Policy Evaluation by the Synthetic Control Approach: The Case of the Swiss Franc

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Abstract

In this paper, we analyse the effect of unconventional monetary policies on the EUR/CHF exchange rate. We apply the synthetic control approach to four events defining a change in the Swiss National Bank's monetary policy during the 2009 to 2011 period before the introduction of the exchange rate floor. We provide evidence that in some periods the EUR/CHF exchange rate shares common factors not only with other exchange rates, but in particular with other safe assets. It is thus possible to construct a counterfactual exchange rate by assigning weights to other exchange rates or safe assets. The synthetic control approach finds major effects for the March 2009 and August 2011 announcements. The methodology seems less appropriate to evaluate the spring 2010 foreign exchange interventions.

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1 Introduction

In this paper we want to see whether the synthetic control approach is suited for analysing the effects of unconventional monetary policies on the EUR/CHF exchange rate before the introduction of the exchange rate floor on 6 September 2011. More precisely, we are interested in measures aiming at dampening the appreciation of the Swiss franc against the euro during the period 2009-2011.[1]

There is a large empirical literature trying to measure the effects of foreign exchange interventions or, more generally, monetary policies that target the exchange rate. However, all studies in this field have to face the issue of simultaneity, leading to endogeneity, which today still represents a major challenge. As central banks tend to intervene just during episodes of strong appreciation (or depreciation) pressure, simple regression estimates of the effect of interventions risk to be heavily biased. Popular approaches to address this problem are, for instance, structural VARs and the use of high-frequency data. However, also these approaches do have drawbacks, and are often only applicable to a limited range of situations or countries, be it due to the lack of data or the economic circumstances.[2]

In this paper, we apply the synthetic control method by Abadie and Gardeazabal (2003) and Abadie et al. (2010, 2015) to study the effects of the SNB's policy measures on the EUR/CHF exchanges rate. Stemming from the comparative case studies literature, this approach provides a solution to the endogeneity problem. It is very popular in the field of political sciences, but relatively new in the literature on foreign exchange interventions. To our knowledge, Chamon et al. (2016) are the first ones to make use of it.[3] They apply the methodology to Brazil to analyze the foreign exchange intervention programs by the Central Bank of Brazil in 2013. Abadie and Gardeazabal (2003), on the other hand, originally developed it to investigate the economic cost of conflict, using the terrorist conflict in the Basque Country as a case study. Abadie et al. (2010) use it to estimate the effect of California's tobacco control program, while Abadie et al. (2015) illustrate the main concepts behind it by estimating the economic impact of the 1990 German reunification.

Using the synthetic control approach, we construct a counterfactual EUR/CHF exchange rate to which we can compare the evolution of the actual EUR/CHF exchange rate after the interventions. The basic idea is to first build a sample of possible comparison units that exhibit similar behaviour to the EUR/CHF exchange rate prior to the date of intervention, but which are not exposed to the SNB's interventions. The methodology by Abadie et al. (2015) then provides a systematic way to assign positive weight to those comparison units that are best able to reproduce the behaviour of the Swiss franc in the pre-intervention period. As Chamon et al. (2016) write, whatever noise and

[1]See Christensen and Krogstrup (2016) for a study of the effects of the unconventional monetary policy measures undertaken by the SNB in the late summer of 2011 on long-term interest rates.

[2]For an overview of studies and approaches in the field of foreign exchange interventions see for example Neely (2005).

[3]However, there are some rare examples where the synthetic control approach has been applied for the estimation of the effects of other types of central bank intervention targeting the exchange rate. Two examples are Aytug (2016) whose focus lies on the long term effect of the Czech National Bank's exchange rate commitment on macro variables, and Opatrny (2016) who studies a policy put into practice by the Central Bank of Turkey to lower the exchange rate volatility.

error is involved in this type of analysis, it will be orthogonal to the problem of endogeneity that the literature on FX interventions is usually facing.

As comparison units we use other exchange rates, on the one hand. On the other hand, given the Swiss franc's role as a safe haven currency (see Ranaldo and Söderlind (2010), for example), we also use safe assets like government bonds and gold. In order to be able to judge whether the synthetic control approach is applicable to the Swiss franc, we first perform a statistical factor analysis. This allows to get a first insight into whether there is a strong co-movement between the EUR/CHF exchange rate and other exchange rates or safe assets, respectively, and provides us with information on how strong such comovements are. We find that in the periods prior to the March 2009 and August 2011 policy announcements, the Swiss franc is quite well explained by a factor model and hence has a lot in common with other exchange rates and, even more, with safe assets. In the spring 2010 period, however, the Swiss franc is less well explained by common factors, and, hence, the synthetic control results should be interpreted with care.

The results of the synthetic control approach are robust and suggest that the March 2009 announcement led to an immediate depreciation of the Swiss franc. This effect, however, disappeared after a few days. The results on the foreign exchange interventions in spring 2010, on the other hand, suggest that if they had an impact at all, they led to a further appreciation of the Swiss franc. The series of announcements in August 2011, finally, triggered a significant depreciation of the Swiss franc.

The structure of the paper is as follows. Section 2 gives an overview of the SNB's monetary policy measures between 2009 and 2011. Section 3 presents the synthetic control approach. In Section 4, the different samples and the data are presented. Section 5 discusses the results of the statistical factor analysis and Section 6 the results of the synthetic control approach. Finally, section 7 concludes and summarizes the main findings.

2 The SNB's monetary policy measures between 2009 and 2011

In reaction to the global financial crisis of 2007-2009, the economic downturn and the deflationary risks that came along with it, the SNB continuously lowered its policy rate, the three-month CHF Libor. While this conventional monetary policy measure[4] reached its limit in March 2009, when the SNB reduced the rate to what was at the time considered the effective lower bound, the accomplishment of price stability - the SNB's primary goal - still required a further relaxation of the monetary conditions. One major factor which was threatening price stability during the years 2009 to 2011 was the persistent appreciation of the Swiss franc against the euro, shown in Figure 1. To counter the resulting tightening of monetary conditions the SNB took unconventional monetary policy actions.

In a press release on 12 March 2009, the SNB announced its first unconventional measures which included additional repo operations (extension of the maturity), buying Swiss franc bonds

[4] In normal times, the SNB aims to steer the three-month CHF Libor through short-term repo operations.

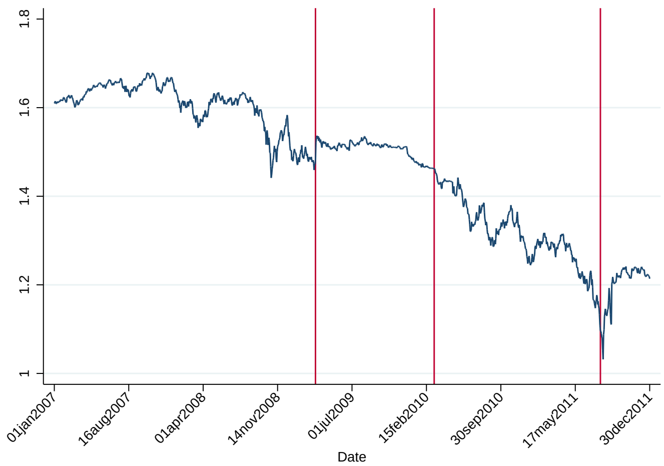


Figure 1: Daily EUR/CHF exchange rate between 2007-2011. The red lines indicate the exchange rate level on the day before the SNB announcement for each of the three announcements under analysis: 12 March 2009, 11 March 2010 and 3 August 2011.

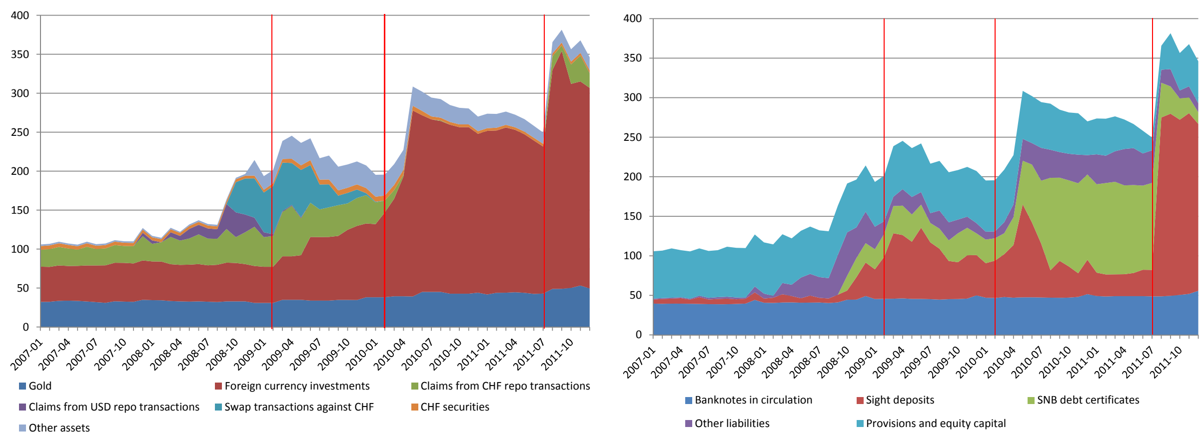
issued by private sector borrowers and purchasing foreign currency on the foreign exchange markets. The bond purchase program was initiated in order to bring about a relaxation of conditions on the capital markets since capital market risk premia had risen substantially after Lehman Brothers filed for bankruptcy in September 2008. Purchases of foreign currency aimed at preventing any further appreciation of the Swiss franc against the euro. The bank's intention was to increase liquidity in the Swiss economy through all three measures. As already mentioned, at the same time the SNB announced another interest rate cut. The target range for the Libor was narrowed from 0–1.00% to 0–0.75%, and hence, from the usual 100 to 75 basis points, with the goal of bringing the Libor down to around 0.25%.[5]

By the end of 2009 the global economy showed signs of recovery and also the downturn in the Swiss economy was not as substantial as expected. A certain stabilization of the Swiss franc took place, which the SNB interpreted as a sign that the monetary policy measures taken in March were effective. Risk premia on the capital markets dropped and so the SNB discontinued its bond purchase program in December 2009. However, tensions on the financial markets increased rapidly again in Spring 2010, and the value of the Swiss franc against the euro increased further. The renewed appreciation was mainly a result of the loss of confidence in the euro caused by the increased concerns about the heavily indebted European countries Greece, Ireland, Portugal and Spain. In the press release following its quarterly assessment of 11 March 2010, and similar to the decisions after earlier quarterly assessments, the SNB announced to act decisively to prevent an excessive appreciation of the Swiss franc against the euro. In addition, it proclaimed that it had been intervening in the foreign exchange market.[6] In fact, the SNB purchased around CHF 31

[5]See press release at `http://www.snb.ch/en/mmr/reference/pre_20090312/source/pre_20090312.en.pdf`

[6]See press release at `http://www.snb.ch/en/mmr/reference/pre_20100311/source/pre_20100311.en.pdf`

billion of foreign exchange in the first and CHF 113 billion in the second quarter of 2010 which is apparent in the increase in the SNB's foreign currency investments in Figure 2(a). Of the Q2-purchases, CHF 85 billion took place alone in May 2010, the month during which the EU members and the IMF agreed on the first bailout package to rescue Greece. By mid-2010 the SNB stopped intervening in the foreign exchange markets. By that time, however, purchases of foreign exchange had resulted in a substantial expansion of the SNB's balance sheet and central bank reserves. A large part of these reserves were gradually absorbed through reverse repo operations and through the issuance of the SNB's own interest-bearing debt certificates, referred to as SNB bills (Figure 2).



(a) (b)

Figure 2: SNB Balance Sheet (in CHF billions, end of month). Panel (a) shows the asset and panel (b) the liabilities side. In both panels, the red lines indicate the previous month for each of the three announcements under analysis, i.e. February 2009 and 2010, and July 2011. Source: SNB.

After May 2010, the European debt crisis continued to worsen. Besides Greece, also Ireland and Portugal turned out to be in immediate danger of a possible default and by August 2011, the sovereign debt crisis shifted to Europe's larger countries, including Italy and Spain. At the same time, the U.S. debt crisis reached its peak. The U.S. Senate passed the plan raising the debt ceiling on 2 August 2011, just in time to avert a national default. These events resulted in safe-haven inflows, caused the franc to appreciate sharply and resulted in a new record low of the EUR/CHF exchange rate at 1.079 in the night of 2 August. On Wednesday, 3 August 2011, the SNB decided to take new measures against the strong Swiss franc. In a press release it stated that it considered the Swiss franc to be massively overvalued and that it would not tolerate a continual tightening of monetary conditions. The SNB immediately set a new aim for the three-month Libor as close to zero as possible, narrowing the target range from 0.00–0.75% to 0.00– 0.25%. This was the first change in the target range since March 2009. At the same time, it announced to increase the supply of liquidity to the Swiss franc money market by no longer renewing repos and SNB Bills that fall due and by repurchasing outstanding SNB Bills. Specifically, the SNB would expand the banks' sight deposits at the SNB from CHF 30 billion to CHF 80 billion over the next few days.[7] The EUR/CHF exchange rate continued to fall despite of these actions and reached a record low on 9 August 2011 at 1.0070. On 10 August 2011 the SNB announced to take additional measures against the strength of the Swiss franc by rapidly expanding the banks' sight deposits from CHF 80 billion to CHF 120 billion, by the use of foreign exchange swaps.[8] The EUR/CHF rate reversed course and started to depreciate, however, not in a sufficient way such that on 17 August 2011 the SNB increased sight deposits again, this time from CHF 120 billion to CHF 200 billion. To achieve this expansion the SNB continued to repurchase outstanding SNB Bills and to employ foreign exchange swaps.[9] Overall, the SNB increased the sight deposits massively in August 2011 (by CHF 170 billion in total) which is evident in Figure 2(b).

Date	Announcement
12 March 2009	Target range for three-month CHF Libor is narrowed to 0–0.75%. In addition, liquidity is increased by additional repo operations, purchases of Swiss franc bonds issued by private sector borrowers and purchases of foreign currency on the foreign exchange markets.
11 March 2010	Since the SNB no longer has any room for manoeuvre, the SNB has been intervening in the foreign exchange market.
03 August 2011	Target range for three-month CHF Libor is narrowed to 0–0.25%. In addition, banks' sight deposits at the SNB will be expanded from CHF 30 billion to CHF 80 billion.

Table 1: SNB Policy Announcements in March 2009, 2010 and in August 2011.

The SNB's three major policy announcements between 2009-2011, which were just described, are summarized in Table 1. We are interested in the effect of these statements and the implementation of the policy measures on the EUR/CHF exchange rate. The actions announced at all three event dates have in common that they are aiming at a relaxation of the tight monetary conditions caused by the Swiss franc appreciation. However, they differ in some important respects. While in March 2009 the SNB took several different policy actions, in March 2010 and August 2011 foreign exchange interventions and the expansion of the monetary base, respectively, were the only or main[10] measures. Note that since the SNB reduced the monetary base after its foreign exchange operations in March 2010 these interventions can be considered as sterilized. The increase in sight deposits in August 2011, on the other hand, can be viewed as quantitative easing.

[7] See press release at `http://www.snb.ch/en/mmr/reference/pre_20110803/source/pre_20110803.en.pdf`

[8] See press release at `http://www.snb.ch/en/mmr/reference/pre_20110810/source/pre_20110810.en.pdf`

[9] See press release at `http://www.snb.ch/en/mmr/reference/pre_20110817/source/pre_20110817.en.pdf`

[10] The interest rate cut announced in August 2011 was not viewed as an effective instrument by the public since the CHF Libor was already at a very low level. In this respect, the increase in sight deposits can be viewed as the main announcement on this day.

3 Synthetic Control Approach

This section presents the synthetic control approach. The methodology was first proposed in Abadie and Gardeazabal (2003). Abadie et al. (2010) and Abadie et al. (2015) provide more proofs and details on its suitable span of application and develop further inferential techniques.

3.1 Example of an Underlying Model

Synthetic controls can provide useful estimates in a wide range of models. Here, and as in Abadie et al. (2010), we assume that the variable of interest can be represented by a factor model. However, using, for example, an autoregressive model with time-varying coefficients, the authors show that the synthetic control estimator is also unbiased in more general models. Since financial return series, including exchange rate returns, often exhibit similar characteristics leading to the belief that they might be driven by some common sources, a factor model seems suitable for our empirical investigation.

In what follows we provide a summary of the synthetic control method suggested in Abadie et al. (2010, 2015) with some links to our empirical analysis. In our case, the term "unit" refers to a currency area or a specific asset, while the term "treatment" can be substituted for "(monetary policy) intervention". Suppose that we observe $J+1$ units and that only the first unit is exposed to the intervention of interest. This leaves us with J remaining units that can serve as potential controls and build the so-called "donor pool". Let Y_{it} denote the observed outcome of the variable of interest (which in our case will be the exchange rate or the asset price), for units $i = 1, \dots, J+1$, and time periods $t = 1, \dots, T$. The intervention of interest is adopted in period $T_0 + 1$, hence, T_0 corresponds to the number of pre-intervention periods. Let Y_{it}^N be the outcome that would occur if no intervention takes place. Y_{it}^I, on the other hand, denotes the outcome that would occur if unit i is exposed to the intervention in periods $T_0 + 1$ to T.

The effect of the intervention for unit i in period t is given by $\alpha_{it} = Y_{it}^I - Y_{it}^N$. By assumption, the intervention has no effect on the outcome variable prior to the policy change, i.e. $Y_{it}^I = Y_{it}^N$ for all i and $t = 1, \dots, T_0$. In Section 4 we discuss this assumption in the context of our empirical investigation. In the presence of potential anticipation effects, it might make sense to choose T_0+1 to be the first period in which the outcome may possibly react to the intervention. Furthermore, and as is mentioned above, it is assumed that none of the units $i = 2, \dots, J+1$ is affected by the intervention.[11] Hence, the observed outcome can be expressed as

$$Y_{it} = Y_{it}^N + \alpha_{it} D_{it}, \tag{1}$$

where D_{it} is equal to 1 if $i = 1$ and $t > T_0$ and 0 otherwise.

The aim of the synthetic control approach is to estimate $\alpha_{1t} = Y_{1t}^I - Y_{1t}^N$ for $t > T_0$. Because Y_{1t}^I is observed ($Y_{1t}^I = Y_{1t}$), this boils down to estimating Y_{1t}^N, i.e. the counterfactual outcome of unit 1 had it not been exposed to the intervention.

[11] Assumption of no interference between units.

Now suppose that Y_{it}^N is given by the following factor model:

$$Y_{it}^N = \delta_t + \boldsymbol{\theta}_t \boldsymbol{Z}_i + \boldsymbol{\lambda}_t \boldsymbol{\mu}_i + \varepsilon_{it}. \quad (2)$$

δ_t is an unobserved common factor with constant factor loadings across units. $\boldsymbol{Z}_i$ represents an $(r \times 1)$ vector of observable (time-invariant) variables (that are unaffected by the intervention) and $\boldsymbol{\theta}_t$ is a $(1 \times r)$ vector of unknown parameters. $\boldsymbol{\lambda}_t$ is a $(1 \times F)$ vector of unobserved common factors and $\boldsymbol{\mu}_i$ is the according $(F \times 1)$ vector of unknown factor loadings. The error terms ε_{it}, finally, are transitory shocks with mean zero.

For the construction of the synthetic control of unit 1, in our case, the syntehtic EUR/CHF rate, each unit of the donor pool is assigned a weight w_j, where $j = 2, \ldots, J+1$. By assumption, $w_j \geq 0 \ \forall j$ and $\sum_{j=2}^{J+1} w_j = 1$. Let $\boldsymbol{W}$ be a $(J \times 1)$ vector of weights w_j. Each value of $\boldsymbol{W}$ defines a weighted average of the available control units and, hence, a synthetic control. The synthetic control for any specific weight vector $\boldsymbol{W}$ is:

$$\sum_{j=2}^{J+1} w_j Y_{jt} = \delta_t + \boldsymbol{\theta}_t \sum_{j=2}^{J+1} w_j \boldsymbol{Z}_j + \boldsymbol{\lambda}_t \sum_{j=2}^{J+1} w_j \boldsymbol{\mu}_j + \sum_{j=2}^{J+1} w_j \varepsilon_{jt}. \quad (3)$$

Suppose that there is a vector $\boldsymbol{W}^*$ of optimal weights that can accurately replicate all pre-intervention observations as well as the observable time-invariant variables of the first unit. That is,

$$\sum_{j=2}^{J+1} w_j^* Y_{jt} = Y_{1t} \quad \text{for } 1 \leq t \leq T_0, \quad \text{and} \quad \sum_{j=2}^{J+1} w_j^* \boldsymbol{Z}_j = \boldsymbol{Z}_1. \quad (4)$$

Abadie et al. (2010) then prove that under standard conditions, the unconditional expectation of $Y_{1t}^N - \sum_{j=2}^{J+1} w_j^* Y_{jt}$ goes to zero if the number of pre-intervention periods is large. Thus, for $t \geq T_0 + 1$, we can use

$$\hat{\alpha}_{1t} = Y_{1t} - \sum_{j=2}^{J+1} w_j^* Y_{jt} \quad (5)$$

as an estimator of α_{1t}. Thus, the intervention's effect on the outcome variable of interest, α_{1t}, can be estimated by $\hat{\alpha}_{1t}$, the gap between the actual outcome and the synthetic control.

3.2 Implementation

The synthetic control approach relies on data-driven procedures to select suitable comparison groups and construct the vector $\boldsymbol{W}$.

Define $\boldsymbol{X}_1$ to be a $(k \times 1)$ vector of pre-treatment characteristics or "predictors" of unit 1, where k is the number of predictors. These pre-treatment characteristics consist of the time-invariant observable variables in $\boldsymbol{Z}_1$, but can also contain individual observations of pre-intervention outcomes Y_{1t}, with $t \leq T_0$, or linear or non-linear combinations of these.[12] $\boldsymbol{X}_0$ is the corresponding $(k \times J)$ matrix containing the same pre-treatment characteristics for all the units in the donor pool.

The vector of optimal weights $\boldsymbol{W}^*$ is chosen such that the difference between the pre-intervention characteristics of the exposed unit, $\boldsymbol{X}_1$, and of the weighted units in the donor pool, $\boldsymbol{X}_0\boldsymbol{W}$, is minimized. In our analysis, the weighted combination of other exchange rates or safe assets is chosen such that it resembles the EUR/CHF rate most closely in terms of pre-intervention characteristics. For this purpose, each pre-treatment characteristic $m = 1, \ldots, k$ is assigned a weight v_m. This weight reflects the relative importance that is given to characteristic m when measuring the discrepancy between $\boldsymbol{X}_1$ and $\boldsymbol{X}_0\boldsymbol{W}$. Hence,

$$\boldsymbol{W}^* = \underset{\boldsymbol{W} \in \mathcal{W}}{\arg\min} \sum_{m=1}^{k} v_m (X_{1m} - X_{0m}\boldsymbol{W})^2, \tag{6}$$

where $\mathcal{W} = \{(w_2, \ldots, w_{J+1})'$ subject to $w_j \geq 0$ for $j = 2, \ldots, J+1$ and $\sum_{j=2}^{J+1} w_j = 1\}$. More formally, we can write,

$$\boldsymbol{W}^* = \underset{\boldsymbol{W} \in \mathcal{W}}{\arg\min} (\boldsymbol{X}_1 - \boldsymbol{X}_0\boldsymbol{W})'\boldsymbol{V}(\boldsymbol{X}_1 - \boldsymbol{X}_0\boldsymbol{W}), \tag{7}$$

where $\boldsymbol{V}$ is a diagonal and positive semi-definite $(k \times k)$ matrix with the main diagonal equal to $(v_1, \ldots, v_k)$. The solution to (7), $\boldsymbol{W}^*(\boldsymbol{V})$, does depend on $\boldsymbol{V}$. Abadie et al. (2010) suggest selecting $\boldsymbol{V}$ such that the root mean square prediction error (RMSPE) of the synthetic control estimator in the pre-intervention period is minimized[13]

$$\boldsymbol{V}^* = \underset{\boldsymbol{V} \in \mathcal{V}}{\arg\min} \left(\frac{1}{T_0} \sum_{t=1}^{T_0} \left(Y_{1t} - \sum_{j=2}^{J+1} w_j^*(\boldsymbol{V}) Y_{jt} \right)^2 \right)^{1/2}, \tag{8}$$

which is equivalent to

$$\boldsymbol{V}^* = \underset{\boldsymbol{V} \in \mathcal{V}}{\arg\min} (\boldsymbol{Z}_1 - \boldsymbol{Z}_0\boldsymbol{W}^*(\boldsymbol{V}))'(\boldsymbol{Z}_1 - \boldsymbol{Z}_0\boldsymbol{W}^*(\boldsymbol{V})), \tag{9}$$

where $\mathcal{V}$ is the set of all nonnegative diagonal $(k \times k)$ matrices. $\boldsymbol{Z}_1$ is a $(T_0 \times 1)$ vector containing the pre-intervention values of the outcome variable of unit 1 and $\boldsymbol{Z}_0$ the corresponding $(T_0 \times J)$ matrix for the units in the donor pool. Thus, $\boldsymbol{V}$ is such that it weights the pre-treatment characteristics

[12] Note that some predictors which we will use in our estimations, such as capital flows or interest rates, are potentially affected by the intervention. This is unproblematic, i.e. our estimator is still unbiased, as long as there are no anticipation effects. The reason is that in the construction of the synthetic control estimator, only periods $t \leq T_0$ are considered. Therefore, estimating equation (2) for the pre-intervention period leads to unbiased estimates of δ_t, $\boldsymbol{\theta}_t$ and $\boldsymbol{\lambda}_t$ and $Y_{1t}^N - \sum_{j=2}^{J+1} w_j^* Y_{jt}$ goes to zero, resulting in an unbiased synthetic control estimator.

[13] Alternatively, the choice of $\boldsymbol{V}$ could be subjective, reflecting previous knowledge about the relative importance of each predictor.

in $\boldsymbol{X}$ in accordance to their predictive power on the outcome.[14]

3.3 Inference

Because the number of units in the control group tends to be low[15], large-sample inferential techniques are not well suited to comparative case studies and, hence, the synthetic control estimator. Instead, Abadie et al. (2010, 2015) propose alternative methods of qualitative and quantitative inference, namely, two types of so-called "placebo studies": "in-time" and "in-space" placebos. The purpose of these exercises is to assess whether the observed gap between synthetic and actual outcome may have been caused by factors or events other than the intervention.

In "in-time" placebos, the synthetic control estimator is applied to dates prior to the actual date of intervention. If we find a large effect not only for the actual intervention date, but also for arbitrary dates where no interventions occurred, this is certainly a bad sign for the estimator's validity. Our confidence that the effect estimated at the event date is attributable to the intervention of the SNB would greatly diminish. We would have to conclude that the synthetic control methodology is probably not applicable to the Swiss franc.

In "in-space" placebos, the synthetic control methodology is applied to all the units in the donor pool, i.e. to the units that are similar to the unit of interest, but are not directly exposed to the intervention being analysed. The results can be used to create a distribution of placebo effects and allow assessing whether the effect estimated for the Swiss franc is large relative to the effect estimated for a currency area or asset chosen at random. A formal way of doing this consists of calculating the ratio of the post-intervention RMSPE to the pre-intervention RMSPE. For each unit, this RMSPE-ratio gives us a measure of how large the deviation of the observed outcome from its synthetic counterpart in the post-intervention period is relative to how well the synthetic control estimator is able to predict the actual outcome in the pre-intervention period. Assume that we find a large effect for the unit of interest. Then the hypothesis that the large synthetic control estimate reflects indeed the effect of the intervention would be supported only if its RMSPE-ratio is large relative to the ratios of the units that are not directly exposed to the intervention. Ordering the units according to the size of their RMSPE-ratios finally even allows constructing some form of p-value. We can compute the fraction (among *all* units) of RMSPE-ratios that are greater than or equal to the RMSPE-ratio of the unit of interest. This fraction then tells us the likelihood of obtaining a RMSPE-ratio at least as high as the one of the unit of interest when picking one of the units at random.

Note that while Abadie et al. (2010, 2015) suggest keeping the unit of interest in the donor pool, we decided to exclude Switzerland when doing the in-space placebo estimations. If a certain unit's outcome is highly correlated with the Swiss outcome in the pre-intervention period, Switzerland is

[14] Note that, instead of reproducing all the elements in $\boldsymbol{X}_1$, alternatively, the synthetic control could be chosen to reproduce only the outcome variable for unit 1. Then, we would replace $\boldsymbol{X}_1$ with $\boldsymbol{Z}_1$ and $\boldsymbol{X}_0$ with $\boldsymbol{Z}_0$ in equation (7). However, this method does not take into account known determinants of the outcome variable and hence, is less appropriate to construct the counterfactual.

[15] In our case, it is below 15.

likely to be assigned a high weight in the construction of that unit's synthetic control. Any effect that the intervention had on Switzerland's outcome would as a consequence then be reflected in this synthetic control. Hence, even if this unit in practice did not react to the intervention of interest, the gap between the observed outcome and its synthetic control would be different from zero and, therefore, suggest the opposite.

3.4 Comparison to the Linear Regression Model

As pointed out in Abadie et al. (2010, 2015), the synthetic control approach has several advantages as compared to traditional regression methods. First, it provides transparency with respect to the contribution of each control unit to the counterfactual and how well the unit of interest can be replicated in terms of pre-intervention characteristics. Second, it does not allow for extrapolation outside the support of the data, since the weights w_j assigned to the units in the donor pool are restricted to lie between 0 and 1.[16] A further advantage is that not only times-series but also static information (the predictors) can be taken into account. A pure time-series analysis would not only reflect the effect of the intervention but also the effect of pre-intervention differences in predictors (see Abadie and Gardeazabal (2003)). Compared to large-sample regression based studies a disadvantage is that standard inference methods cannot be applied. However, as described above, Abadie et al. (2010, 2015) solve this problem by providing new methods to perform inferential exercises in comparative case studies.

4 Sample and Data

The three interventions that we want to apply the synthetic control approach to are the ones described in Section 2. We build the following four samples. The first three samples consist of daily data, where the day of the policy announcement is chosen as the event or intervention date. The first sample around the event date 12 March 2009 comprises the period from 8 January to 14 April 2009. The second sample around 11 March 2010 spans the period from 7 January to 13 April 2010. The third sample around the August 2011 interventions covers the period from 1 June to 5 September 2011, with the first announcement taking place on 3 August. Each of these three samples consists of 45 pre-, and 24 post-intervention (business) days. Finally, we also construct a sample of weekly data for the spring 2010 interventions. While the SNB publishes data on foreign currency investments on a monthly basis only, data on sight deposits is available at a weekly frequency. Large increases in sight deposits have proven to be a reliable hint for interventions on the foreign exchange market. While the data on foreign currency investments in Figure 2 tell us that the SNB was more or less constantly intervening in spring 2010, the weekly data on sight deposits allows pining down a week that represents a break in its intervention policy. As can be seen in Figure 3, sight deposits started rising strongly starting in the first week of May (week of 3 to 7 May). We

[16] Without this restriction, $\boldsymbol{X}_1$ could be perfectly replicated as long as the rank of $\boldsymbol{X}_0$ is equal to k, irrespective of how much $\boldsymbol{X}_1$ differs from the elements in $\boldsymbol{X}_0$.

therefore define our last sample to be around this first week of May and to cover the period from the first week of January 2010 (week of 4 to 8 January) to the first week of July 2010 (week of 5 to 9 July). The sample consists of 17 pre-, and 10 post-intervention periods.

Note that the assumption of no anticipation effects of Section 3 might be violated in the context of our analysis. An appreciation of the Swiss franc potentially leads to the expectation that the SNB will take measures against it sooner or later. Since such expectations are immediately incorporated in asset prices, the effect of the intervention would be reflected in the exchange rate before the event date or week, which would lead to an underestimation of the true effect in our model. We mainly suspect such anticipation effects to be present in the two samples covering the foreign exchange interventions in spring 2010. Usually, one could shift the event date or week backwards to the first period in which the outcome may react to the intervention, however, in the 2009-2011 period, where policy actions were taken one after another, this is no solution.

The idea of the synthetic control approach is to build a counterfactual based on a sample of comparison units that exhibit similar characteristics like the unit of interest, but are not exposed to the intervention that is being analysed. Obviously, the EUR/CHF exchange rate is first of all an exchange rate, and the most straightforward way to form the group of control units is therefore to take other exchange rates. In their paper on the Brazilian real, this is what Chamon et al. (2016) do. However, as it is widely known, the Swiss franc also has a strong tendency to appreciate during times of high global or regional market uncertainty and hence exhibits safe haven patterns (see for example Ranaldo and Söderlind (2010) and Yeşin (2016)). For this reason, we build two potential donor pools, one containing exchange rates and another containing safe assets.

To construct the donor pool of exchange rates, we consider advanced economies with a flexible exchange rate regime[17]. Our exchange rate donor pool consists of 9 currency areas: Australia, Czech Republic, Israel, Japan, Korea, Norway, Sweden, the United Kingdom and the United States. As the aim in this paper is to build a counterfactual of the EUR/CHF exchange rate, we take all the currencies vis-à-vis the euro, i.e. the euro is the reference currency. In the donor pool of safe assets, we consider prices of 10-year zero coupon government bonds as well as the precious metals gold (XAU) and silver (XAG). We use government bond data for all the countries mentioned above apart from Korea, plus Germany and Canada. Hence, our safe asset donor pool overall consists of 12 assets. The gold and silver prices are the prices from the London bullion market. All data is from Thomson Reuters. Exchange rates are defined such that they are equal to the price of the euro in terms of the other currency's units. Likewise, bond and gold prices are inverted so that they indicate the price of the euro in terms of government bonds or metals.

One assumption on which the synthetic control method relies is that the units in the donor pool are not affected by the intervention. For our analysis this implies that only the EUR/CHF exchange rate is exposed to the SNB's interventions while the other exchange rates and safe assets are unaffected. Given that the turnover of Swiss franc on the global foreign exchange market

[17] As a consequence, we exclude Denmark, Hong Kong and Singapore.

is relatively small, this is a reasonable assumption.[18] Moreover, the synthetic control method requires that we discard from the donor pool all countries whose currencies or government bonds were subject to large idiosyncratic shocks. Thus, countries that for instance made major policy announcements affecting the exchange rate or that were actively and strongly intervening in the foreign exchange market during one sample period would need to be excluded from this specific sample. The years 2009 to 2011 span the ending of the financial crisis and the outbreak of the European sovereign debt crisis. Many of the major central banks put into practice unconventional monetary policy measures like large asset purchase programs. After a first inspection of the press releases of the central banks of the countries that we consider in our pool of potential comparison units, however, we see no reason to exclude any of the countries.

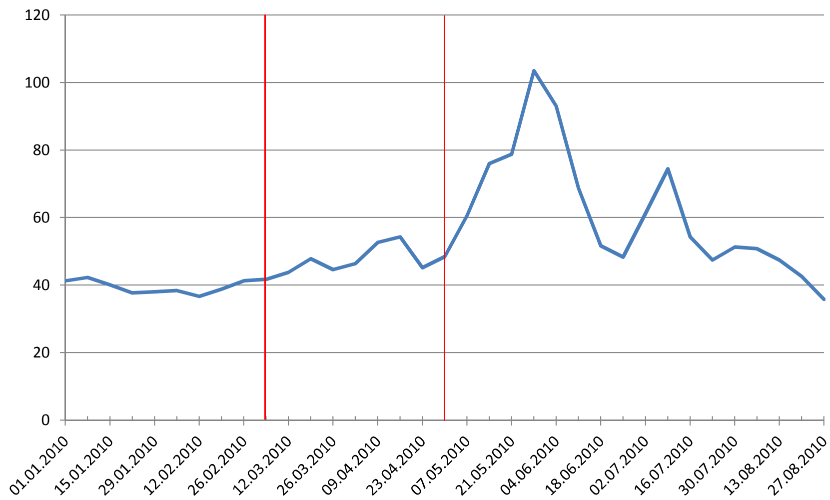


Figure 3: Weekly Sight Deposits of Domestic Banks at the SNB (in CHF billions, averaged over the week). The date indicates the end of the week and the red lines indicate the value in the previous week for the two weeks under analysis: the week ending on 12 March and the week ending on 7 May 2010. Source: SNB.

The synthetic control method offers the possibility to take into account specific predictors or relevant pre-intervention characteristics of the outcome variables when choosing the weights. Despite the empirical difficulties in explaining the movements in nominal exchange rates we still want to include some potential determinants of exchange rates in the estimations that are based on the exchange rate donor pool. Namely, we consider inflation, short-term interest rates, gross and net capital flows as potential predictors. The data is from the IMF International Financial Statistics (IFS). For the short-term interest rate we use the monthly money market rate, i.e. the rate on short-term lending between financial institutions. The data on (year-on-year) inflation is available on a monthly[19] and the data on capital flows on a quarterly basis. For the estimations we use the average over the two months or the average over the four quarters prior to the month or quarter in

[18]In 2010, the CHF's share in global daily foreign exchange market turnover was 6.3%. Source: BIS.
[19]For Australia and New Zealand only quarterly data is available.

which the announcement of the intervention took place. For the synthetic control estimator to be unbiased, predictors must be unaffected by the intervention (i.e. exogenous) if there are anticipation effects. As mentioned before, such effects might be present in the two samples covering the 2010 interventions. Since some predictors, e.g. Swiss capital flows or interest rates, are most likely influenced by the intervention, our estimates might then be biased. Therefore, as an alternative to capital flows we consider credit default swaps (CDS) spreads as a predictor. CDS spreads are not affected by the intervention even if there are anticipation effects and are therefore exogenous. Similar to capital flows, CDS spreads reflect the attractiveness of a currency for investments. A CDS provides the buyer an insurance against the default of the underlying loan. In turn, he has to compensate the seller with regular premium payments, called the CDS spreads. Therefore, CDS data gives information about how the market views credit risk. We use daily data on sovereign CDS from Datastream. Following Chamon et al. (2016) we also consider bond and stock market returns as explanatory variables. We use the MSCI price index from Datastream as stock market and prices of the 10-year zero coupon government bonds, which we also use in the safe assets sample, as bond market index. Both series are measured in euros.[20]

Finding specific pre-intervention characteristics that can be used for all safe assets is less obvious. In particular due to the gold and silver prices it is hard to think of suitable asset specific predictors. The reason is that it only makes sense to choose predictors to which all units in a donor pool are expected to react in the same way. If this condition was not fulfilled, choosing assets that resemble the EUR/CHF exchange rate as closely as possible in terms of pre-intervention characteristics would lead to an inappropriate choice of comparison units.[21] This excludes inflation as a potential predictor, even tough one might initially think that world inflation, for example, could be used as the gold-specific characteristic. However, the relationship between gold and world inflation differs from the relationship between a given country's inflation and the price of its currency or government bonds. While high inflation in a country is expected to lead to a depreciation of its currency and a decrease in its government bond prices, the relationship between inflation and gold, on the other side, is just the other way round: The price of gold is likely to increase as world inflation increases, as it serves as a hedge. Implied volatilities and risk reversals would be possible predictors that do not face this problem, but unfortunately data is incomplete or even missing for the 2009 to 2011 period. However, there are two other characteristics that contain information about how similar two assets are. The first one is the pre-intervention mean, and the other is the pre-intervention variance. We include these two in our estimations. A summary of all predictors used in the paper is provided in Table A.18 in the Appendix.

For the implementation of both, the statistical factor analysis as well as synthetic control approach, we take the log changes of the outcome variables, i.e. the exchange rates as well as government bond and gold and silver prices. Furthermore, we "demean" our outcome variables,

[20]The raw data is measured in local currency.

[21]Remember also equation (2): The parameter vector θ_t is the same across all units, hence, the effect of the time-invariant variables Z_i must be the same for exchange rates or assets.

	March 2009		March 2010		May 2010		August 2011	
	XRates	Safe Assets	XRates	Safe Assets	XRates	Safe Assets	XRates	Safe Assets
AUS	0.21	0.46	0.24	0.46	0.23	0.18	0.18	0.46
CAN	0.66	0.50	0.17	0.26	0.23	0.44	0.27	0.33
CHE	0.35	0.27	0.65	0.68	0.67	0.70	0.33	0.23
CZE	0.41	0.43	0.33	0.45	0.45	0.27	0.24	0.48
GBR	0.39	0.41	0.36	0.45	0.77	0.49	0.36	0.15
GER		0.28		0.24		0.17		0.21
ISR	0.24	0.88	0.22	0.78	0.23	0.35	0.39	0.65
JPN	0.23	0.34	0.40	0.28	0.37	0.19	0.16	0.22
KOR	0.32		0.34		0.21		0.10	
NOR	0.49	0.64	0.31	0.78	0.27	0.44	0.38	0.50
NZL	0.19		0.21		0.50		0.34	
SWE	0.19	0.41	0.40	0.28	0.32	0.49	0.35	0.67
USA	0.14	0.31	0.16	0.20	0.22	0.26	0.09	0.13
XAG		0.37		0.57		0.22		0.36
XAU		0.36		0.33		0.11		0.31

Table 2: Unexplained Variance. This table shows the fraction of the variance of each variable that cannot be explained by common factors. The analysis uses a model of three common factors for both, the samples of exchange rate returns (columns "XRates") and the samples of safe assets (columns "Safe Assets").

that is, we subtract the pre-intervention mean. While, technically, this should make no difference[22], it leads to a slightly better fit in the pre-intervention period (the qualitative statements, however, remain unchanged).

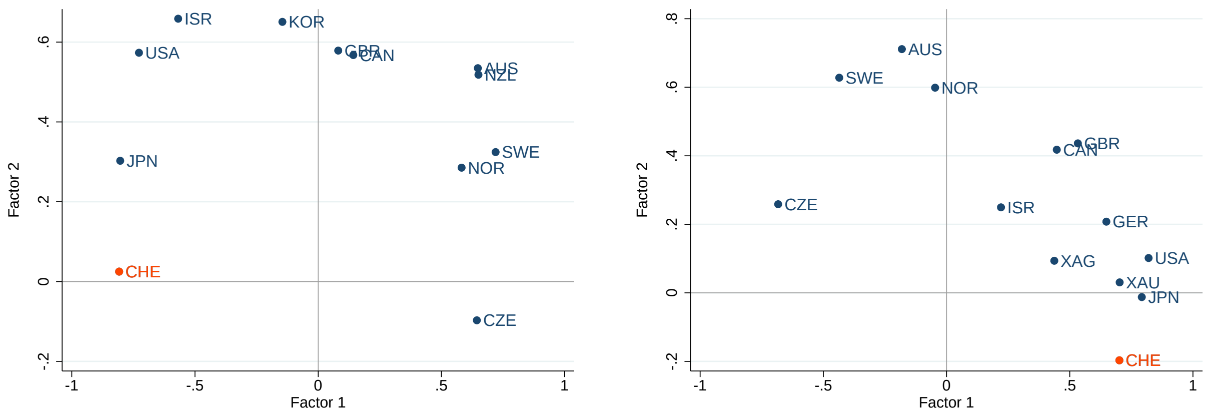
5 Factor Model

It has always been difficult explaining or even forecasting short run movements in exchange rates in the empirical literature. It has proven to be hard to find a model that beats a simple random walk when considering short horizons. Also over longer horizons, the determinants of exchange rates are not always obvious. This holds in particular for the Swiss franc. Yeşin (2016), for example, finds that a traditional determinant of exchange rates, namely the interest rate differential, shows only weak co-movement with the Swiss franc.

The synthetic control approach does not need the variables of interest to be predictable, and the role of determinants is of second order only. The methodology mainly relies on the co-movement of the variables of similar units, resulting from, potentially unobservable, common drivers. With the euro being the reference currency in our sample, it is obvious that there will inevitably be at least one major common driver, namely, all shocks that have a direct impact on the euro. Policy changes by the ECB as well as news and other shocks within the euro area leading to up- or downward

[22]See Section A in the Appendix for a formal proof.

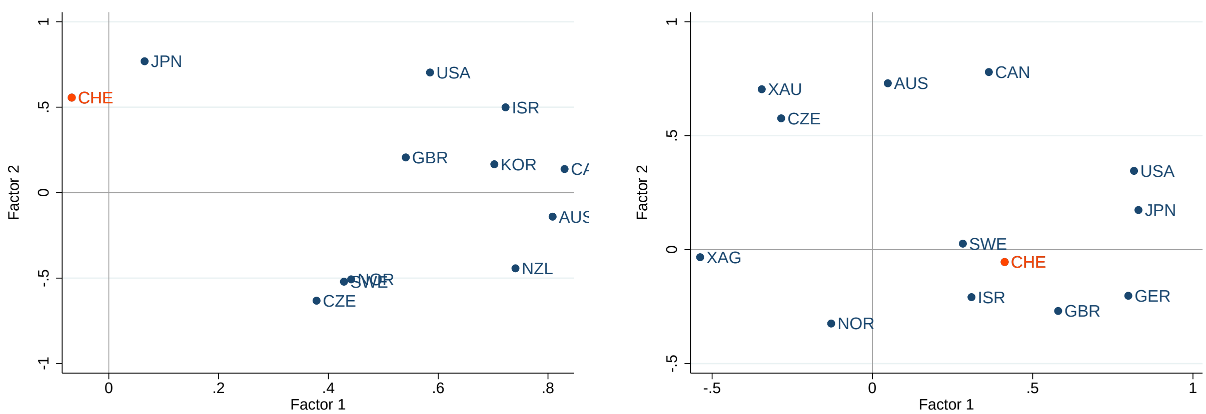
pressure on the euro represent an aggregate shock to all the other currencies or assets. Given that all the interventions we are studying in this paper took place during the euro area crisis, a majority of the news that financial markets reacted to at the time were coming from the euro area and hence represent common shocks to and are likely to be reflected in all the currency pairs and assets we are looking at.



(a) Exchange Rates

(b) Safe Assets

Figure 4: Factor Loadings: Pre-Intervention Period 2009. Factor Loadings on first two factors for the exchange rate sample (see Figure (a)) and the safe asset sample (see Figure (b)).

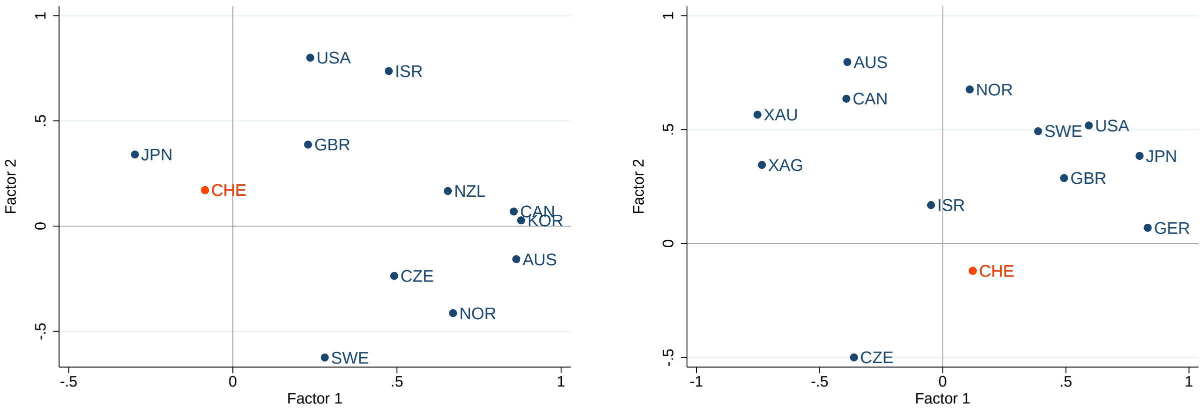


(a) Exchange Rates

(b) Safe Assets

Figure 5: Factor Loadings: Pre-Intervention Period March 2010. Factor Loadings on first two factors for the exchange rate sample (see Figure (a)) and the safe asset sample (see Figure (b)).

Before applying the synthetic control approach to the Swiss franc, we want to see whether there is indeed evidence for common factors among our sample of exchange rates and safe assets and how closely they are related to Switzerland's currency. A popular econometric tool that helps reveal whether some observed variables do have unobserved common drivers and how well these are able



(a) Exchange Rates

(b) Safe Assets

Figure 6: Factor Loadings: Pre-Intervention Period May 2010 (weekly data). Factor Loadings on first two factors for the exchange rate sample (see Figure (a)) and the safe asset sample (see Figure (b)).

to account for the variation of each of the variables is the so-called statistical factor analysis[23]. If a variable is well explained by a factor model, the synthetic control approach is likely to work well for this variable. We estimate a non-parametric factor model of the form:

$$Y_{it}^{N} - \delta_i = \boldsymbol{\lambda}_t \boldsymbol{\mu}_i + \varepsilon_{it} \tag{10}$$

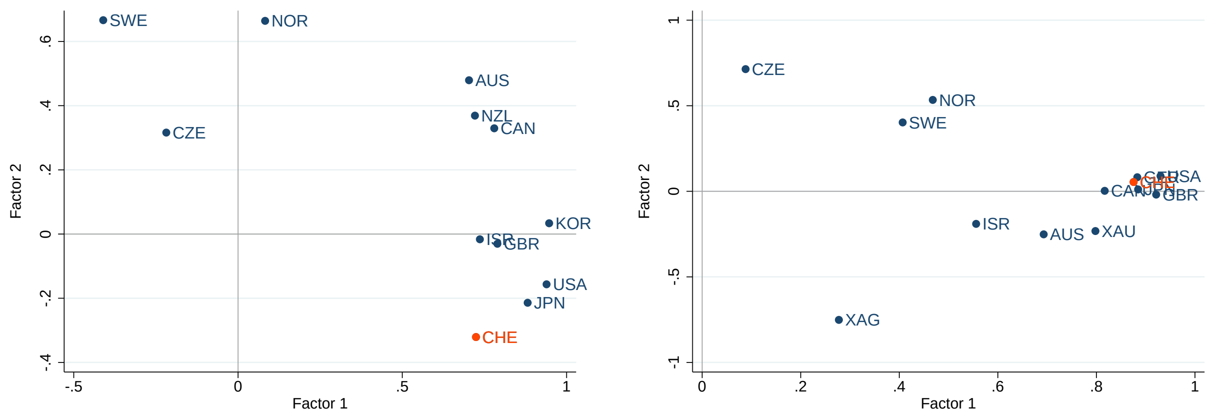
Compared to the factor model in equation (2), this simple statistical factor model neglects potential observable variables $\boldsymbol{Z}_i$. δ_i is the variable-specific mean. Remember that Y_{it}^{N} is the value of the observation on the ith variable in period t. For the purpose of this factor analysis, it is standardized to have variance 1, i.e. $Var[Y_{it}^{N}] = 1$. $\boldsymbol{\lambda}_t$ is a vector of F common (unobservable) factors with $E[\boldsymbol{\lambda}_t] = \mathbf{0}$ and $Cov[\boldsymbol{\lambda}_t] = \boldsymbol{I}_F$. $\boldsymbol{\mu}_i$ represents the unknown factor loadings, and ε_{it} the specific error or unique factor of variable i with $E[\varepsilon_{it}] = 0$ and $Var[\varepsilon_{it}] = \sigma_i^2$. The model is estimated with the principal-component method.[24][25]

We estimate the model for all the pre-intervention samples and both types of units we are considering, currency areas and safe assets, i.e. Y_{it}^{N} represents either exchange rate returns or returns on a safe asset. For each sample, we use a model of three common factors ($F = 3$). First, consider the model for safe assets in the pre-intervention period of the August 2011 interventions. It is the sample that yields the most promising results. The results are displayed in Table 2 (last column), in Figure 7(b) and in Table A.8 in the Appendix. Table A.8 reveals that the first two factors can account for roughly 64 percent of the variation in the variables. The unexplained

[23] For an introduction to statistical factor analysis of financial time series, see for example Tsay (2005).

[24] A key property of the statistical factor model is that the F factors and the corresponding factor loadings are unobservable. Therefore equation (10) which looks similar to a multivariate linear regression model cannot be estimated via linear regression methods.

[25] As Engel et al. (2015), we use the term factor to refer to a data generating process driven by factors, even if we use the principal components method for the estimation.



(a) Exchange Rates **(b)** Safe Assets

Figure 7: Factor Loadings: Pre-Intervention Period 2011. Factor Loadings on first two factors for the exchange rate sample (see Figure (a)) and the safe asset sample (see Figure (b)).

variance, also called uniqueness, in Table 2 gives the proportion of the variance of a variable (Var(Y_{it}^N)) that is not associated with the three factors in the model.[26] Intuitively, variables with a low uniqueness share more in common with the other variables. In the case of the EUR/CHF exchange rate, Table 2 reports a uniqueness of only 23%. This implies that the behaviour of the Swiss franc is quite well explained by three factors. On the other hand, it suggests that if we observed the other safe variables but not the EUR/CHF exchange rate, we can deduce the likely behaviour of the Swiss franc. Figure 7(b) furthermore reveals that the Swiss franc not only shares common factors with the other assets that we include in this safe asset category, but even shows a very strong co-movement with some of them. The traditional safe assets - Japanese, British, US, Canadian and German government bonds as well as gold - display factor loadings very similar to the Swiss franc on the first two factors, i.e. the factors that account for the largest part of the variance.

Overall, the results are similar when doing the same analysis for the sample of exchange rates instead of safe assets (see Table 2, Figure 7(a) and Table A.7). However, the uniqueness of the Swiss franc is now a bit higher (33%), implying that its variability is less well explained by exchange rate factors than by safe asset factors. Besides, also the co-movement with other exchange rates is likely to be less strong than the co-movement with other safe assets as can be inferred from the slightly more dispersed pattern of factor loadings in Figure 7(a).

The results for the pre-intervention period of the March 2009 intervention reveal that while generally also relatively low, the uniqueness of the EUR/CHF exchange rate is again lower when considering the safe asset sample than when considering the exchange rate sample (27% versus

[26] The uniqueness, also called specific variance, is defined as $1 - communality$, where the *communality* is the proportion of the variance of a particular variable $Var[Y_{it}^N]$ that is due to common factors (i.e. $communality = (\mu_{i1}^2 + ... + \mu_{iF}^2)$) and hence shared with other variables.

35%, see Table 2). Concerning the co-movement of the Swiss franc with other variables, we can see in Figure 4 that while the factor loadings of the Swiss franc on the first factor are of similar magnitude like some others (namely the Japanese, United States and the gold variable), the Swiss franc's factor loading on the second factor differs strongly from the other variables' loadings. Given that the SNB interventions of interest took place during periods of high global market uncertainty, it seems intuitive that generally the safe haven characteristics dominate exchange rate characteristics of the Swiss franc and, hence, that in turn the Swiss franc can be better represented by a sample of safe assets.

Altogether, the statistical factor analysis so far provides supporting evidence for the existence of major common factors that can also account for an important part of the Swiss franc's variability. This encourages the application of the synthetic control method to the EUR/CHF exchange rate to evaluate the effects of the March 2009 and August 2011 announcements. The results of the factor analysis for the pre-intervention periods of the spring 2010 interventions are less encouraging. First of all, the uniqueness values of the Swiss franc are considerably higher. For the exchange rate as well as for the safe asset sample it is both times above 60%. Figures 5 and 6 also show that the Swiss franc's factor loadings on the first two factors are relatively low if not zero. The patterns suggest that there is only low co-movement with other exchange rate or safe assets in these periods. Thus, the results of the synthetic control approach on the spring 2010 interventions should be interpreted with more care.

6 Results

This section describes the results of the synthetic control estimations. The estimations that are based on the exchange rate sample include some arbitrary pre-intervention observations of the outcome variable[27] plus inflation and CDS spreads as predictors. The estimations based on the safe asset sample include some arbitrary pre-intervention observations of the outcome variables plus the pre-intervention mean and volatility as predictors. All other predictors mentioned in section 4 are used in the robustness analysis.

6.1 Effect of the SNB's announcements on 12 March 2009

In order to prevent any further appreciation of the Swiss franc against the euro, on 12 March 2009, the SNB announced an interest rate cut, additional repo transactions and purchases of Swiss franc bonds issued by private sector borrowers as well as foreign currency on the foreign exchange market. Figure 8 shows the results for the change in the log EUR/CHF exchange rate when the synthetic control approach is applied to this announcements on 12 March 2009. The figures in the left column display the results one obtains when building the counterfactual EUR/CHF exchange rate based on the sample of other exchange rates, the figures in the right column display the corresponding results we get when building the counterfactual based on the sample of safe assets. Figures (a) and

[27] By including some arbitrary pre-intervention observations, we follow Abadie et al. (2010).

(b) plot the actual versus the synthetic exchange rate return. The red line indicates the day before the intervention. The weights assigned to the comparison units are reported in Tables A.9 and A.10 in the Appendix. Tables A.11-A.14 finally provide information on the diagonal elements of the $\boldsymbol{V}$-matrix and on the pre-intervention characteristics of the EUR/CHF rate and the synthetic control unit. The synthetic control group based on the sample of exchange rates assigns positive weight to the EUR/AUD, EUR/CZK, EUR/GBP, EUR/ILS, EUR/KRW and in particular to the EUR/JPY exchange rate. The synthetic control group based on safe assets assigns positive weight to Australian, Israeli, Japanese and in particular to German government bonds. While Figures (a) and (b) show that in both cases, the synthetic control series can reproduce the pre-intervention EUR/CHF rate quite well, the pre-intervention RMSPE of the safe assets series is slightly lower (0.0058 versus 0.0051, see top of Figures (e) and (f)). This finding is in line with the results of the factor analysis where we found that the Swiss franc exchange rate is better represented by a model of safe asset factors than a model of exchange rate factors. This implies that the results based on the control group of safe assets are more trustworthy.

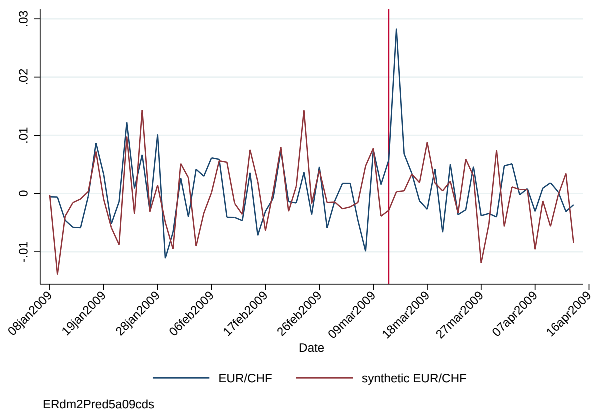
Concerning the effect of the intervention, we can see in Figures (a) and (b) that there is a large difference (around 3 percentage points) in the actual change in EUR/CHF and its synthetic control on the day of the announcement. In order to illustrate the implied effect on the level of the exchange rate, we calculate for both, the actual and the synthetic exchange rate, the cumulative sum of the log differences. The gap between the two is set to zero at time T_0[28], i.e. the last observation before the intervention, and is reported in Figures (c) and (d), respectively. Thus, the level of this gap in any period t corresponds to the accumulated log differences from the announcement to period t. Hence, for any t of the period after the intervention, Figures (c) and (d) tell us by how many percentage points the %-change in the exchange rate between T_0 and t would have been lower had there been no intervention, i.e. a positive value indicates that without the intervention, the Swiss franc would have appreciated more than its counterfactual. The bold dark blue line indicates the gap between the actual EUR/CHF and its synthetic counterpart. The thin lines correspond to the results of the "in-space" placebos, i.e. the gaps one obtains when applying the synthetic control methodology to the units in the donor pool. For the safe asset sample, the gap for the EUR/CHF exchange rate is slightly positive and quite stable in the pre-intervention period. It increases sharply on the day of the intervention, before gradually decreasing again over the following days. The results imply that the SNB's announcement caused a depreciation of the Swiss franc of a bit more than 3%, but that this effect vanished after just around 14 days. Note that the jump in the EUR/CHF gap right after the announcement is a big outlier. None of the placebos shows a similar pattern in the post-intervention period. Note also that while by construction, the EUR/CHF as well as the placebo gaps are equal to zero at $t = 0$ (i.e. the period before the first observation) as well as at $t = T_0$ (period before intervention), the EUR/CHF gap in the pre-intervention period is among the smallest ones, indicating that as compared to the others, the EUR/CHF exchange rate is very well represented by the synthetic control estimator.

[28] As we are demeaning the outcome variables, the gap will anyway by construction be equal to zero at T_0.

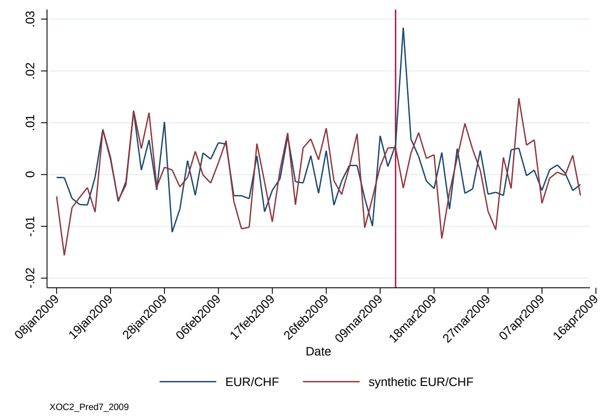
Figures (e) and (f), finally, report the ratios of the post-intervention RMSPE to the pre-intervention RMSPE for the EUR/CHF exchange rate and all control units (from the "in-space" placebos). The RMSPE measures the magnitude of the gap in the outcome variable, i.e. the difference in the log exchange rate for instance, between the actual outcome and its synthetic value. Recall that this RMSPE ratio tells us how large the deviation of the observed outcome from its synthetic counterpart in the post-intervention period is relative to how well the synthetic control estimator is able to predict the actual outcome in the pre-intervention period. A large post-intervention RMSPE is no evidence for a large effect of the intervention if the synthetic control is not capable of closely reproducing the outcome of interest prior to the intervention. While in Figure (e), the EUR/CHF exchange rate exhibits only the third largest RMSPE-ratio, in Figure (f), it clearly stands out as the safe asset with the highest RMSPE-ratio. If we were to pick an asset at random, the likelihood of observing a ratio as big as the one of the EUR/CHF exchange rate would be $1/13 \simeq 7.7\%$. Given that the synthetic EUR/CHF based on exchange rates has a lower pre-intervention RMSPE as compared to the synthetic EUR/CHF based on safe assets, the results on the latter are the ones we should trust.

Exchange Rates

Safe Assets



(a)



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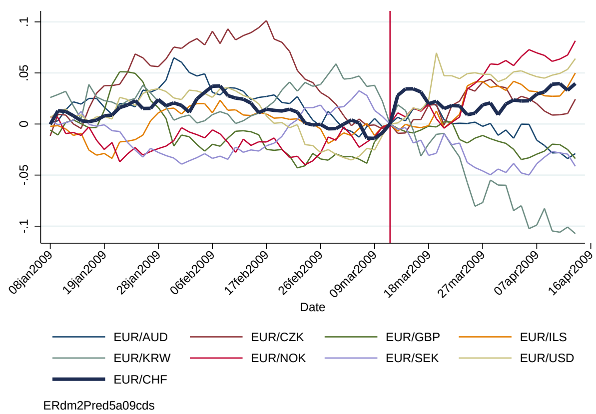
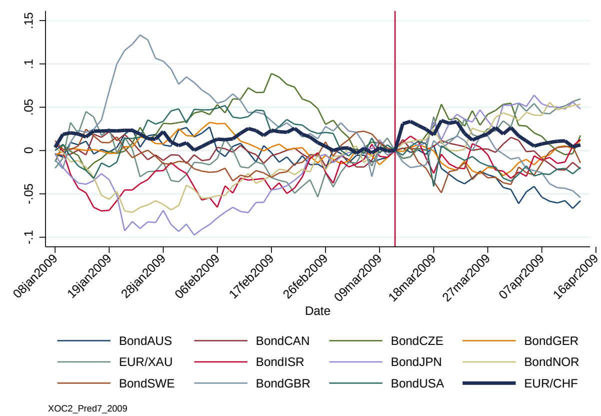


(c)



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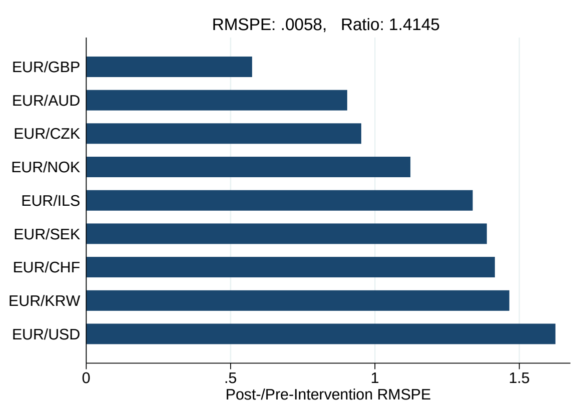
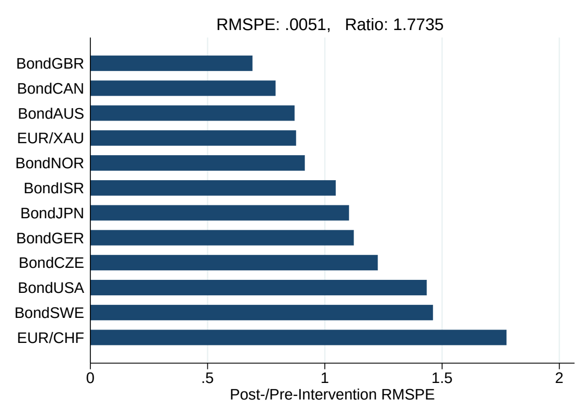


(e)



(f)

Figure 8: Synthetic Control Estimation Results: Announcement of 12 March 2009. Figures (a) and (b) plot the actual and the synthetic (demeaned) difference in the log EUR/CHF exchange rate. Figures (c) and (d) plot the gap between the accumulation of the actual and the synthetic outcome variable (set to zero in the period before the intervention). The red line indicates 11 March. Figures (e) and (f) report the ratio of the post- to the pre-intervention RMSPE. Daily data from 8 January to 14 April 2009. For exchange rates we use five arbitrary pre-intervention observations (*outcomes t-x*), *CDS* and *inflation* as predictors. *EUR/JPY* is not included in in-space placebo estimations. For safe assets we use five arbitrary pre-intervention observations (*outcomes t-x*), *mean* and *variance* as predictors. *EUR/XAG* is not included in in-space placebo estimations.

6.2 Effect of the SNB's press release of 11 March 2010

The second date we test is 11 March 2010. After its quarterly assessment, the SNB announced that it would continue to intervene on the foreign exchange market and to act decisively to prevent an excessive appreciation of the Swiss franc of the euro. Recall from the results of the factor analysis that the EUR/CHF exchange rate was not very well explained by neither exchange rate factors nor safe asset factors during the period prior to this press release. This raises some doubts whether the synthetic control approach is applicable to this date in the first place. Certainly, the results displayed in Figure 9 should be looked at with care.

Our concerns are confirmed in Figures (a) and (b). They reveal that the synthetic control series is not particularly successful at reproducing the actual pre-intervention series of the log change in EUR/CHF (the RMSPEs are again slightly smaller for the safe asset sample, 0.0034 versus 0.0028). Taking this into account, we can see that the differences in the post-intervention period are even larger, and interestingly almost constantly negative. This, in turn, translates into the first growing, then more or less constant negative gaps in the post-intervention period in Figures (c) and (d). These gaps suggest that without the announcement, the Swiss franc would within the next month have appreciated by around 3 percentage points less. Finally, in Figures (e) and (f), the EUR/CHF exchange rate exhibits the highest RMSPE ratio and is ranked last, suggesting that it is not by chance that we observe this persistent negative gap.

In other words, the results of the synthetic control approach suggest that while on 11 March 2010 the SNB announced to act decisively to prevent an excessive appreciation of the Swiss franc against the euro, this press release, if it had an impact at all, resulted in an even stronger appreciation.

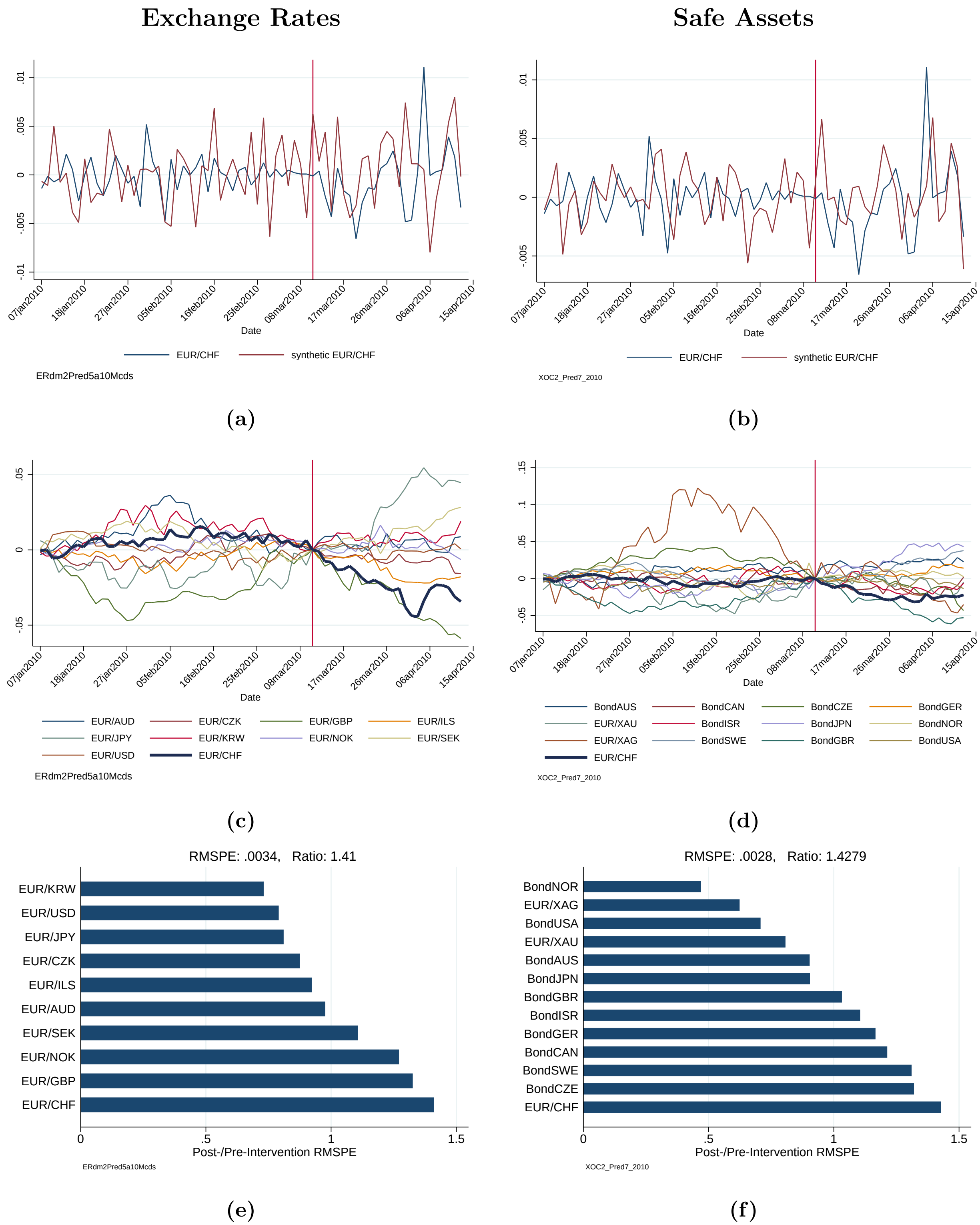


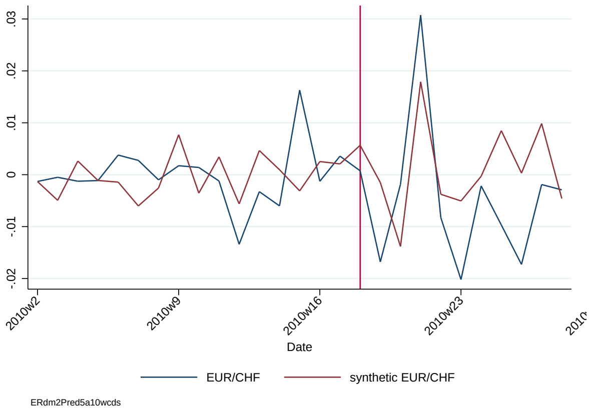
Figure 9: Synthetic Control Estimation Results: Announcement of 11 March 2010. Figures (a) and (b) plot the actual and the synthetic (demeaned) difference in the log EUR/CHF exchange rate. Figures (c) and (d) plot the gap between the accumulation of the actual and the synthetic outcome variable (set to zero in the period before the intervention). The red line indicates 10 March. Figures (e) and (f) report the ratio of the post- to the pre-intervention RMSPE. Daily data from 7 January to 13 April 2010. Same predictors as for Figure 8 are used.

6.3 Effect of the SNB's interventions in May 2010

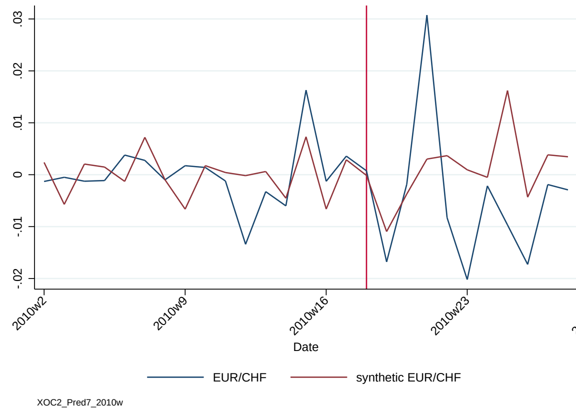
Sight deposits data suggest that in the week of 3 to 7 May 2010, the SNB started to intensify its purchases of foreign currency assets. This is the third date we apply the synthetic control method to. As opposed to the other events we are analysing, this sample is built on weekly data. The results are plotted in Figure 10. Recall from the factor analysis that the EUR/CHF exchange rate was not very well explained by exchange rate factors, but still relatively well explained by safe asset factors during the period prior to May 2010. Figures (a) and (b) and the corresponding RMSPE's (0.0069 versus 0.0053) confirm this finding. Hence, again, the results based on the sample of safe assets are more reliable. The safe assets that are assigned a positive weight in the construction of the synthetic change in the EUR/CHF exchange rate are silver, the government bonds of the Czech Republic, Germany and Israel (see Table A.10).

Table (b) reveals that the differences between the actual outcome and the counterfactual in the post-intervention period are mostly negative. This translates again into a negative gap in the post-intervention period as can be seen in Figure (d). However, there is no evidence for any immediate effects, the gap arises only gradually. Similar to the findings on the March 2010 press release, the negative gap suggests that without the announcement, the Swiss franc would within the next two months have appreciated by around 5 percentage points less. Finally, in terms of RMSPE-ratio, the EUR/CHF exchange rate is only ranked second. This suggests that it might be only by chance that we observe this negative gap.

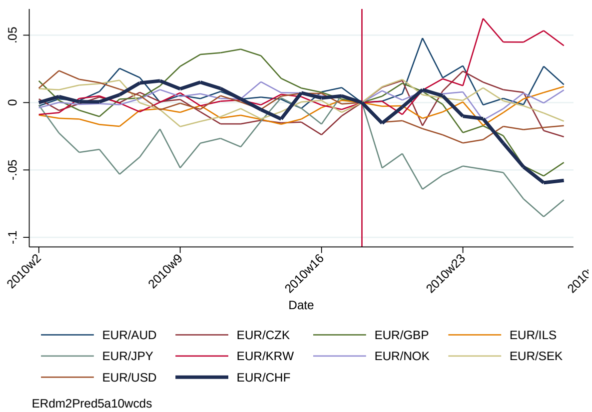
Exchange Rates | **Safe Assets**



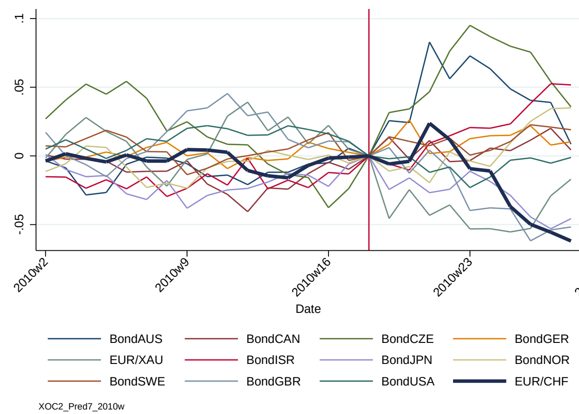
(a)



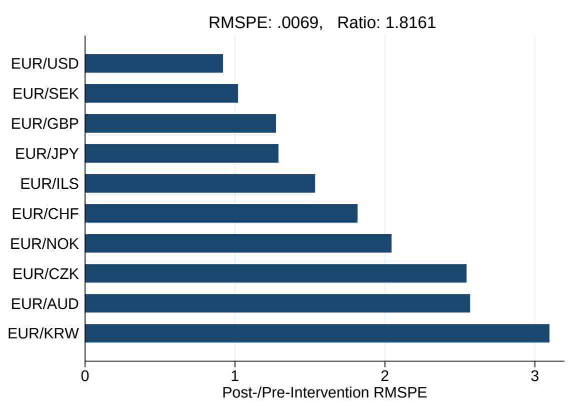
(b)



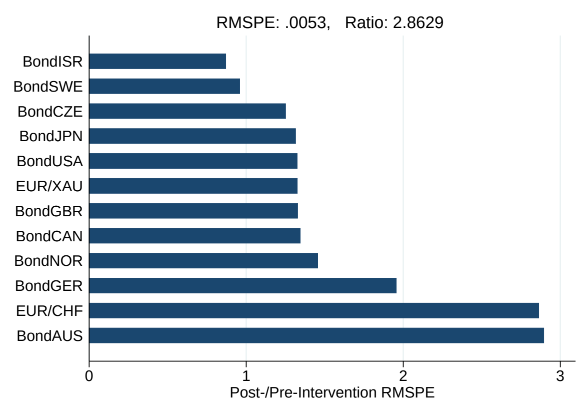
(c)



(d)



(e)



(f)

Figure 10: Synthetic Control Estimation Results: Interventions of first week of May 2010. Figures (a) and (b) plot the actual and the synthetic (demeaned) difference in the log EUR/CHF exchange rate. Figures (c) and (d) plot the gap between the accumulation of the actual and the synthetic outcome variable (set to zero in the period before the intervention). The red line indicates the week before the intervention date. Figures (e) and (f) report the ratio of the post- to the pre-intervention RMSPE. Weekly data from first week of January to first week of July 2010. Same predictors as for Figure 8 are used. *EUR/XAG* is not included in in-space placebo estimations for safe assets.

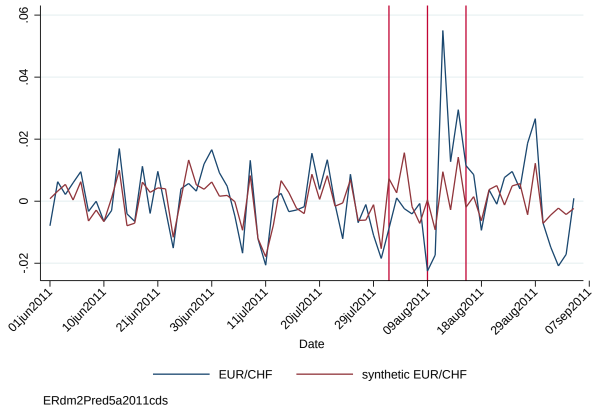
6.4 Effect of the SNB's announcements in August 2011

Finally, we apply the synthetic control method to the events in August 2011. On 3 August, 10 August as well as 17 August, the SNB announced an increase in sight deposits amounting to a total of 170 billion CHF. Figure 11 shows the results for when the synthetic control approach is applied to the first of this series of announcements, i.e. to 3 August 2011. Figures (a) and (b) show that in both cases, the synthetic control series can reproduce the pre-intervention EUR/CHF rate very well. Like in all the previous cases, the pre-intervention RMSPE of the safe assets series is lower than the RMSPE of the exchange rate series (0.0059 versus 0.0046). The safe assets that are assigned a positive weight in the construction of the synthetic change in the EUR/CHF exchange rate are the most traditional ones, i.e. the government bonds of Germany, Japan and the United States as well as gold (see Table A.10).

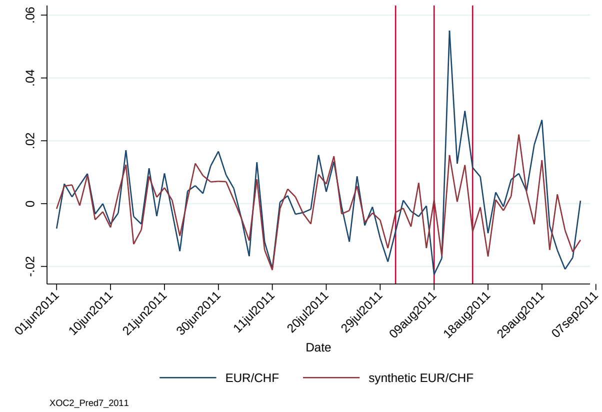
Concerning the effect of the announcement of 3 August, Figure (d) suggests that, at first, there was none at all. The gap remains very close to zero the days after this first intervention. It is only after the second announcement that the EUR/CHF starts to react. It increases sharply over the following days and continues along this positive trajectory also after the third and last announcement. Overall, the results suggest that the Swiss franc was around 13 percentage points weaker than it would have been without these policy measures. Given that we only observe an impact after the second announcement, we also applied the synthetic control approach directly to 10 August, i.e. treating the week of 3 to 9 August as additional pre-intervention period. The respective results are reported in Figure A.1 in the Appendix. Note that now the gap for the EUR/CHF exchange rate in Figure (d) is even more an outlier as compared to the placebos in the post-announcement period, with none of the placebos experiencing a comparably high shift.

In terms of the RMSPE-ratios, finally, the Swiss franc exchange rate is ranked first in all the various specifications (see Figures 11(e) and (f) as well as A.1(e) and (f)). Hence, overall, the synthetic control method is able to provide strong evidence for the effectiveness of the August 2011 interventions.

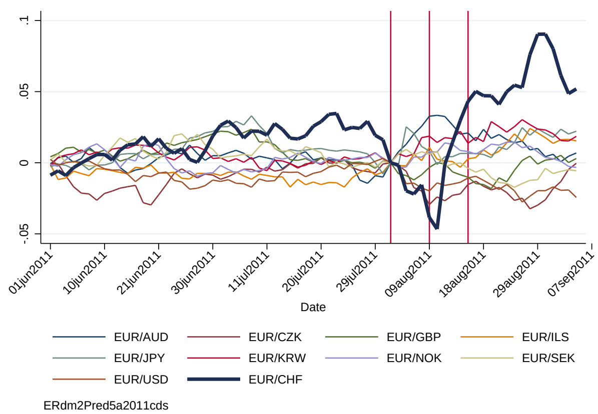
Exchange Rates **Safe Assets**



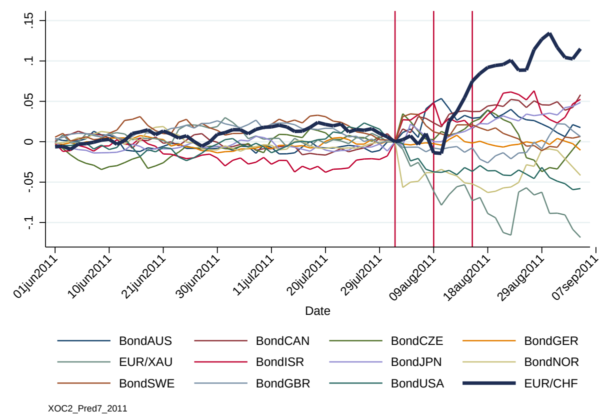
(a)



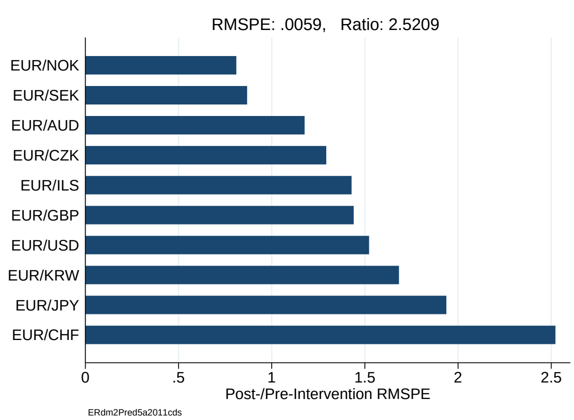
(b)



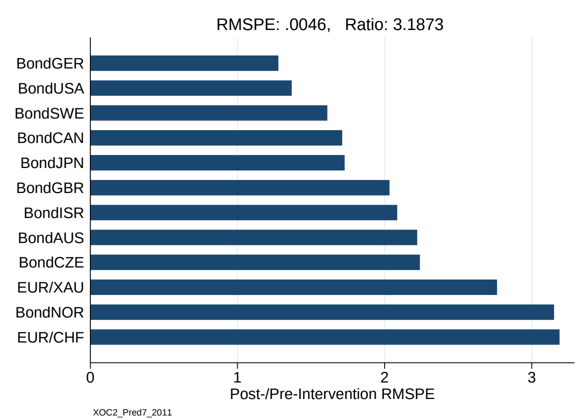
(c)



(d)



(e)



(f)

Figure 11: Synthetic Control Estimation Results: Announcement of 3 August 2011. Figures (a) and (b) plot the actual and the synthetic (demeaned) difference in the log EUR/CHF exchange rate. Figures (c) and (d) plot the gap between the accumulation of the actual and the synthetic outcome variable (set to zero in the period before the intervention). The red lines indicate 2, 9 and 16 August, respectively. Figures (e) and (f) report the ratio of the post- to the pre-intervention RMSPE. Daily data from 1 June to 5 September 2011. Same predictors as for Figure 8 are used. *EUR/XAG* is not included in in-space placebos estimations for safe assets.

6.5 Inference: In-Time Placebos

This section presents the results of the "in-time" placebo estimations. For each of the 4 samples, we perform the same estimation again, but shift the intervention period 15 days (in case of the daily samples), or 5 weeks (in case of the weekly sample), respectively, back and cut the samples off at the period before the actual intervention. The respective gap figures (corresponding to Figures (c) and (d) in the previous Figures) are plotted in Figure 12. The evolution of the EUR/CHF gap series are relatively stable, there are no big deviations from zero also after the intervention date. In terms of the RMSPE ratios, the EUR/CHF exchange rate is now always far from being ranked first and hence no outlier. This exercise supports our results and strengthens our confidence in the synthetic control method: While we did find effects at the dates of actual policy interventions, we find no effects when we artificially reassign the intervention date in our data to an earlier period.

6.6 Robustness

In order to provide further evidence for the robustness of our results we have performed additional estimations with alternative specifications of the sets of predictors and donor pools. Figures A.2 and A.3 and Tables A.15-A.17 in the Appendix show the results for the four intervention dates when the exchange rate and the safe asset samples are merged into one large donor pool. We use the same predictors as in the above exchange rate sample, namely five arbitrary pre-intervention observations of the outcome variable, CDS and $inflation$. Since we cannot use *inflation* as a predictor for gold and silver we have to remove these two safe assets from the donor pool. We are left with 18 comparison units.[29] Overall, the results are very similar to the ones in Figures 8-11. For the March 2009-sample the pre-intervention RMSPE improves slightly as compared to the two separate samples. Also the ratio of post- to pre-intervention RMSPE increases. However, this ratio is now only ranked second among the in-space placebos. For the August 2011-sample the pre-intervention RMSPE only improves compared to the exchange rate sample but not compared to the safe asset sample. We can conclude that in this case it is preferable to use separate samples for exchange rates and safe assets and that the safe asset sample still provides the best results.

Figures A.4-A.7 show estimations with alternative predictor sets. For the exchange rate sample we use five arbitrary pre-intervention observations of exchange rates, gross capital in- and outflows, net capital outflows, interest rates and inflation as predictors. For the safe asset sample we use five arbitrary pre-intervention observations of safe assets, CDS spreads and inflation.[30] For all specifications the results are very similar as before. For the exchange rate sample around 12 March 2009 the pre-intervention fit of the CHF/EUR rate slightly worsens while for the sample around 3 August 2011 it is almost identical. Also the ranking of the RMSPE ratio does not change. For the safe asset samples around 12 March 2009 the pre-intervention fit slightly improves while for the

[29] The donor pool consists of the 9 units from the exchange rate sample, the 12 units from the safe asset sample, minus gold, silver and the Canadian bond. For Canada, there is no data on CDS spreads available.

[30] For the safe asset sample we again omit gold, silver and the Canadian bond for the same reasons as we omit them in the merged sample.

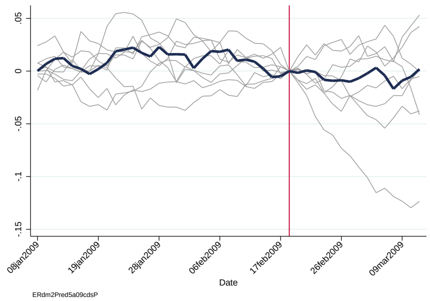
sample around 3 August 2011 it slightly worsens. Again, the ranking of the RMSPE ratio does not change for both periods.

We also perform an estimation with exchange rates as the outcome variable where in addition to the predictors used in the main estimations we consider bond and stock market indices, as done by Chamon et al. (2016). The results are shown in Figure A.8 in the Appendix.[31] Since there is no comparable data available for Swiss zero-coupon bonds before 14 December 2010, we perform this estimation for the August 2011-sample only. The results are again very similar to the main results in Figure 11. The EUR/CHF rate is equally well replicated, the pre-intervention RMSPE are almost identical and the ranking of the RMSPE ratio does not change.

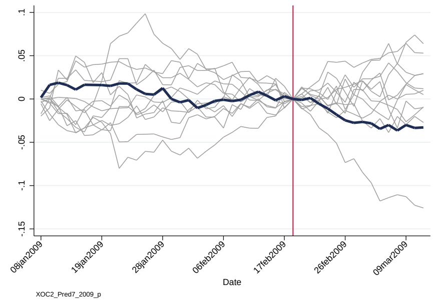
Generally, it can be said that the choice of predictors only has little impact on the (qualitative and quantitative) results. Adding stock and bond market indices to the predictors, or neglecting the pre-intervention mean and variance hardly has an effect, i.e. the results are quite robust. We can conclude that our main findings are robust with respect to alternative predictors and alternative donor pools.

[31] There is no comparable data available for Korean zero-coupon bonds, therefore we omit the KRW/EUR rate and are left with 8 units in the donor pool.

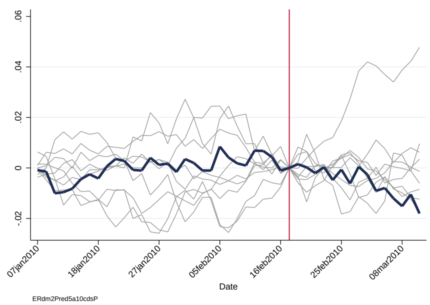
Exchange Rates **Safe Assets**



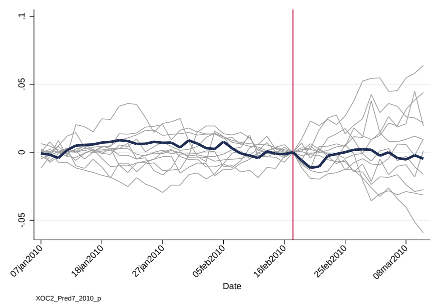
(a) February 2009



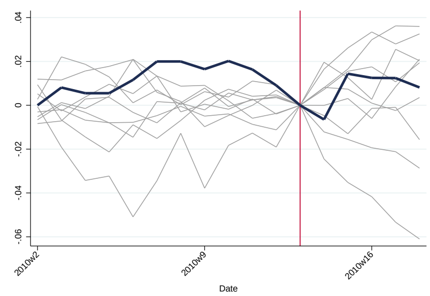
(b) February 2009



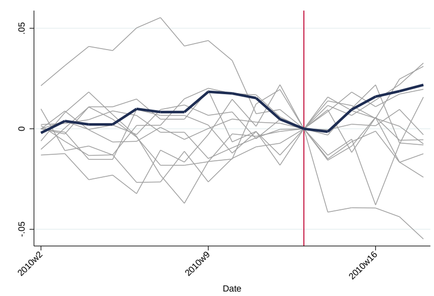
(c) February 2010



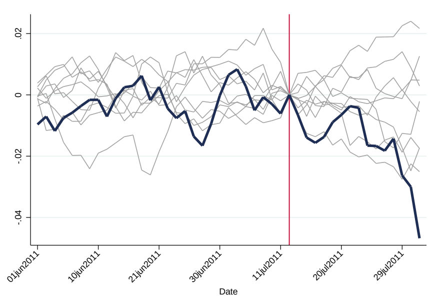
(d) February 2010



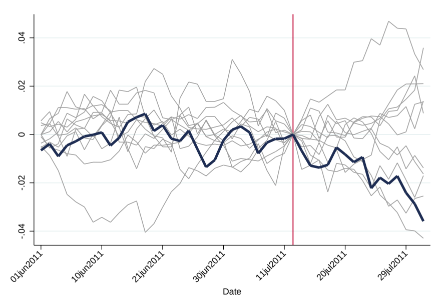
(e) April 2010



(f) April 2010



(g) July 2011



(h) July 2011

Figure 12: In-Time Placebo Estimations. Synthetic control estimation applied to date 15 periods (in case of daily samples) or 5 periods (in case of weekly sample) prior to actual intervention date. The bold line represents the gap between the accumulation of the actual and the synthetic difference in the log EUR/CHF (set to zero in the period before the intervention). The thin lines correspond to the "in-space" placebos.

7 Conclusions

In this paper, we use the synthetic control approach to evaluate the impact of changes in the SNB's policy on the EUR/CHF exchange rate over the period 2009 to 2011. We find that, in general, the synthetic control approach is a suitable technique for this purpose. Based on a sample of comparison units, reproducing the EUR/CHF exchange rate in periods prior to interventions works quite well, especially when the sample of comparison units consists of other safe assets. Furthermore, the synthetic control method does find large effects at those events where we would expect it to find large effects. Overall, the exchange rate samples have a lower goodness of fit, but in general support the results we find when using the safe asset samples, hence, our findings are quite robust. The results of the synthetic control approach suggest that the March 2009 announcement led to an immediate depreciation of the Swiss franc. This effect, however, disappeared after a few days. The results on the foreign exchange interventions in spring 2010, on the other hand, suggest that if they had an impact at all, they led to a further appreciation of the Swiss franc. The series of announcements in August 2011, finally, triggered a significant depreciation of the Swiss franc.

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A Implications of Demeaning

Let ρ_i be any unit-specific constant. Suppose the underlying model has the form of equation (2). Subtracting ρ_i from both sides of this equation yields:

$$\begin{aligned} Y_{it}^N - \rho_i &= \delta_t + \theta_t \boldsymbol{Z}_i + \lambda_t \mu_i - \rho_i + \varepsilon_{it} \\ \Leftrightarrow Y_{it}^N - \rho_i &= \delta_t + \theta_t \boldsymbol{Z}_i + (\lambda_t, 1)\left(\mu_i', -\rho_i\right)' + \varepsilon_{it} \\ \Leftrightarrow \widetilde{Y_{it}^N} &= \delta_t + \theta_t \boldsymbol{Z}_i + \widetilde{\lambda}_t \widetilde{\mu}_i + \varepsilon_{it} \end{aligned} \tag{11}$$

Equation (11) has the same form as equation (2). Thus, whatever statements are true for equation (2) will hold for equation (11) as well. In particular, this implies that the synthetic control estimator will also be applicable to a "demeaned" version of Y_{it}, namely $\widetilde{Y_{it}} = Y_{it} - \frac{1}{T_0}\sum_{t=1}^{T_0} Y_{it}$ (i.e. with ρ_i equal to the pre-intervention mean). Note that this way of "demeaning" does not rely on any assumption on the mean. In particular, it does not imply that the pre- and the post-intervention mean are equal.

B Tables and Figures

B.1 Factor Model

	Eigenvalue	Proportion	Cumulative
Factor1	4.312	0.359	0.359
Factor2	2.686	0.224	0.583
Factor3	1.190	0.099	0.682
Factor4	0.841	0.070	0.752
Factor5	0.730	0.061	0.813
Factor6	0.686	0.057	0.870
Factor7	0.464	0.039	0.909
Factor8	0.395	0.033	0.942
Factor9	0.270	0.022	0.965
Factor10	0.196	0.016	0.981
Factor11	0.140	0.012	0.993
Factor12	0.089	0.007	1.000

Table A.1: Factor Analysis - Exchange Rates: March 2009. Factor analysis of pre-intervention period.

	Eigenvalue	Proportion	Cumulative
Factor1	4.122	0.317	0.317
Factor2	1.854	0.143	0.460
Factor3	1.362	0.105	0.564
Factor4	1.336	0.103	0.667
Factor5	1.033	0.079	0.747
Factor6	0.826	0.064	0.810
Factor7	0.677	0.052	0.862
Factor8	0.496	0.038	0.900
Factor9	0.461	0.035	0.936
Factor10	0.360	0.028	0.964
Factor11	0.188	0.014	0.978
Factor12	0.169	0.013	0.991
Factor13	0.115	0.009	1.000

Table A.2: Factor Analysis - Safe Assets: March 2009. Factor analysis of pre-intervention period.

	Eigenvalue	Proportion	Cumulative
Factor1	4.072	0.339	0.339
Factor2	2.877	0.240	0.579
Factor3	1.271	0.106	0.685
Factor4	0.965	0.080	0.765
Factor5	0.601	0.050	0.815
Factor6	0.495	0.041	0.857
Factor7	0.482	0.040	0.897
Factor8	0.393	0.033	0.930
Factor9	0.310	0.026	0.955
Factor10	0.261	0.022	0.977
Factor11	0.153	0.013	0.990
Factor12	0.120	0.010	1.000

Table A.3: Factor Analysis - Exchange Rates: March 2010. Factor analysis of pre-intervention period.

	Eigenvalue	Proportion	Cumulative
Factor1	3.313	0.255	0.255
Factor2	2.384	0.183	0.438
Factor3	1.555	0.120	0.558
Factor4	1.274	0.098	0.656
Factor5	0.873	0.067	0.723
Factor6	0.836	0.064	0.787
Factor7	0.770	0.059	0.846
Factor8	0.631	0.049	0.895
Factor9	0.410	0.032	0.926
Factor10	0.367	0.028	0.955
Factor11	0.262	0.020	0.975
Factor12	0.227	0.017	0.992
Factor13	0.101	0.008	1.000

Table A.4: Factor Analysis - Safe Assets: March 2010. Factor analysis of pre-intervention period.

	Eigenvalue	Proportion	Cumulative
Factor1	3.878	0.323	0.323
Factor2	2.153	0.179	0.503
Factor3	1.492	0.124	0.627
Factor4	0.957	0.080	0.707
Factor5	0.906	0.075	0.782
Factor6	0.790	0.066	0.848
Factor7	0.659	0.055	0.903
Factor8	0.592	0.049	0.952
Factor9	0.238	0.020	0.972
Factor10	0.175	0.015	0.987
Factor11	0.137	0.011	0.998
Factor12	0.022	0.002	1.000

Table A.5: Factor Analysis - Exchange Rates: May 2010. Factor analysis of pre-intervention period.

	Eigenvalue	Proportion	Cumulative
Factor1	3.645	0.280	0.280
Factor2	2.973	0.229	0.509
Factor3	2.075	0.160	0.669
Factor4	1.320	0.102	0.770
Factor5	0.895	0.069	0.839
Factor6	0.660	0.051	0.890
Factor7	0.478	0.037	0.927
Factor8	0.343	0.026	0.953
Factor9	0.245	0.019	0.972
Factor10	0.195	0.015	0.987
Factor11	0.091	0.007	0.994
Factor12	0.051	0.004	0.998
Factor13	0.029	0.002	1.000

Table A.6: Factor Analysis - Safe Assets: May 2010. Factor analysis of pre-intervention period.

	Eigenvalue	Proportion	Cumulative
Factor1	6.090	0.508	0.508
Factor2	1.635	0.136	0.644
Factor3	1.082	0.090	0.734
Factor4	0.883	0.074	0.807
Factor5	0.722	0.060	0.868
Factor6	0.509	0.042	0.910
Factor7	0.334	0.028	0.938
Factor8	0.256	0.021	0.959
Factor9	0.205	0.017	0.976
Factor10	0.147	0.012	0.989
Factor11	0.089	0.007	0.996
Factor12	0.048	0.004	1.000

Table A.7: Factor Analysis - Exchange Rates: August 2011. Factor analysis of pre-intervention period.

	Eigenvalue	Proportion	Cumulative
Factor1	6.605	0.508	0.508
Factor2	1.693	0.130	0.638
Factor3	0.998	0.077	0.715
Factor4	0.809	0.062	0.777
Factor5	0.668	0.051	0.829
Factor6	0.542	0.042	0.870
Factor7	0.469	0.036	0.906
Factor8	0.444	0.034	0.941
Factor9	0.281	0.022	0.962
Factor10	0.180	0.014	0.976
Factor11	0.148	0.011	0.987
Factor12	0.103	0.008	0.995
Factor13	0.061	0.005	1.000

Table A.8: Factor Analysis - Safe Assets: August 2011. Factor analysis of pre-intervention period.

B.2 Synthetic Control Approach - Main Results

	March 2009	March 2010	May 2010	August 2011
EUR/AUD	0.17	0.00	0.00	0.00
EUR/CZK	0.17	0.29	0.48	0.00
EUR/GBP	0.16	0.00	0.08	0.11
EUR/ILS	0.08	0.09	0.00	0.00
EUR/JPY	0.38	0.28	0.02	0.81
EUR/KRW	0.03	0.19	0.00	0.00
EUR/NOK	0.00	0.02	0.10	0.08
EUR/SEK	0.00	0.00	0.12	0.00
EUR/USD	0.00	0.12	0.20	0.00

Table A.9: Synthetic Control Weights: Exchange Rates. $\boldsymbol{W}$-weights assigned to comparison units.

	March 2009	March 2010	May 2010	August 2011
BondAUS	0.09	0.13	0.00	0.00
BondCAN	0.00	0.00	0.00	0.00
BondCZE	0.00	0.19	0.25	0.00
BondGER	0.62	0.67	0.55	0.32
EUR/XAU	0.00	0.01	0.00	0.22
BondISR	0.12	0.00	0.19	0.00
BondJPN	0.17	0.00	0.00	0.19
BondNOR	0.00	0.00	0.00	0.00
EUR/XAG	0.00	0.00	0.01	0.00
BondSWE	0.00	0.00	0.00	0.00
BondGBR	0.00	0.00	0.00	0.00
BondUSA	0.00	0.00	0.00	0.27

Table A.10: Synthetic Control Weights: Safe Assets. $\boldsymbol{W}$-weights assigned to comparison units.

	March 2009	March 2010	May 2010	August 2011
CDS	0.60	0.00	0.00	0.05
inflation	0.00	0.01	0.00	0.71
outcome t-5	0.04	0.00	0.00	0.07
outcome t-15	0.28	0.34		0.08
outcome t-25	0.00	0.43		0.09
outcome t-35	0.02	0.21		0.00
outcome t-45	0.05	0.00		0.00
outcome t-8			0.00	
outcome t-11			0.00	
outcome t-14			0.89	
outcome t-17			0.10	

Table A.11: V-Weights: Exchange Rates. Diagonal elements of the $\boldsymbol{V}$-matrix. A description of predictors is provided in Table A.18.

	March 2009	March 2010	May 2010	August 2011
mean	0.01	0.01	0.00	0.04
variance	0.15	0.31	0.00	0.45
outcome t-5	0.16	0.03	0.04	0.03
outcome t-15	0.17	0.01		0.27
outcome t-25	0.25	0.02		0.04
outcome t-35	0.22	0.03		0.01
outcome t-45	0.04	0.60		0.15
outcome t-8			0.07	
outcome t-11			0.85	
outcome t-14			0.01	
outcome t-17			0.03	

Table A.12: V-Weights: Safe Assets. Diagonal elements of the $\boldsymbol{V}$-matrix. A description of predictors is provided in Table A.18.

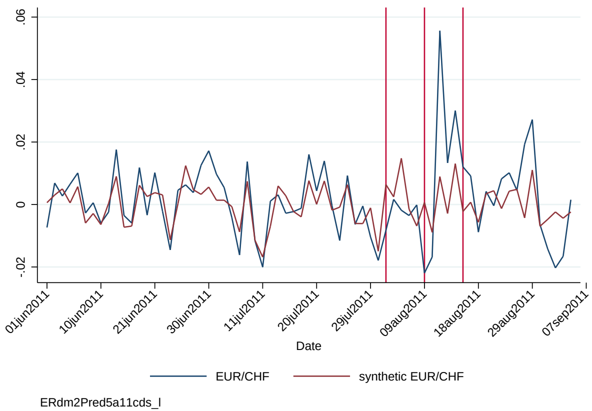
	March 2009		March 2010		May 2010		August 2011	
	$\boldsymbol{X}_{1m}$	$\boldsymbol{X}_{0m}\boldsymbol{W}$	$\boldsymbol{X}_{1m}$	$\boldsymbol{X}_{0m}\boldsymbol{W}$	$\boldsymbol{X}_{1m}$	$\boldsymbol{X}_{0m}\boldsymbol{W}$	$\boldsymbol{X}_{1m}$	$\boldsymbol{X}_{0m}\boldsymbol{W}$
CDS	149.6090	146.5529	50.4066	84.5576	46.6936	61.3033	35.8251	55.1420
inflation	0.0000	0.0002	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
outcome t-5	-0.0046	-0.0015	0.0005	-0.0011	-0.0060	0.0010	-0.0069	-0.0062
outcome t-15	0.0074	0.0080	-0.0001	-0.0001			0.0025	0.0066
outcome t-25	0.0030	-0.0034	-0.0048	-0.0048			0.0120	0.0039
outcome t-35	0.0122	0.0098	-0.0022	-0.0021			-0.0041	-0.0079
outcome t-45	-0.0006	-0.0003	-0.0014	-0.0007			-0.0079	0.0008
outcome t-8					-0.0012	0.0034		
outcome t-11					-0.0010	-0.0026		
outcome t-14					-0.0011	-0.0011		
outcome t-17					-0.0013	-0.0013		

Table A.13: Pre-Intervention Characteristics: Exchange Rates. Predictor values for the unit affected by the intervention and the synthetic control unit. A description of predictors is provided in Table A.18.

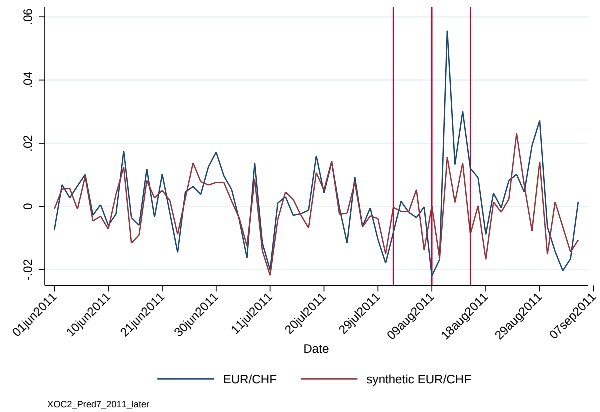
	March 2009		March 2010		May 2010		August 2011	
	$\boldsymbol{X}_{1m}$	$\boldsymbol{X}_{0m}\boldsymbol{W}$	$\boldsymbol{X}_{1m}$	$\boldsymbol{X}_{0m}\boldsymbol{W}$	$\boldsymbol{X}_{1m}$	$\boldsymbol{X}_{0m}\boldsymbol{W}$	$\boldsymbol{X}_{1m}$	$\boldsymbol{X}_{0m}\boldsymbol{W}$
mean	-0.0003	-0.0001	-0.0003	-0.0008	-0.0020	-0.0035	-0.0025	-0.0014
variance	0.0000	0.0001	0.0000	0.0000	0.0000	0.0001	0.0001	0.0001
outcome t-5	-0.0046	-0.0102	0.0005	-0.0005	-0.0060	-0.0045	-0.0069	-0.0060
outcome t-15	0.0074	0.0080	-0.0001	0.0028			0.0025	0.0047
outcome t-25	0.0030	-0.0016	-0.0048	-0.0006			0.0120	0.0069
outcome t-35	0.0122	0.0123	-0.0022	-0.0003			-0.0041	-0.0129
outcome t-45	-0.0006	-0.0042	-0.0014	-0.0011			-0.0079	-0.0016
outcome t-8					-0.0012	0.0004		
outcome t-11					-0.0010	-0.0010		
outcome t-14					-0.0011	0.0015		
outcome t-17					-0.0013	0.0024		

Table A.14: Pre-Intervention Characteristics: Safe Assets. Predictor values for the unit affected by the intervention and the synthetic control unit. A description of predictors is provided in Table A.18.

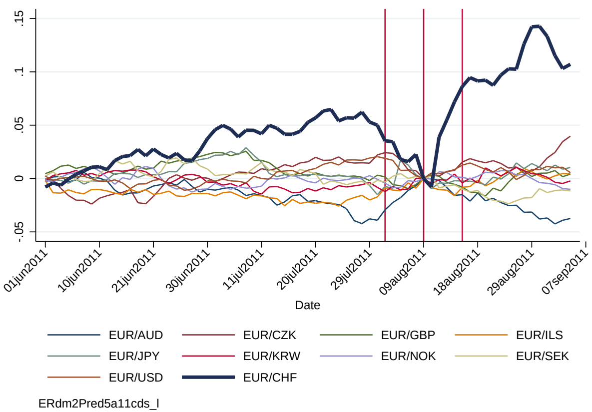
Exchange Rates | **Safe Assets**



(a)



(b)



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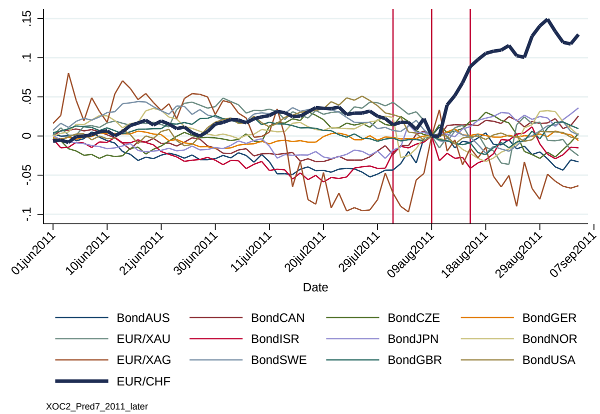
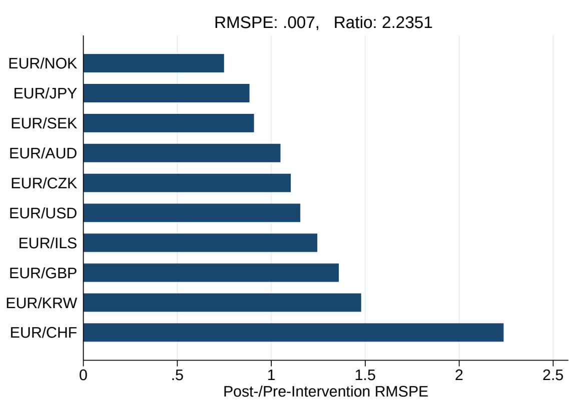
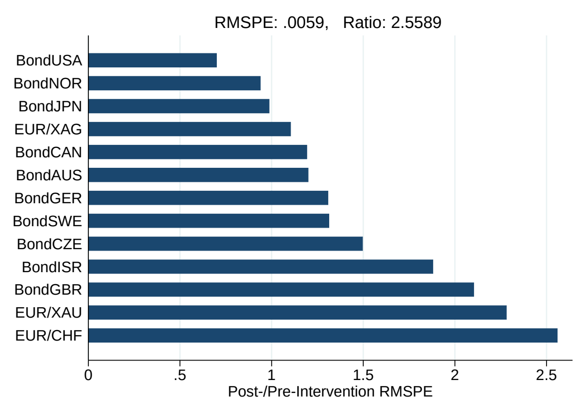


(d)



(e)

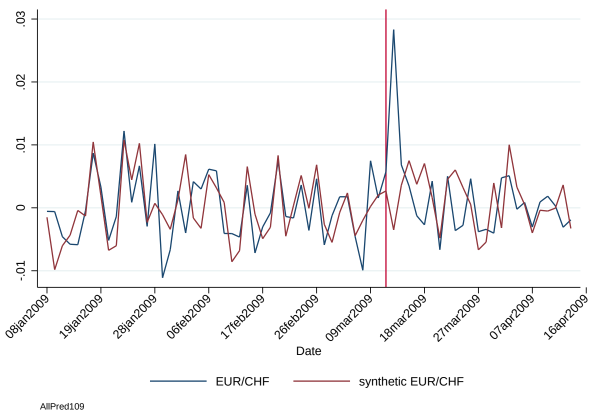


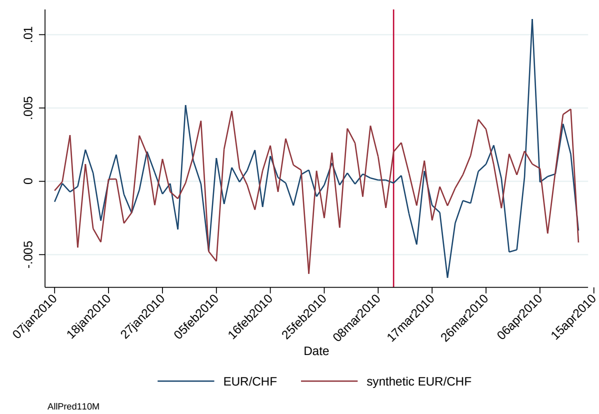
(f)

Figure A.1: Synthetic Control Estimation Results: Announcement of 10 August 2011. Figures (a) and (b) plot the actual and the synthetic (demeaned) difference in the log EUR/CHF exchange rate. Figures (c) and (d) plot the gap between the accumulation of the actual and the synthetic outcome variable (set to zero in the period before the intervention). The red lines indicate 2, 9 and 16 August, respectively. Figures (e) and (f) report the ratio of the post- to the pre-intervention RMSPE. Daily data from 1 June to 5 September 2011.

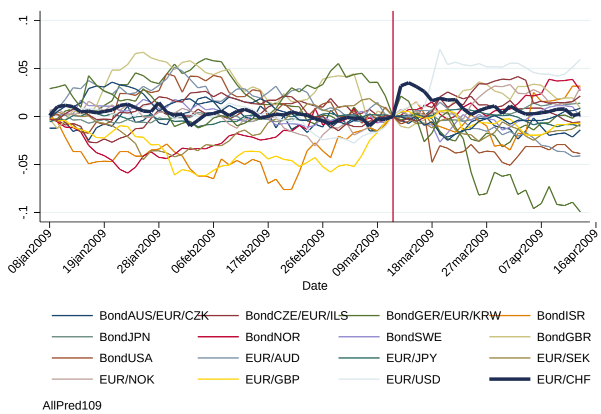
B.3 Synthetic Control Approach - Robustness

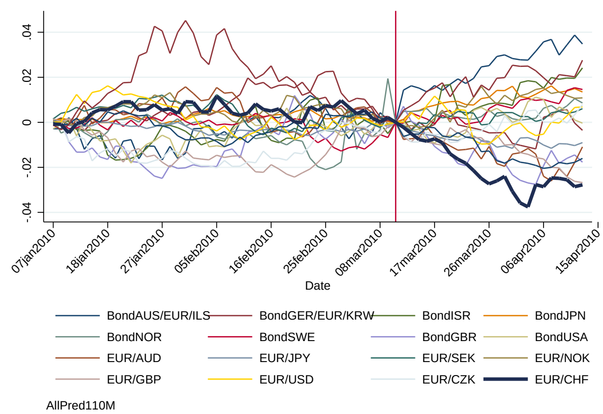
March 2009 **March 2010**



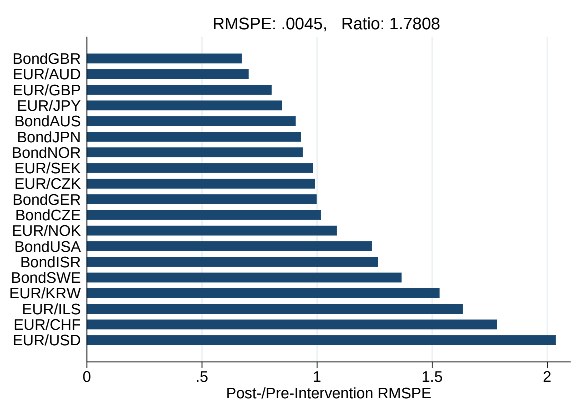


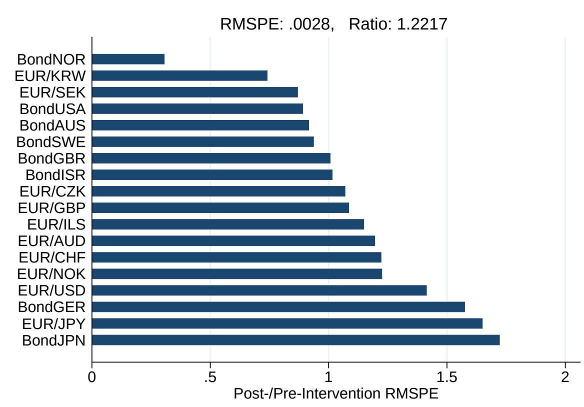
(a) **(b)**





(c) **(d)**

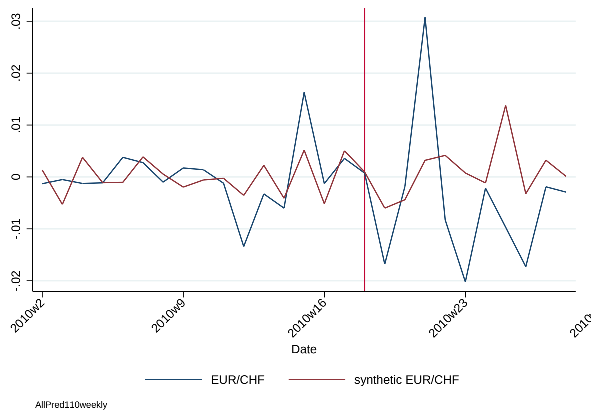


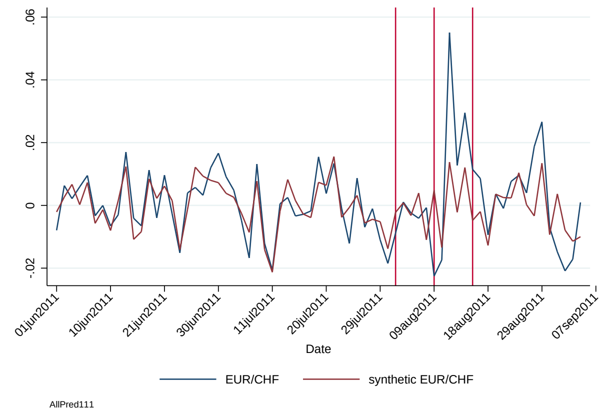


(e) **(f)**

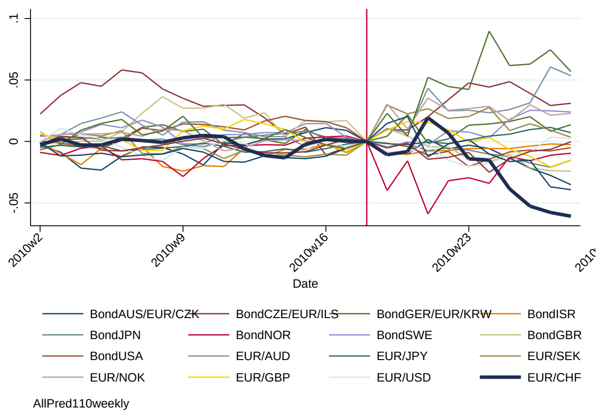
Figure A.2: Robustness Analysis: Combining the Two Donor Pools. Figures (a) and (b) plot the actual and the synthetic (demeaned) difference in the log EUR/CHF exchange rate. Figures (c) and (d) plot the gap between the accumulation of the actual and the synthetic outcome variable (set to zero in the period before the intervention). The red lines indicate 11 March 2009 and 10 March 2010, respectively. Figures (e) and (f) report the ratio of the post- to the pre-intervention RMSPE. We use five arbitrary pre-intervention observations (*outcomes t-x*), *CDS* and *inflation* as predictors. In the March 2010-sample *BondCZE* is not used in the in-space placebo estimations.

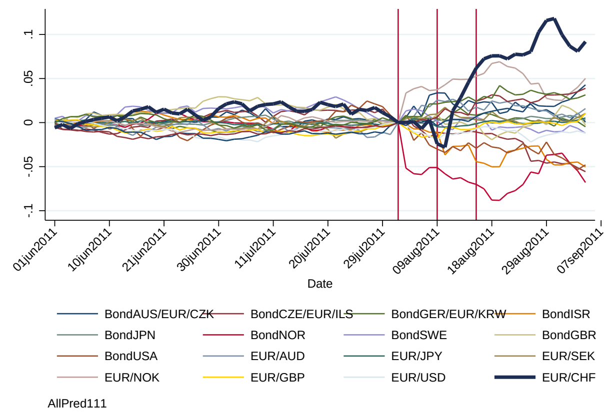
May 2010 | August 2011



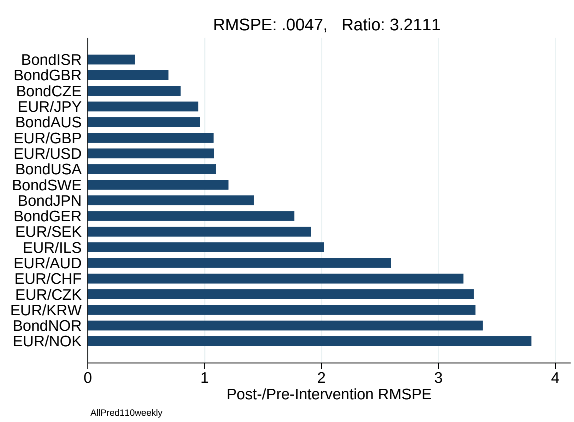


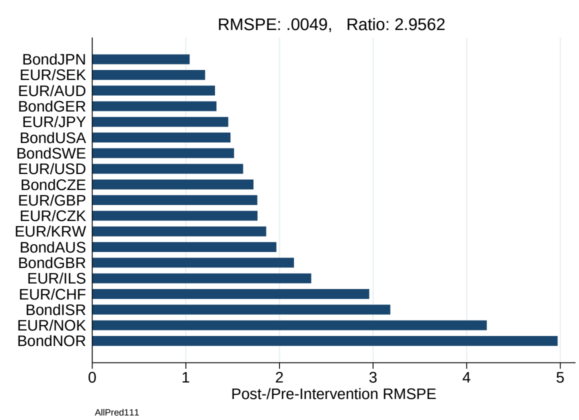
(a) **(b)**





(c) **(d)**





(e) **(f)**

Figure A.3: Robustness Analysis: Combining the Two Donor Pools. Figures (a) and (b) plot the actual and the synthetic (demeaned) difference in the log EUR/CHF exchange rate. Figures (c) and (d) plot the gap between the accumulation of the actual and the synthetic outcome variable (set to zero in the period before the intervention). The red lines indicate the week before the intervention date and 2, 9 and 16 August, respectively. Figures (e) and (f) report the ratio of the post- to the pre-intervention RMSPE. The same predictors as for Figure A.2 are used.

	March 2009	March 2010	May 2010	August 2011
BondAUS	0.00	0.00	0.00	0.00
BondCZE	0.00	0.00	0.18	0.00
BondGER	0.41	0.46	0.43	0.42
BondISR	0.00	0.00	0.00	0.00
BondJPN	0.15	0.00	0.00	0.28
BondNOR	0.00	0.06	0.00	0.00
BondSWE	0.00	0.00	0.00	0.00
BondGBR	0.00	0.00	0.00	0.00
BondUSA	0.00	0.16	0.00	0.30
EUR/AUD	0.00	0.06	0.00	0.00
EUR/JPY	0.00	0.06	0.00	0.00
EUR/SEK	0.00	0.00	0.00	0.00
EUR/NOK	0.00	0.00	0.00	0.00
EUR/GBP	0.00	0.00	0.00	0.00
EUR/USD	0.22	0.00	0.03	0.00
EUR/CZK	0.21	0.20	0.22	0.00
EUR/ILS	0.00	0.00	0.15	0.00
EUR/KRW	0.00	0.00	0.00	0.00

Table A.15: Synthetic Control Weights: Combining the Two Donor Pools. $\boldsymbol{W}$-weights assigned to comparison units.

	March 2009	March 2010	May 2010	August 2011
CDS	0.03	0.14	0.00	0.25
inflation	0.04	0.04	0.45	0.01
outcome t-5	0.66	0.00	0.01	0.29
outcome t-15	0.17	0.00		0.00
outcome t-25	0.00	0.46		0.37
outcome t-35	0.02	0.35		0.03
outcome t-45	0.07	0.00		0.06
outcome t-8			0.01	
outcome t-11			0.01	
outcome t-14			0.51	
outcome t-17			0.01	

Table A.16: V-Weights: Combining the Two Donor Pools. Diagonal elements of the $\boldsymbol{V}$-matrix. A description of predictors is provided in Table A.18

	March 2009		March 2010		May 2010		August 2011	
	$\boldsymbol{X}_{1m}$	$\boldsymbol{X}_{0m}\boldsymbol{W}$	$\boldsymbol{X}_{1m}$	$\boldsymbol{X}_{0m}\boldsymbol{W}$	$\boldsymbol{X}_{1m}$	$\boldsymbol{X}_{0m}\boldsymbol{W}$	$\boldsymbol{X}_{1m}$	$\boldsymbol{X}_{0m}\boldsymbol{W}$
CDS	149.6090	119.1103	50.4066	50.7132	46.6936	66.6036	35.8251	45.8047
inflation	0.0000	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0002
outcome t-5	-0.0046	-0.0044	0.0005	-0.0010	-0.0060	-0.0041	-0.0069	-0.0056
outcome t-15	0.0074	0.0083	-0.0001	0.0029			0.0025	0.0082
outcome t-25	0.0030	-0.0033	-0.0048	-0.0048			0.0120	0.0080
outcome t-35	0.0122	0.0108	-0.0022	-0.0021			-0.0041	-0.0108
outcome t-45	-0.0006	-0.0015	-0.0014	-0.0006			-0.0079	-0.0021
outcome t-8					-0.0012	-0.0003		
outcome t-11					-0.0010	0.0006		
outcome t-14					-0.0011	-0.0011		
outcome t-17					-0.0013	0.0013		

Table A.17: Pre-Intervention Characteristics: Combining the Two Donor Pools. Predictor values for the unit affected by the intervention and the synthetic control unit. A description of predictors is provided in Table A.18.

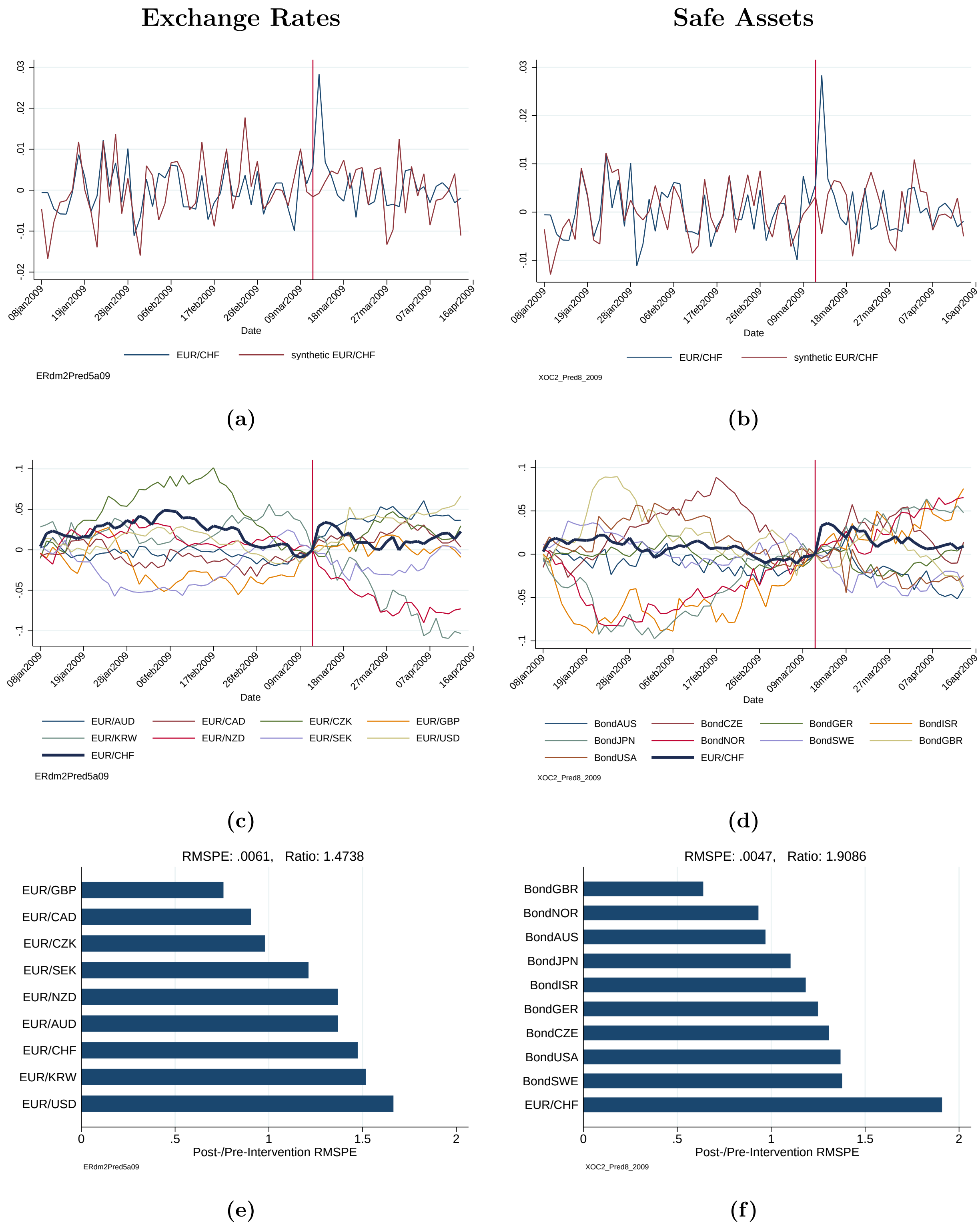
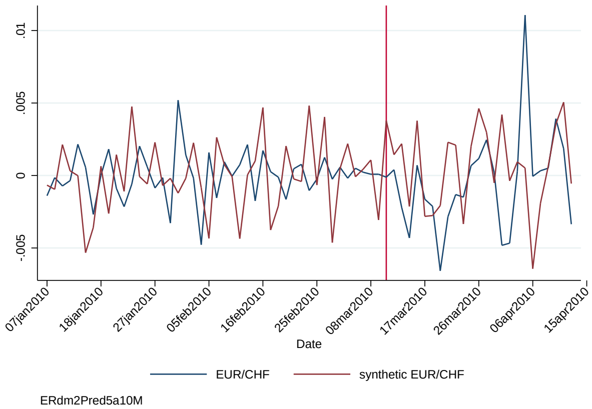
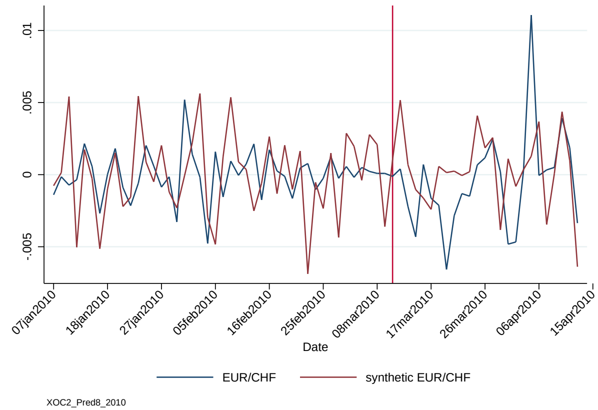


Figure A.4: Robustness Analysis: Using Alternative Predictors, Announcement of 12 March 2009. Figures (a) and (b) plot the actual and the synthetic (demeaned) difference in the log EUR/CHF exchange rate. Figures (c) and (d) plot the gap between the accumulation of the actual and the synthetic outcome variable (set to zero in the period before the intervention). The red line indicates 11 March. Figures (e) and (f) report the ratio of the post- to the pre-intervention RMSPE. For exchange rates we use five arbitrary pre-intervention observations (*outcomes t-x*), *capital inflows*, *capital outflows*, *capital outflows net*, *mm rate* and *inflation* as predictors. *EUR/JPY* rate is not included in in-space placebo estimations. For safe assets we use five arbitrary pre-intervention observations (*outcomes t-x*), *CDS* and *inflation* as predictors.

Exchange Rates | **Safe Assets**



(a)



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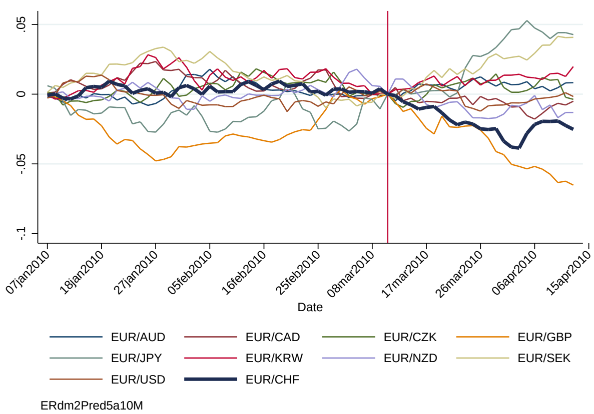
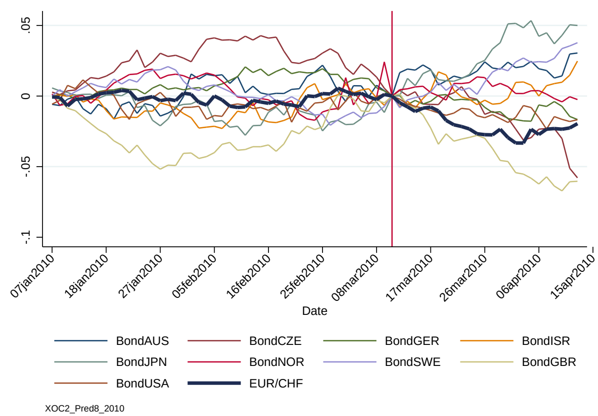
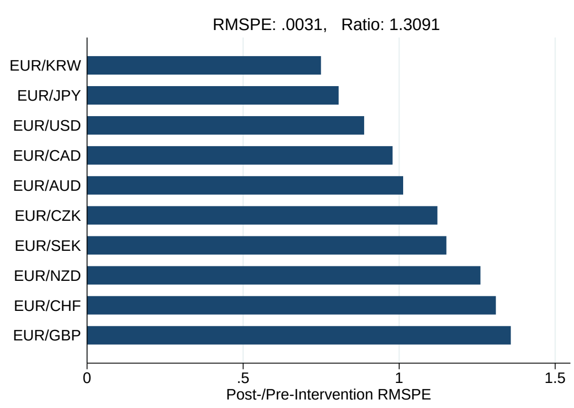


(c)



(d)



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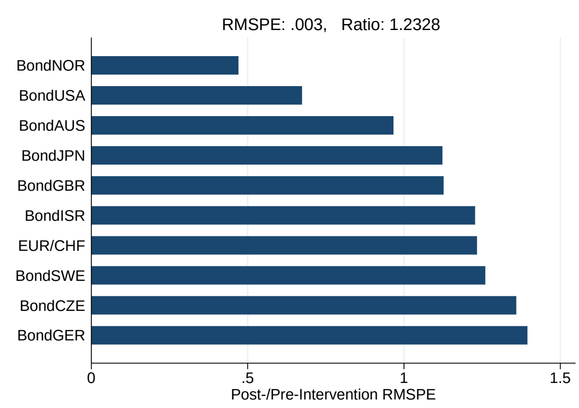
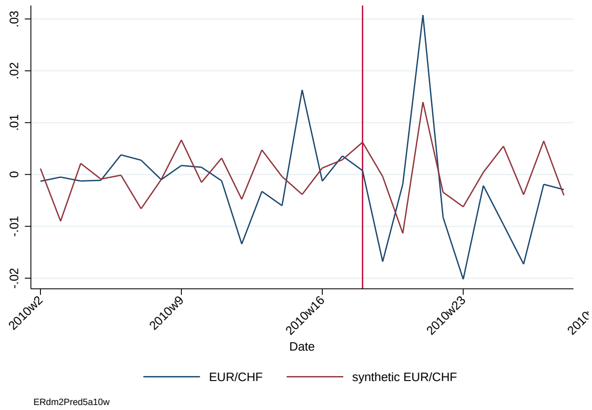


(f)

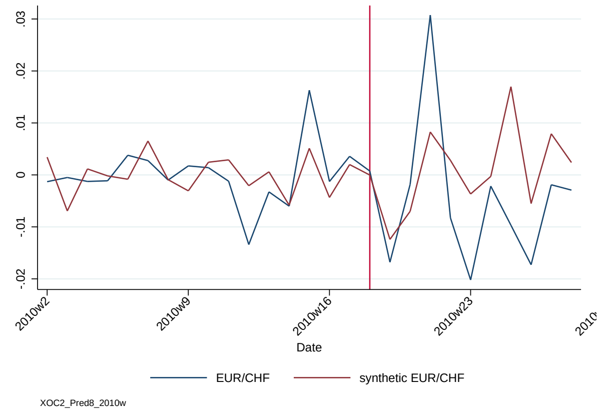
Figure A.5: Robustness Analysis: Using Alternative Predictors, Announcement of 11 March 2010. Figures (a) and (b) plot the actual and the synthetic (demeaned) difference in the log EUR/CHF exchange rate. Figures (c) and (d) plot the gap between the accumulation of the actual and the synthetic outcome variable (set to zero in the period before the intervention). The red line indicates 10 March. Figures (e) and (f) report the ratio of the post- to the pre-intervention RMSPE. Same predictors as for Figure A.4 are used.

Exchange Rates

Safe Assets



(a)



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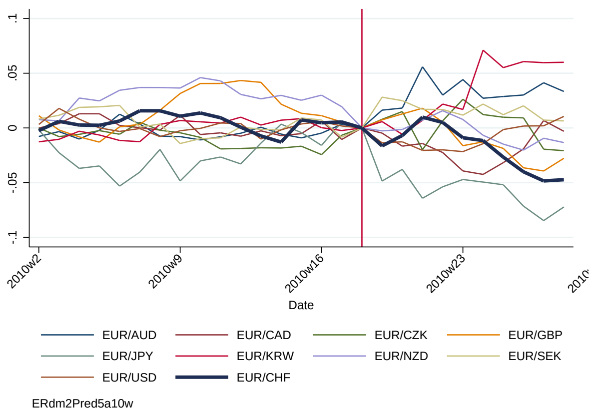
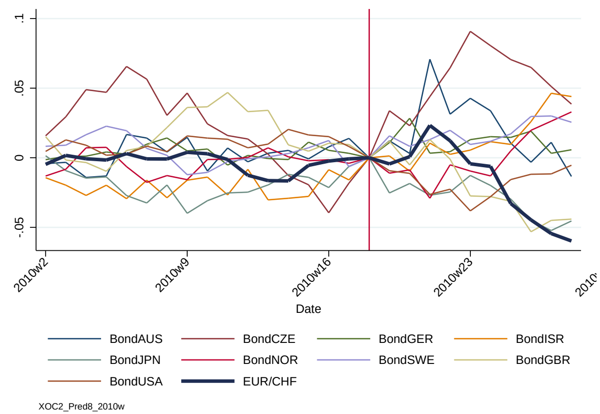


(c)



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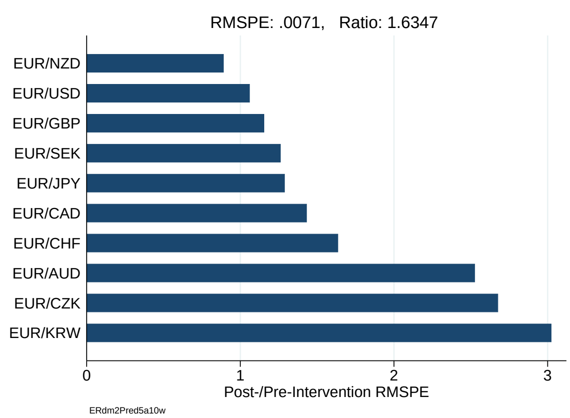

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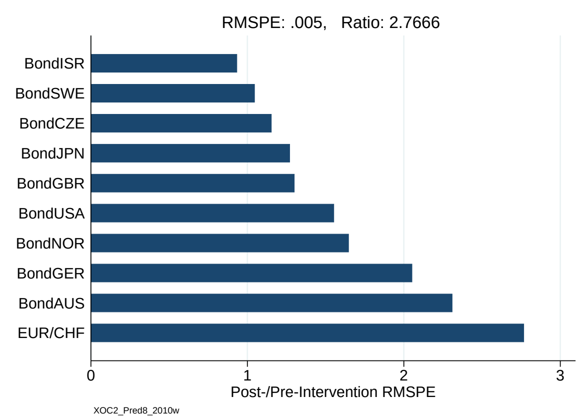
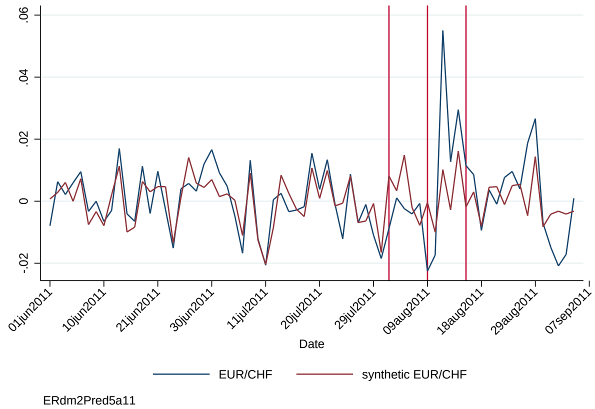


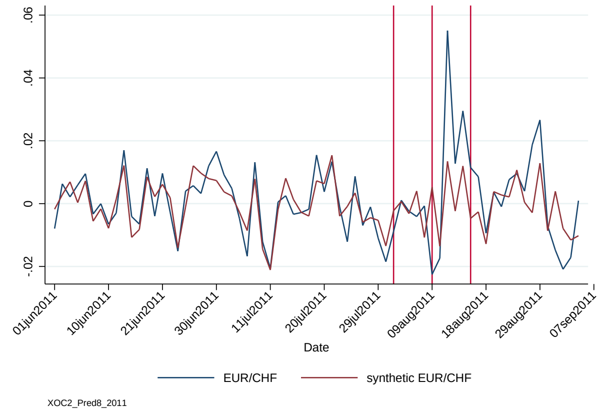
(f)

Figure A.6: Robustness Analysis: Using Alternative Predictors, Interventions of first week of May 2010. Figures (a) and (b) plot the actual and the synthetic (demeaned) difference in the log EUR/CHF exchange rate. Figures (c) and (d) plot the gap between the accumulation of the actual and the synthetic outcome variable (set to zero in the period before the intervention). The red line indicates the week before the intervention date. Figures (e) and (f) report the ratio of the post- to the pre-intervention RMSPE. Same predictors as for Figure A.4 are used.

Exchange Rates | **Safe Assets**



(a)



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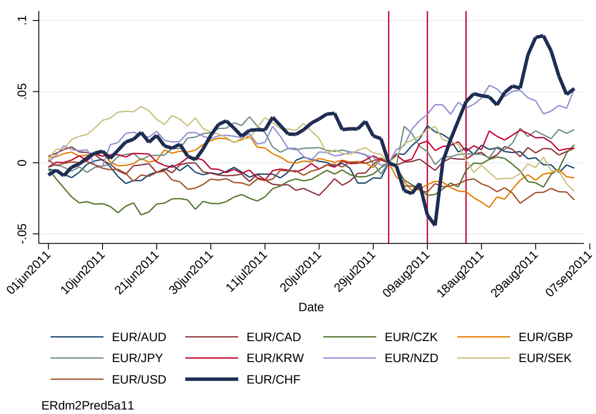
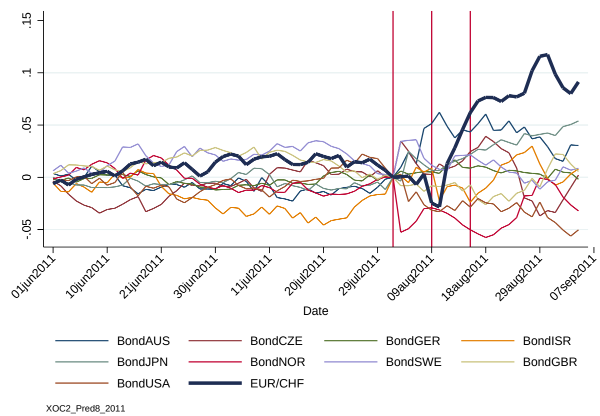


(c)



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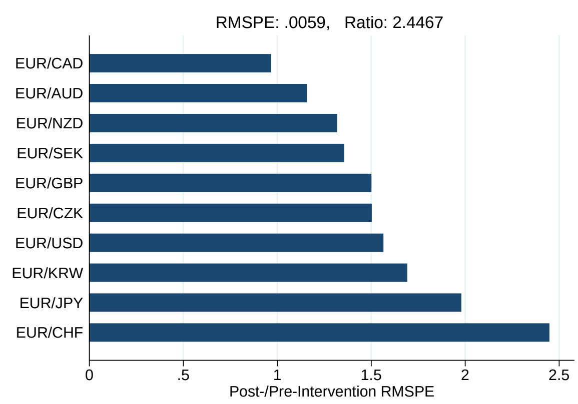

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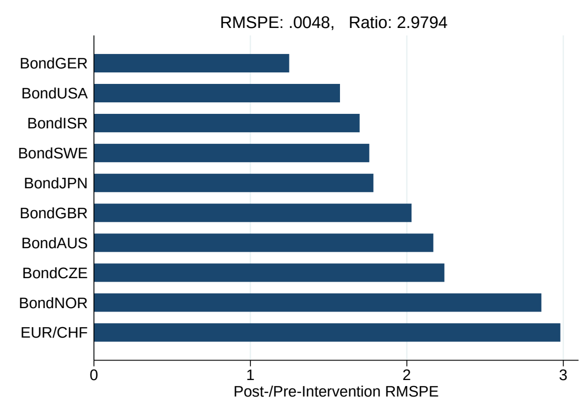
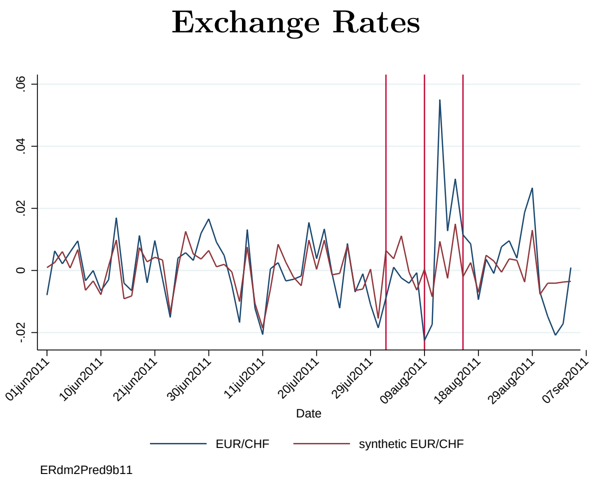
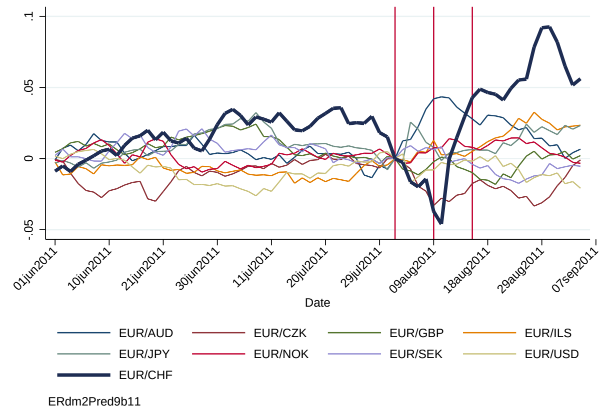


(f)

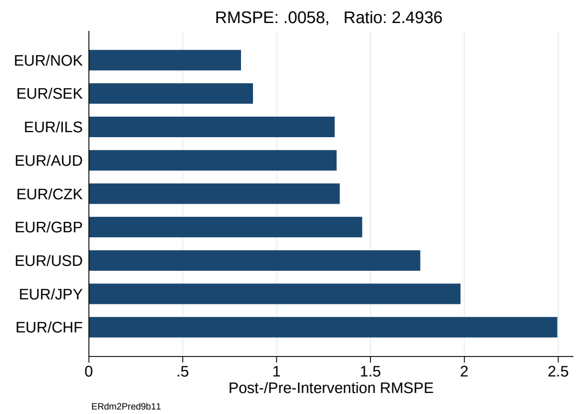
Figure A.7: Robustness Analysis: Using Alternative Predictors, Announcement of 3 August 2011. Figures (a) and (b) plot the actual and the synthetic (demeaned) difference in the log EUR/CHF exchange rate. Figures (c) and (d) plot the gap between the accumulation of the actual and the synthetic outcome variable (set to zero in the period before the intervention). The red lines indicate 2, 9 and 16 August, respectively. Figures (e) and (f) report the ratio of the post- to the pre-intervention RMSPE. Same predictors as for Figure A.4 are used.



(a)



(b)



(c)

Figure A.8: Robustness Analysis: Using alternative predictors for Exchange Rates, Announcement of 3 August 2011. Figure (a) plots the actual and the synthetic (demeaned) difference in the log EUR/CHF exchange rate. Figure (b) plots the gap between the accumulation of the actual and the synthetic outcome variable (set to zero in the period before the intervention). The red lines indicate 2, 9 and 16 August, respectively. Figure (c) report the ratio of the post- to the pre-intervention RMSPE. We use five arbitrary pre-intervention observations (*outcomes t-x*), *CDS*, *inflation*, *dLmsci* and *dLpbond* as predictors.

Predictor	Description	Frequency of raw data
capital inflows	Average gross capital inflows (in USD, excluding derivatives) over the four quarters prior to the intervention. Scaled by the 2008 GDP (Q4)[1] for each country.	quarterly
capital outflows	Average gross capital outflows (in USD, excluding derivatives) over the four quarters prior to the intervention. Scaled by the 2008 GDP (Q4)[1] for each country.	quarterly
capital outflows net	Average net capital outflows (in USD, excluding derivatives) over the four quarters prior to the intervention. Scaled by the 2008 GDP (Q4)[1] for each country.	quarterly
CDS	Average sovereign CDS spread (in basis points, 1bp=0.01%) over pre-intervention period.[2]	daily
dLmsci	Average log change in MSCI stock market price index over pre-intervention period (in local currency, converted in EUR).	daily
dLpbond	Average log change in 10-year government discount bond price (zero-yield) over pre-intervention period (in local currency, converted in EUR).	daily
inflation	Average log change in Consumer Price Index (all items, year on year) over the two months prior to the intervention.	monthly (period averages)
mean	Average log change in exchange rates or (inverse) bond prices (asset returns) over pre-intervention period.	daily
mm rate	Money market rate, i.e. rate on short-term lending between financial institutions.	monthly
outcome t-x	Log change in exchange rates or bond prices (demeaned) in period t-x, where t is the intervention period (T_0+1) and x is the number of days or weeks.	daily
variance	Variance of log changes in exchange rates or (inverse) bond prices (asset returns) over pre-intervention period.	daily

Table A.18: Predictors. For inflation we use data from the IMF IFS (line 64), for capital flows from the IMF BOP and for all other variables we use data from Datastream. GDP used to scale capital flows is from the OECD statistics.

[1] Quarterly GDP in million US dollars, current prices, annual levels, seasonally adjusted.

[2] For the March 2009-sample we use CDS data averaged over the period 16 January - 11 March 2009 instead of the whole pre-intervention period. The reason is that CDS data for Switzerland is only available form 16 January 2009 on.