International inflation spillovers – the role of different shocks*

Gregor Bäurle†, Matthias Gubler‡, and Diego R. Känzig§

Abstract

How do international price fluctuations spill over to country-specific inflation? We show that accounting for the drivers of international inflation and their effects on overall economic conditions is crucial to getting a more thorough view of spillover effects. We find substantial heterogeneity in the magnitude of spillovers, depending on the shocks driving inflation abroad. While all identified shocks are inflationary, their effects on activity, interest and exchange rates differ. Disaggregated price responses suggest that these general equilibrium effects are important. We show this by looking at spillovers to Switzerland using a structural DFM relating disaggregated prices to key macroeconomic factors.

JEL classification: C11, C32, E31, E52, F62

Keywords: international spillovers, inflation, monetary policy, Bayesian factor model, sign restrictions

*We thank Juan Antolin-Diaz, Carlos Lenz, Ana Mitreska, Tsvetelina Nenova, Juan Rubio-Ramirez, Paolo Surico, the editor, Pierpaolo Benigno and two anonymous referees as well as participants at the SNB Brown Bag Seminar, the CFE conference 2015 in London, the SSES meeting 2016 in Lugano, the EEA conference 2016 in Geneva, and the NBP-SNB joint seminar 2017 in Zurich for useful comments and suggestions. We would also like to thank Santiago Ernesto Alvarez-Blaser for excellent research assistance. The views expressed in this paper are those of the authors and do not necessarily reflect those of the SNB. A previous version of this paper circulated under the title "Does independent monetary policy shield against international spillovers to inflation? An empirical study with Swiss data".

†Swiss National Bank, Economic Analysis, P.O. Box, CH-8022 Zurich, Switzerland, e-mail: gregor.baeurle@snb.ch

‡Swiss National Bank, Inflation Forecasting, P.O. Box, CH-8022 Zurich, Switzerland, e-mail: matthias.gubler@snb.ch

§London Business School, London NW1 4SA, UK, e-mail: dkaenzig@london.edu

1 Introduction

In recent decades, the world has moved closer together along many dimensions. Increased economic integration goes hand-in-hand with potentially major, international spillover effects. A deep understanding of spillovers is thus key to ensuring optimal policy decisions, particularly in open economies with strong international ties. From a monetary policy perspective, international spillovers to consumer prices are of particular interest. However, the empirical evidence on the impact of spillovers to country-specific inflation is ambiguous. Some authors find that "inflation is largely a global phenomenon" (Ciccarelli and Mojon 2010), while others document that the importance of domestic factors for country-specific inflation has not diminished (Rieth 2015).

Recent, influential studies have proposed a new focus on pass-through effects: accounting for the underlying shocks and the overall changes in economic conditions, i.e. general equilibrium effects. Forbes et al. (2018) and Comunale and Kunovac (2017) examine the exchange-rate pass-through, while Bobeica et al. (2019) look at the pass-through of labor costs to prices. In this paper, we take up the idea of shock-dependent pass-through by examining how various foreign shocks, all of which have in common that they push up international inflation, affect country-specific inflation and its subcomponents. To do so, we use a structural dynamic factor model (SDFM) for Switzerland – a small, open economy that is particularly suited for studying international spillover effects. This model relates a large set of disaggregated Swiss consumer prices to key international and domestic macroeconomic factors, and allows for multiple transmission channels.

Accounting for the underlying shocks of international inflationary pressures may help to reconcile the ambiguous empirical evidence. Although the identified shocks all push up international inflation, their effects on other foreign and domestic macro variables, such as real activity, interest rates or exchange rates, may differ. As a result, this could lead to different spillover effects. To the best of our knowledge, we are the first to examine whether there is empirical evidence for shock-dependence of international inflation spillovers. Moreover, by comparing the relative price changes of goods and services with different degree of tradability, we can get a sense of the importance of indirect, general equilibrium effects relative to the direct, mechanical pass-through of international to country-specific inflation and of how this may vary with the shocks.

Our framework also allows us to study the joint responses of the exchange rate and the interest rate differential, shedding some light on how monetary policy can shape the response to the respective shocks. Traditionally, flexible exchange rates in tandem with independent monetary policy are thought to be effective in cushioning the effect of international shocks on the domestic economy (see, e.g., Woodford 2007). However, if country-specific inflation is mainly driven by global factors, this could indicate that "domestic inflation rates may (at least partly) escape the control of the national central bank" (Monacelli and Sala 2009).

Preview of results. We find that foreign shocks explain up to 50% of Swiss price variations, while common domestic shocks account for approximately 20% (the remaining part being due to item-specific shocks). To a substantial degree, domestic inflation is thus driven by foreign factors. However, this does not necessarily imply that Swiss monetary policy has not been able to have an impact on international spillover effects to domestic inflation. In fact, we show that spillover effects on Swiss prices depend on the nature of the underlying shocks, because their transmission varies, among other factors, with the distinct foreign and domestic monetary policy responses.

Following an increase in inflation abroad due to a positive demand shock, foreign monetary policy counteracts the business cycle upturn strongly, while the Swiss monetary policy reaction turns out to be less restrictive. Consistent with the change in the relative monetary policy stance, the Swiss franc depreciates and inflation picks up, even somewhat more than abroad. By contrast, in response to an increase in foreign inflation due to an expansionary monetary policy shock, monetary policy becomes relatively tighter in Switzerland and the exchange rate appreciates – mitigating spillover effects to Swiss inflation. Finally, a cost-push shock driving up inflation (and decreasing real activity) abroad has no significant effect on the relative monetary policy stance. The effects on the exchange rate turn out to be negligible, and the increase in Swiss inflation is comparable to that of inflation abroad. These results indicate that spillover effects need to be analyzed in a framework allowing for different transmission channels: an increase in inflation abroad may affect inflation in an open economy differently, depending on the source of the foreign shock and thus on movements in other factors such as interest and exchange rates.

This analysis of the different items of the Swiss CPI points to substantial heterogeneity in the transmission of foreign inflationary shocks. It turns out that energy prices play a crucial role. The impact of foreign inflationary shocks on the Swiss CPI is markedly lower, and the transmission appears to be slower when energy prices are excluded. Furthermore, there is some heterogeneity in the transmission to the prices of imported goods, domestic goods and services, which are likely related to differences in tradability and exchange rate sensitivity. This suggests that while a certain part of spillovers is likely to be mechanical, general equilibrium effects are important as well. While we find short to medium-run changes in relative prices in response to the foreign shocks, we do not find significant effects on relative prices in the long run, in line with previous findings in the literature (Mumtaz and Surico 2009, Boivin et al. 2009). This further underlines the importance of the relative stance of monetary policy through its effect on the exchange rate.

Our results turn out to be robust along a number of dimensions, including the model specification, the choice of the prior, and the sample period. In the baseline model, we use the euro area – Switzerland's largest trading partner by far – as the foreign block. However, the results based on a global foreign block consisting of export-weighted indicators of Switzerland's major trading partners are very similar, suggesting that our findings do not uniquely pertain to spillovers from the euro area, but to international spillovers to Switzerland more generally.

Related literature. This paper is related to at least three different strands of the literature. First, it is related to a large body of literature studying the comovement of international inflation rates (Ciccarelli and Mojon 2010, Neely and Rapach 2011, Mumtaz and Surico 2012). This literature finds that country-specific inflation rates are largely a global phenomenon, i.e., individual countries tend to inherit global inflationary pressures. In contrast, various other recent studies focusing on the impact of specific global factors, such as commodity prices or global business cycles, on domestic inflation dynamics find ambiguous empirical results (see Rieth 2015, for an overview).

Second, our analysis is also related to the extensive literature on the international transmission of external shocks (see Eichenbaum and Evans 1993, Kim 2001, Canova 2005, Maćkowiak 2007, Aastveit et al. 2016, Georgiadis 2016, Potjagailo 2017, Dedola et al. 2017, among others). Our paper connects these two strands of the literature by analyzing the role of international factors for domestic inflation from a more structural perspective, building on an approach that has recently gained a lot of attention in the literature on the exchange-rate pass-through (Shambaugh 2008, Forbes et al. 2017, 2018, Comunale and Kunovac 2017). In contrast to these studies, our focus is not on the exchange-rate pass-through per se, but on international inflation spillovers. In our analysis, the exchange rate is one of several *endogenous* variables, although an important one, through which the effects of the foreign inflationary shocks transmit to Switzerland. As such, our results are not intended to be directly comparable to studies that quantify how exogenous exchange rate fluctuations affect prices (see, e.g., Stulz 2007 and Fleer et al. 2016, for evidence on Switzerland).

Third, our approach of incorporating a set of disaggregated prices allows us to compare our results with a relatively new and growing literature that looks at how global factors affect specific sub-components of inflation, and how important they are for headline inflation (see, e.g., Mumtaz and Surico 2009, Hałka and Szafranek 2016, Parker 2016, Altansukh et al. 2017).

Moreover, we are aware of two papers close to the topic of our article. Mumtaz and Surico (2009) use a similar framework to study how global shocks transmit to the UK economy. However, while they look at spillover effects more generally, our focus is on inflation dynamics. Furthermore, we provide new empirical evidence on how the strength of the spillovers varies with the relative monetary policy stance and the exchange rate response. Hałka and Kotłowski (2017) also study the effects of global shocks on inflation of three small open economies (Czech Republic, Poland and Sweden) using aggregate and disaggregated price data. However, they use a different modelling approach and focus on contemporaneous effects, while we examine the dynamic effects of shocks driving international inflation. This can be important because the transmission of these shocks might take some time, as can be seen from our results. Moreover, we provide new evidence on the quantitative importance of foreign inflationary pressures using variance decompositions, and we show that the impact on the distribution of prices depends on the nature of the underlying inflationary shock.

Structure of the paper. The remainder of this paper is organized as follows. Section 2 covers our econometric approach, including details about the modeling framework, the model specification, the data and the estimation and identification strategy. In section 3, we present our results and discuss their implications. Section 4 concludes the paper.

2 Econometric approach

To study the potential spillover effects of foreign inflationary pressures on the Swiss economy and in particular on Swiss prices, we set up a structural dynamic factor model for the Swiss economy. The model relates a large set of disaggregated price data to the key domestic and foreign macroeconomic factors. Building on the framework proposed by Bäurle and Steiner (2015), it takes into account the characteristics of a small open economy. The structural shocks are identified using two different types of restrictions. First, we exploit that economic conditions in Switzerland, a small open economy, are unlikely to impact global economic conditions. This allows us to separate foreign from domestic shocks. Second, we use sign restrictions motivated by economic theory to disentangle different types of foreign shocks.

2.1 Modeling framework

A dynamic factor model is a framework relating a large panel of economic indicators to a number of observed and unobserved common factors. The premise behind this type of model is that the economy can be characterized by a limited number of factors that drive the comovements of the indicators in the panel. Formally, the model consists of two different equations: an observation equation and a state equation. The observation equation relates the panel of economic indicators X_t^S to the common factors f_t that drive the economy:

$$X_t^S = \lambda(L) f_t + v_t, \tag{1}$$

where $\lambda(L) = \lambda_0 + \lambda_1 L + \lambda_2 L^2 + \ldots + \lambda_q L^q$ are the factor loadings, L is the lag operator, and v_t is a vector of item-specific components. Thus, the indicators X_t^S are allowed to load on the factors both contemporaneously and on their lags.[1] Following Boivin and Giannoni (2006), we allow v_t to be autocorrelated of order one by specifying $v_t = \psi v_{t-1} + \xi_t$ with $\xi_t \sim N(0, R)$. For our specific application, X_t^S compromises a large number of disaggregated data on Swiss consumer prices. To make our model suitable for a small open economy, we partition the common factors f_t into two blocks: a foreign and a domestic block. The domestic block is further partitioned into a block of unobserved factors and a block of observed factors. Hence, the common factors can be written as $f_t = (f_t^{S\prime},\ X_t^{M\prime},\ X_t^{M*\prime})'$, where f_t^S are the domestic unobserved common factors, X_t^M are the domestic observed common factors, and X_t^{M*} are foreign observed common factors. The joint dynamics of these factors are described by the following state equation:

$$\phi(L) f_t = Q\varepsilon_t, \tag{2}$$

where $\phi(L) = I - \phi_1 L - \phi_2 L^2 - \ldots - \phi_p L^p$ are coefficient matrices, ε_t is a vector of common structural shocks with the same dimension as f_t, and Q is the structural impact matrix mapping the shocks to the common factors. This is essentially a vector autoregression (VAR) in the factors. The shocks ε_t are assumed to be Gaussian white noise, i.e., $\varepsilon_t \sim N(0, I)$. Moreover, the common shocks ε_t and the idiosyncratic shocks ξ_t, which we call item-specific shocks, are postulated to be uncorrelated. The vector of common shocks ε_t can be partitioned into vectors of foreign shocks ε_t^{M*} and domestic shocks ε_t^M, whose dimensions correspond to X_t^{M*} and X_t^M, respectively. The small open economy assumption is then implemented by modeling the foreign block of the model as exogenous to the Swiss economy. To this end, we assume that foreign variables do not react to domestic shocks at all lags by restricting $\phi(L)$ and the covariance matrix Q appropriately. More precisely, we restrict the block of $\phi(L)$ that relates X_t^{M*} to the lags of X_t^M and the elements of Q that relate X_t^{M*} to the domestic shocks ε_t^M to zero.

[1] Note that it is possible to rewrite the model in 'static form', by including lagged factors into the state vector. This reveals that there is a close connection between the dimension of f_t and the number of lags in the observation equation q. However, increasing q may be a more parsimonious way than increasing the dimension of f_t to relate observed variables to lagged factors as the former implies restrictions on the state equation in the static form. Ultimately, whether these restrictions are supported by the data is an empirical question. We investigate the robustness of our results to the choice of the number of factors and q in Section 3.4.

2.2 Discussion of modeling choice

The dynamic factor model described in the previous section allows us to model a large set of time series jointly. As compared to a VAR in all variables, the factor structure reduces the number of parameters substantially. Indeed, the number of parameters grows linearly with the number of observed series (for a given number of factors), while the number of parameters in a VAR increases quadratically with the number of series. As an alternative to the factor structure, Bayesian versions of the VAR have been proposed to deal with this curse of dimensionality. We do not pursue this route mainly for two related reasons. First, our setting allows for a different treatment of our macro series and individual price series. The fact that aggregate series do not react to individual price series, but only to factors containing aggregate price information is a reasonable assumption in our view. In a VAR, each individual price series reacts to any other series including the macro series and vice versa. Second, and related to this, the distinction between macro series (including the factors) and price series helps to identify macroeconomic shocks. In addition to the "standard" identifying assumption needed within a VAR (see also discussion in Section 2.5), we impose that the idiosyncratic components are orthogonal to the macroeconomic shocks, making identification of aggregate shocks even possible.

A note on the terminology is due at this point. Our model may also be described as a factor-augmented VAR (FAVAR). A FAVAR is, formally, a special case of a SDFM with some factors perfectly observed (Section 5.2 in Stock and Watson 2016 and Bernanke et al. 2005). Indeed, as we assume that some factors, X_t^M and X_t^{M*}, are observed, our implementation of the dynamic factor model fits into this category. We prefer to use the general term "dynamic factor model", however, because we think our motivation is not primarily to "augment" the VAR with information from price series, but to model the joint dynamics of macro variables and the price series.

2.3 Specification and data

Our baseline specification includes six observed common factors. As discussed above, these factors are grouped into two blocks: a foreign and a domestic one. The foreign block contains measures for output, the short-term interest rate, and consumer prices.

The domestic block consists of the same type of measures except consumer prices because they are implicitly contained in the disaggregated price data. To link the domestic to the foreign economy, we also include the nominal exchange rate. In this modeling framework it is possible, on the one hand, to study spillovers to disaggregated Swiss consumer prices, and, on the other hand, to keep the model as parsimonious as possible. Furthermore, the inclusion of the above mentioned observed common factors allows us to identify standard macroeconomic shocks.

As discussed in Bäurle and Steiner (2015), the selection of the remaining model dimensions is not trivial. Parsimony in mind, we start with dimensions in the lower range of what is chosen in the literature in our baseline specification, setting the number of unobserved factors to one and the lag order in the state and the observation equation to $p = 2$ and $q = 1$, respectively.[2] Later, we will check the robustness of our results with respect to this choice.

Because the euro area is Switzerland's most important trading partner, we choose it as the foreign block of the model. For the measures of output, short-term interest rates, and consumer prices, we use euro area real GDP, the 3M Euribor, and euro area CPI, respectively. For Switzerland, we use Swiss real GDP and the 3M Libor. Finally, the EURCHF is selected as the relevant nominal exchange rate. The exchange rate is quoted indirectly; hence, a positive exchange rate change implies an appreciation of the Swiss franc. For the disaggregated price data, we rely on a panel of 148 Swiss CPI items.[3] The frequency of the data is quarterly, and the sample spans the period from 1992Q1 to 2011Q2. We choose this particular sample period because it was characterized by a relatively stable monetary policy regime and flexible exchange rates, which is important as our model does not allow for time-variation in the model parameters. All variables enter the model as quarter-on-quarter (qoq) growth rates except for the interest rates, which enter in levels. Following the literature, the series are standardized such that they have zero mean and a variance equal to one. After estimation, the quantitative results are transformed back into the original scale.

[2] As an example, Mumtaz and Surico (2009) set $p = 4$ and (implicitly) $q = 0$. They set the number of unobserved factors in the domestic economy to 4. However, as we add three observed factors, the total number of domestic factors in our model is four as well.

[3] The panel is constructed from item-level price data collected by the Swiss Federal Statistical Office (SFSO). A more detailed description of the disaggregated price data can be found in Appendix A.

[Figure 1 about here.]

It is important to note that despite not including Swiss CPI inflation explicitly as an observed factor in the state equation, the remaining factors contain almost all consumer price information. Figure 1 shows Swiss CPI inflation (qoq) together with the fitted values of the following OLS regression:

$$\pi_t = \beta f_t + u_t. \quad (3)$$

One sees that the fit based on the seven factors in the baseline model (the six observed factors and the unobserved factor) is excellent, matching basically all peaks and troughs, with an R^2 of slightly above 75%. Thus, misspecification as a consequence of excluding inflation explicitly should be minor.

2.4 Estimation

The model is estimated using Bayesian methods. Because it is not possible to derive analytical results for high-dimensional estimation problems such as the one at hand, we have to rely on numerical techniques to approximate the posterior. In particular, we use a Gibbs Sampler, iterating over the following two steps (see, e.g., Kim and Nelson 1999). First, for a given (initial) set of model parameters, a realization of the distribution of the factors conditional on this set of parameters is drawn. Given this draw, a new set of parameters can be drawn from the distribution of parameters conditional on the draw of the factors.

The two steps are repeated $J = 100,000$ times. From these draws, we discard the first 20,000 to assure that the chain has converged to its ergodic distribution. Geweke's spectral-based measure of relative numerical efficiency (RNE, see, e.g., Geweke 2005) suggests that efficiency loss of the algorithm due to the remaining autocorrelation in these evaluated draws is minimal.[4] The efficiency loss is less than 50% for almost all of the parameters, i.e., vis-à-vis a hypothetical independence chain, and we need no more than 50% additional draws to achieve the same numerical precision. Moreover, the maximum inverse RNE is 4.6, which is well below the value of 20 that is mentioned in the literature

[4] The spectrum at frequency zero is calculated using a quadratic spectral kernel as described in Neusser (2009)

as a critical threshold (see, e.g., Carriero et al. 2014, Baumeister and Benati 2013 or Primiceri 2005). Additionally, we use Geweke (1992)'s test to assess the convergence of the algorithm, confirming that posterior means for partitions of the chain do not differ.[5] We also investigate convergence visually by looking at the posterior means based on an expanding number of draws, finding no evidence of changes after less than half of the draws.

Our choices for the prior distributions are the following. The prior for the coefficients in the observation equation is proper. This mitigates the problem that the likelihood is invariant to an invertible rotation of the factors. The problem of rotational indeterminacy in this Bayesian context is discussed in detail in Bäurle (2013).[6] The determination of the coefficients describing the factor dynamics reduces to the estimation of a standard VAR. We implement the restrictions reflecting the exogeneity assumption on foreign factors following Karlsson (2013) and Bauwens et al. (1999). Furthermore, we impose stationarity by rejecting the draws that do not satisfy the stationarity condition. It is important to note that the likelihood is only informative about $\Sigma = QQ'$, but not about Q directly. Therefore, we first derive the posterior distribution of Σ and impose certain restrictions based on economic considerations to pin down the distribution of Q in a second step. The strategy for identifying Q depends on the specific application and is described in the subsequent subsection. As compared to the procedure in Bäurle and Steiner (2015), we implement two changes to the prior distribution. Both changes help us to make the estimation procedure more robust especially in short samples. First, we assume that a priori, the variances of the parameters in $\lambda(L)$ are decreasing with the squared lag number. Second, we assume a Minnesota-type prior for the parameters in the state equation as described in Karlsson (2013). We set the hyper-parameters as follows: in Karlsson (2013)'s notation, we use $\pi_1 = \pi_2 = \pi_3 = 1$ to implement a very loose prior and set the prior mean of the first own lag to zero as we model stationary series. Further details on the estimation method and the implementation can be found in Appendix B.

[5] We follow Geweke (1992) and test whether the parameter means based on the first 10^{th} of the draws (after discarding the burn-in sample) are significantly different from the second half of the draws.

[6] Bayesian analysis is always possible in the context of nonidentified models as long as a proper prior on all coefficients is specified, see, e.g., Poirier (1998). Note that rotating the factors does not have an impact on the impulse response functions as long as no restrictions on the responses of the factors to shocks are set.

2.5 Identification

To analyze how foreign inflationary pressures affect the Swiss economy, we identify three different foreign inflationary shocks: a demand shock, a monetary policy (MP) shock, and a cost-push shock, all originating in the euro area. The shocks are identified using two different types of restrictions. First, we exploit that economic conditions in Switzerland are unlikely to have an impact on economic conditions abroad. Thus, domestic shocks are restricted to have no effect on foreign variables as implemented by short-run zero restrictions on Q. In this way, domestic shocks are separated from foreign ones. Note that in combination with the restrictions on $\phi(L)$ described in Subsection 2.1, domestic shocks do not influence foreign variables at all lags. Second, we use sign restrictions to disentangle the different types of foreign shocks. Following Uhlig (2005), we restrict the sign of the response of selected elements of X^M_{t+h}, but do not directly impose restrictions on the reaction of X^S_{t+h}. Specifically, we assume that a positive shock to foreign demand leads to an increase in output, prices, and the real interest rate (nominal interest rate minus CPI inflation) in the euro area. In contrast, an expansionary foreign monetary policy shock is assumed to decrease the policy rate and to increase output and prices in the euro area. Finally, we assume that a cost-push shock in the euro area causes output to fall and foreign prices to rise. An overview of the sign restrictions used can be found in Table 1. It is important to note that we place restrictions only on the responses of foreign factors and remain agnostic about the reaction of the domestic economy as well as the exchange rate.[7] As a baseline, we impose these restrictions for $h \leq 1$ periods.[8]

[Table 1 about here.]

We chose this identification scheme with short-run and sign restrictions because it is well established in the literature and theoretically founded. To check whether the identification scheme makes sense, we also compute the contributions of the structural foreign shocks and the domestic shocks to quarterly changes in the de-trended levels of the Swiss real

[7] As the foreign shocks are block identified, additionally identifying domestic shocks is irrelevant for the identification of the foreign shocks for a given set of reduced form parameters. However, if sign-restrictions are used, they may have an influence on the posterior distribution of reduced form parameters. This is because different draws of the reduced form parameters may have different probabilities of satisfying the sign-restrictions. We do think that it is sensible to use sign-restrictions solely to inform us on the probability of the reduced form parameters, such that we do not follow this route.

[8] By restricting two quarters (the current and one future quarter), this horizon is consistent with the horizon chosen by Uhlig (2005), who uses 5 periods with monthly data.

GDP, the Swiss CPI and the EURCHF as well as the de-trended level of the 3M Libor.[9] The results point to reasonably identified shocks as shown in Figure 2. For example, positive foreign demand shocks contributed strongly to real GDP growth in Switzerland and also supported Swiss CPI inflation in the period from around 2006 to 2008. During that period, real GDP growth in the euro area was particularly strong. The same is true for the early-2000s. At the end of 2007 and the beginning of 2008, Swiss inflation picked up due to cost-push shocks. In this period, the oil price increased strongly, before collapsing right after the onset of the financial crisis. This is reflected in negative cost-push shocks in late 2008. At that time, negative foreign demand shocks and restrictive monetary policy shocks also weighed on Swiss inflation.

[Figure 2 about here.]

To implement the sign restrictions conditional on the zero restrictions, we use the method proposed by Arias et al. (2018).[10] Based on the draws that satisfy the identification scheme, we compute statistics that facilitate the interpretation of the results. In particular, we look at impulse response functions (IRFs) and the fraction of forecast error variance decomposition (FEVD). Highest probability density (HPD) intervals on these statistics are calculated 'pointwise', i.e., for each horizon separately.

3 Results

In this section, we present the results of our empirical analysis. We start by discussing the transmission of inflationary shocks in the euro area to the Swiss economy. Subsequently, we analyze the quantitative importance of foreign and domestic shocks on a set of Swiss

[9] All variables are de-trended with the use of the two-sided Hodrick-Prescott filter. Note that the variables are not de-trended in the baseline model. However, as shown in the robustness analysis, de-trending the variables does not alter our conclusions.

[10] This is a difference to a previous version of this paper (Bäurle et al. 2017), in which we rely on the algorithm proposed in Arias et al. (2014). As Arias et al. (2018) show, in order to correctly draw from the structural parametrization, one needs to take into account the effects of the change of variable induced by the mapping from the orthogonal reduced- from parametrization to the structural parametrization by introducing an additional importance sampling step. As we implement zero restrictions on the reduced form, we cannot use the conjugate prior suggested in Arias et al. (2018). However, as we use the same structural parametrization, applying their importance sampling step to our "proposal distribution" (i.e. the distribution derived with the algorithm from Arias et al. 2014) correctly adjusts for the change of variable. Note that as robustness tests, we first estimate the model with our prior but refraining from implementing zero restrictions on the reduced form. It turns out, that the results hardly differ when the small open economy assumption is dropped. We then proceed by using the conjugate prior of Arias et al. (2018). The results are again robust to this change in the specification. These results are available from the authors on request.

macroeconomic variables – with a specific focus on consumer prices. After studying the effects at the aggregate level, we investigate whether disaggregated Swiss consumer prices are affected differently by international inflation spillovers. Finally, we check the robustness of our results and discuss the implications for monetary policy.

3.1 International spillovers to the Swiss economy

How do foreign inflationary pressures originating from different shocks in the euro area transmit to the Swiss economy and in particular to consumer prices? We analyze this question by looking at the impulse responses to the identified shocks. The impulse responses to the three identified foreign shocks – demand, monetary policy and cost-push shocks – are presented in Figures 3 and D.1. In addition, Figure 4 shows the responses of the relative consumer price indices as well as the nominal and real interest rate spreads between the euro area and Switzerland to these shocks. The median response is depicted by the solid black line. The light gray shaded areas represent 68% HPD intervals. Cumulative responses are shown for all variables except the interest rates. The response of the Swiss CPI is calculated based on the disaggregated price responses and the corresponding CPI weights.[11] Similarly, we can compute the responses of different categories of the CPI.

[Figure 3 about here.]

Response to foreign demand shocks. A positive shock to demand in the euro area leads to a persistent rise in foreign output, consumer prices, and the real interest rate – consistent with our identifying restrictions. The demand driven boom in the euro area has substantial spillover effects on the Swiss economy. Both Swiss output and prices rise strongly, consistent with the fact that Switzerland is an open economy and thus heavily dependent on the foreign economic development.[12] However, while the demand driven upturn is counteracted by substantial hikes in policy rates in the euro area, the Swiss monetary policy reaction turns out to be less restrictive (as reflected by a weaker response of the real interest rate shown in Figure 4). Consistent with these changes in the relative

[11] To be more precise, the CPI is computed as a weighted average of the prices of the different CPI items, $\log(\text{CPI}_t) = \sum_{i=1}^{148} \omega_{i,t} \log(\text{price}_{i,t})$, where $\omega_{i,t}$ is the weight of item i in the CPI from the SFSO.

[12] In contrast, Mumtaz and Surico (2009) find no significant change in real activity in the UK in response to an unanticipated increase in foreign real activity.

monetary policy stance, the Swiss franc depreciates against the euro.[13] Spillover effects to Swiss consumer prices turn out to be substantial. Compared to the euro area, Swiss consumer prices initially increase more sluggishly but eventually attain a higher level in the longer run (see Figure 4).

Response to foreign monetary policy shocks. By construction, an expansionary monetary policy shock in the euro area leads to a fall in the 3M Euribor stimulating consumption and investment, which in turn causes output and consumer prices to increase. The economic upturn initiated by the expansionary monetary policy shock also has substantive effects on Switzerland: both output and prices increase significantly. In contrast to what we observe in response to foreign demand shocks, however, the monetary policy stance becomes relatively more restrictive in Switzerland for approximately one year. Furthermore, the Swiss franc now appreciates against the euro. This has likely cushioning effects on the magnitude of spillovers to Swiss prices. Indeed, it turns out that Swiss consumer prices rise by less than in the euro area, as shown in Figure 4.

In light of the substantial positive impact of an expansionary monetary policy shock in the euro area on Swiss output, our results do not confirm that a beggar-thy-neighbor mechanism is at work. Liu et al. (2014) find similar results for the UK since the 1990s. This result suggests that the expenditure switching effect – where Swiss consumers increasingly buy imported instead of locally produced products as imports become relatively cheaper because of the Swiss franc appreciation – does not dominate. Indeed, import prices fall in contrast to the increase following a positive foreign demand shock, but the response remains limited (see Figure D.1 in appendix D). In particular, there is no clear evidence of relative price changes between domestic and imported goods in the long run.

[Figure 4 about here.]

[13] The exchange rate response is broadly consistent with the predictions of the uncovered interest rate parity (UIP). While the focus of this paper is not on the UIP (puzzle) in particular, we nevertheless compute the responses of the forward discount premium, defined as in Mumtaz and Surico (2009), to all three shocks. After the demand shock, it is, although hardly statistically significant, negative over a prolonged period. This reflects the longer-lasting depreciation of the Swiss franc depicted in Figure 3. After the monetary policy and the cost-push shock, the forward discount premium is slightly positive in the short run, but not statistically significant. The response of the forward discount premium to the monetary policy shock is in line with the evidence found by Mumtaz and Surico (2009) for domestic monetary policy shocks in the UK. The results are available from the authors upon request.

Response to foreign cost-push shocks. A cost-push shock in the euro area is associated with a rise in consumer prices together with a fall in output. This shock introduces a trade-off for most central banks. Even if price stability is the primary concern, central banks often also consider developments in the real economy for their decision-making.[14] We find that on impact, the price response dominates and monetary policy in the euro area becomes more restrictive to counteract the inflationary pressures. As time evolves, the adverse effects on output become more pronounced and euro area monetary policy becomes more expansive again. The economic downturn in the euro area also has non-negligible effects on the Swiss economy. After a slight delay, Swiss output starts to fall significantly but the response turns out to be less pronounced than in the euro area. Despite the 3M Euribor rising slightly more strongly than the 3M Libor in the short term, the relative monetary policy stance remains fairly unchanged given that the real interest rate in Switzerland moves almost in step with that of the euro area. This may prevent the Swiss franc from depreciating more strongly. Swiss consumer prices also rise significantly but the magnitude of the response is comparable to the price response in the euro area (see Figure 4).

Comparison of responses. To summarize, all three foreign shocks result by construction in temporary higher inflation in the euro area. Likewise, the shocks are associated with temporary higher Swiss inflation. This is not surprising given the strong trade linkages between the euro area and Switzerland. Interestingly, however, we find that the magnitude of the spillover effects on Swiss prices depends crucially on the underlying forces driving foreign inflationary pressures and the associated general equilibrium effects.

While the inflation differential between the euro area and Switzerland narrows in response to positive demand shocks, it widens in response to expansionary monetary policy shocks and does not change significantly in response to cost-push shocks. This illustrates the importance of taking the underlying source of the international inflationary pressures as

[14] The Swiss National Bank's mandate is described in the National Bank Act (Article 5, Paragraph 1): "[...] It shall ensure price stability. In so doing, it shall take due account of economic developments." The Lisbon Treaty (Article 127, Paragraph 1) states that "The primary objective of the European System of Central Banks [...] shall be to maintain price stability. Without prejudice to the objective of price stability, [the European System of Central Banks] shall support the general economic policies in the Union with a view to contributing to the achievement of the objectives of the Union [...]." These objectives include "full employment" and "balanced economic growth".

well as the corresponding general equilibrium effects into account when analyzing spillovers to domestic inflation. In particular, the foreign shocks have very different implications on the relative monetary policy stance and exchange rates. While monetary policy becomes relatively more restrictive in the euro area and the exchange rate depreciates after demand shocks, the relative monetary policy becomes less restrictive and the exchange rate appreciates after monetary policy shocks and remains broadly unchanged after cost-push shocks. These differences are consistent with the varying degree of spillovers to consumer prices. In addition, also note that the responses of the exchange rate and inflation abroad and in Switzerland to all three shocks are in line with the purchasing power theory, without imposing any restrictions on the joint behavior of these variables.

Overall, our findings are in line with recent evidence of Forbes et al. (2018) and Comunale and Kunovac (2017), who document that the exchange rate pass-through is dependent on the nature of the shocks, and Bobeica et al. (2019), who find shock-dependent pass-through effects of labor costs to prices. We show that the same is true for international inflation spillovers. This can also help to reconcile the ambiguous empirical evidence on the comovement of domestic and global inflation.

3.2 Foreign versus domestic inflationary pressures

As shown in the previous subsection, foreign inflationary shocks can have substantial spillover effects on the Swiss economy. An important question in this context is how important are spillover effects induced by foreign shocks relative to domestic forces? To answer this question and to obtain a better understanding of the relative importance of the different foreign shocks, we conduct a variance decomposition exercise.

Figure 5 shows the variance decomposition for the domestic common factors and the CPI constructed from the disaggregated price data. Depicted is the fraction of forecast error variance that is explained by the three identified foreign shocks as well as the unidentified domestic common and item-specific shocks at different horizons. Note that the set of unidentified domestic common shocks also includes reduced-form shocks to the exchange rate. It turns out that foreign shocks account for a substantial part of the variance of Swiss variables. In the medium run, they explain up to about 25% of the variation in the exchange rate, 40% of real GDP, 80% of the 3M Libor, and 50% of the CPI. In case of the CPI, the remaining part is explained by domestic common and item-specific shocks.[15] Approximately 30% of the variations in the CPI are explained by item-specific shocks, while domestic common shocks account for approximately 20%. The finding that approximately half of the variation of the Swiss CPI is driven by foreign shocks is in line with the findings of Jordan (2015). It is also in line with results for other (small) open economies (Aastveit et al. 2016).

[Figure 5 about here.]

The bulk of the foreign contribution to output, the interest rate as well as the exchange rate is due to foreign demand shocks. Monetary policy shocks generally account for a smaller fraction, which is a common finding in the literature and can be reconciled with the fact that this shock is thought to capture unsystematic variations in the policy stance, which should be small. Consumer prices turn out to be heavily driven by foreign cost-push shocks, particularly in the short run. At longer horizons, however, demand shocks become more important, whereas the contribution of foreign cost-push shock slightly decreases. The variations in the relative importance of the different foreign shocks point to heterogeneous spillover effects to Swiss prices.

By way of summary, our results indicate that international spillovers to the Swiss economy and to Swiss prices in particular are quantitatively important. Foreign demand shocks turn out to be an important driver of Swiss macroeconomic variables in general, and for Swiss prices, foreign cost-push shocks appear to be particularly important as well.

3.3 Heterogeneity in spillovers to Swiss consumer prices

So far, we have focused our analysis on spillover effects at the aggregate level. However, our dynamic factor modeling framework allows us to study these effects at a highly disaggregate level as well, as it includes a vast number of disaggregated data on Swiss consumer prices. This may give valuable insights on item-specific differences. Furthermore, by comparing items with different degree of tradability we can shed some light on the importance of indirect, general equilibrium effects relative to the direct, mechanical pass-through of international to country-specific inflation and how this varies with different

[15] Recall that the CPI does not enter our system as an observable but is constructed from the disaggregated price data and thus features, in contrast to the other aggregates shown, an idiosyncratic part.

foreign inflationary shocks. Finally, working with disaggregated prices also allows us to get a sense of how the aggregation level of inflation can influence the estimated degree of spillovers.

[Figure 6 about here.]

In the top panels of Figure 6, we report the posterior median responses of the 148 CPI items for the three identified shocks. There is substantial heterogeneity in the price responses to all three shocks. Most prices tend to increase, however, some prices increase by a substantially smaller amount, while other prices even decrease. Interestingly, the price responses are less dispersed in the short run for foreign demand shocks but then become more dispersed over time. In contrast, the price dispersion tends to be larger in the short run for cost-push shocks and does not change much over the response horizon for monetary policy shocks. This is also confirmed by the middle panels in Figure 6, which show the standard deviation of the responses across items over the response horizon. One can see that for the demand shock, the standard deviation increases gradually. For the monetary policy shock, the price dispersion is relatively constant over the response horizon after a strong an quick initial increase. Finally, the price dispersion after cost-push shocks spikes significantly in the first couple of quarters, which appears to be driven by the responses of energy prices, and then fluctuates at a lower level. In the bottom panels of Figure 6, we show that the distribution of price responses is positively skewed, particularly in the first 8-10 quarters. The increase in skewness indicates that foreign inflationary shocks transmit to the Swiss economy as shocks to relative prices in Switzerland. In line with Mumtaz and Surico (2009), we find a positive relationship between skewness and the aggregate price response, which is supportive of the fact that shocks to relative prices can be inflationary.

To take into account the uncertainty around these estimates, we follow Mumtaz and Surico (2009) and analyze for each item its distribution of relative price responses. For each item i and draw from the posterior j, we compute the relative price response $\ln p_i^j - \ln \bar{p}^j$, where $\ln \bar{p}^j$ is the average (log) price response over all items for draw j. After having done this for all draws j, we compute for each item the fraction of relative price responses that are positive (across j), which we denote by α_i. By looking at the proportion of items which fall into $\mathcal{S}_\alpha = \{i : \alpha_i < 0.05 \text{ or } \alpha_i > 0.95\}$ (i.e., items for which more than 95% of the responses decrease or increase, respectively, compared to the average response over all items), we can then evaluate whether the change in relative prices shows some statistical significance. If the share of items falling into $\mathcal{S}_\alpha$ is larger than 10%, we may conclude that the measured change in relative prices is not the result of estimation uncertainty.[16]

[Figure 7 about here.]

Figure 7 shows the fraction of items falling into $\mathcal{S}_\alpha$. Our results for the foreign monetary policy shock and the cost-push shock are in line with Boivin et al. (2009) for domestic monetary policy shocks and Mumtaz and Surico (2009) for international supply shocks: in the short to medium run, there is evidence for significant relative price movements, as can be seen by the fact that the proportion of items falling into $\mathcal{S}_\alpha$ lies above 10% at horizons for up to one year. In the longer run, however, the responses converge to the average, as can be seen from the fact that the share of items that differ significantly from the average converges to zero. The results for the demand shock turn out to be quite different. While there seems to be no significant change in relative prices in the very short run, there is some evidence of significant relative price changes in the medium run as the share gets close to 10% (even though it never surpasses the threshold) and only slowly diminishes towards the forecast horizon. This is consistent with the persistent aggregate price response after a positive foreign demand shock.

An analysis of a selection of different categories of the CPI reveals insights on the channels leading to the dispersed responses. Specifically, we look at core CPI, energy, imported goods excluding energy, domestic goods excluding energy, private services excluding rents, and public services. In defining the core measure, we follow the Swiss Federal Statistical Office (SFSO) and exclude fresh and seasonal items as well as energy. Moreover, we define all items with an average import share of above 50% over the sample period to be imported. Analogous to aggregate CPI, the statistics for these categories are computed based on the weights of the items. We focus here on the variance decomposition of the different categories; however, the corresponding impulse responses can be found in appendix D.[17] Figure 8 presents the variance decomposition for aggregate CPI and the

[16] Mumtaz and Surico (2009) interpret a fraction of responses above this threshold as significant, stating that 'one would typically expect 10% of the price responses to be significantly different from the average'.

[17] Note that we calculate the decomposition for the particular indices, which are obtained by aggregating the items included in the categories of interest. Because of this, however, our results are not directly comparable to those of Monacelli and Sala (2009), who use a simple average of the decompositions for the single items in a given category. In Appendix C, we discuss the role of the aggregation in more detail.

selected price categories at different horizons.

The main results are twofold: first, the contribution of foreign shocks to core CPI is substantially lower when compared to the headline, particularly in the shorter term. It turns out that these differences are likely driven by energy prices. Energy prices are heavily affected by foreign shocks, and the transmission appears to occur quite fast as the foreign contribution stands at approximately 60% on impact and remains roughly at the same level afterwards. A large part of this contribution can be attributed to foreign cost-push shocks, which seems quite intuitive because these shocks likely reflect to a large extent unexpected changes in global energy prices (e.g., supply driven oil price shocks). The strong and direct impact of foreign cost-push shocks on energy prices appears to be transmitted to headline CPI, for which cost-push shocks also explain a dominant share, particularly in the shorter term. In contrast, the major part of the foreign contribution in core CPI, which does not include energy prices, is due to demand shocks, whereas cost-push shocks explain considerably less.

[Figure 8 about here.]

Second, there are some interesting heterogeneities in the relative importance of foreign shocks, which are likely related to differences in tradability and exchange rate sensitivity of the respective price categories. For categories featuring a high tradability, e.g. energy prices, foreign shocks explain a large share of the price variations. In contrast, foreign shocks account for a smaller fraction of categories that are hardly tradable, such as domestic private services, while domestic common shocks turn out to be relatively more important. Still, foreign shocks explain a non-negligible part of the variation in domestic goods and service inflation. This is in line with the findings of Hałka and Szafranek (2016) for the Czech Republic, Poland and Sweden.

These results suggest that while a certain part of spillovers to Swiss consumer prices is likely mechanical due to direct effects on import prices, general equilibrium effects are important as well. The relative importance of these effects also seems to vary with the shocks. While monetary policy and cost-push shocks explain a comparably rather low, but roughly equal share of the variations in the prices of imported (excluding energy) and domestic goods, demand shocks account for a much larger share of the variations in prices of imported goods excluding energy. In contrast, cost-push shocks (and to some extent also monetary policy shocks) explain a much higher share of the variance in energy prices. The contribution of demand shocks to energy prices is, however, much smaller and more in the range of those to prices of other domestic goods and services.

To summarize, our empirical findings point to significant differences between different price categories. It turns out that energy prices play an important role. Indeed, foreign shocks explain a markedly lower share of consumer prices when energy prices are excluded. This finding is in line with recent empirical evidence presented in other studies. Parker (2016) documents that global factors are particularly important in explaining energy prices, and Hałka and Kotłowski (2017) conclude that commodity-specific shocks are an important source of inflation variability in the Czech Republic, Poland and Sweden. Altansukh et al. (2017) argue that in a low inflation environment such as the one analyzed in this paper, the volatility of energy inflation has become relatively more important for explaining short-run changes in headline inflation.

3.4 Robustness

We check the robustness of our results along a number of dimensions, including the specification of the model, the choice of priors, the identifying assumptions, as well as the the sample period. All the results are shown in Appendix D.

Model specification. An important question is whether our results do uniquely pertain to spillovers from the euro area or to international inflation spillovers more generally. To address this issue, we replace the euro area block of the model with a global block consisting of export-weighted indicators of Switzerland's most important trading partners.[18] The results based on the global factors are in line with the results based on the factors for the euro area (see Figures D.2 and D.3). Consequently, our findings do not only pertain to spillovers emerging from the euro area but to international inflation spillovers to Switzerland more generally.

The baseline specification does also not include a measure of global financial conditions,

[18] In particular, we use export-weighted real GDP as a measure of foreign demand, an export-weighted CPI as a measure of foreign CPI, an export-weighted policy rate of the US, euro area, and Japan as a measure of the foreign policy stance, and the nominal effective exchange rate (NEER) as the relevant exchange rate index. A positive exchange rate change implies an appreciation of the Swiss franc as in the baseline analysis with the EURCHF.

which may be another transmission channel for international inflation spillovers. To control for this channel, we augment the global block by a trade-weighted financial conditions index (FCI).[19] The impulse responses of our constructed FCI to the three identified shocks are as expected (see Figure D.4). More importantly, the conclusions drawn from the baseline model remain intact (see also Figure D.5), even after controlling for financial conditions abroad.

Another potential concern is that in our baseline we include short-term interest rates, which were constrained by the effective lower bound (ELB) in the last part of our sample.[20] To analyze whether our results are effected by this, we re-estimate our model using short-term shadow interest rates. The shadow rates are from Krippner (2013) (see Figure D.6).[21] The results are shown in Figures D.7 and D.8. Overall, the results turn out to be robust to this change.

Some of the (nominal) variables in our model exhibit a slight downward trend in the first part of the sample. Therefore, we check the robustness of our conclusions to estimates with all variables de-trended using the two-sided Hodrick-Prescott filter. From the results shown in Figures D.9 and D.10, we can conclude that our findings are robust to the treatment of these trends. However, the impulse responses of Swiss GDP and CPI to foreign demand and cost-push shocks are somewhat more volatile than in the baseline estimation.

Finally, in our baseline specification, the disaggregated prices load on seven factors, six observed and one unobserved, both contemporaneously and on one lag. Instead of allowing for one lag in the observation equation, we estimate the model with two unobserved factors. The results support our conclusions. While the variance decomposition in the model with two unobserved factors and $q = 0$ points to slightly stronger spillover effects of

[19] We focus here on the model using the global variables because of the lack of a good proxy for financial conditions with sufficient time coverage for the euro area. For the period from 1999 onwards, we construct a trade-weighted financial conditions index using the US excess bond premium provided by Gilchrist and Zakrajšek (2012) and a BBB bond spread for the euro area as used in Jarocinski and Karadi (2018). For the period before 1999, we extrapolate the series with the US excess bond premium only.

[20] Note that in the last part of our sample the 3M Libor and 3M Euribor were close to or stuck at zero. The European Central Bank and the Swiss National Bank lowered short-term rates to negative levels only after the end of our sample.

[21] We are grateful to Leo Krippner for sharing the data. Since they were only available from a later point in time than the starting quarter of our estimation period, we link them with the observed interest rates in 1999, when the euro was established. This should not be a problem, given that interest rates were not constrained by the ELB in the period from 1992 to 1999.

foreign demand shocks on Swiss inflation of domestic goods (see Figure D.12), the impulse responses of the observed factors and Swiss CPI inflation are very similar to those in our baseline model (see Figure D.11).

Figures D.13 and D.14 show the results with fewer lags in the estimation equations. The state equation contains only one lang ($p = 1$) and the observation equation only the contemporaneous impact ($q = 0$). Having fewer lags in the model results in more persistent impulse responses, particularly for the interest rates. Moreover, the variance decomposition suggests smaller explanatory power of foreign shocks for Swiss inflation. Adding lags, however, does not alter the baseline model results considerably, with one exception, the tendency of the Swiss franc to appreciate in response to an expansionary foreign monetary policy shock is weaker. Figures D.15 and D.16 show the impulse responses and variance decomposition with the lag order in the state and the observation equations of $p = 3$ and $q = 2$, respectively. The findings suggest that the number of lags in the baseline model is sufficient to capture the relevant dynamics.

Estimation and identification. We also checked the sensitivity to the prior tightness. We find that the results are robust to a change in the prior parameters from $\pi_1 = \pi_2 = \pi_3 = 1$ to $\pi_1 = 0.2$, $\pi_2 = 0.7$, $\pi_3 = 2$ (which is in the region used by Karlsson (2013) in his forecasting exercise). Given the increased prior tightness, we allow for four lags in the state equation. Figures D.17 and D.18 show the results. The most noticeable difference is that the exchange rate response to a foreign demand shock becomes somewhat weaker, but the sign remains the same such that our conclusions are still supported.

In our baseline model specification, both demand shocks seem to have permanent effects on the GDP level, although not or only hardly statistically significant. Nevertheless, this indicates that the assumption of monetary policy neutrality in the long term is violated. Therefore, we impose long-run zero restrictions on the effect of the two demand shocks on foreign GDP. The results (see Figures D.19 and D.20) remain robust to this modification in the shock identification strategy.

Sub-sample analysis. To ensure that the impact of the financial crisis and the Great Recession does not drive our results, we estimate the model with data until 2007Q4. We find that the main results do not change with one exception (see Figures D.21 and D.22). After a demand shock, the interest rate differential between the Euribor and the 3M Libor is more stable in nominal terms, and in real terms, there is almost no reaction once the crisis period is removed from the sample.[22]

The fact that the interest differential is less stable when the crisis period is included might reflect that the 3M Libor was close to zero in 2010 and 2011. As a result, after the onset of the financial crisis, Swiss monetary policy might have been limited to some extent in counteracting negative foreign demand shocks with its interest rate instrument, making a stabilization of the interest rate differential infeasible. Indeed, Bäurle and Kaufmann (2018) find that the response of the trade weighted Swiss franc exchange rate to risk shocks becomes more pronounced at the effective lower bound for nominal interest rates (ELB). Thus, our result that the relative interest rate reaction is influenced by the ELB periods and the exchange rate reaction changes supports their result. Furthermore, it supports our conclusion that monetary policy can affect the spillovers of shocks. Indeed, in line with a stable interest rate differential in the pre-crisis period, the Swiss franc does not depreciate in response to a positive foreign demand shock.[23]

4 Conclusion

In this paper, we analyze how different shocks driving up inflation abroad translate into inflationary pressures in Switzerland, putting particular emphasis general equilibrium effects such as the relative monetary policy and exchange rate responses. Based on a structural dynamic factor model relating a large set of disaggregated Swiss consumer prices to key foreign and domestic factors, we study how foreign inflationary shocks are transmitted to Swiss prices. We identify three different types of inflationary shocks that are widely discussed in the literature: a positive demand shock, an expansionary monetary policy, and a cost-push shock, all originating abroad.

[22] Note that the size of the demand shock is smaller in the shorter sample, offering an explanation for the more muted reaction of the foreign interest rate level.

[23] We even see a tendency of a slight appreciation. However, the appreciation disappears when we replace the euro area with a broader measure for the foreign economy as described above. With the other responses remaining very similar (this result is not shown but can be obtained by the authors), we do not want to over-emphasize this result. In line with the exchange rate response, the spillover effects through imported inflation to Swiss CPI inflation are more muted in the shorter sample.

We find that foreign shocks explain up to approximately 50% of Swiss price variations, while common domestic shocks account for only approximately 20% (with the remaining part being due to item-specific shocks). Thus, domestic inflation is to a substantial degree driven by foreign shocks. However, this does not imply that Swiss monetary policy has not been able to affect international spillover effects to domestic inflation. Indeed, spillover effects on Swiss prices are crucially dependent on the nature of the underlying shock and the associated general equilibrium effects. Following an increase in foreign inflation due to a positive demand shock, foreign monetary policy counteracts the business cycle upturn strongly, while the Swiss monetary policy reaction turns out to be less restrictive. Consistent with the change in the relative monetary policy stance, the Swiss franc depreciates and inflation picks up even somewhat more than abroad. In contrast, in response to an increase in inflation abroad due to an expansionary monetary policy shock, monetary policy becomes relatively tighter in Switzerland and the franc appreciates – mitigating spillover effects to Swiss inflation. Finally, a cost-push shock driving up inflation (and decreasing real activity) abroad has no significant effects on the relative monetary policy stance. The effects on the exchange rate turn out to be negligible, and the increase in Swiss inflation is comparable to inflation abroad.

Our analysis of the different items of the Swiss CPI points to substantial heterogeneities intransmission of foreign inflationary shocks. It turns out that energy prices play a crucial role in the transmission, particularly in the short run. The impact of foreign inflationary shocks on Swiss CPI is lower, and the transmission appears to be slower when energy prices are excluded. Furthermore, by comparing the relative price changes of goods and services with different degree of tradability, we can get a sense of the importance of the indirect, general equilibrium effects relative to direct, mechanical spillover effects. Our results indicate that while a certain part of spillovers is likely mechanical, general equilibrium effects are important as well. Interestingly, the importance of these effects also seems to vary with the underlying shocks.

These results indicate that spillover effects need to be analyzed in a framework allowing for different transmission channels: an increase in inflation abroad may affect the inflation in an open economy differently, depending on the source of the foreign shock, and thus, movements in other factors such as activity, interest and exchange rates. This may also partly explain the ambiguity of the empirical evidence on the impact of spillovers found so far.

References

Aastveit, K. A., H. C. Bjørnland, and L. A. Thorsrud (2016): "The world is not enough! Small open economies and regional dependence," *The Scandinavian Journal of Economics*, 118, 168–195.

Altansukh, G., R. Becker, G. Bratsiotis, and D. R. Osborn (2017): "What is the Globalisation of Inflation?" *Journal of Economic Dynamics and Control*, 74, 1–27.

Arias, J. E., J. F. Rubio-Ramírez, and D. F. Waggoner (2014): "Inference Based on SVARs Identified with Sign and Zero Restrictions: Theory and Applications," Federal Reserve Bank of Atlanta Working Paper Series 2014-1, Federal Reserve Bank of Atlanta.

Arias, J. E., J. F. Rubio-Ramírez, and D. F. Waggoner (2018): "Inference based on structural vector autoregressions identified with sign and zero restrictions: Theory and applications," *Econometrica*, 86, 685–720.

Baumeister, C. and L. Benati (2013): "Unconventional Monetary Policy and the Great Recession: Estimating the Macroeconomic Effects of a Spread Compression at the Zero Lower Bound," *International Journal of Central Banking*, 9, 165–212.

Bäurle, G. (2013): "Structural Dynamic Factor Analysis Using Prior Information From Macroeconomic Theory," *Journal of Business and Economic Statistics*, 31, 136–150.

Bäurle, G., M. Gubler, and D. Känzig (2017): "International inflation spillovers - the role of different shocks," SNB Working Paper 2017-07, Swiss National Bank.

Bäurle, G. and D. Kaufmann (2018): "Measuring Exchange Rate, Price, and Output Dynamics at the Effective Lower Bound," *Oxford Bulletin of Economics and Statistics*, 80, 1243–1266.

Bäurle, G. and E. Steiner (2015): "How do individual sectors respond to macroeconomic shocks? A structural dynamic factor approach applied to Swiss data," *Swiss Journal of Economics and Statistics*, 151, 167–225.

Bauwens, L., M. Lubrano, and J.-F. Richard (1999): *Bayesian Inference in Dynamic Econometric Models*, Oxford University Press.

Bernanke, B., J. Boivin, and P. S. Eliasz (2005): "Measuring the Effects of Monetary Policy: A Factor-augmented Vector Autoregressive (FAVAR) Approach," *The Quarterly Journal of Economics*, 120, 387–422.

Bobeica, E., M. Ciccarelli, and I. Vansteenkiste (2019): "The link between labor cost and price inflation in the euro area," ECB Working Paper No 2235, European Central Bank.

Boivin, J. and M. Giannoni (2006): "DSGE Models in a Data-Rich Environment," NBER Working Paper 0332, National Bureau of Economic Research.

Boivin, J., M. P. Giannoni, and I. Mihov (2009): "Sticky prices and monetary policy:

Evidence from disaggregated US data," *The American Economic Review*, 99, 350–384.

Canova, F. (2005): "The transmission of US shocks to Latin America," *Journal of Applied Econometrics*, 20, 229–251.

Carriero, A., T. Clark, and M. Marcellino (2014): "No Arbitrage Priors, Drifting Volatilities, and the Term Structure of Interest Rates," CEPR Discussion Paper 9848, Centre for Economic Policy Research.

Ciccarelli, M. and B. Mojon (2010): "Global inflation," *The Review of Economics and Statistics*, 92, 524–535.

Comunale, M. and D. Kunovac (2017): "Exchange rate pass-through in the euro area," ECB Working Paper No 2003, European Central Bank.

Dedola, L., G. Rivolta, and L. Stracca (2017): "If the Fed sneezes, who catches a cold?" *Journal of International Economics*, 108, 23 – 41.

Eichenbaum, M. and C. L. Evans (1993): "Some empirical evidence on the effects of monetary policy shocks on exchange rates," NBER Working Paper 4271, National Bureau of Economic Research.

Fleer, R., B. Rudolf, and M. Zurlinden (2016): "Price change dispersion and time-varying pass-through to consumer prices," SNB Working Paper 2016-17, Swiss National Bank.

Forbes, K. J., I. M. Hjortsoe, and T. Nenova (2017): "Shocks versus structure: explaining differences in exchange rate pass-through across countries and time," External MPC Unit Discussion Papers 50, External MPC Unit, Bank of England.

——— (2018): "The shocks matter: improving our estimates of exchange rate pass-through," *Journal of International Economics*, 114, 255–275.

Georgiadis, G. (2016): "Determinants of global spillovers from US monetary policy," *Journal of International Money and Finance*, 67, 41–61.

Geweke, J. (1992): "Bayesian Statistics," in *Bayesian Statistics*, ed. by J. Bernardo, J. Berger, A. Dawid, and A. Smith, Oxford University Press,, vol. 4.

——— (2005): *Contemporary Bayesian Econometrics and Statistics*, John Wiley & Sons, Inc.

Gilchrist, S. and E. Zakrajšek (2012): "Credit spreads and business cycle fluctuations," *American Economic Review*, 102, 1692–1720.

Hałka, A. and J. Kotłowski (2017): "Global or domestic? Which shocks drive inflation in European small open economies?" *Emerging Markets Finance and Trade*, 53, 1812–1835.

Hałka, A. and K. Szafranek (2016): "Whose Inflation Is It Anyway? Inflation Spillovers Between the Euro Area and Small Open Economies," *Eastern European Economics*, 54, 109–132.

Jarocinski, M. and P. Karadi (2018): "Deconstructing monetary policy surprises: the role of information shocks," ECB Working Paper No 2133.

Jordan, T. J. (2015): "The Impact of International Spillovers on Inflation Dynamics and Independent Monetary Policy: the Swiss Experience," Jackson Hole Conference Paper, Swiss National Bank.

Karlsson, S. (2013): "Forecasting with Bayesian Vector Autoregressions," in *Handbook of Economic Forecasting*, ed. by G. Elliott and A. Timmermann, Elsevier Amsterdam, vol. 2, chap. 15, 791–897.

Kim, C.-J. and C. R. Nelson (1999): *State-Space Models with Regime Switching*, The MIT Press.

Kim, S. (2001): "International transmission of US monetary policy shocks: Evidence from VAR's," *Journal of Monetary Economics*, 48, 339–372.

Krippner, L. (2013): "A tractable framework for zero-lower-bound Gaussian term structure models," Reserve Bank of New Zealand Discussion Paper No DP2013/02, Reserve Bank of New Zealand.

Liu, P., H. Mumtaz, and A. Theophilopoulou (2014): "The transmission of international shocks to the UK. Estimates based on a time-varying factor augmented VAR," *Journal of International Money and Finance*, 46, 1–15.

Maćkowiak, B. (2007): "External shocks, US monetary policy and macroeconomic fluctuations in emerging markets," *Journal of Monetary Economics*, 54, 2512–2520.

Monacelli, T. and L. Sala (2009): "The international dimension of inflation: evidence from disaggregated consumer price data," *Journal of Money, Credit and Banking*, 41, 101–120.

Mumtaz, H. and P. Surico (2009): "The transmission of international shocks: a factor-augmented VAR approach," *Journal of Money, Credit and Banking*, 41, 71–100.

——— (2012): "Evolving International Inflation Dynamics: World and Country-specific Factors," *Journal of the European Economic Association*, 10, 716–734.

Neely, C. J. and D. E. Rapach (2011): "International comovements in inflation rates and country characteristics," *Journal of International Money and Finance*, 30, 1471–1490.

Neusser, K. (2009): *Zeitreihenanalyse in den Wirtschaftwissenschaften*, Vieweg + Teubner Verlag, 3rd ed.

Parker, M. (2016): "Global inflation: the role of food, housing and energy prices," Reserve Bank of New Zealand Discussion Paper No DP2016/05, Reserve Bank of New Zealand.

Poirier, D. (1998): "Revising Beliefs in Nonidentified Models," *Econometric Theory*, 14, 483–509.

Potjagailo, G. (2017): "Spillover effects from Euro area monetary policy across Europe: A factor-augmented VAR approach," *Journal of International Money and Finance*, 72, 127–147.

Primiceri, G. E. (2005): "Time Varying Structural Vector Autoregressions and Monetary Policy," *Review of Economic Studies*, 72, 821–52.

Rieth, M. (2015): "Can central banks successfully lean against global headwinds?" DIW Roundup 88, Deutsches Institut für Wirtschaftsforschung.

Shambaugh, J. (2008): "A new look at pass-through," *Journal of International Money and Finance*, 27, 560–591.

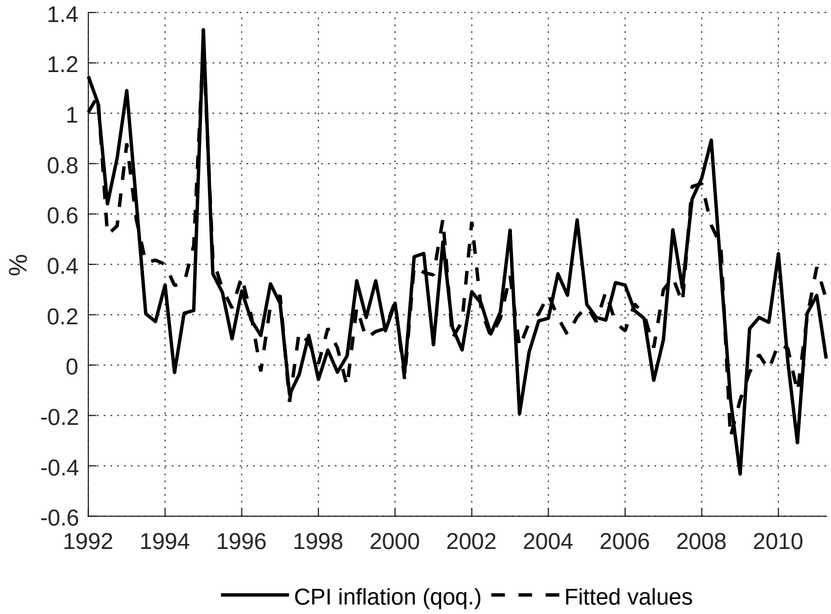
Stock, J. H. and M. W. Watson (2016): "Dynamic factor models, factor-augmented vector autoregressions, and structural vector autoregressions in macroeconomics," in *Handbook of Macroeconomics*, ed. by J. B. Taylor and H. U. (eds.), Elsevier, vol. 2A, chap. 8, 415–525.

Stulz, J. (2007): "Exchange rate pass-through in Switzerland: Evidence from vector autoregressions," Economic Studies 2007-4, Swiss National Bank.

Uhlig, H. (2005): "What are the effects of monetary policy on output? Results from an agnostic identification procedure," *Journal of Monetary Economics*, 52, 381–419.

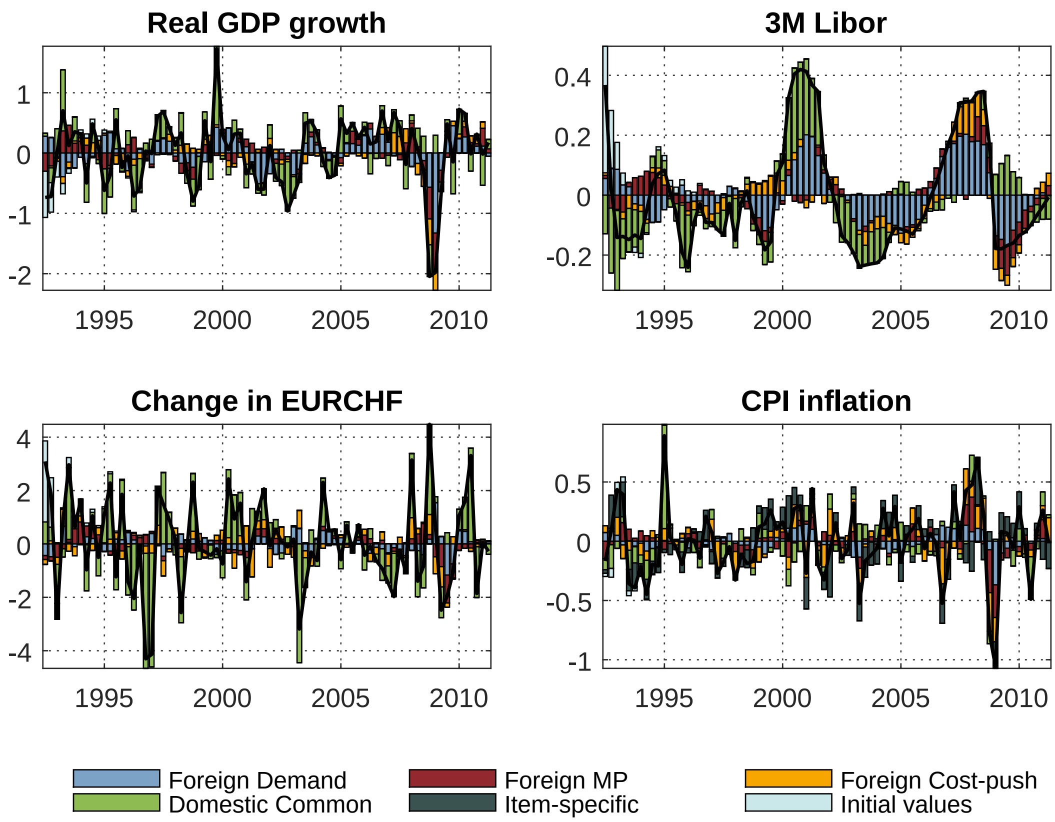
Woodford, M. (2007): "Globalization and Monetary Control," NBER Working Paper 13329, National Bureau of Economic Research.

Figure 1 – Swiss CPI inflation (qoq) versus fitted values



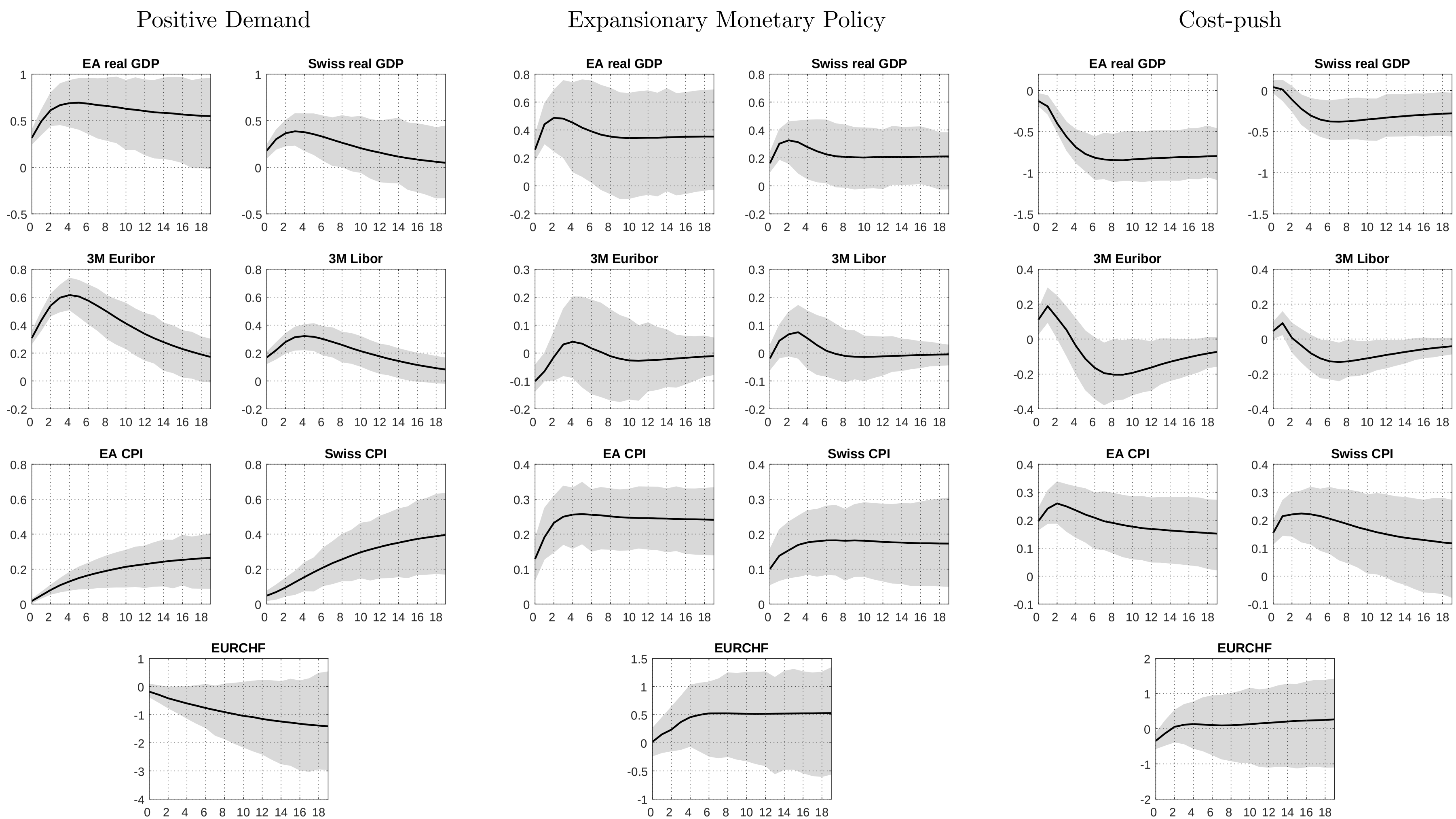
Note: The figure illustrates Swiss CPI inflation (qoq) and the fitted values of an OLS regression of Swiss CPI inflation on one unobserved factor and six observed factors. The observed factors are euro area real GDP, the 3M Euribor, euro area CPI, the EURCHF, Swiss real GDP, and the 3M Libor. All observed variables enter the model as quarter-on-quarter growth rates except for the interest rates, which enter in levels.

Figure 2 – Historical decomposition of de-trended Swiss macroeconomic variables



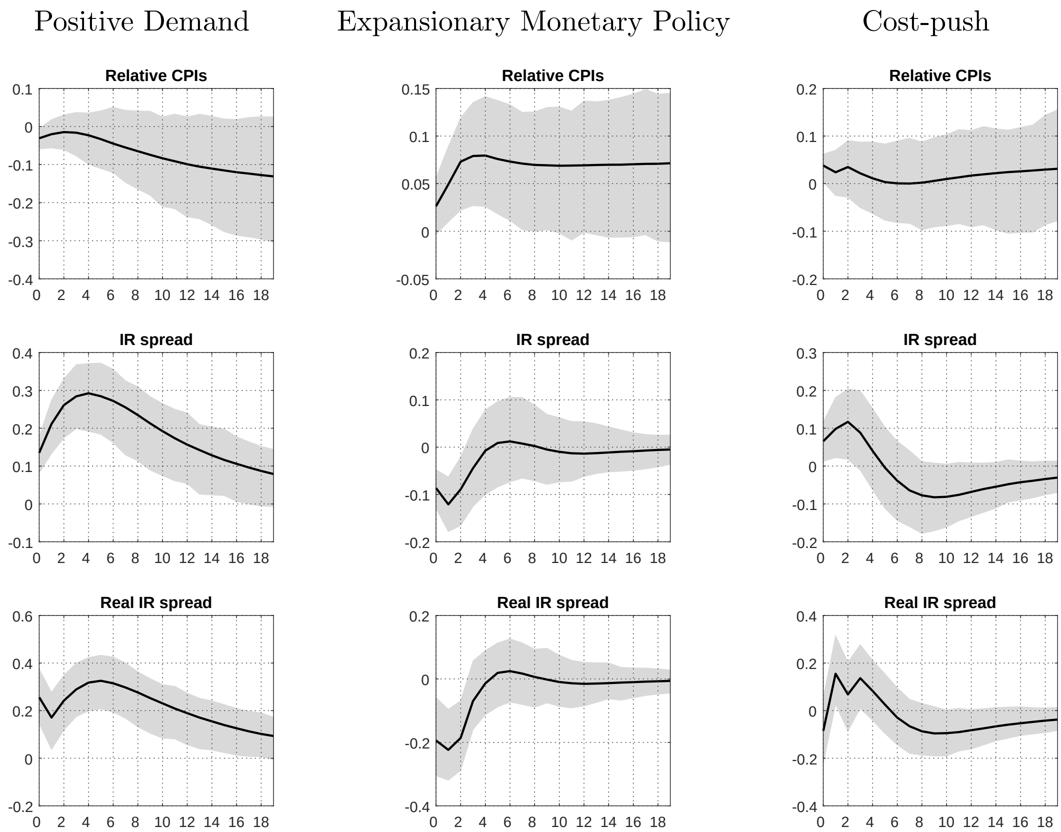
Note: The figure shows the historical contributions of the structural foreign shocks and the domestic shocks to quarterly changes in the de-trended levels of the Swiss real GDP, the Swiss CPI and the EURCHF as well as the de-trended level of the 3M Libor. All variables are de-trended with the use of the two-sided Hodrick-Prescott filter.

Figure 3 – Impact of foreign inflationary shocks on common factors and aggregate Swiss CPI



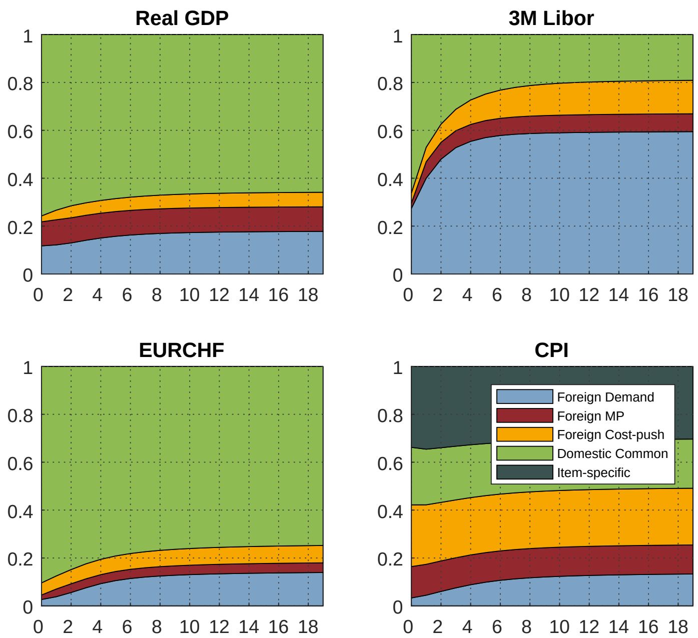
Note: The figure illustrates the impulse responses to one standard deviation structural shocks at horizons up to 20 quarters (along the x-axis). The median response is depicted by the bold black line. The light gray shaded area represents the 68% HPD interval. For all variables, the cumulative responses are shown except for the interest rates. The responses of the interest rates along the y-axis can be interpreted as the annualized quarter-on-quarter change in percentage points. All other responses along the y-axis denote percentage changes.

Figure 4 – Impact of foreign inflationary shocks on spreads between Swiss and euro area CPI and interest rates



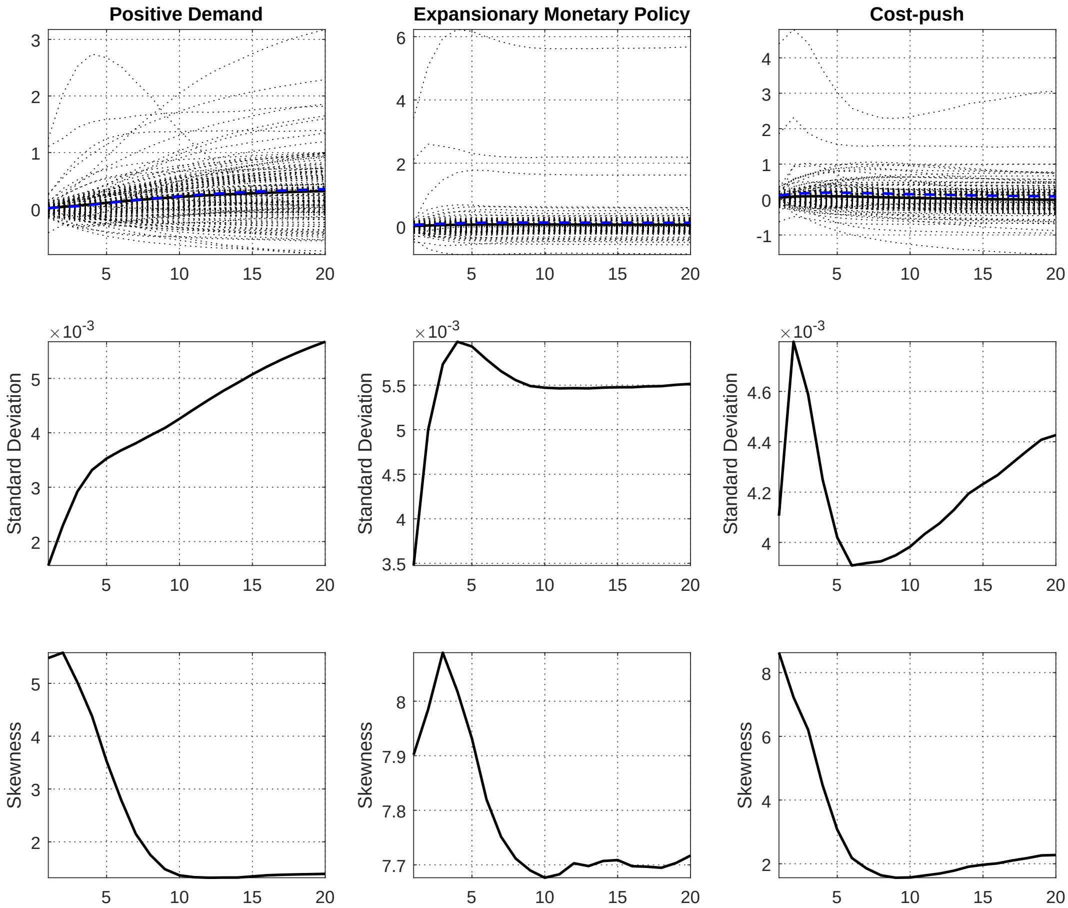
Note: The figure illustrates the impulse responses to one standard deviation structural shocks at horizons up to 20 quarters (along the x-axis). The median response is depicted by the bold black line. The light gray shaded area represents the 68% HPD interval. For the relative CPIs, the cumulative responses are shown. The responses of the interest rate spreads along the y-axis can be interpreted as the annualized quarter-on-quarter change in percentage points. The responses of the relative CPIs along the y-axis denote percentage changes. Relative CPIs: log EA CPI minus log Swiss CPI. IR spread: 3M Euribor minus 3M Libor. Real IR spread: Real 3M Euribor (3M Euribor minus EA CPI inflation) minus real 3M Libor (3M Libor minus Swiss CPI inflation).

Figure 5 – Variance decomposition of Swiss common factors and aggregate CPI



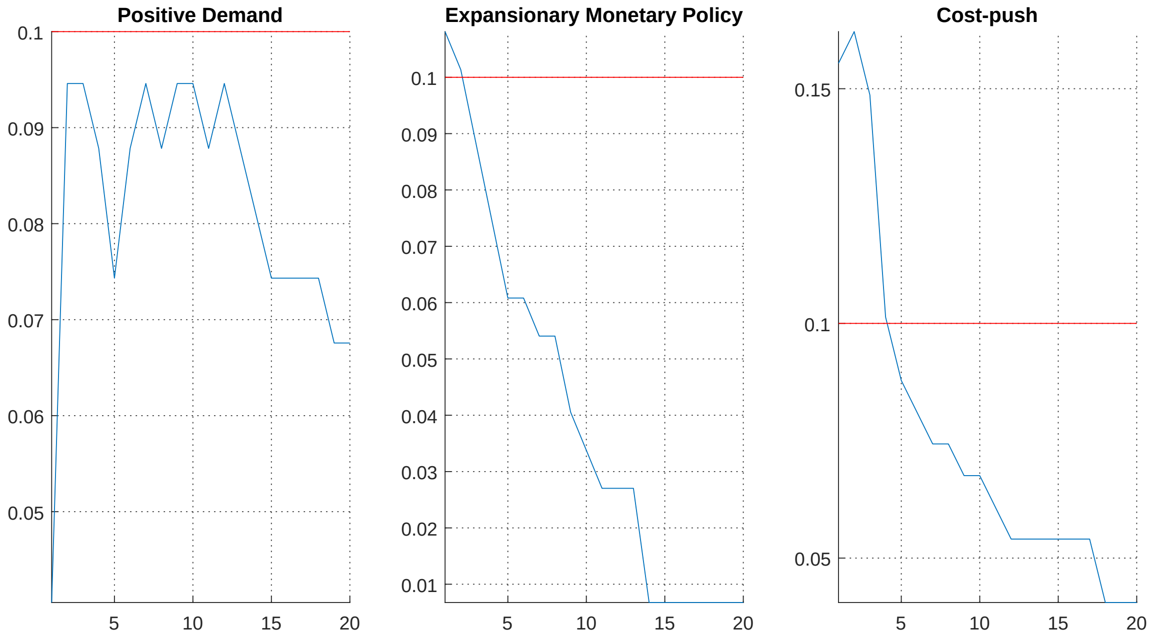
Note: The figure illustrates the posterior mean of the forecast error variance decomposition of shocks (along the y-axis) at horizons up to 20 quarters (along the x-axis).

Figure 6 – Impact of foreign inflationary shocks on common factors on disaggregated prices



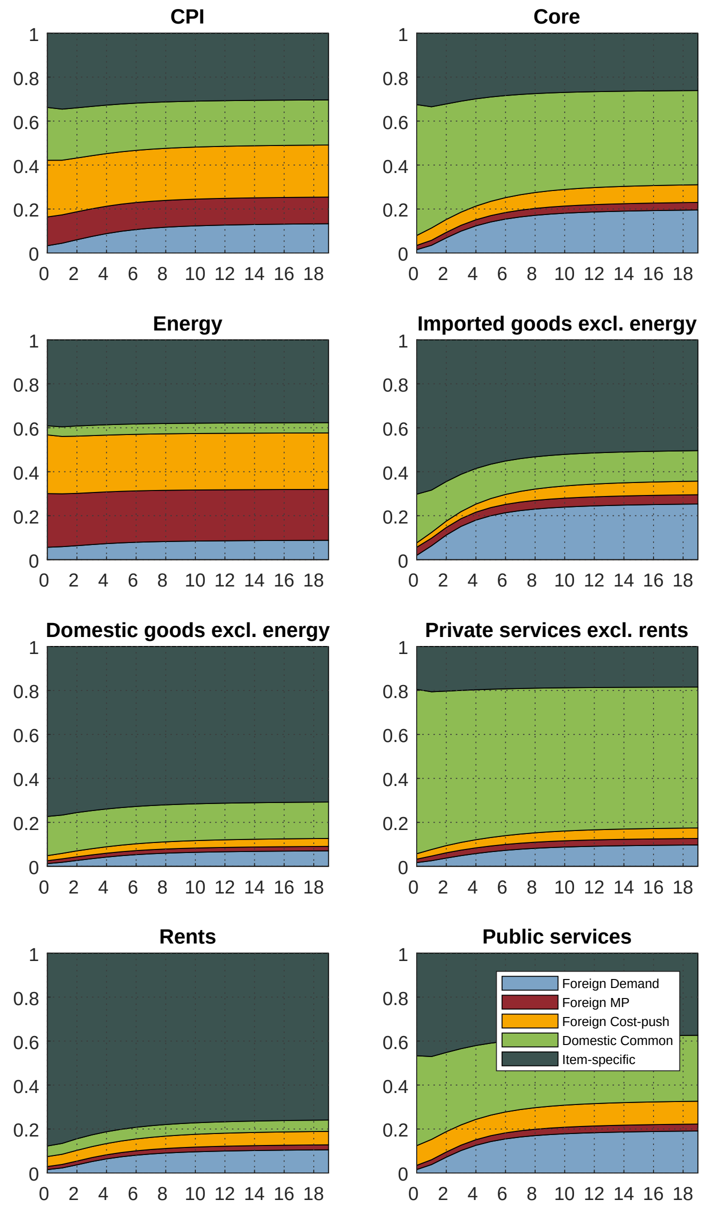
Note: The top panels of the figure illustrates the posterior median responses of the 148 CPI items for the three identified shocks at horizons up to 20 quarters (along the x-axis). The middle (bottom) panels show the standard deviation (skewness) of the responses across items for the three identified shocks at horizons up to 20 quarters (along the x-axis).

Figure 7 – Fraction of items for which $\alpha < 0.05$ or $\alpha > 0.95$



Note: For each item i and draw j, we compute the relative price response $\ln p_i^j - \ln \bar{p}^j$, where $\ln \bar{p}^j$ is the average (log) price response over all items for draw j. After having done this for all draws j, we compute for each item the fraction of relative price responses that are positive (across j), which we denote by α_i. The figure shows for the three identified shocks the fraction of items for which $\alpha_i < 0.05$ or $\alpha_i > 0.95$.

Figure 8 – Variance decomposition of different categories of Swiss consumer prices



Note: The figure illustrates the posterior mean of the forecast error variance decomposition of shocks (along the y-axis) at horizons up to 20 quarters (along the x-axis).

Table 1 – The identification scheme

Variable/Shock	Demand	Monetary policy	Cost-push
Real GDP growth euro area	+	+	−
Policy rate euro area	(+)	−	*
CPI inflation euro area	+	+	+
Real interest rate euro area	+	(−)	*

Note: The signs in parentheses are implicitly fulfilled, given the explicit sign restrictions imposed to identify the shock.