated with these operations.

Then, we performed a range of robustness tests changing the model specification, control variables, outcomes, and sample range. For most alternative specifications, the results are robust. The only exception is when we add more controls, the signalling shock is less well identified. However, adding controls may also introduce background noise in the data, hampering identification due to an ‘error-in-variables’ problem. We therefore prefer our baseline specification. An interesting additional finding is that the term spread (8Y-3M) falls in response to a signalling shock and the effect is larger in absolute size than on the long-term interest rate. This suggests that the signalling shock increases the short end of the yield curve while leading to a decline in long-term interest rates. Estimating the model on subsamples does not yield satisfactory identification of the signalling shock. This result comes with the caveat that, because the number of observations is smaller, we have to apply a narrower definition of other events we control for in the estimation. We also used a more efficient VAR approach to estimate dynamic effects. The responses are qualitatively similar but more precisely estimated.

We also explored changes to the identification scheme. We varied the definition of days without an event from narrow (excluding official monetary policy decisions of the SNB and ECB, as well as USD repo and USD SNB Bill auctions) to broad (excluding SNB speeches and dates with data releases for the CPI, PPI, and GDP, in addition to the events in the baseline). The results suggest that excluding reverse repo auctions are key to identify the signalling shock. In addition, excluding speeches and important data releases do not change the results; if anything the signalling shock is better identified. We also imposed alternative identifying restrictions. Whether we identify one or two SNB Bill shocks, or restrict the exchange rate rather than stock prices, does not qualitatively change the results. The shock is not well identified, however, when restricting risk premia, inflation expectations, or the term spread. This highlights that the shock we identify is different from a large-scale asset purchase shock, where we expect that it works mostly through changing the term premium and risk premia of corporate bonds.

Finally, we used the IV estimator by Rigobon and Sack (2004) and the F-test for weak instruments proposed by Lewis (2020). The IV estimator is a more efficient estimator; however, we can only identify one shock. We associate the SNB Bill shock with a change in stock prices or the exchange rate, in line with the signalling shock in our baseline. In both cases, the F-statistic is comfortably above the threshold proposed by Lewis (2020). In addition, the effects are qualitatively similar than in the baseline.

6. Concluding remarks

In the aftermath of the financial crisis, many central banks used central bank bills and reverse repo operations to steer short-term interest rates in an environment with large excess reserve balances. Policy makers argued that these tools do not affect financial markets and the broader economy as long as commercial banks hold excess reserve balances (SNB, 2011; Federal Reserve Board, 2012). This paper argues that they do. We find that these operations, which are arguably monitored only by a small number of experts, may affect financial market participants’ expectations through a signalling channel.

That the signalling channel can be more important than a change in the policy instrument has been well documented in the literature on official monetary policy announcements. Our paper shows that this may apply to liquidity-absorbing operations in between official decisions. Indeed, the overnight rate shock explains little of the movements in forward-looking financial market variables compared to the signalling shock. Meanwhile, the signalling shock causes a relevant decline in stock prices, a persistent appreciation of the Swiss franc, as well as a decline in long-term interest rates. Moreover, it leads to an increase in corporate bond spreads and a fall in inflation expectations.

These results are relevant for policy makers who consider to use reserve-absorbing tools in an environment with large excess reserve balances. Such tools allow central banks to control the overnight interest rate and implement a more restrictive monetary policy. However, such tools affect financial markets by revealing information about the central bank’s future policy actions. Therefore, using reserve-absorbing tools can be contractionary beyond their immediate effect on the short-term interest rate.

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Appendix A. Supplementary data

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