The Speed of the Exchange Rate Pass-Through*

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PRELIMINARY AND INCOMPLETE

Abstract

This paper analyzes the speed of the exchange rate pass-through into importer and exporter prices for a large, unanticipated and unusually 'clean' exchange rate shock. Our shock originates from the Swiss National Bank's decision to lift the minimum exchange rate policy of one euro against 1.2 Swiss francs. This action resulted in a permanent appreciation of the Swiss franc by more than 11% against the euro. We analyze the response of unit values to this exchange rate shock at the daily frequency for different invoicing currencies, using the universe of Switzerland's transactions-level trade data. The main finding is that the speed of price adjustment is fast: it starts on the second working day after the exchange rate shock and reaches the medium-run pass-through after seven working days on average. Moreover, while the degree of the pass-through is different across product groups and invoicing currencies, the speed at which price adjustment occurs is similar. These observations suggest that nominal rigidities play only a minor role in the face of large exchange rate shocks.

Keywords: daily exchange rate pass-through, speed, large exchange rate shock
JEL Classification: F14, F31, F41

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1 Introduction

Understanding the manner in which exchange rate changes pass through into prices of tradable goods is of importance for international economics. The exchange rate pass-through is not only informative about market structures, the pricing and markups of firms, it also determines the transmission of nominal shocks induced, e.g., by monetary policy across borders. For some time, measuring and explaining the degree of the exchange rate pass-through has been the central challenge of the literature.[1] Recent work, however, has turned its attention to the speed at which prices react to exchange rate shocks. Typical estimates for the adjustment period range from 4 to 18 months.[2]

This paper analyzes the speed of the pass-through for a large, unanticipated and unusually 'clean' exchange rate shock. Our shock originates from the Swiss National Bank's (SNB) decision to lift the minimum exchange rate policy of one euro against 1.2 Swiss francs. This action resulted in a permanent appreciation of the Swiss franc against all major currencies and more important to an appreciation by more than 11% against the euro. We analyze the response of unit values to this exchange rate shock at the daily frequency for different invoicing currencies, using the universe of Switzerland's transactions-level trade data.

Our main results are twofold. First, we document that price adjustments are extremely fast: the medium-term pass-through starts two working days and it essentially reaches the medium-run pass-through after seven working days. We thus find that the exchange rate shock passes through into prices much faster than previous studies would suggest. Second, we show that, while the degree of exchange rate pass-through differs by invoicing currency, the speed of price adjustments is similar across groups of invoicing currencies. Thus, the fast adjustment of importer prices does not stem from a "mechanical adjustment", which arises under nominal rigidities if traded goods are invoiced in the exporter's currency. Our findings support the view that nominal rigidities have played only a minor role during the adjustment period.

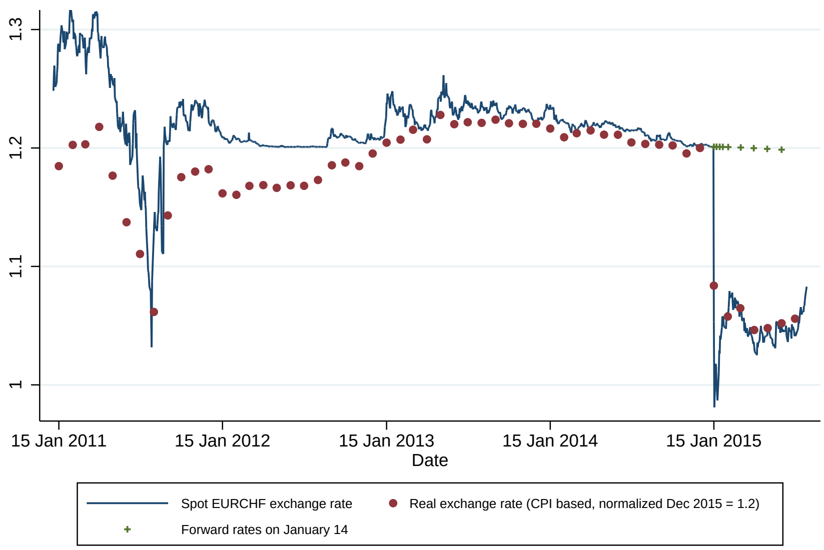
Key to our analysis is the large, unanticipated and, as we argue, exogenous exchange rate shock that originated from the SNB's policy decision. Figure 1 illustrates the dynamics of the nominal bilateral exchange rate

[1]See Dixit (1989) and Feenstra (1989) for early theoretical and empirical contributions, Menon (1995) for a survey of the earlier literature.

[2]Campa and Goldberg (2005) find that most of the pass-through materializes after two quarters, in Gopinath et al. (2010) it requires about 18 months to be completed.

(solid line) and the monthly real exchange rate (dots) starting January 1, 2012 through June 30, 2015. On January 15, 2015, the series shows a persistent appreciation of at least 11%. Apart from a temporary overshooting, the fluctuations before and after this shock are mild relative to the drop itself. Further, the forward rates (diamonds) from January 14, 2015, which are around the 1.2 threshold, strongly indicate that the January 15, 2015 decision was not anticipated by financial markets.

Figure 1: EURCHF exchange rate from January 2011 to June 2015



Sources: SNB, BIS, EZV, own calculations.

The main message of our remarkably fast pass-through finding is that the suddenness and size of an economic shock can quickly undo frictions defined by staggered contracts or lengthy deliveries. At a minimum, the evidence suggests that nominal rigidities did unravel in a matter of days after the exchange rate shock from January 15, 2015. Of course, this does not imply that nominal frictions are nonexistent. Instead, our findings indicate that firms are able to adjust prices rapidly if confronted with unexpected and large changes to their operating environment. This observation is especially striking in the context of cross-border trade, where transport is time-intensive and contracts could be expected to be written with a horizon of quarters, introducing the corresponding nominal frictions.[3]

Burstein et al. (2005) are closest to our study on export and import prices. The authors document that import and export prices of tradable goods respond rapidly to large exchange rate shocks, while retail prices of tradable goods are much slower to adapt due to local components such as retail costs. We confirm that export and import prices react promptly to a large exchange rate shock and make two important advancements. First, we show that the prices appear to be extremely flexible even at the daily scale, i.e., on a much finer time-grid than the monthly price indices or weekly survey data in Burstein et al. (2005). Second, we confirm that price adjustments occur irrespective of invoicing currencies. This latter observation is important, because adjustments of export and import prices in Burstein et al. (2005) may mechanically occur if a large share of traded goods is invoiced in foreign currencies (a presumption that is highly likely in the sample of developing and emerging countries considered, see Kenen (2011)). Our analysis, instead, shows that Swiss export and import prices measured in CHF adjust also when originally invoiced in CHF. This observation complements Burstein et al. (2005) in that it allows us to conclude that nominal rigidities are quickly overcome in face of large exchange rate shocks.

In view of the fact that price adjustments are rather infrequent in normal times, our findings constitute strong support for state-dependent pricing frameworks à la Dotsey et al. (1999) and Golosov and Lucas (2007).[4] Klenow and Kryvtsov (2008) analyze micro level data for the United States and show that size and timing of price changes vary considerably for a given item, but the size and probability of a price change are unrelated to the time since the last price change. Using Mexican consumer price data, Gagnon (2009) shows that the frequency of price adjustments comoves with inflation and concludes that "pricing models should endogenize the timing of price changes

[3]Foreign goods shipped to the United States spend about two months in transit, see Amiti and Weinstein (2011). Letters of credit, the most common means of trade finance, cover a typical span of 90 days, see BIS (2014).

[4]Typical measures of price adjustments frequencies are low: the median (non-sales) price adjustment is known to take place every 8 to 11 months for prices of U.S. consumer goods, see Nakamura and Steinsson (2008), and every 10 to 14 months for prices of U.S. import goods, see Gopinath et al. (2010), suggesting non-negligible adjustment costs. For Swiss domestic prices in the CPI basket, Kaufmann (2009) reports that 13,8% of prices are adjusted within a quarter between 2000 and 2005, which amounts to a median duration between price changes of 4.6 months. This is extremely close to the 4.3 months reported in Bils and Klenow (2004). Lein (2010) reports survey data of Swiss firms covering 1999 to 2007, showing that only 33% of firms surveyed have changed their prices in the previous quarter.

if they wish to make realistic predictions at both low and high inflation levels." Adding to recent work documenting the empirical relevance of state-dependent pricing frameworks, our findings support this general message.[5]

By documenting that a 11% exchange rate shock induces responses very similar those of full price flexibility, our study may also add valuable information for refined calibrations of state-dependent pricing models. While the frequency of adjustment in tranquil times is well documented and the according parameters are readily calibrated, we provide rare evidence on the reaction of prices and price adjustment frequencies in response to large, permanent, and unanticipated shocks.[6]

Gauging the flexibility of international prices in response to a large shock at the daily frequency is a novelty. The gains from working with an unusually detailed dataset containing information about the exact transaction require us to compromise in other dimensions. The dataset do not allow us to identify exact products as Gopinath et al. (2010) and thus cannot report price changes or pass-through rates conditional on price changes. We rely instead on 8-digit HS product classes similar to Berman et al. (2012). While this latter study uses firm level data, we are only able to proxy those with a postal code-product combination.

Our findings contribute to several strands of the pass-through literature. First, our findings connect to the broad literature that addresses the degree, determinants, and characteristics of the (medium-run) exchange rate pass-through. The average degree of an economy's exchange rate pass-through is typically found to vary between 0.4 (a 10% appreciation in the exporter's exchange rate is associated with a 4% rise in export prices) and 1 for most countries (see Campa and Goldberg (2005)) and varies across sectors (e.g., Feenstra (1989)).[7]

[5]Feltrin and Guimaraes (2015), for example, use prices of Brazilian CPI behavior in Brazil following the large devaluation of the Brazilian real in 1999 and show that the frequency of adjustment is higher right after the depreciation. Grinberg (2015) uses micro data from Mexican CPI and shows that "the effects of nominal rigidities in retail prices are quantitatively small and short-lived", concluding that models with "time-dependent nominal frictions in prices (e.g. Calvo prices) can substantially underestimate the response of prices to a large depreciation, implying large real effects of the nominal shock".

[6]Our findings are thus in line with Vavra (2013) who shows that "greater volatility leads to an increase in aggregate price flexibility." Relatedly, large shocks are thus likely to impact inflation persistence and the determinants of Phillips Curves, as analyzed in Bakhshi et al. (2007).

[7]A fast growing literature has identified number of firm- and product-specific determinants of the exchange rate pass-through. Recent empirical contributions highlight the role of firm size, e.g., Berman et al. (2012), the share of imported inputs, e.g., Amiti et al. (2014), or the role of product quality, e.g., Chen and Juvenal (2013) and Auer et al.

Regarding the more specific question of the speed of price adjustment, the existing empirical evidence suggests that in normal times this speed is rather limited. Campa and Goldberg (2005) observe that "[m]ost of the pass-through response occurs over the first and second [quarter] after an exchange rate change" while Gopinath et al. (2010) analyzing more detailed transactions-level import prices find that the pass-through requires about 18 months to be completed. Burstein and Jaimovich (2012), in turn, find quicker adjustments using Canadian and U.S. scanner data. They show that retail prices adjust to exchange rate shocks within about four months. Gorodnichenko and Talavera (2014) show that price adjustment is even faster in the particular case of online markets. We complement this rich set of findings by analyzing the speed of the exchange rate pass-though into prices of tradeable at the daily frequency. We attribute the difference of our findings to those in the literature to the fact that we analyze a particularly large exchange rate shock. While firms may delay price adjustment to small shocks (see Corsetti et al. (2008)) the need to adjust prices can be quite different in the face of large shocks.

Our work also connects to the strand of empirical research on episodes of large exchange rate changes.[8] Previous studies have examined large exchange rate devaluations mainly for developing countries. Flach (2014), for example, uses the depreciation of the Brazilian real to identify its causal effects on export prices. Further, Cravino and Levchenko (2015) use the devaluation of the peso during Mexico's Tequila Crisis and show its substantial distributional impact. Similarly, Alessandria et al. (2015) consider export expansion in emerging markets after a large devaluation. We contribute to this literature on large exchange rate shocks in that we analyze a single-day, large, and unanticipated exchange rate appreciation. Our large exchange rate shock, moreover, is novel to the literature in that it concerns an industrialized country and a major currency.

A further contribution adds to the empirical literature on international price settings that work with large micro-datasets at ever higher frequencies. Our study is the first to estimate the exchange rate pass-through for transactions-level trade data with over 29 million observations at the daily frequency. This represents an advancement over previous studies by Auer and Schoenle (2016) and Gopinath et al. (2010) that work with similar

(2014).

[8]Our results are consistent with the evidence that the exchange rate pass-through for import prices is high and fast for developing economies, yet the evidence for industrial economies with a low inflation environment tends to exposit low and slow exchange rate pass-through.

datasets at the monthly frequency and studies by Burstein et al. (2005) and Gorodnichenko and Talavera (2014) that use 'scanner' (barcode) data and web-based retailers at the weekly frequency. As we show for import prices invoiced in euros, daily data are able to identify an immediate and complete pass-through.

Our work also makes advances by addressing the endogenous nature of exchange rates. It is well known that traditional pass-through estimations suffer identification problems because of the endogeneity of the exchange rate.[9] Our shock, which was not anticipated by financial markets, is 'purely nominal'. In other words, the shock does not result from fundamentals so that our estimated price adjustments are not mixing reactions to the nominal exchange rate and, simultaneously, to shocks to fundamentals.

The remainder of the paper is organized as follows. Section 2 describes the nature of the exchange rate shock, the transactions-level trade data, and the estimation strategy. Section 3 first presents the empirical results at the monthly frequency. This is done to facilitate comparison with the previous literature, which primarily provides estimates at the monthly frequency. Section 4 presents the main results at the daily frequency. Section 5 presents further robustness checks on the speed of price adjustment. Section 6 concludes.

2 Data description and empirical strategy

The identification strategy to estimate the speed of the exchange rate pass-through relies, first, on a large and exogenous exchange rate shock and, second, on detailed transactions-level trade data at the daily frequency. The discussion is divided into three subsections. The next subsection discusses the special case of the SNB floor and why its lifting is argued to have induced an exogenous shock. Thereafter, we discuss the main features of the Swiss customs data. Finally, we present our estimation specifications that allow us to take advantage of the exogenous shock.

[9] Corsetti et al. (2008) observe that "the estimation bias in pass-through regressions is a function of the volatility of the nominal exchange rate and the covariance between the exchange rate and the determinants of import prices." The authors present a model of variable firm markups and sticky prices where exchange rates and nominal prices are driven by productivity shocks. With concrete reference to a specific good, Gopinath et al. (2010) write that "the Canadian exchange rate is more likely to be driven by the price of its main export commodities than the other way round." While this criticism is especially prevalent for 'commodity currencies' (see Chen and Rogoff (2003)), reverse causality will always affect traditional estimation to some degree.

2.1 The exchange rate shock

This paper takes the sudden appreciation of the EURCHF exchange rate on January 15, 2015 as an exogenous, unanticipated shock to estimate the causal impact of exchange rate changes on export (and import) prices.[10] This subsection motivates the identifying assumption, arguing that the appreciation was exogenous to export pricing. Moreover, the exchange rate shock was preceded by an extended period of exceptional exchange rate stability.[11]

The SNB pursued a policy of a minimum exchange rate of 1.2 Swiss francs against the euro from September 6, 2011 to January 15, 2015. This unconventional policy was introduced in response to the appreciation pressures on the Swiss franc during the summer months in 2011. In particular, the Swiss franc had appreciated against the euro by more than 20% in June and July 2011. At the time, the SNB argued that the rapid appreciation of the Swiss franc would harm the Swiss economy through imported deflation.[12] Throughout the period of the minimum exchange rate policy, it was repeatedly mentioned that the Swiss franc was overvalued and that the SNB was fully committed to the policy. The period during which the SNB defended the exchange rate floor was characterized by an exceptional low level of fluctuations in the real and nominal exchange rate vis-a-vis Switzerland's most important trade partner, the euro area.

In reference to the discussion in the introduction on the dynamics of the Swiss franc shock, Figure 1 plots the nominal EURCHF exchange rate (daily data), the real EURCHF exchange rate (monthly data) and the EURCHF forward rates on January 14, 2015.[13] The figure shows that the nominal EURCHF and the real EURCHF exchange rate move closely together over the entire period from January 2010 to June 2015. During the period of the minimum exchange rate (September 6, 2011 to January 15, 2015), the Swiss franc fluctuated between 1.2 and 1.25. Yet for most of the floor's period,

[10] Efing et al. (2015) use the SNB exchange rate shock to examine the impact on investor behavior. Previous studies have also used a similar strategy for large devaluations. For example, Burstein et al. (2005) and Verhoogen (2008) consider the large Mexican devaluation in 1994 as their exchange rate shock. Other authors such as Forbes et al. (2015) argue that these crisis and their exchange rate shocks in emerging markets were anticipated.

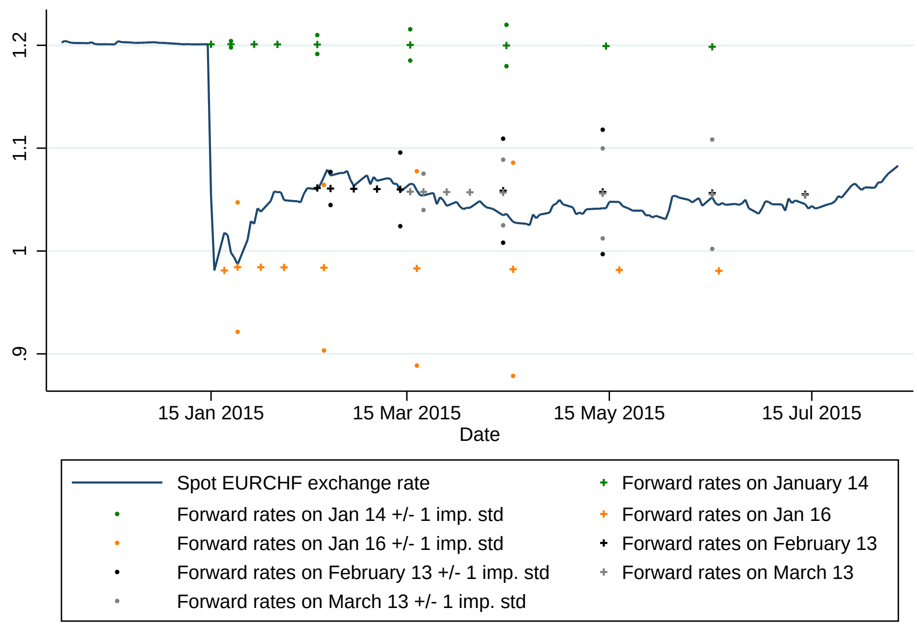
[11] This latter fact grants that our estimates are not contaminated by lagged price adjustments to prior exchange rate fluctuations.

[12] The SNB press release from September 6, 2011 stated "[t]he current massive overvaluation of the Swiss franc poses an acute threat to the Swiss economy and carries the risk of a deflationary development."

[13] The real exchange rate is constructed using the CPI indices from the euro area and Switzerland and is normalized to 1.2 for December 2014.

the Swiss franc hovered near the minimum rate and the implied volatility dropped to historically low levels during this period.

Figure 2: EURCHF spot rates and forward rates with implied standard deviations from January 2015 to June 2015



Sources: SNB, Datastream, own calculations.

The period of exchange rate stability ended abruptly with the lifting of the floor on January 15, 2015. The timing of the SNB's announcement was motivated by the changing global market conditions, in particular, increasing differentials in monetary policy actions.[14] The SNB's announcement to terminate its policy of the minimum exchange rate took financial markets by storm.[15] Shortly after the SNB announcement, the EURCHF appreciated

[14]The SNB press release from January 15, 2015 stated "[r]ecently, divergences between the monetary policies of the major currency areas have increased significantly a trend that is likely to become even more pronounced. ... In these circumstances, the SNB concluded that enforcing and maintaining the minimum exchange rate for the Swiss franc against the euro is no longer justified."

[15]The list of market commentary regarding the SNB's decision on January 15, 2015 is long. One of many examples is from Reuters, see http://www.reuters.com/article/us-swiss-snb-cap-idUSKBN0KO0XK20150116.

from 1.20 to 0.87 against the euro – the largest single-day movement for a major currency since 1945. The announcement triggered a five-fold jump in the implied volatility of the EUR-CHF exchange rate. The currency turmoil also affected international bond markets for several days. Figure 1 shows that the Swiss franc appreciated by 11% against the euro by the end of January. The daily EURCHF rate averaged 1.057 for the post-minimum exchange rate period. The Swiss franc appreciation was sudden and large.

The exchange rate shock was not only large and persistent, but it was also unanticipated. Figure 2 zooms in on January 2015 and contains information on EURCHF forward rates. More specifically, it shows that the forward rates from January 14, 2015, i.e., one day before the SNB's announcement (crosses), stayed at the minimum rate of 1.2. Note that the +/- implied standard deviations of the forward rates are also included when available. The implied standard deviations of the January 14 forward rates are small indicating little uncertainty. Forward rates quoted in January 16, February 13, 2015 and March 13, 2015 are also shown. These forward rates first dropped to about 0.98 the day right after the announcement before stabilizing at just under 1.06 in February and March. Another difference between the forward rates is their implied volatility. After the exchange rate shock, the level of uncertainty was four times greater one day after the shock as opposed to a month after the shock. Although the one-time appreciation was permanent, the level of volatility in the short run had dissipated quickly. These observations underpin our claim that the exchange rate drop was not only large but also unanticipated.

2.2 Swiss transactions-level trade data

The source for the trade data is the Swiss Customs Administration or Eidgenössische Zollverwaltung (EZV), which records Swiss customs transactions.[16] The sample is from January 2, 2014 to June 30, 2015. The data include information on the value in Swiss francs (f.o.b. for exports and c.i.f. for imports), mass, product, partner country, transactions date, Swiss postal code, currency invoice, and transportation mode (road, plane, rail, water, pipeline, self-propelled). These data are reported on the transactions level at the daily frequency. The data cover all legal customs declarations made to the Swiss Customs Administration. A unit of observation is one

[16] The geographical coverage is Switzerland, Liechtenstein, and the two enclaves Campione d'Italia and Büsingen.

transaction.[17]

Each observation contains an 8-digit HS number as well as a statistical key specific to the EZV dataset. We refer to the combination of HS number and statistical key as an "augmented 8-digit HS number". Each observation contains the net mass of the shipping expressed in kilo. Some observations also contain a "supplementary unit", which can be liters, meters, squared meters, cubic meters, karat, pieces, pairs, or other specific units (e.g., Liter at 15C). We construct unit values by dividing the value of the transaction by the supplementary unit when available and by the mass when not.[18]

Figure 3 plots the import and export unit values indices computed by the Swiss Customs Administration. The import index exhibits a sharp drop on January 2015. Moves after January are small in comparison, and the index stabilizes quickly after the drop. The export index shows a more delayed drop. However, as we point out below, this is at least partially due to exchange rate used to convert amounts invoiced in euros. Moreover, these figures do not account for different invoicing currencies or fixed effects, and are computed on the universe of Swiss transactions (i.e., not restricted to the euro area).[19] Still, they point toward a fast reaction of unit values that stabilizes after a short period.

Compared to earlier studies that use Swiss customs data, our dataset contains two additional variables, which are key for the empirical exercise.[20] The first variable is the transactions date. Unlike other trade data, and fortunately for our purpose, the transactions date is not recorded at the monthly but at the daily frequency. More precisely, the transactions date (*Veranlagungsdatum*) reports the day when the customs form is filled in and the legal transaction takes place. The submission can be done either at the customs office or electronically. Given the unique identification of our exchange rate shock – January 15, 2015 – the daily frequency of our data is of great value to identify the dynamics of price reactions, in particular, the speed of the exchange rate pass-through.

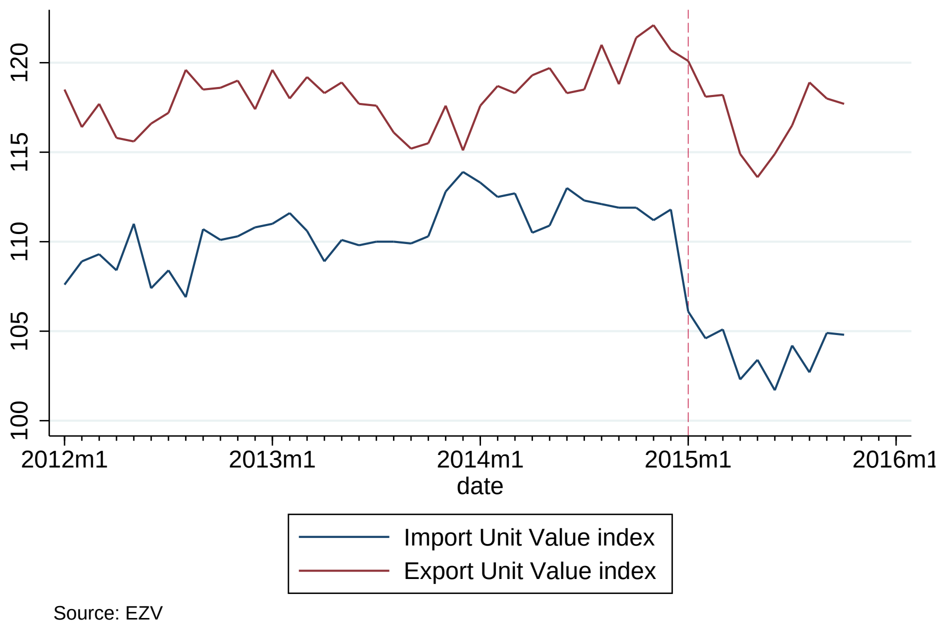
[17]Thus, we operate with the universe of Swiss trade transactions instead of survey data as in Gopinath and Rigobon (2008) and Gopinath et al. (2010).

[18]For exports, based on the number of transactions, 22.2% have the supplementary unit. Based on value, it is 23.6%. For imports, based on the number of transactions, 24.4% have supplementary units. Based on value, it is 25.7%.

[19]Since the share of Swiss imports coming from the euro area is larger than the share of Swiss export to the euro area, the import unit value index is closer to what we are analyzing.

[20]The EZV data have been previously used at the monthly level by Kropf and Sauré (2014) and Egger and Lassmann (2015).

Figure 3: Swiss Customs Administration's unit value indices



The vertical line represents the January 2015 shock. Unit value indices are computed by the Swiss Customs Administration and cover all goods and countries relevant to Swiss trade (see Federal Customs Administration (2006) for details on the methodology).

The second variable concerns the currency in which transactions are invoiced. More precisely, we know whether the invoicing currency of a given transaction was either of the following five categories: CHF, EUR, USD, other EU currencies and other currencies.[21] If the invoicing was not in CHF, the value is converted using a specific exchange rate. The exchange rate used for imports is published daily by the EZV. It corresponds to the market exchange rate observed the working day before the declaration is made. For example, if a transaction is declared on a Monday, the Friday exchange rate is used. [22] For exports, the general rule is that the same exchange rate as for imports is used. However, the monthly average exchange rate or the 'international groups' internal accounting exchange rate can be used if the firm is registered with the EZV. The monthly average applicable to a transaction in month, m, is the average of the daily exchange rate observed between the 25th of the month $m-2$ and the 24th of the month $m-1$. The uncertainty as to which exchange rate was used complicates the interpretation of our results for the export transactions taking place in January.

The currency information is important not only because the invoicing currency is known to be a crucial determinant of the exchange rate pass-through. More importantly, under sticky prices and by pure mechanics, the exchange rate shock is in the short run (i) fully passed through in the case when transactions are invoiced in exporter currency (ii) not passed through at all in the case when transactions are invoiced in importer currency. The distinction between CHF, EUR, and all other currencies is therefore crucial to identify the speed of actual pass-through via active price adjustments. Practically, we mainly focus on the transactions invoiced in CHF and EUR since our exercise focusses on transactions between Switzerland and the euro area, the vast majority of which is invoiced in either of the two currencies.

Figure 4 plots shares of Swiss exports and imports to and from the euro area invoiced in CHF, EUR, or other currencies from 2014 to the first

[21] There is a large literature on optimal invoicing currency, for example, Bacchetta and Van Wincoop (2005), Engel (2006), and Goldberg and Tille (2008). Our study is silent on this issue, but as in Gopinath et al. (2010) and Devereux et al. (2015) we contribute to the empirical literature on currency invoicing.

[22] The exchange rate is published early in the morning (e.g. 04:30 am for December 14, 2014). Particularly, on January 15, 2015, the exchange rate was published before the SNBs announcement and its value for January 15, 2015 (applicable to the January 16, 2015 transactions) is 1.21303. However, the EZV allowed a non-published exchange rate to be used for transactions registered on January 16 if appropriate justifying documents were produced by importers.

semester of 2015 at the monthly frequency.[23] The shares are computed based on the transactions (top panel) and based on the values (bottom panel). The figure conveys two messages. First, almost all trade is invoiced either in CHF or EUR. In fact, only 0.02% of export transactions (value) was invoiced in other currencies. Second, the respective shares are stable over time and, in particular, do not appear to have shifted the invoicing currency in response to the exchange rate shock in January 2015.[24]

To assess whether 'firms' switch the invoicing currency, Figure 4 also reports the share of transactions (value) that stem from the subset of 'firms' (i.e., proxied by the triplets of HS-product, postal code, and destination), who have always invoiced in the same currency throughout the 18-month sample. These shares are indicated by the dashed lines, which separate the CHF or EUR shares into two areas. The respective area below the dashed lines consists of transactions from 'firms' who always invoiced in the respective currency. These are between a quarter to half of the respective shares.

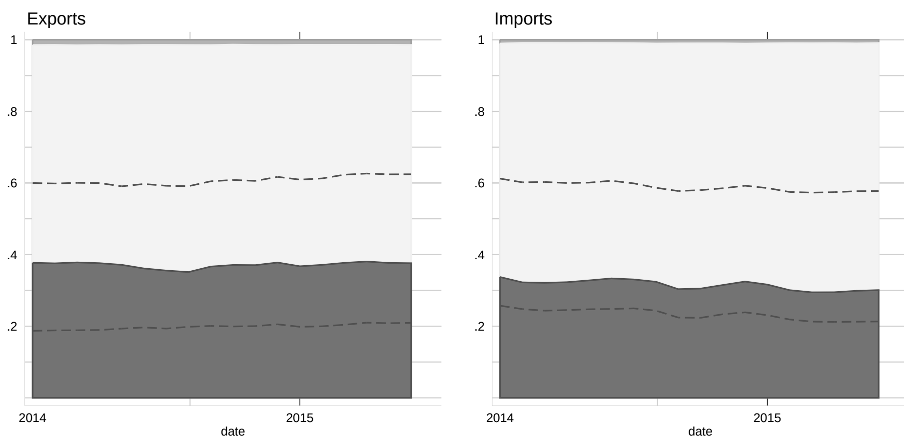
There are important limitations to the transactions-level data. First, we do not observe prices of unique goods but are limited to the augmented 8-digit categories of the HS classification system, which means that our study must rely, just as in Berman et al. (2012), on unit values instead of prices. The limitation implies, in particular, that we are unable to directly measure price stickiness, as Gopinath and Rigobon (2008), who track the frequency of price adjustments. Specifically, we cannot follow Gopinath et al. (2010), who estimate the exchange rate pass-through conditional on price adjustments. This limitation is unfortunate for obvious reasons, in particular, because the median frequency of nominal price adjustments of 10.6 (12.8) months for U.S. imports (exports) reported in Gopinath and Rigobon (2008) suggests that average price adjustments have long lags in normal times. Nevertheless, we argue that our findings provide strong indirect evidence that nominal rigidities play a minor role for the period immediately following our exchange rate shock. This argument is underpinned by the fast pass-through of our exchange rate shock even in goods priced in destination currency. While unit values are also unable to capture compositional shifts inside a good category such as a shift towards higher quality products, we argue that this is unlikely

[23]We conveniently divide each month into the first half (days 1-15) and the second half (days 16-end).

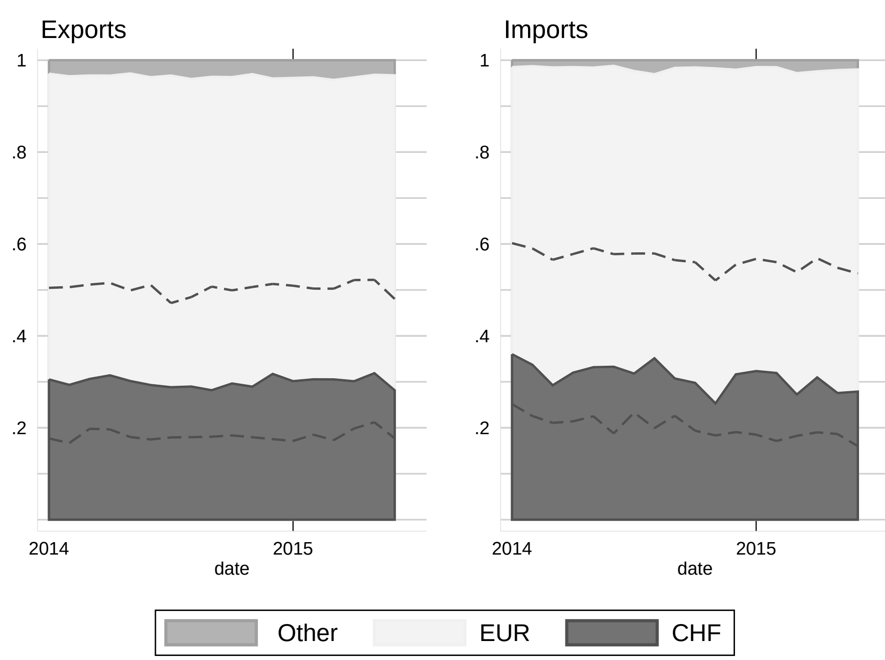
[24]See, Appendix 1 for further information on the extent of switching from one invoicing currency to another in response to the exchange rate shock.

Figure 4: Monthly shares of currency in the Swiss trade with euro area

(a) Based on Transactions



(b) Based on Values



The dark area represents the share of transactions (value) invoiced in CHF, the light area in EUR and the gray area in other currencies. The area below the dashed line represents the share of transactions (value) originating from a triplet (postal code - HS - country) that always invoiced in the same currency from January 2014 to June 2015. The area above the dashed line represents the share of transactions (value) originate from a triplet that has invoiced in different currencies.

to drive our results. First, after the appreciation, imports are likely to be of higher quality, thus the change in import unit values is biased upwards, which goes against our inference of fast price change. We also point out that we find a larger pass-through for imports than for exports, indicating that import unit values go down more than export unit values. If quality shifts were to drive the results, the opposite would be observed as import unit values' adjustment are downsized while export unit values' adjustment are oversized by the shift in quality. A second limitation is that the dataset does not identify intrafirm transactions.[25] Thus, we cannot exclude them from the analysis to extract only market price reactions to the exchange rate shock as in Gopinath et al. (2010). We remedy this shortcoming by analyzing intermediate and investment goods separately from final consumption goods in a robustness check.

Table 1 provides statistics for the transactions data for the full sample (January 2, 2014 to June 30, 2015), the pre-shock period (January 2, 2014 to January 14, 2015), and the post-shock period (January 15, 2015 to June 30, 2015). The number of transactions for imports (29,2 million) is considerably greater than for exports (16,3 million). Both for imports and exports the share of euro invoicing is around two-thirds. Differences in the share of euro invoicing between the pre- and post-shock period are not detected.

2.3 Identification strategy

The identification strategy rests on the assumption that the SNB's lifting of the floor has induced an exogenous exchange rate shock. To assess how fast this shock has translated into export (and import) prices, we estimate two models. The first model is a standard pass-through model in levels:

$$\ln(p_{k,t}) = \alpha_{i_k j_k s_k} + \sum_{m=0}^{M} \beta_m \ln(e_{t-m}) + X_{k,t}\gamma + \varepsilon_{k,t} \tag{1}$$

where k indicates one specific export transaction, i indicates the specific product (augmented HS-classification), j indicates the destination country, s the postal code of the sender, and t the day of the transaction. Note, the exact definition of the periods varies across specifications. In our baseline specification, the dependent variable, $p_{k,t}$, is the unit value of the exported or imported product. The bilateral exchange rate, e_t is expressed in EUR per CHF. The EZV exchange rate does not carry the index of the destination, j,

[25] Neiman (2010) shows for U.S. transactions data that prices of intrafirm trade exhibit a high pass-through.

Table 1: Summary statistics

	Total sample	Pre-shock period	Post-shock period
Imports (Euro area to Switzerland)			
Based on transactions			
Unit value (log)	3.470	3.504	3.396
	(2.218)	(2.213)	(2.226)
Share of available supplementary unit	0.244	0.243	0.248
Share of prices invoiced in EUR	0.676	0.668	0.692
Share of prices invoiced in CHF	0.315	0.322	0.299
Share of prices invoiced in other	0.009	0.010	0.009
Based on (log) value			
Unit value (log)	3.566	3.599	3.497
	(2.464)	(2.454)	(2.481)
Share of available supplementary unit	0.257	0.255	0.261
Share of prices invoiced in EUR	0.708	0.699	0.726
Share of prices invoiced in CHF	0.283	0.291	0.264
Share of prices invoiced in other	0.010	0.010	0.010
Number of transactions	29 193 217	19 683 395	9 509 822
Exports (Switzerland to euro area)			
Based on transactions			
Unit value (log)	4.085	4.118	4.016
	(2.476)	(2.472)	(2.483)
Share of available supplementary unit	0.222	0.219	0.227
Share of prices invoiced in EUR	0.614	0.616	0.611
Share of prices invoiced in CHF	0.371	0.369	0.375
Share of prices invoiced in other	0.014	0.014	0.014
Based on (log) value			
Unit value (log)	4.223	4.252	4.167
	(2.598)	(2.594)	(2.606)
Share of available supplementary unit	0.236	0.235	0.240
Share of prices invoiced in EUR	0.643	0.644	0.642
Share of prices invoiced in CHF	0.340	0.340	0.342
Share of prices invoiced in other	0.016	0.016	0.016
Number of transactions	16 265 607	11 051 418	5 214 189
EURCHF exchange rate	1.197	1.234	1.057
	(0.074)	(0.012)	(0.022)

Note: Standard deviation is shown in parenthesis when relevant.

because the focus of our analysis is on Swiss trade with the euro area. $X_{k,t}$ represents a wide range of control variables. These include fixed effects of each triplet (postal code - augmented HS-classification - partner country), and, in some specifications, the importer country's log GDP and log CPI. Separate regressions are run for transactions invoiced in euro and in Swiss franc.

The baseline model in (1) is specified in levels instead of changes. This is because our trade data is reported at the transactions-level and thus does not have a panel structure. Specific firms may not necessarily export to certain destinations within some months (thus unbalancing the panel), but the same firms may also export the very same product to the same destination country more than once within the same unit of time (be it a month or even a day). It is this latter feature that inhibits a definition of a panel structure. To ensure comparability with estimates using price changes as the dependent variable, we add a 2-digit HS - destination country specific trend that ensure suitable fixed effects remain when differencing equation (1).

In the second model, we use dummy variables to capture the effect of the January 15, 2015 shock:

$$\ln(p_{k,t}) = \alpha_{i_k j_k s_k} + \sum_{m=0}^{M} D_m + X_{k,t}\gamma + \varepsilon_{k,t}, \tag{2}$$

where D_m is a dummy taking value, v, if t is the m's period following the exchange rate shock. The value of the dummy, v, is set to the average log change in the exchange rate between the floor period and after the shock, so that the interpretation of the coefficient is the pass-through of the overall exchange-rate shock. The advantage of this specification over the traditional specification as defined in (1) is that potential endogeneity issues with the exchange rate are avoided. A shortcoming, however, is that the coefficient on the dummy variable cannot be fully attributed to the identified January 15, 2015 exchange rate shock, as exchange rate changes after the shock also affects prices.

The data used for the baseline specification spans from January 2, 2014 to June 30, 2015. During this 18-month period, the influence of cyclical factors can be assumed to play a minor role.[26] The empirical presentation reports clustered standard errors by region (postal code). We run both

[26] Goldfajn and Werlang (2000) have emphasized the procyclical behavior of pass-through when the economy enters a recession and margins are compressed. The event-study nature of our setup excludes this possibility.

models in levels, since the use of unit values as well as the data gaps impede definitions of differences at monthly or daily frequency.

3 Monthly Estimation Results

Before presenting the main findings at the daily frequency, we assess the speed of the pass-through in a pooled regression of the type specified in (1) at the monthly frequency. These regressions facilitate comparability with the literature, which has presented estimates primarily at the monthly frequency. The results support the view that a large share of the pass-through is completed in the contemporaneous month. In other words, within the first 11 working days after the January 15, 2015 shock.

The unit of time, m, corresponds to one month (the exchange rate is from the Swiss Customs Administration, see discussion in footnote 21). Table 2 presents regression results for imports with t-values in parenthesis based on standard errors clustered by postal code. All regressions contain augmented 8-digit HS code - postal code - country fixed effects and a 2-digit HS code - country specific trend The last three columns also include two controls: five lags of the log of the CPI index of the exporting country and four lags of the quarterly log of the GDP of the exporter country.

The regressions in Table 2 show that the speed of the import price adjustment is extremely fast. The first column reports the results of a regression containing all transactions regardless of the invoicing currency. The pass-through coefficient for the first month, β_0, is 0.85. Thereafter, the cumulative pass-through coefficients for the first two months, $\beta_0 + \beta_1$, remains at 0.84. Both coefficients are highly statistically significant. The cumulative pass-through coefficients for $m > 2$ are stable, suggesting that the pass-though reaches its medium-run pass-through after a month.

The next two columns show that the pass-through depends on currency invoicing. However, this does not alter the pass-through's speed. The second column reports regression results separately for euro invoiced transactions. The pass-through coefficient for the first month, β_0, is 1.04 and for the first two months, $\beta_0 + \beta_1$, is 0.97. Both of these coefficients are highly statistically significant at the 0.001% level. The cumulative pass-through coefficients of higher lag orders are stable, suggesting that the pass-through is fully completed after a month. The third column repeats the same regression for transactions invoiced in Swiss francs. As to be expected the coefficient of β_0 is lower at 0.45 and is statistically significant at the 0.1% level. The cumulative pass-through coefficient of $\beta_0 + \beta_1$ is 0.55. The cu-

Table 2: Imports monthly continuous estimations

	Without controls			With controls		
	(1)	(2)	(3)	(4)	(5)	(6)
	ALL	EUR	CHF	ALL	EUR	CHF
β_0	0.850***	1.038***	0.450***	0.570**	0.594**	0.253
	(40.21)	(42.32)	(14.98)	(3.16)	(3.11)	(0.81)
$\sum_{m=0}^{1} \beta_m$	0.841***	0.966***	0.554***	0.645***	0.665***	0.402
	(50.56)	(55.97)	(19.11)	(4.98)	(4.84)	(1.82)
$\sum_{m=0}^{2} \beta_m$	0.862***	1.010***	0.515***	0.590***	0.612***	0.315
	(48.09)	(58.23)	(14.58)	(4.22)	(4.12)	(1.31)
$\sum_{m=0}^{3} \beta_m$	0.923***	1.047***	0.654***	0.773***	0.838***	0.496***
	(47.67)	(58.40)	(16.58)	(10.38)	(10.68)	(3.87)
$\sum_{m=0}^{4} \beta_m$	0.917***	1.043***	0.663***	0.706***	0.725***	0.464*
	(46.29)	(51.53)	(18.67)	(6.33)	(6.17)	(2.40)
$\sum_{m=0}^{5} \beta_m$	1.015***	1.117***	0.792***	0.814***	0.814***	0.573**
	(51.76)	(55.94)	(21.98)	(7.32)	(6.87)	(3.00)
Observations	27830722	18623056	8608821	27830722	18623056	8608821
R^2	0.856	0.857	0.881	0.856	0.857	0.881
CPI (control)	No	No	No	Yes	Yes	Yes
GDP (control)	No	No	No	Yes	Yes	Yes

t statistics in parentheses

All regressions include augmented 8-digit HS code - country - postal code fixed effects and a 2-digit HS code-country specific trend

CPI refers to lags 0-5 of monthly exporter's CPI and GDP refers to lags 0-3 of quarterly GDP

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3: Exports monthly continuous estimations

	Without controls			With controls		
	(1)	(2)	(3)	(4)	(5)	(6)
	ALL	EUR	CHF	ALL	EUR	CHF
β_0	0.363***	0.547***	0.0841	0.692***	0.689***	0.436***
	(12.37)	(16.10)	(1.66)	(9.50)	(8.64)	(3.40)
$\sum_{m=0}^{1} \beta_m$	0.715***	0.937***	0.373***	1.014***	1.023***	0.711***
	(24.73)	(31.51)	(7.02)	(12.31)	(12.05)	(4.72)
$\sum_{m=0}^{2} \beta_m$	0.617***	0.813***	0.280***	0.876***	0.857***	0.506**
	(21.13)	(27.34)	(5.12)	(9.32)	(8.69)	(3.01)
$\sum_{m=0}^{3} \beta_m$	0.687***	0.895***	0.364***	0.901***	0.898***	0.530**
	(23.63)	(29.27)	(6.73)	(8.33)	(7.79)	(2.70)
$\sum_{m=0}^{4} \beta_m$	0.584***	0.813***	0.190**	0.798***	0.836***	0.266
	(16.33)	(22.98)	(2.75)	(6.83)	(6.77)	(1.24)
$\sum_{m=0}^{5} \beta_m$	0.721***	0.867***	0.474***	0.960***	0.898***	0.550*
	(21.17)	(25.81)	(7.44)	(7.79)	(6.83)	(2.48)
Observations	15976749	9826817	5865037	15976749	9826817	5865037
R^2	0.856	0.872	0.856	0.856	0.872	0.856
CPI (control)	No	No	No	Yes	Yes	Yes
GDP (control)	No	No	No	Yes	Yes	Yes

t statistics in parentheses
All regressions include augmented 8-digit HS code - country - postal code fixed effects
and a 2-digit HS code-country specific trend. Errors are clusters at the postal code level
CPI refers to lags 0-5 of monthly exporter's CPI and GDP refers to lags 0-3 of quarterly GDP
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

mulative pass-through coefficients for $m > 2$ suggests that the pass-through reaches its medium-run after a month.

The addition of controls for monthly CPI prices and quarterly GDP do not change the monthly results for the speed of the pass-through, however the pass-through coefficients are sensitive to the introduction of controls. Columns 4 to 6 present the regressions that repeat the exercise of columns 1 to 3 with the addition of monthly CPI and quarterly GDP. The pass-through coefficients are lower, however the speed of the pass-through appears to be complete after a month.

Table 3 presents the same information as in Table 2 but now for export prices. Again, column 1 presents the pass-through coefficients for the full sample without controls for CPI and GDP. The coefficient for β_0 is 0.36 and the coefficient for $\beta_0 + \beta_1$ jumps to 0.72. The cumulative coefficient for higher order lags appear to be stable, suggesting that the partial pass-through reaches is medium-run after six weeks. Next, column 2 shows that the pass-through of exports invoiced in euros is 0.55 in January. The cumulative pass-through coefficient for $\beta_0 + \beta_1$ is 0.94, suggesting that the pass-through is not immediate. Similarly, column 3 shows that the cumulative pass-through for exports invoiced in Swiss francs is only 0.08 in January and the cumulative pass-through after six weeks is 0.37. Columns 4 to 6 show the regressions with the addition of the controls. The estimates tend to suffer in that the pass-through coefficients are slightly higher and the standard errors increase.

The regression results in Tables 2 and 3 suggest that the speed of price adjustment is faster for imports than for exports. The evidence indicates that the pass-through for imports appears to be nearly complete after a month. This fast speed of adjustment is observed in that β_0 is close to the cumulative pass-through coefficients, say $\beta_0 + \beta_1$.

Tables 4 and 5 show the regressions for import and export prices for equation (2) (in this specification, $m = 0$ only corresponds to the days in January 2015 following January 15^{th}). The regression results from this specificiation are more encouraging for several respects. First, regressions in Tables 4 and 5 replicate the pass-through estimates for β_0 in Tables 2 and 3 in columns 1 to 3. Second, the regressions in Tables 4 and 5 are not sensitive to the introduction of controls. Third, and most interesting, the speed of price adjustment is uniform for imports and exports. The evidence suggests that price adjustment is complete within the first half-month.

Table 4: Imports monthly dummies estimations

	Without controls			With controls		
	(1)	(2)	(3)	(4)	(5)	(6)
	ALL	EUR	CHF	ALL	EUR	CHF
M0	0.905***	1.104***	0.477***	0.876***	1.076***	0.456***
	(58.68)	(70.20)	(19.50)	(41.23)	(45.79)	(14.15)
M1	0.729***	0.851***	0.460***	0.682***	0.803***	0.429***
	(66.39)	(75.65)	(23.65)	(32.92)	(34.44)	(13.21)
M2	0.746***	0.869***	0.460***	0.659***	0.782***	0.391***
	(63.26)	(75.72)	(19.86)	(31.20)	(33.93)	(11.30)
M3	0.908***	1.047***	0.605***	0.832***	0.965***	0.522***
	(67.06)	(82.64)	(22.42)	(32.83)	(36.32)	(12.07)
M4	0.889***	1.010***	0.637***	0.816***	0.932***	0.540***
	(68.58)	(75.54)	(27.63)	(33.99)	(36.50)	(13.11)
M5	0.908***	1.010***	0.691***	0.835***	0.924***	0.582***
	(67.80)	(72.56)	(28.60)	(31.07)	(32.22)	(12.57)
Observations	27830722	18623056	8608821	27830722	18623056	8608821
R^2	0.856	0.857	0.881	0.856	0.857	0.881
CPI (control)	No	No	No	Yes	Yes	Yes
GDP (control)	No	No	No	Yes	Yes	Yes

t statistics in parentheses

All regressions include augmented 8-digit HS code - country - postal code fixed effects and a 2-digit HS code-country specific trend

CPI refers to lags 0-5 of monthly exporter's CPI and GDP refers to lags 0-3 of quarterly GDP

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 5: Exports monthly dummies estimations

	Without controls			With controls		
	(1)	(2)	(3)	(4)	(5)	(6)
	ALL	EUR	CHF	ALL	EUR	CHF
M0	0.469***	0.709***	0.110**	0.560***	0.810***	0.180***
	(20.81)	(27.87)	(2.79)	(19.38)	(25.46)	(3.54)
M1	0.557***	0.745***	0.271***	0.649***	0.851***	0.351***
	(28.92)	(37.78)	(7.63)	(17.25)	(21.48)	(5.11)
M2	0.578***	0.759***	0.278***	0.604***	0.810***	0.253**
	(30.30)	(39.19)	(7.80)	(13.72)	(17.59)	(3.19)
M3	0.651***	0.861***	0.324***	0.643***	0.924***	0.219*
	(32.33)	(40.94)	(8.63)	(11.49)	(15.53)	(2.16)
M4	0.646***	0.871***	0.269***	0.615***	0.933***	0.0945
	(28.26)	(37.82)	(6.10)	(9.91)	(14.15)	(0.83)
M5	0.663***	0.831***	0.381***	0.614***	0.898***	0.127
	(29.59)	(36.79)	(9.11)	(9.34)	(12.90)	(1.06)
Observations	15976749	9826817	5865037	15976749	9826817	5865037
R^2	0.856	0.872	0.856	0.856	0.872	0.856
CPI (control)	No	No	No	Yes	Yes	Yes
GDP (control)	No	No	No	Yes	Yes	Yes

t statistics in parentheses

All regressions include augmented 8-digit HS code - country - postal code fixed effects and a 2-digit HS code-country specific trend

CPI refers to lags 0-5 of monthly exporter's CPI and GDP refers to lags 0-3 of quarterly GDP

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

4 Daily Estimation Results

Motivated by the remarkable speed of adjustment uncovered at the monthly frequency, we next use daily data to obtain more precise pass-through estimates. We estimate a variant of equation (2) with daily dummies to capture the (daily) exchange rate pass-through but without controls for CPI and GDP.[27] The daily specification is as follows:

$$\ln(p_{k,t}) = \alpha_{i_k j_k s_k} + \sum_{d=0}^{30} \beta_d^d D_d + \sum_{m=2}^{5} \beta_m^m M_m + X_{k,t}\gamma + \varepsilon_{k,t}, \tag{3}$$

where $p_{k,t}$ is the unit value for a single cross border transaction, k, at time, t. D_d is a daily (working day) pass-through dummy with 30 daily dummies until the end of February 2015. M_m are the monthly pass-through dummies from March 2015 to June 2015. The variable, $X_{k,t}$, represent the controls. These include country-postal code - augmented 8-digit HS code fixed effects, and a country-2-digit HS specific trend. We treat weekend transactions as if they take place on Fridays.[28]

The large number of dummies in equation (3) enables us to interpret the coefficient of the daily dummies close in time to the shock as capturing the shock's effect.[29] This is justified by the fact that lagged exchange rate changes are close to zero and other price determinants such as tastes or marginal costs are unlikely to change in such a short time window.

In the daily estimation, we also provide a measure of *speed of adjustment*. We define a *start* and an *end* day. The start of the adjustment is defined as the first day for which the dummy is significantly different from 0. The end of the adjustment is defined as the last day for which the dummy is both significantly different from 0 and not significantly different from the medium-run pass-through, where the medium-run pass-through is defined as the average of the last four monthly dummies. Formally, d_{start} is such that the null hypothesis $D_{d_{start}} = 0$ is rejected and $D_{d_{start-i}} = 0$ is not rejected for all i. d_{end} is such that the null hypothesis $4 * D_{d_{end}} = \sum_m M_m$ where m covers all months after the 30 daily dummies, namely March to June 2015, is not rejected, while $4 * D_{d_{end}} = 0$ is rejected.

The empirical evidence for daily transactions data is presented using time plots of the daily coefficients for euro and Swiss franc invoiced transactions

[27] The daily dummies coefficient are left unaltered by the inclusion CPI and GDP.

[28] Weekend transactions represent 3.07% of the number of transactions (Saturday is 2.5%, Sunday is 0.57%), and 1.71% of total value (1.49% for Saturday and 0.22% for Sunday).

[29] Appendix 3 discusses the role of lagged exchange rates biasing pass-through estimates.

together with their 95% confidence intervals. Similarly, the medium-run (monthly) estimates are also plotted. Their coefficients are denoted as circles with 95% confidence intervals. For all graphs, the top panel presents estimates for euro invoiced transactions and the bottom panel presents estimates for Swiss franc invoiced transactions. Vertical lines indicate the speed measures: *start* and *end* day of adjustment defined above. The accumulated change in the exchange rate relative to January 15^{th} pre-shock level is also shown.

For imports invoiced in euros shown in the top panel of Figure 5, the mechanical effect of the exchange rate shock is, as expected, immediate. The daily dummies closely follow the exchange rate, except for the first day after the shock (January 16^{th}). This is explained by the fact that the (one-day lag in the) official exchange rate had not yet adjusted to the shock. The estimates in the figure are consistent with a full pass-through and little nominal price adjustment in the period covered by daily and monthly dummies.

The fast pass-through of imports invoiced in euro is not surprising. More striking are the fast responses of import prices invoiced in Swiss francs shown in the lower panel of Figure 5. Already two working days after the shock, prices drop significantly as much as a fraction of 0.33 of the exchange rate change. After eight working days, the pass-through is about 0.51 and is not statistically different from the 0.57 average pass-through of the last four months of the sample (to which we refer to as medium-run pass-through). We interpret the results such that a less-than full medium-term pass-through is identified, however it materializes at an exceptionally fast speed. This finding suggests a fast price adjustment of imports invoiced in Swiss francs.

Figure 6 shows that unit values for exports behave slightly differently. The euro invoiced exports do not show the expected full and instantaneous mechanical adjustment. We attribute this finding to accounting differences. A portion of exporting firms do not use the daily exchange rate in their customs declaration, but rather the previous month average or their internal accounting exchange rate.[30] The daily dummies in February are much closer to the exchange rate than those in January, a result consistent with the use of the updated monthly rate of January for February transactions. The monthly dummies at the end of the sample seem to indicate a partial medium-run pass-through of about 0.84%.

The Swiss franc invoiced exports do not suffer from the issue of the properly applied exchange rate, so the interpretation of the results is simpler. Figure 6 shows that exports invoiced in Swiss francs experience a drop in

[30] Recall, this accounting practice is not permitted for imported goods.

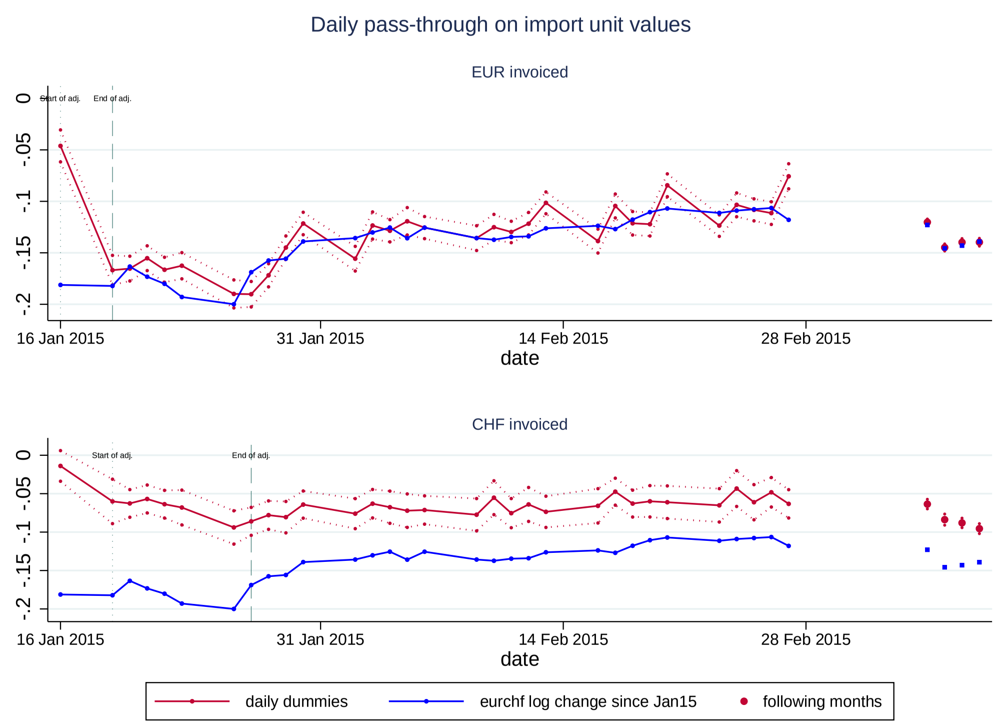


Figure 5: Daily dummies for import unit values (specification 3). The regression includes augmented HS-postal code-country triplets fixed-effects and a 2-digit HS-country specific trend. Errors are clustered at the postal code level.

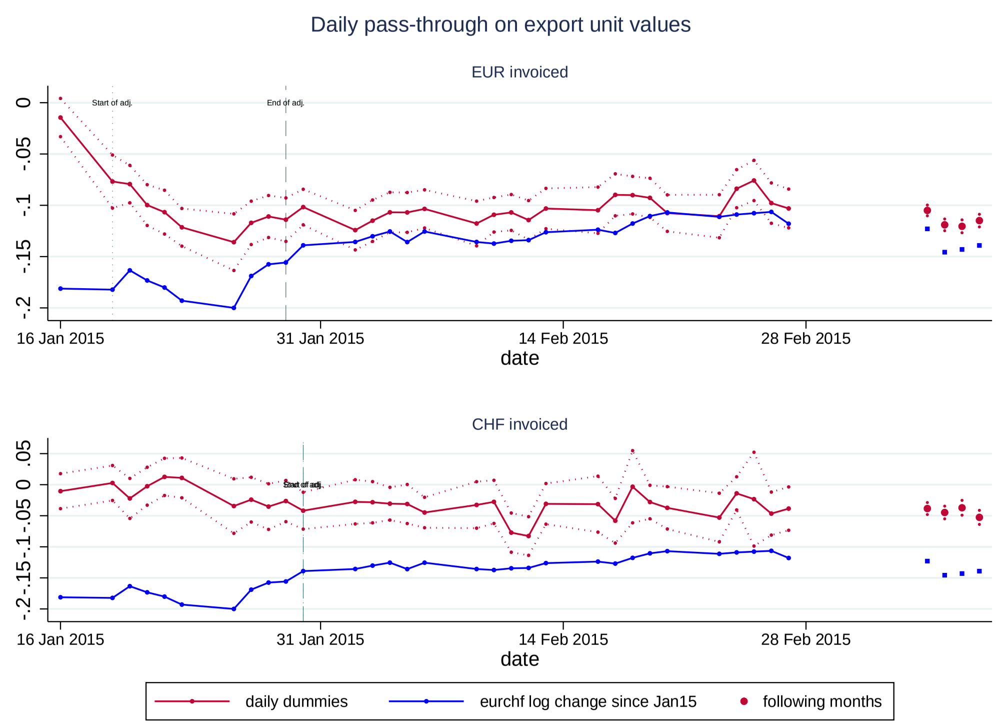


Figure 6: Daily dummies for export unit values (specification 3). The regression includes augmented HS-postal code-country triplets fixed-effects and a 2-digit HS-country specific trend. Errors are clustered at the postal code level.

their prices of about 0.05% (or a pass-through of 0.30) after about eleven working days, a value similar to the medium-run pass-through of 0.31.[31]

The results suggest a fast adjustment process. Nominal rigidities seem to have little importance in the face of such a big shock. Import prices show a fast and persistent pass-through. On the export side, the fast reaction of Swiss franc invoiced unit values is also striking: a significant price adjustment already takes place before the end of January, that is in 11 working days. In the next section, several robustness checks are performed to determine whether our speed finding is driven by select categories of goods.

5 Regressions at the Daily Frequency by Product- and Other Characteristics

This section presents robustness checks on the previous section's main result that the speed of price adjustment to a large exchange rate shock is remarkably fast. Robustness checks are based on equation (3) at the daily frequency. Robustness checks show that the price adjustment is not dependent on product classification, shipment size, nor good's type. The presentation is summarized in Table 6, where results for imports are presented in the upper part of the table and results for exports are presented in the lower part of the table. Graphs of the daily price dynamics are in Appendix 2.

5.1 When the quantity is measured precisely

The regressions in the previous section use unit values sometimes constructed by using mass as a proxy for quantity. For some goods, this might lead to imprecise measures, and we test if this has an impact on our results by restricting the sample to those observations where the 'supplementary units' are available. The speed measures (start and end) for unit values and unit prices are listed as restriction 1 in Table 6.

The unrestricted and restricted regressions reveal slight differences in the speed of the price adjustment, however they differ by less than two weeks and therefore support the fast dynamics observed in the previous section. For example, the second panel of Table 6 presenting the results for CHF invoiced imports shows that the unrestricted regression for imports invoiced

[31] Note, in the case of exports invoiced in Swiss francs, the *end* day is before the *start* day. This is due to a large standard deviation of the daily dummies which makes it difficult to reject equality with the medium-run pass-through.

in CHF ('All observations: 1) none') results in a statistically significant pass-through of 0.33 after two working days and a medium run pass-through of 0.57 attained after 8 working days. The restricted estimates ('Sup. units available: 1) none') show a similar start day and imply that the medium-run pass-through is reached after 7 working days. Overall, it is clear that the adjustment starts early in both cases and that the pass-through reaches its medium-run value in less than two weeks.

5.2 Postal code and good importance

A second robustness check restricts the sample to the biggest combinations of postal code and 8-digit HS code that make up two-thirds of the total import (or export) value. These are combinations of goods and location that are the most likely to contain big firms.

Restriction 2 in Table 6 shows that the medium-run pass-through is slightly lower for big importers combinations than the full sample and slightly higher than average for big exporters combinations. Our quantities of interest, the measures of speed of adjustment, however, are similar for this subsample. Comparing rows 1 and 2 in Table 6 reveals that both have their start day at similar dates and while the end day can differ of up to 6 days, the values always indicate that the medium-run pass-through is attained after about two weeks at the maximum.

5.3 Shipment size

The third robustness check separates transactions by value. The Swiss Custom Administration adds a value added tax on imports worth more than CHF 300. We treat this value as a threshold to define small and large value shipments.[32]

Restrictions 3 and 4 in Table 6 show the start and end days with the pass-through estimates for shipment size. Again, no notable differences are observed for the start dates, whereas a faster response to the medium-run pass-through is more frequently observed for smaller shipments. This is consistent with big shipments being negotiated longer in advance and subject to greater nominal rigidities than small transactions. However, we do not wish to stress this point, because the differences in the number of working days are slight between the two shipment categories.

[32] In Appendix 2, Figure 12 (10) shows the daily results for the export (import) unit values of transactions of less than CHF 300. Figure 13 (11) shows the daily results for the export (import) unit values of transactions of more than CHF 300.

5.4 Types of goods

The fourth robustness check tests the role of goods type. We use the Swiss Customs Administration classification of goods categories to assess the speed of adjustment for consumption goods, raw materials, and investment goods. The customs office classifies each 8-digit HS code as either consumption good, raw material, investment good, energy good, or cultural good. We perform the daily analysis on consumption and intermediate goods (defined as raw material and investment goods) separately, keeping only those transactions whose HS code is classified in a unique category.

Restrictions 5 and 6 in Table 6 show the start and end days with the pass-through estimates for consumption and intermediate goods.[33] Again, the results for exports and imports show that the price adjustment is immediate (i.e., after 1 or 2 working days) and reaches its medium-run pass-through estimate after 8 working days.

5.5 Product-level regressions

The last robustness exercise considers whether the speed of price adjustment differs across HS product classifications. Separate regressions are estimated for each 2-digit HS product classification. We restrict the minimum number of observations within these classes to 1000, which leaves us with 47 (48) different estimates for each β_m when estimations are based on transactions invoiced in euro (Swiss franc) for exports and 20 (56) for imports.[34]

Restriction 7 in Table 6 shows the median start and end day of the 2-digit HS code regressions, as well as the median pass-through and observation number. We do not report the results of this exercise restricting the sample to observation where the more precise unit of measure is available as this would reduce the sample by a too large extent. The median start and end day statistics are somewhat different from the pooled regression ones. However, the values remain below two weeks, which confirms our findings that the adjustment takes place remarkably fast.

[33] In Appendix 2, Figure 17 (15) shows the daily estimates on export (import) unit values for the intermediate goods, while figure 16 (14) presents those for consumption goods.

[34] In Appendix 2, Figure 19 (18) plots the median, the upper 95 and the lower 5 percentiles values of the daily HS-2d specific coefficients for exports (imports).

Table 6: Daily regression results (specification 3)

Imports	Restrictions	Start day	End day	Start day ERPT	End day ERPT	Medium run ERPT	Observations
Invoiced in EUR							
All observations	1) none	1	2	0.255	0.916	1.006	18623056
	2) big HS-postal code	1	3	0.266	1.070	1.064	3707584
	3) value > 300	1	2	0.241	1.018	1.051	10598660
	4) value < 300	1	3	0.253	0.877	0.890	7705332
	5) consumption goods	1	3	0.357	0.971	0.988	8571651
	6) intermediate goods	1	2	0.168	1.044	1.022	9878896
	7) median HS2	1	2	0.628	0.903	0.912	89840
Sup. units available	1) none	1	3	0.175	1.112	1.054	4233113
	2) big HS-postal code	1	9	0.222	1.260	1.275	1074131
	3) value > 300	1	2	0.221	0.933	1.023	2377542
	4) value < 300	2	3	0.558	0.984	1.088	1778563
	5) consumption goods	1	3	0.297	1.121	1.217	2476401
	6) intermediate goods	2	2	0.918	0.918	0.827	1668723
Invoiced in CHF							
All observations	1) none	2	8	0.330	0.509	0.570	8608821
	2) big HS-postal code	3	8	0.189	0.311	0.446	1668782
	3) value > 300	2	8	0.176	0.304	0.413	3306723
	4) value < 300	1	7	0.163	0.620	0.660	5164279
	5) consumption goods	2	7	0.515	0.663	0.668	4489595
	6) intermediate goods	4	8	0.214	0.372	0.436	4003166
	7) median HS2	3	4	0.328	0.328	0.600	48920
Sup. units available	1) none	2	7	0.347	0.397	0.577	2273930
	2) big HS-postal code	2	13	0.200	0.376	0.558	548443
	3) value > 300	2	12	0.239	0.418	0.497	1062915
	4) value < 300	2	7	0.367	0.450	0.627	1165621
	5) consumption goods	2	2	0.499	0.499	0.653	1437461
	6) intermediate goods	6	6	0.453	0.453	0.333	754600

Exports	Restrictions	Start day	End day	Start day ERPT	End day ERPT	Medium run ERPT	Observations
Invoiced in EUR							
All observations	1) none	2	10	0.422	0.732	0.840	9826817
	2) big HS-postal code	2	7	0.401	0.832	0.897	2936690
	3) value > 300	1	10	0.139	0.794	0.889	5684867
	4) value < 300	2	5	0.324	0.537	0.737	4102162
	5) consumption goods	2	8	0.641	0.732	0.900	2336815
	6) intermediate goods	2	7	0.349	0.670	0.817	7417892
	7) median HS2	2	3	0.558	0.562	0.841	49709
Sup. units available	1) none	2	6	0.551	0.728	0.882	1870875
	2) big HS-postal code	1	3	0.305	0.634	0.787	420270
	3) value > 300	1	4	0.192	0.716	0.854	1133752
	4) value < 300	2	6	0.375	0.608	0.816	727963
	5) consumption goods	2	7	0.707	0.775	1.019	1010057
	6) intermediate goods	2	3	0.373	0.517	0.722	842290
Invoiced in CHF							
All observations	1) none	11	11	0.301	0.301	0.313	5865037
	2) big HS-postal code	7	7	0.386	0.386	0.457	872103
	3) value > 300	3	7	0.178	0.262	0.428	2636485
	4) value < 300	19	19	0.527	0.527	0.237	3192966
	5) consumption goods	3	3	0.274	0.274	0.446	2052072
	6) intermediate goods	11	11	0.339	0.339	0.246	3779972
	7) median HS2	3.5	9.5	0.198	0.202	0.342	35210
Sup. units available	1) none	12	12	0.632	0.632	0.507	1588116
	2) big HS-postal code	12	12	0.887	0.887	0.525	290679
	3) value > 300	7	7	0.342	0.342	0.451	882044
	4) value < 300	9	12	0.300	0.647	0.561	696421
	5) consumption goods	3	3	0.412	0.412	0.537	1041825
	6) intermediate goods	11	11	0.531	0.531	0.471	528112

All regressions include augmented 8 digits HS code - country - postal code fixed effects and a 2 digits HS code-country specific trend.
Errors are clustered at the postal code level.
The start day is the first day after which the daily dummy is significantly different from 0.
The end day is the first day after which the daily dummy is significantly different from 0 and not significantly different from the medium-run pass through.

6 Conclusion

This paper is the first to analyze the speed of price adjustments for tradeable goods to an unusually large exchange rate shock at the daily frequency. The narrow event window ensures that price adjustment is in response to an exchange rate shock and not to other information. This high frequency setup allows us to uncover a richer set of price dynamics than has previously been examined. The shock is the SNB's decision to lift the minimum exchange rate policy, which resulted in a permanent appreciation of the Swiss franc of more than 11% against the euro. The pass-through estimates indicate that price adjustment begins one to two working days after the lifting of the minimum exchange rate and reaches on average it's medium-run pass-through after seven workings. Although the extent of the price adjustment may not be uniform across product groups, we show that the timing of the price adjustment is homogenous.

Our pass-through results have two important policy implications. First in modeling price setting behavior, the fast adjustment of prices suggests that nominal rigidities play only a minor role in the face of large exchange rate shocks. These considerations lead us to strongly believe that international firms demonstrate a high level of flexibility in their ability to respond to large sudden changes in their operating environment. Our findings tend to support state-dependent pricing models by Dotsey et al. (1999) as opposed to time-dependent pricing models by Calvo (1983). Second in forecasting import and export prices, the new pass-through estimates highlight the view that price adjustment is heavily dependent on the nature of the exchange rate shock. Past literature has focused primarily on price adjustment in response to frequent and small exchange rate shocks with the claim that the pass-through is thereby slow for major currencies. Instead, we find the opposite can also hold. A fast pass-through is uncovered for a large shocks.

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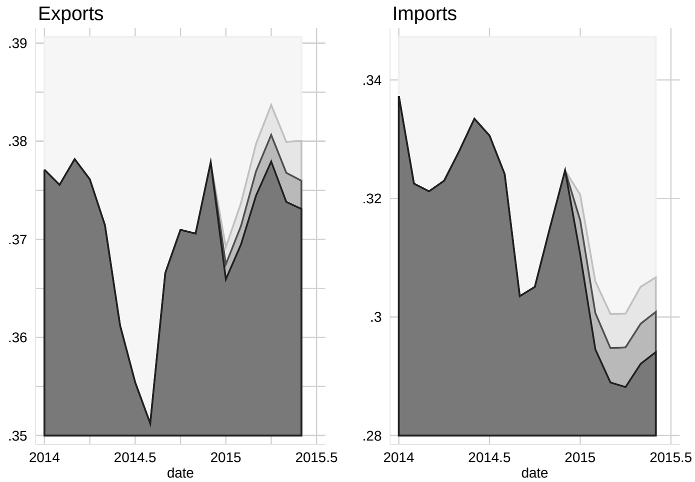
A Appendix 1: Currency switching and the exchange rate shock

This Appendix presents information on whether the pass-through estimates are biased because of currency invoice switching at the time of the exchange rate shock. It is argued in Gopinath et al. (2010) that in the face of small frictions, currency invoice switching should not occur. In the figure below, we show that the Gopinath et al. (2010) claim holds in the face of large shocks for Swiss exports and imports. The figure shows four pictures. Two sets of graphs for exports and imports are presented for the number of transactions and their value. Each of these graphs are shaded as follows: the dark area is the share of euro invoicing, light is the share of Swiss franc invoicing, light grey is the share of switching from Swiss franc to euro invoicing after January 15, 2015, and grey is the share of switching from euro to Swiss franc invoicing after January 15, 2015. A switch in currency invoicing is for firm proxied by the triplet: postal code, HS product, and distination/source.

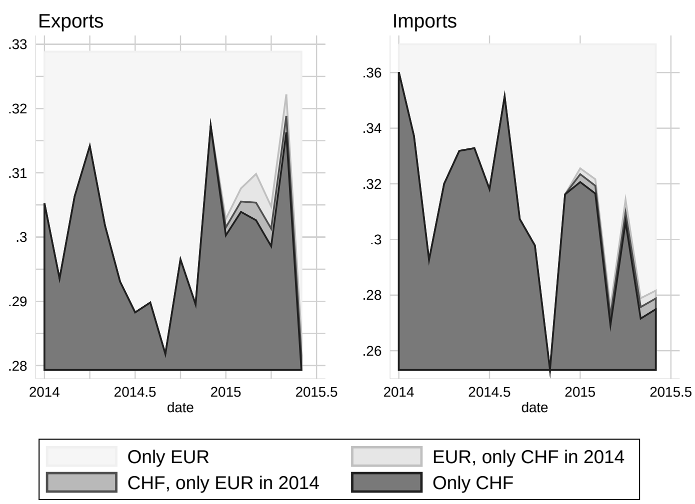
The results show that the level of switching after January 15, 2015 is particularly low. It is less than 0.01% for each of the four categories. Further, the small degree of switching in the invoice currencies occurs in both directions, suggesting that the effect is neutral at best. From this we conclude that our daily pass-through estimates are not subject to switching effects at the time of the exchange rate shock.

Figure 7: **Currency switching in 2015 - Swiss trade with the euro area**

(a) Based on Transactions



(b) Based on Values



Notes: The dark area is the share of euro invoicing, light is the share of Swiss franc invoicing, light gray area is the share of switching from Swiss franc to euro invoicing after January 15, 2015, and gray is the share of switching from euro to Swiss franc invoicing after January 15, 2015.

B Appendix 2: Graphs to the robustness checks

5.2 Graphs for big HS-postal code combinations

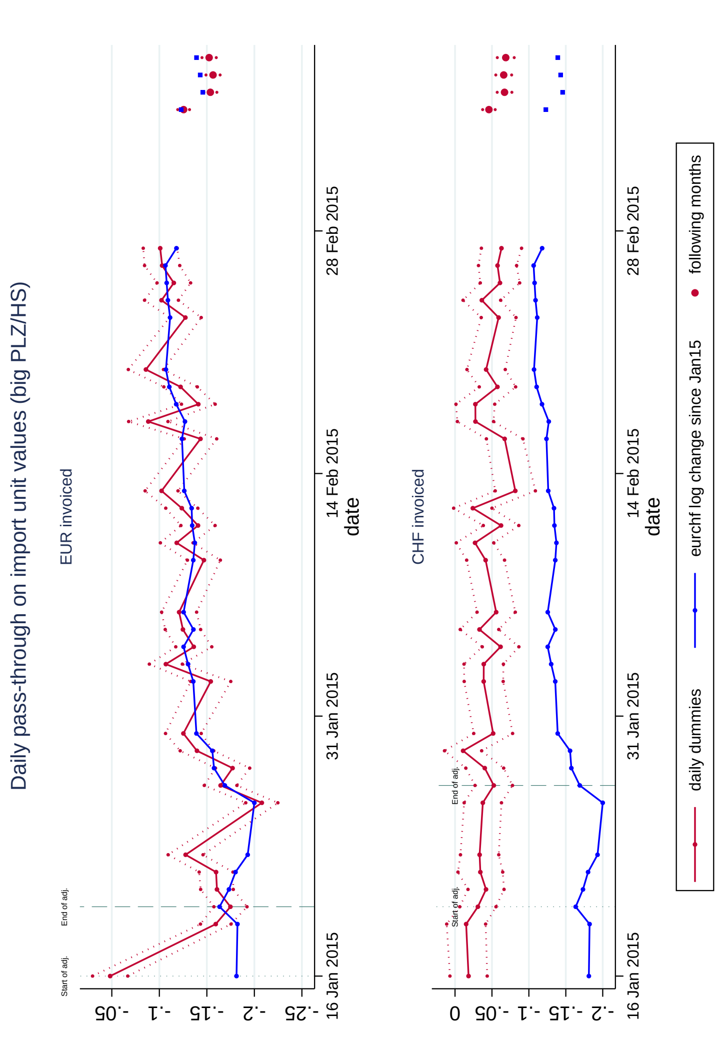


Figure 8: Daily dummies for import unit values for big HS-postal code combinations (specification 3). The regression includes augmented HS-postal code-country triplets fixed-effects and a 2-digit HS -country specific trend. Error are clustered at the postal code level.

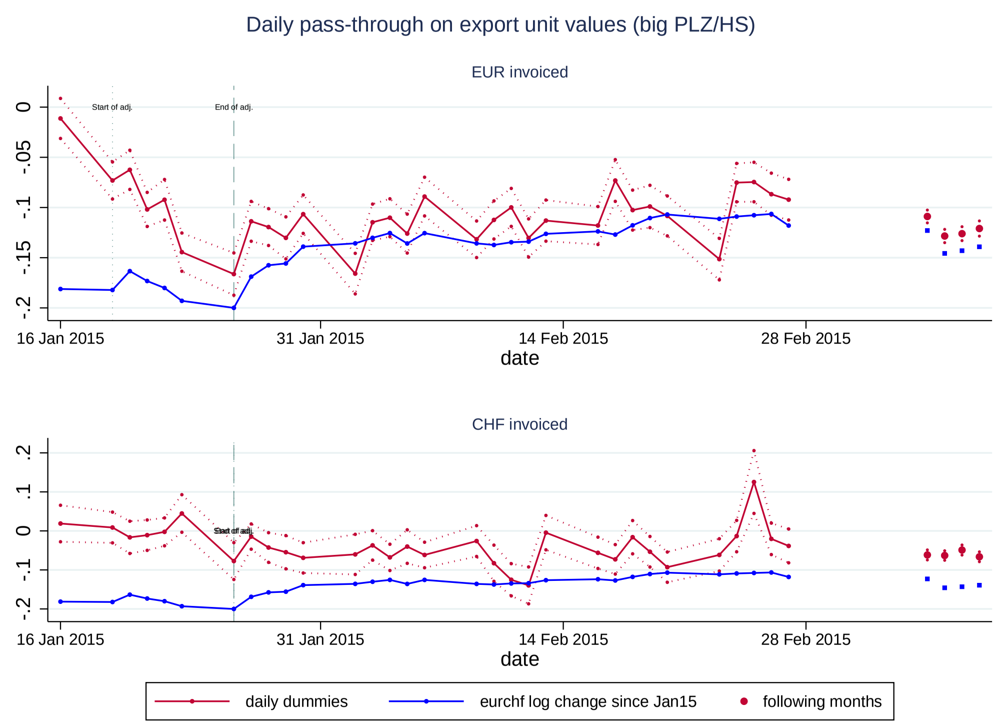


Figure 9: Daily dummies for export unit values for big HS-postal code combinations (specification 3). The regression includes augmented HS-postal code-country triplets fixed-effects and a 2-digit HS -country specific trend. Error are clustered at the postal code level.

5.3 Graphs for shipment size

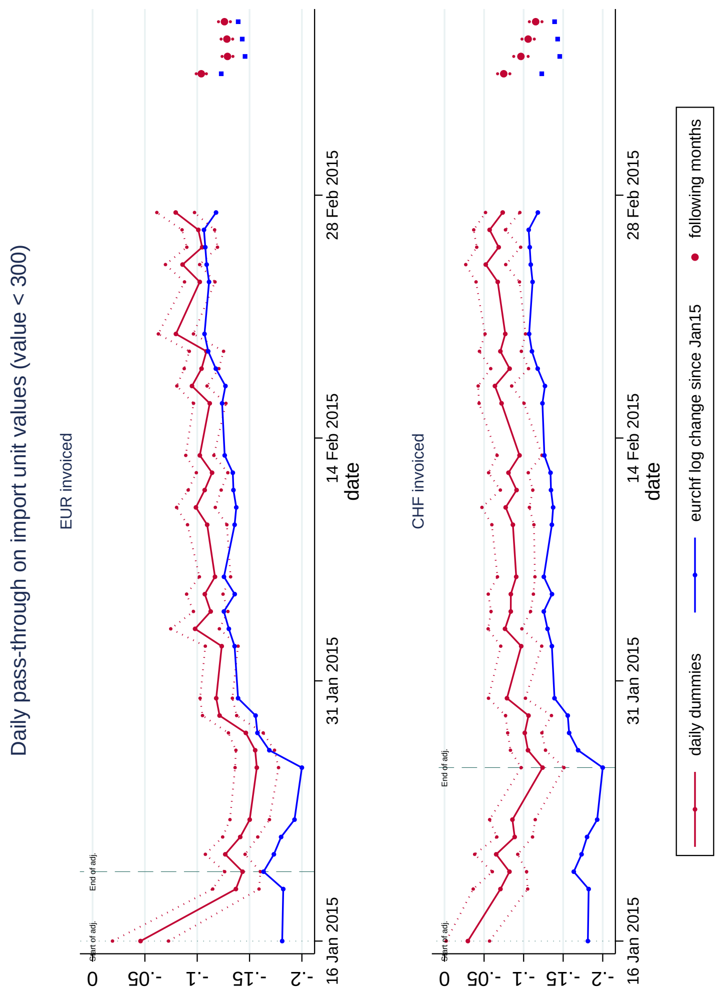


Figure 10: Daily dummies for import unit values for shipments worth less than CHF 300 (specification 3). The regression includes augmented HS-postal code-country triplets fixed-effects and a 2-digit HS -country specific trend. Errors are clustered at the postal code level.

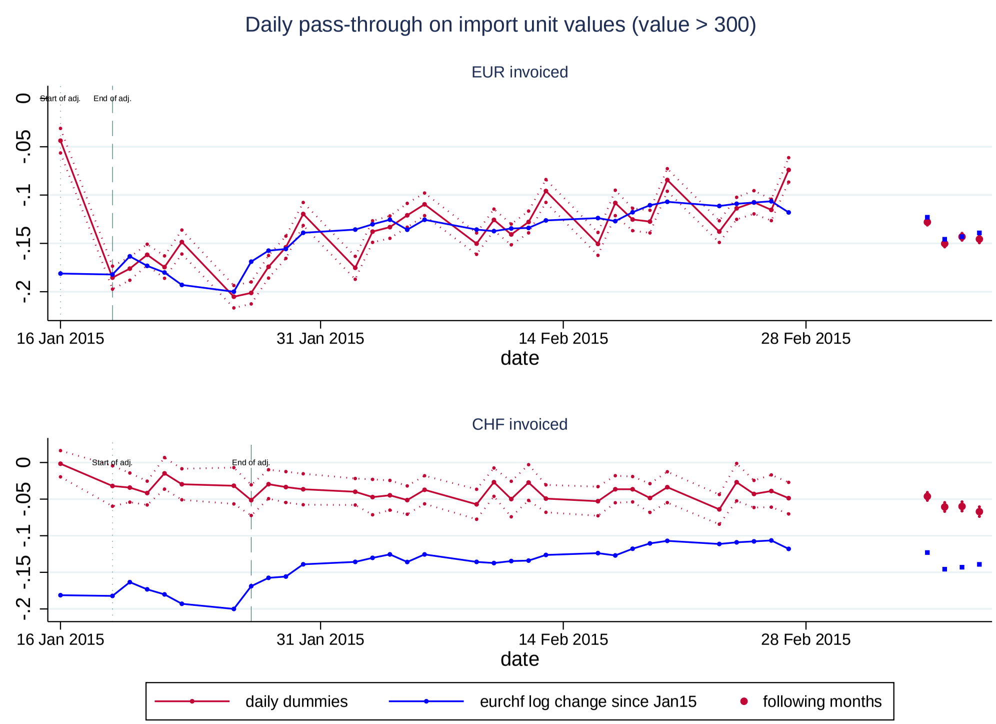


Figure 11: Daily dummies for import unit values for shipments worth more than CHF 300 (specification 3). The regression includes augmented HS-postal code-country triplets fixed-effects and a 2-digit HS-country specific trend. Errors are clustered at the postal code level.

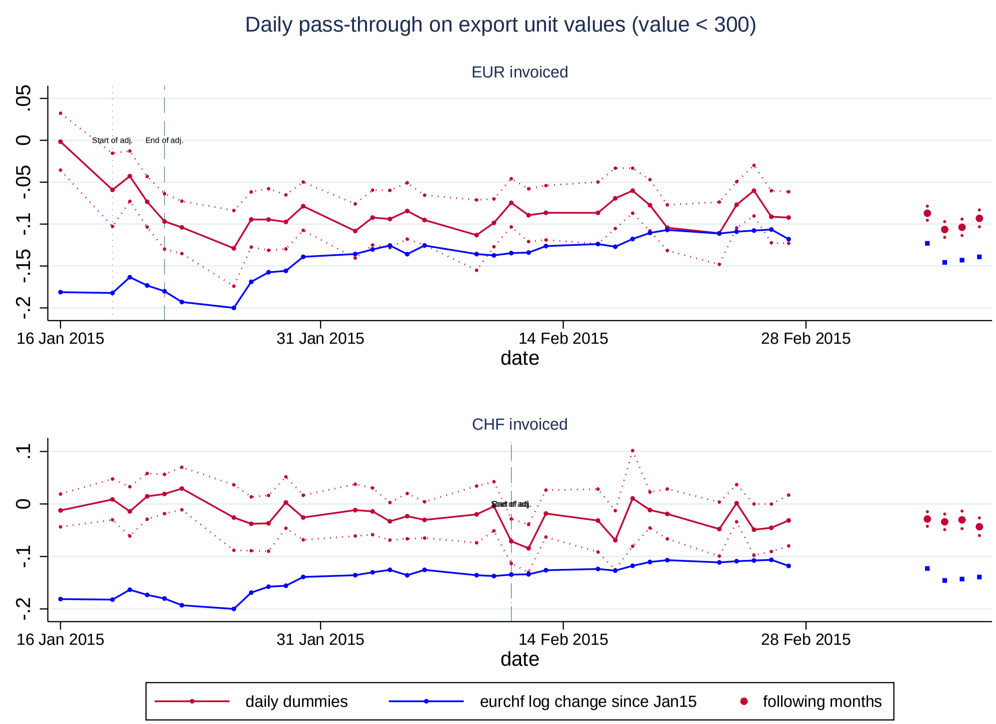


Figure 12: Daily dummies for export unit values for shipments worth less than CHF 300 (specification 3). The regression includes augmented HS-postal code-country triplets fixed-effects and a 2-digit HS -country specific trend. Errors are clustered at the postal code level.

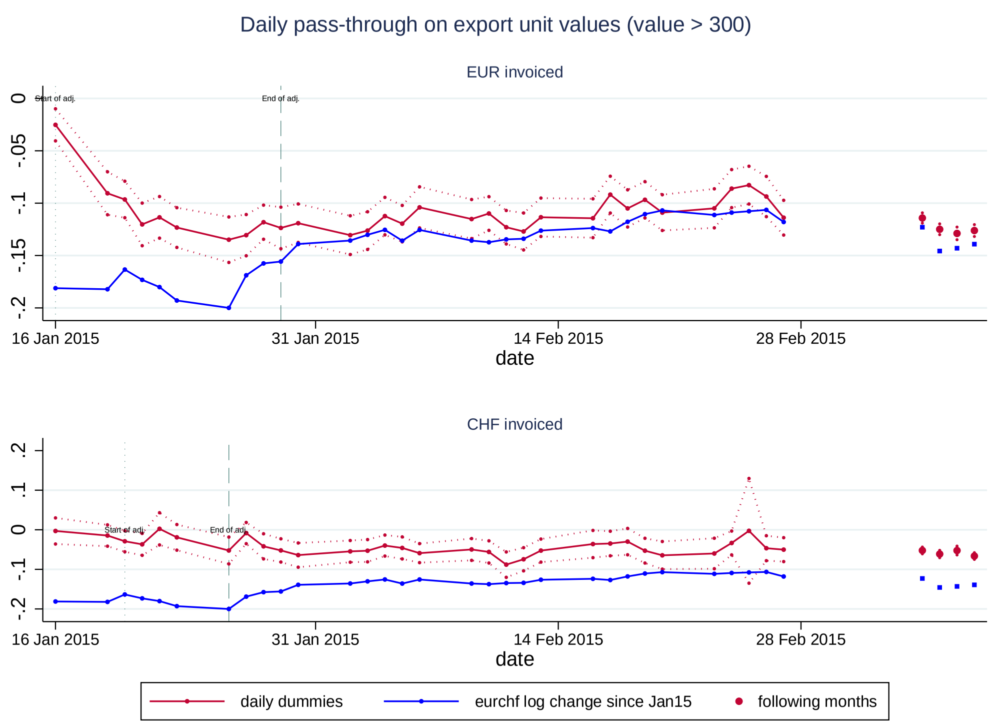


Figure 13: Daily dummies for export unit values for shipments worth more than CHF 300 (specification 3). The regression includes augmented HS-postal code-country triplets fixed-effects and a 2-digit HS -country specific trend. Errors are clustered at the postal code level.

5.4 Graphs for types of goods

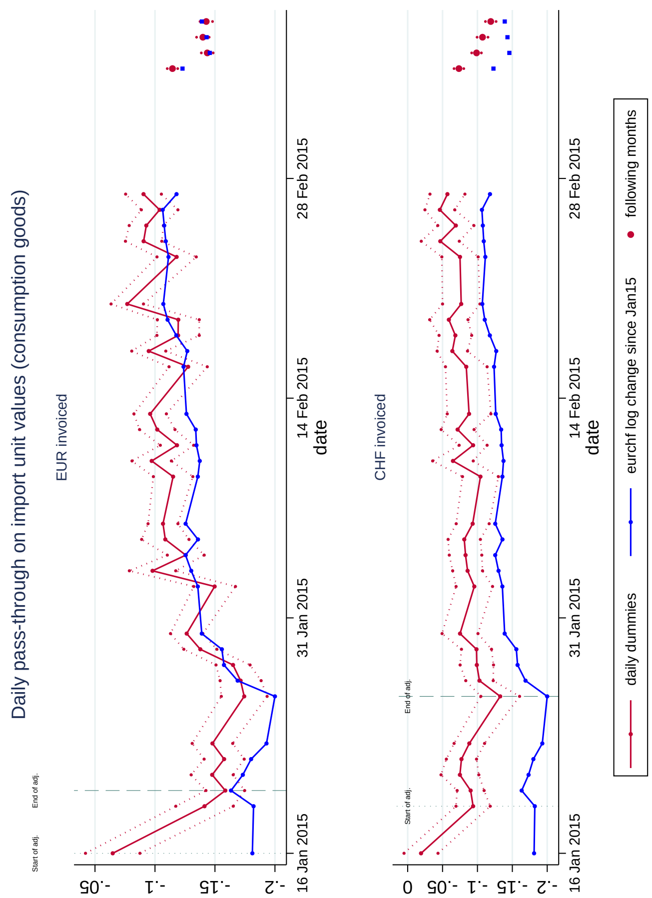


Figure 14: Daily dummies for import unit values for consumption goods (specification 3). The regression includes augmented HS-postal code-country triplets fixed-effects and a 2-digit HS -country specific trend. Errors are clustered at the postal code level.

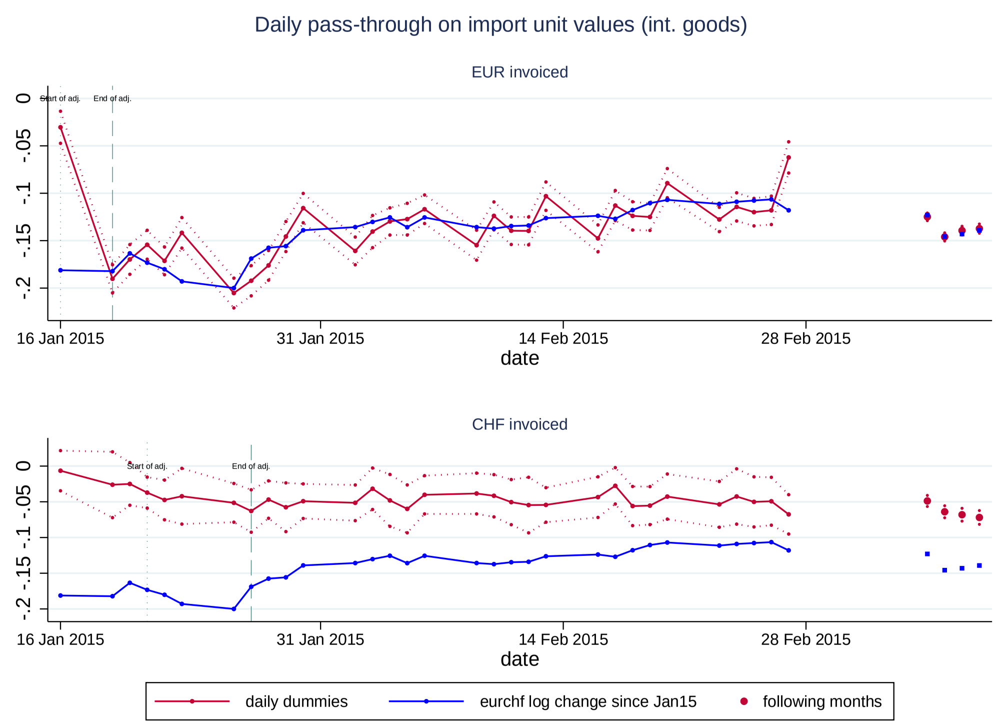


Figure 15: Daily dummies for import unit values for intermediate goods and raw materials (specification 3). The regression includes augmented HS-postal code-country triplets fixed-effects and a 2-digit HS-country specific trend. Errors are clustered at the postal code level.

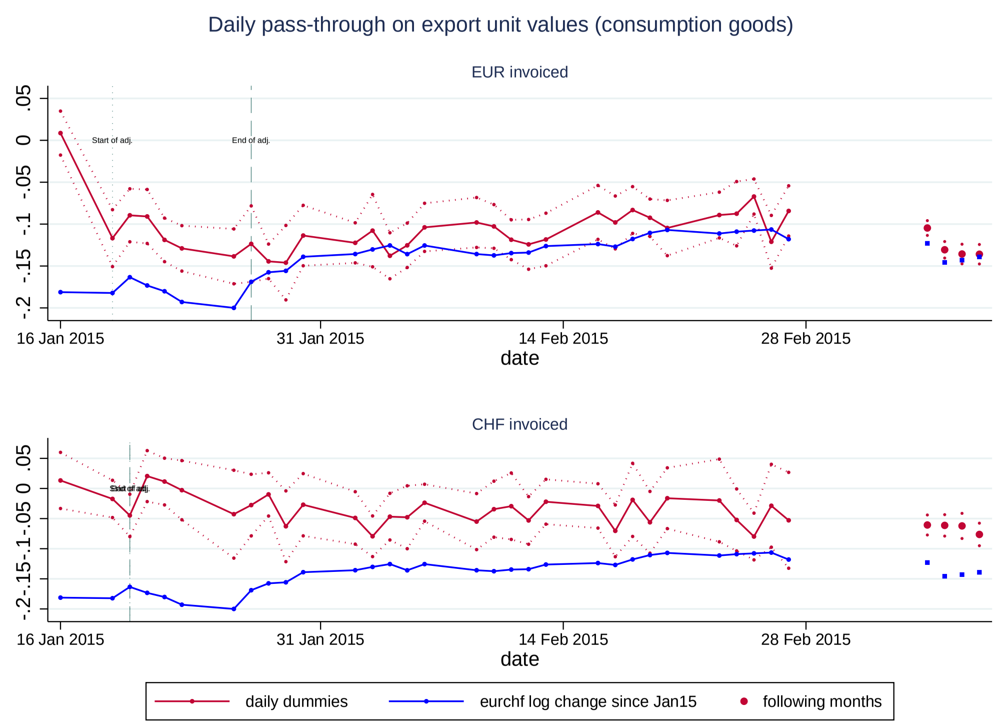


Figure 16: Daily dummies for export unit values for consumption goods (specification 3). The regression includes augmented HS-postal code-country triplets fixed-effects and a 2-digit HS-country specific trend. Errors are clustered at the postal code level.

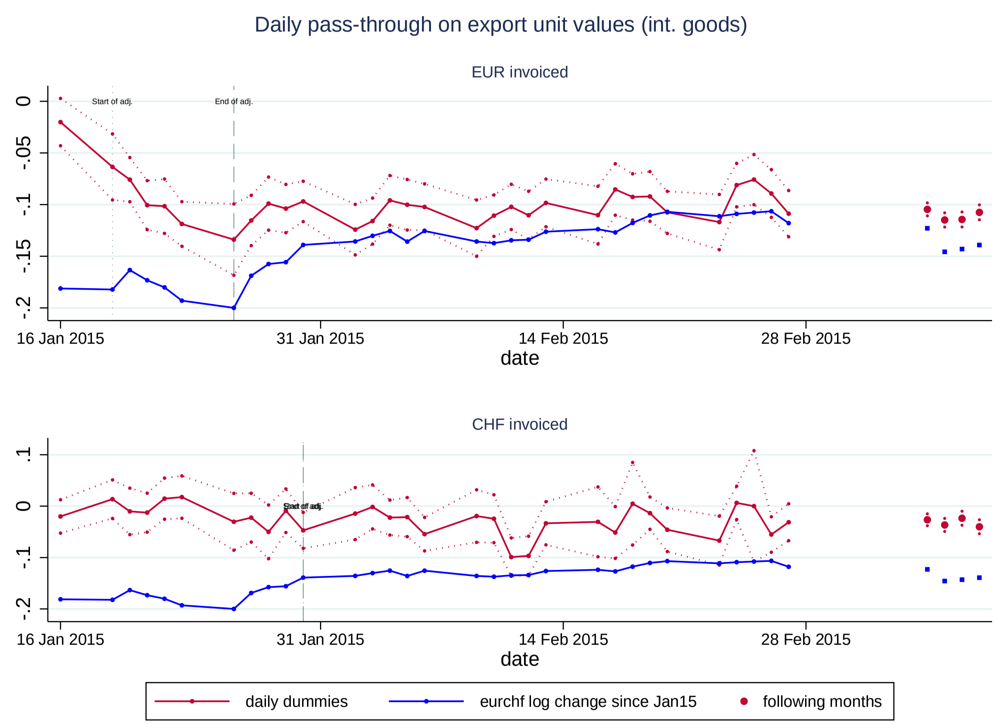


Figure 17: Daily dummies for export unit values for intermediate goods and raw materials (specification 3). The regression includes augmented HS-postal code-country triplets fixed-effects and a 2-digit HS country specific trend. Errors are clustered at the postal code level.

5.5 Graphs for product-level regressions

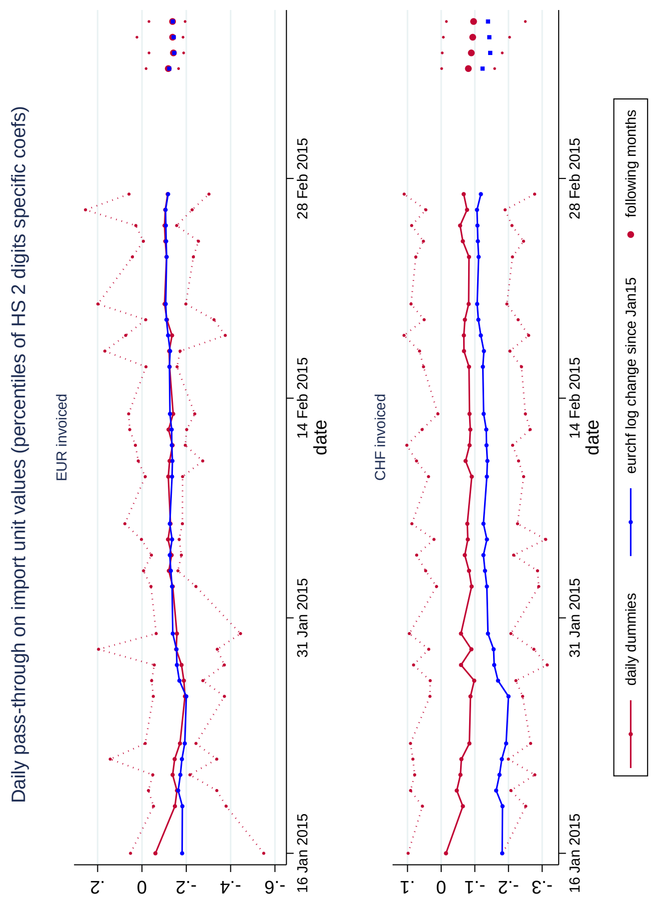


Figure 18: Median, 5% and 95% of each 2-digit HS specific daily coefficients on import unit values (specification 3). The regression includes augmented HS-postal code-country triplets fixed-effects and a country specific trend. Errors are clustered at the postal code level.

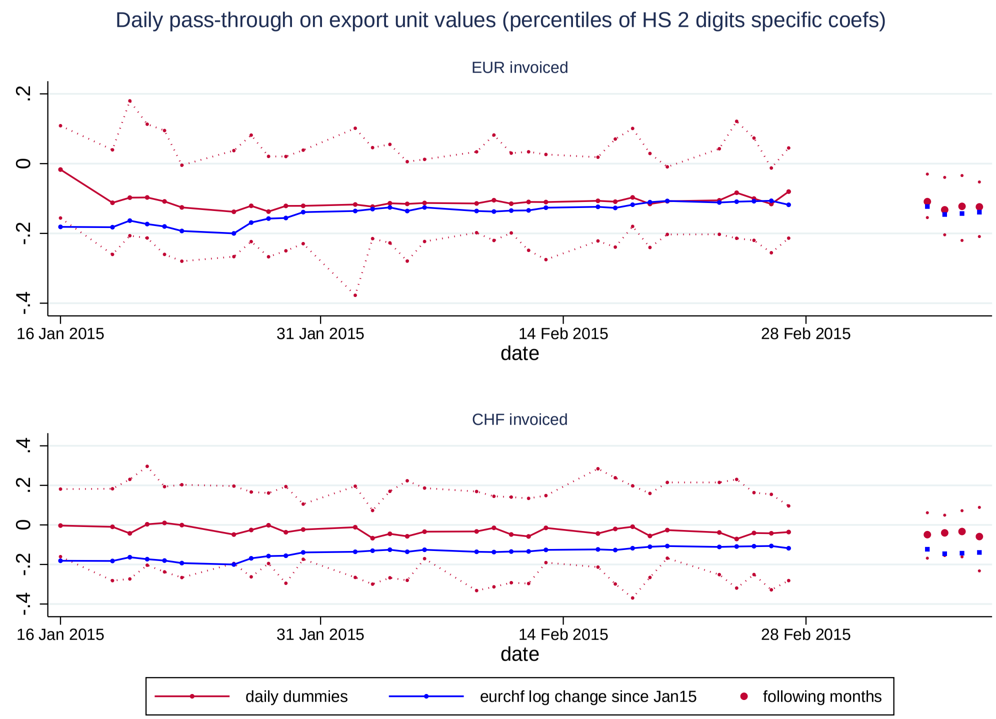


Figure 19: Median, 5% and 95% of each 2-digit specific daily coefficients on export unit values (specification 3). The regression includes augmented HS-postal code-country triplets fixed-effects and a country specific trend. Errors are clustered at the postal code level.

C Appendix 3: Standard estimation procedure

Traditional estimates of pass-through into export prices typically take the form

$$\Delta p_{ij,t} = \sum_{l=0}^{L} \beta_l \Delta e_{j,t} + Z_{ij,t}\gamma + u_{ij,t} \tag{4}$$

where $\Delta p_{ij,t}$ denotes the change in the price of good i exported from a given country C to country j, at time t, $\Delta e_{j,t}$ denotes the change in the exchange rate of country C's and country j's currencies, $Z_{ij,t}$ is a set of potentially country- and good-specific control variables and $u_{ij,t}$ is an error term.

Estimations of this specification crucially rely on the underlying assumption that the error term is uncorrelated with the independent variables, that is, $E[\Delta e_{j,t-l} u_{ij,t}] = 0$ holds for all lags included. If this condition is violated, the estimates suffer from endogeneity bias.

In the following paragraphs, we argue that the crucial assumption may be violated through a number effects and mechanisms described by the literature.

Endogeneity would occur if the theoretical price parity condition holds, as the exchange rate and prices should be jointly determined. While, this violation is usually rejected because exchange rate and prices are not found to be cointegrated (see e.g. Campa and Goldberg (2005)), other sources of endogeneity exist and imperfect measurement or omitted variables are likely to affect the estimation. Corsetti et al. (2008), for example, stress the need to correctly control for marginal cost and demand.

In an early paper, Meese and Rogoff (1988) conjecture that real shocks (such as productivity shocks) drive real exchange rate changes. Relatedly, Enders et al. (2011) present evidence that productivity shocks induce appreciations of the real exchange rate. Thus, real shocks may actually drive innovations in the exchange rate and, simultaneously, innovations in producer's cost. If the marginal cost cannot be adequately controlled for, omitting this variable results in biased estimates because $E[\Delta e_{j,t} u_{ij,t}] \neq 0$ if prices adapt instantaneously and $E[\Delta e_{j,t} u_{ij,t+l}] \neq 0$ $(l > 0)$ if they adjust sluggishly.

Engel and West (2005) take a different approach by stressing the asset-price nature of exchange rates. The authors suggest that exchange rates depend on expectations of future fundamentals, arguing, in particular, that innovations in the exchange rates should be correlated with news about future fundamentals. Empirically, they find evidence that exchange rates

Granger-cause fundamentals. In such a setting, an anticipated technological shock impacts the exchange rate at time t, and producer's cost at time $t+l$. Here again, if the marginal cost cannot be correctly controlled for, $u_{ij,t}$ and $\Delta e_{j,t}$ may both react to the same shock, implying that $E[e_{j,t-\hat{l}} u_{ij,t}] = \eta_{\hat{l}} \neq 0$ for a lag $\hat{l} > 0$.[35]

To frame these arguments formally, consider the following OLS estimator of $(\beta', \gamma')'$ in (4):

$$\begin{pmatrix} \hat{\beta} \\ \hat{\gamma} \end{pmatrix} = \begin{pmatrix} \beta \\ \gamma \end{pmatrix} + \begin{pmatrix} e'e & e'Z \\ Z'e & Z'Z \end{pmatrix}^{-1} \begin{pmatrix} e'u \\ Z'u \end{pmatrix} \tag{5}$$

where $e = \left(\Delta e_0 \ \Delta e_1 \ \ldots \ \Delta e_L \right)$ is the matrix of exchange rate lags, Z the matrix of control variables and u the error vector. Inverting the partitioned matrix, the bias on $\hat{\beta}$ is given by:

$$\hat{\beta} - \beta = \begin{pmatrix} A & -A(e'Z)(Z'^{-1} \\ & \end{pmatrix} \begin{pmatrix} e'u \\ Z'u \end{pmatrix} \tag{6}$$

with $A = (e'e - e'Z(Z'Z)^{-1}Z'e)^{-1} = (e'M_z e)^{-1}$. If all variables in Z are exogenous, we get that $plim \frac{Z'u}{T} = 0$, so that the direction of the asymptotic bias only depends on the behavior of A and $e'u$.

In the case that the lags of exchange rate changes are uncorrelated (for example in the case of a random walk in the exchange rate), $plimA$ is a diagonal matrix whose elements are equal to $plim(e_l' M_z e_l)^{-1}$, which is positive because M_z is positive definite. The asymptotic bias on each $\hat{\beta}_{\hat{l}}$ is then equal to $\hat{A}_{\hat{l}} \eta_{\hat{l}}$, where $\hat{A}_{\hat{l}} = plim(e_{\hat{l}}' M_z e_{\hat{l}})^{-1}$, and is thus of the same sign as $\eta_{\hat{l}}$. If, in addition, the error terms are autocorrelated[36], the bias does not affect $\hat{\beta}_l$ only. For example, if $u_{ij,t} = \rho u_{ij,t-1} + \epsilon_t$, then $E[u_{ij,t} \Delta e_{j,t-\hat{l}-l}] = \rho^l \eta_{\hat{l}} \neq 0$ follows for $l > 0$ so that all estimates on lags "further away" than $\hat{l}$ are inconsistent. The direction of the bias then depends on $\eta_{\hat{l}}$ and on ρ.

For a concrete example, consider a positive anticipated shock to the technology of the exporting country in a world like in Engel and West (2005).

[35] If the marginal cost is measured with an error (e.g. proxied using expenditure shares and price changes of input prices), the exchange rate will still be correlated with $u_{ij,t}$ if it is also correlated with the measurement error. An other example is a shock in preferences in the demand for the exporter's good which would have a similarly uncontrolled effect on both the price and the exchange rate.

[36] Note that using residuals derived from the inconsistent $\hat{\beta}$, one might be unable to detect such autocorrelation because in this case the residuals are not a consistent estimator of the error term.

In this setup, the anticipated technology shock in period t leads to an appreciation of the exchange rate at time $t - l$. Defining the exchange rate as home currency per foreign currency, this means $\Delta e_{j,t-\hat{l}} < 0$. At the same time, this shock is associated with a negative shock on the price at time t ($u_{ij,t} < 0$). In sum, such a positive technological shock (inducing an appreciation of the exporter's currency and a future reduction in costs) generates $\eta_{\hat{l}} > 0$. A positive ρ is consistent with persistency in the shock. Overall, the bias on the lags would thus be positive, resulting in an overestimation of the delayed pass-through.

The shock to the EURCHF exchange rate used in this paper is arguably unrelated to any shock that might produce endogeneity issues. The shock was unrelated to any technological or taste shock, but was purely due to the SNB's decision. Thus, our estimates tale place in a setting free of endogeneity concerns.