Exchange Rate Pass-Through in Switzerland: Evidence from Vector Autoregressions*

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Abstract

This paper investigates the pass-through of exchange rate and import price shocks into different aggregated prices in Switzerland. The baseline analysis is carried out with identified vector autoregressive (VAR) models. The data set comprises monthly observations and pass-through effects are quantified by means of impulse response functions. Evidence shows that the exchange rate pass-through is substantial (although incomplete) into import prices, but very moderate into total consumer prices. These results are remarkably robust to a number of alternative specifications of the model, such as the use of different information sets, identification schemes and consumer price measures. Moreover, a sub-sample analysis reveals that the pass-through into consumer prices decreased significantly in the 1990s as compared to previous decades. This decrease coincided with a shift towards lower and more stable consumer price inflation.

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1 Introduction

The extent to which exchange rate changes are reflected in prices of goods and services, often referred to as the exchange rate pass-through relationship, has been of interest in international economics since the breakdown of the Bretton Woods system in 1973. For monetary policy makers, a thorough understanding of the pass-through mechanisms is particularly important, as the degree of pass-through has both an impact on the transmission mechanism of monetary policy and on inflation forecasts.

The international empirical literature on the exchange rate pass-through is extensive. A robust stylized fact in this literature is that the exchange rate pass-through is in general incomplete. Such evidence is documented in the survey article by Menon (1995) for a wide range of countries. Most of the earlier studies focus on the exchange rate pass-through into import or export prices. A more recent stream of literature, represented for instance by the cross-country analysis in McCarthy (2000) and Mihailov (2005), examines the pass-through into different prices. In general, these studies find that the pass-through into consumer prices, which is the major concern for monetary policy, is small and often even insignificant.

Given the particular relevance of the pass-through issue for small open economies, the empirical evidence for Switzerland is surprisingly scarce. Moreover, the few available studies sometimes come up with contradicting results. Campa and Goldberg (2005) find evidence for strong and in the long run nearly complete exchange rate pass-through into import prices. This does not correspond to McCarthy (2000), who reports relatively small pass-through into Swiss import prices, compared to other industrialized countries. Moreover, his estimate of the exchange rate pass-through into consumer prices is virtually zero. By contrast, Gagnon and Ihrig (2004) acknowledge a somewhat positive, although not statistically significant, pass-through of exchange rate shocks into consumer prices.

The aim of this paper is to provide thorough empirical evidence on the degree of the aggregated pass-through into different prices in Switzerland. Unlike the cross-country studies above, I exclusively focus on the Swiss case. This enables a custom-made econometric setup to be found, which accounts for specific features of the Swiss data. Several ways to examine pass-through effects have been used in the literature. According to Mihailov (2005), two mutually different approaches may be distinguished. The *direct approach* relies on survey data. In so-called event studies, the direct effect of actual currency fluctuations on prices of certain goods (typically manufacturing goods) is then investigated. The *indirect approach*, by contrast, postulates theoretical relationships between variables of interest, and focusses on the estimation of key correlations and regression coefficients. In this paper, I follow this second approach by exploiting the

information in macroeconomic time series and estimating the aggregated exchange rate pass-through into both import and consumer prices. Aggregated price data are used, as this is of direct relevance for monetary policy authorities.

In a first step, I examine the transmission of exchange rate and aggregated import price shocks into aggregated import and consumer prices over a long time period from January 1976 to December 2004 (*full-sample* analysis). The empirical literature knows different methodologies to estimate the pass-through. Campa and Goldberg (2005), for instance, use single-equation models, which are estimated by ordinary least squares (OLS). Following Choudhri et al. (2005) and others, this paper relies on vector autoregressive (VAR) models, which account for endogeneity of the variables. The degree of pass-through at different time horizons is then quantified by means of impulse response functions. In the baseline case, the structural shocks are identified by a standard Choleski decomposition, in which the ordering of the endogenous variables follows both theoretical and empirical considerations. As evidence from VAR models may heavily depend on the model specification, several robustness tests, such as the use of alternative information sets, identification schemes and consumer price measures, are carried out.

In a second step, the changes in pass-through mechanisms over time are investigated. To this aim, I perform a *sub-sample* analysis, thereby paying special attention to the link between the degree of pass-through into consumer prices and the inflation environment, i.e. the possible role of monetary policy in influencing the pass-through.

Previewing the results, in the *full-sample* analysis the exchange rate pass-through into import prices is found to be significant, yet incomplete. The pass-through of import prices into consumer prices is surprisingly strong and, in the longer run, virtually complete. By contrast, exchange rate shocks cause small and only borderline significant responses in consumer prices. These results are remarkably robust to changes in the model setup. Furthermore, evidence from *sub-sample* estimations indicates that the degree of pass-through decreased in the 1990s, as compared to previous decades. This is particularly true for the pass-through into consumer prices, and it coincides with a change in the inflationary environment, i.e. a shift towards lower and more stable inflation. This finding is in line with a recent stream in the literature which claims that a decrease in the exchange rate pass-through into consumer prices may be attributed to increased emphasis on inflation stabilization by central banks.

The paper is organized as follows. The next section gives an overview of the theoretical literature on the pass-through issue. Section 3 presents the data set and the applied econometric framework. In section 4, the pass-through estimates of the baseline model are discussed. The robustness of these results is examined in section 5. Section 6

presents sub-sample estimates in order to assess the changes in pass-through mechanisms over time. Section 7 concludes and points to promising further research directions.

2 Theoretical background

Early theoretical research on the pass-through issue used to be predominantly microeconomic in nature. The classic article by Goldberg and Knetter (1997) provides a comprehensive overview of this literature. It is characterized by the aim to explain the incompleteness of pass-through from an industrial-organization perspective. The pass-through is then examined in an environment of imperfect competition, usually in the form of market segmentation or product differentiation. Such a setup allows exporting firms with some market power to discriminate prices across destination markets, i.e. to set export prices to each destination as the product of the common marginal cost and a destination-specific markup. Krugman (1987) introduced the concept of pricing-to-market, which stands for exchange rate induced price discrimination across countries. In other words, it describes a situation where exporting firms adjust their (destination-specific) markups in order to compensate for exchange rate changes. Pricing-to-market may thus be considered as a microeconomic explanation for incomplete exchange rate pass-through into import prices.

In macroeconomics, by contrast, research that focusses on the pass-through mechanisms is a relatively new field. Traditional open economy macroeconomic models were characterized by perfect competition, fully flexible prices and purchasing power parity. In these models, the pass-through was necessarily complete. In the early days of the new open economy macroeconomic era, microeconomic evidence on incomplete pass-through was not yet incorporated, neither. In their pioneering work, Obstfeld and Rogoff (1995) introduced nominal rigidities and market imperfections into a microfounded dynamic general equilibrium model. However, purchasing power parity was still maintained at all times, and the pass-through was complete. Betts and Devereux (1996, 2000) then developed an extended version of the Obstfeld-Rogoff model allowing for pricing-to-market. More precisely, whereas the two models feature the same simple form of price rigidity (prices are predetermined for one period), they differ in the assumed pricing strategy of firms. In the Obstfeld-Rogoff-model, nominal prices are set in producers' currencies (*producer currency pricing*). Consequently, nominal exchange rate fluctuations cause one-to-one reactions in prices of imported goods, i.e. the short-run exchange rate pass-through is complete.[1] The policy implication is then straightforward: since flexible

[1] To be precise, in the Obstfeld-Rogoff-model with sticky prices, the short-run exchange rate pass-through into consumer prices equals the share of imported goods in total consumer goods.

exchange rates can serve as a substitute for flexible nominal prices, and therefore help to achieve relative price adjustments, a flexible exchange rate regime is desirable. By contrast, in the Betts-Devereux-model, a fraction of firms is allowed to set prices in destination countries' currencies (*local currency pricing*). This dampens the effect of exchange rate changes on domestic prices. In fact, if all firms price-discriminate across countries, the short-run transmission of exchange rate shocks into prices is completely blocked, i.e. the pass-through is zero.[2] Devereux and Engel (2003) demonstrate that in this setup a fixed exchange rate regime is preferable.

However, these two early model types neglect several important aspects. In particular, neither the original Obstfeld-Rogoff-model nor the Betts-Devereux-model do explicitely distinguish different stages of the distribution chain. More recently, a strand in the literature has been established that considers imports as intermediate goods that undergo nontraded production oder distribution processes before being consumed. These production or distribution channels may dampen the impact of exchange rate shocks on consumer prices. Hence, imperfect pass-through into consumer prices may be observed even in the case of producer currency pricing. McCallum and Nelson (1999), for instance, provide a model in which imports serve as raw materials in the production and distribution process. The physical good is then only a part of what the consumer actually buys. The other part comprises nontraded marketing, distribution and retailing services. Consequently, as exchange rate changes only affect the physical goods' prices, the pass-through into consumer prices is likely to be small. A related approach was chosen by Corsetti and Dedola (2002). Again, their model incorporates distributive trade, whose production is intensive in local inputs. Furthermore, they focus on the consequences of vertical interactions between monopolistic producers and retailers for international transmission.

A further key issue in the macroeconomic literature is the relationship between the exchange rate pass-through into consumer prices and monetary policy. This field of research has mainly been motivated by the observed decline in the degree of pass-through in most countries in recent years. As this decline has often coincided with increased emphasis of central banks for inflation stabilization, it was natural to assume a link between the two phenomena. In its November 2000 *Monetary Policy Report* (p. 9), the Bank of Canada claims that "the low inflation environment itself is changing price-setting behavior. When inflation is low and the central bank's commitment to keeping it low is highly credible, firms are less inclined to quickly pass higher costs on to consumers in the form of higher prices." Taylor (2000) was the first to come up with a theoretical framework

[2]Note that the assumption of sticky prices is crucial to this result. With flexible prices, complete pass-through prevails even in a world with *local currency pricing*.

in which the degree of pass-through depends on the inflationary environment. He uses a microeconomic model of staggered price setting in which a lower pass-through is caused by lower perceived persistence of cost changes. Moreover, he presents evidence for a positive correlation between the level and persistence of inflation in the U.S. He therefore concludes that the low inflation itself has caused the low pass-through.[3] Drawing on the work by Taylor (2000), the link between pass-through and inflation was examined in many studies. Gagnon and Ihrig (2004), for example, carried out a cross-country analysis comprising twenty industrialized countries. They find that the exchange rate pass-through declined in most countries that were characterized by a regime shift towards more inflation stabilization in the early nineties. I will come back to the relationship between the degree of pass-through and the inflation environment in section 6.

3 Empirical model

This section presents the econometric setup applied in this paper. First, the choice of the information set is motivated. Hereafter, I introduce the baseline VAR model and the identification strategy of relevant shocks.

3.1 Data set

This paper aims to shed light on the transmission of fluctuations in the exchange rate (EX) into import prices (IPI) and consumer prices (CPI). These three variables are thus the centre of the empirical analysis. It is assumed that prices are set along the distribution chain, i.e. exchange rate shocks are initially passed along to import prices and finally lead to a reaction in consumer prices. Next, the model includes a measure of the output gap (gap) in order to control for domestic economic activity. A broad measure of money (M) allows for effects of monetary policy. Finally, foreign consumer prices (CPIW) are considered. Note that the choice of the information set is largely in the spirit of Choudhri et al. (2005), who examine the performance of a variety of new open economy macroeconomic models by comparing the predicted results with evidence based on VAR models.

A detailed description of the data and figures of relevant transformations are provided in Appendix A. In short, the data are monthly observations from 1976.01 to 2004.12. All series, except the nominal exchange rate, are seasonally adjusted by means of the Census-X-12 procedure. Using monthly instead of quarterly data is motivated by the fact

[3] It is implicitely assumed in this line of argument that the persistence of aggregate inflation is a proxy for the perceived persistence of cost changes.

that monetary policy authorities are particularly interested in short-run pass-through dynamics, which are relevant for short-term inflation forecasts. Most series exist on a monthly basis. The only exception is the output gap, as all conventional measures of this series are based on GDP figures, which are only available quarterly. In order to obtain a monthly GDP series, I applied the Chow-Lin procedure (Chow and Lin, 1971). Details are again given in appendix A. The output gap is then computed as the deviation of actual monthly GDP from potential GDP, whereby the latter is calculated by means of a Hodrick-Prescott filter.

3.2 Econometric approach

The baseline empirical model is estimated as a VAR with five endogenous and one exogenous variables. The reduced form representation of the model may be written as

$$D(L)\, y_t = c + \varphi(L)\, x_t + \varepsilon_t \qquad E\left(\varepsilon_t \varepsilon_t^{'}\right) = \Sigma, \tag{1}$$

where $y_t = [\Delta ex_t, \Delta ipi_t, gap_t, \Delta m_t, \Delta cpi_t]$ is the vector of $m = 5$ endogenous variables. $x_t = \Delta cpiw$ is the only exogenous variable, meaning that foreign prices are given for the small open Swiss economy. $D(L) = (I + D_1 L + \ldots D_p L^p)$ and $\varphi(L) = \left(\varphi_0 + \varphi_1 L + \ldots \varphi_q L^q\right)$ are matrix and vector polynomials in the lag operator. c is a vector of constants and ε_t a vector of residuals. Lower cases indicate natural logarithms and Δ denotes first differences. All series, except the output gap, enter the model as log-differences. This reflects that the variables are assumed to contain unit roots.[4] As there is no strong and robust evidence that the system is cointegrated, no vector error correction models are used. The reduced form model (1) is then estimated with six lags for both endogenous and exogenous variables, i.e. $p = q = 6$.[5]

As may be seen from the non-diagonal covariance matrix $\Sigma = \{\sigma_{ij}, i, j = 1, 2, \ldots m\}$, the residuals $\varepsilon_{i,t}$ are correlated with each other. A structural VAR representation in accordance with (1) is given by[6]

$$B(L)\, y_t = u_t \qquad E\left(u_t u_t^{'}\right) = I, \tag{2}$$

with vector u_t containing mutually uncorrelated shocks with unit variance. However, u_t is not directly observable, but needs to be identified. Given that $B(L)$ is invertable, (2)

[4] Evidence from Augmented Dickey-Fuller and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) tests points to I(1)-behaviour of all variables, except the output gap. The latter is I(0) by construction.

[5] Successive lag reduction tests (F-tests) suggested to include five lags. Using five lags, however, left the estimated residuals partly autocorrelated. Allowing for six lags was sufficient to solve the problem of autocorrelated residuals. Including more than six lags did not improve the properties of the estimated model.

[6] In the notation of (2), deterministic terms (i.e. the constant and the exogenous variable) are suppressed for simplicity.

is equivalent to the structural vector moving average representation

$$y_t = A(L)\, u_t = A_0 u_t + A_1 u_{t-1} + A_2 u_{t-2} + A_3 u_{t-3} + \ldots, \tag{3}$$

with $A(L) = B(L)^{-1}$. In the model with five endogenous variables we need 10 restrictions (in addition to the 15 restrictions provided by the assumption that the covariance matrix of the structural innovations equals the identity matrix) in order to identify the structural shocks. In the baseline model, identification is achieved by setting A_0 equal to the Choleski decomposition of Σ, i.e. $A_0 A_0' = \Sigma$ with A_0 being lower triangular.

Identification by means of a Choleski-decomposition is only unique up to the ordering of the variables. In the baseline case, the following ordering has been chosen

$$\Delta ex_t \rightarrow \Delta ipi_t \rightarrow gap_t \rightarrow \Delta m_t \rightarrow \Delta cpi_t. \tag{4}$$

The ordering according to (4) is motivated by both theoretical and empirical reasons. Theoretically, the small open economy framework in hand suggests to place the two foreign variables (the exchange rate and import prices) first. The exchange rate is then allowed to be hit contemporaneously only by its own innovations. Import prices may, in addition, react simultaneously to exchange rate shocks. The output gap is ordered next, followed by broad money. The last variable in the system are consumer prices, meaning that they are exposed to contemporaneous influence of every type of structural shock in the economy. In the empirical literature, the decision on the ordering of the variables in VAR models is often made on the basis of evidence from pairwise granger causality tests.[7] Table 1 below reports results from such tests between the endogenous variables.

Table 1: Pairwise granger causality tests

y_i	Δex	Δipi	gap	Δm	Δcpi
Δex	∘	–>	-	-	–>
Δipi	-	∘	–>	-	–>
gap	-	–>	∘	–>	-
Δm	-	-	-	∘	-
Δcpi	-	-	-	-	∘

–>: variable in row granger causes variable in column

- : variable in row does not granger cause variable in column

[7] These tests do, strictly speaking, not provide evidence on the simultaneous relationship between the data, but only on the effect of lagged observations. Nevertheless, they are likely to be indicative for the causal link between the data.

The evidence in table 1 largely supports the chosen ordering. Only the position of the output gap is somewhat controversial: while there is no evidence for any causality between the gap and exchange rate changes, a feedback relationship between the output gap and import price changes is indicated. From an empirical point of view, it would thus be possible to put the output gap in front of the foreign variables. In fact, such orderings have been used in some related studies, e.g. McCarthy (2000) and Hahn (2003). I will consider a respective setup in section 5, when examining the robustness of the results.

4 Results

Based on the identified VAR, the degree of pass-through is quantified by means of impulse-response functions. The system is shocked by a structural innovation in the equation for one of the endogenous foreign variables (exchange rate or import prices) and the pass-through of this shock into prices (import prices or consumer prices) is observed. Figures 1 to 3 track the estimated pass-through patterns within 24 months. Note that the shocks (impulses) in the log-differenced variables are normalized to one. Hence, responses may be interpreted as approximate percentage point changes in the respective price index following a one percent shock in a foreign variable, i.e. as pass-through elasticities. Solid lines are the *accumulated* impulse responses. Two standard error bands are plotted with dotted lines.[8] Appendix B.2.1 provides additional tables with results.

4.1 Pass-through into import prices

Figure 1: Exchange rate pass-through into import prices

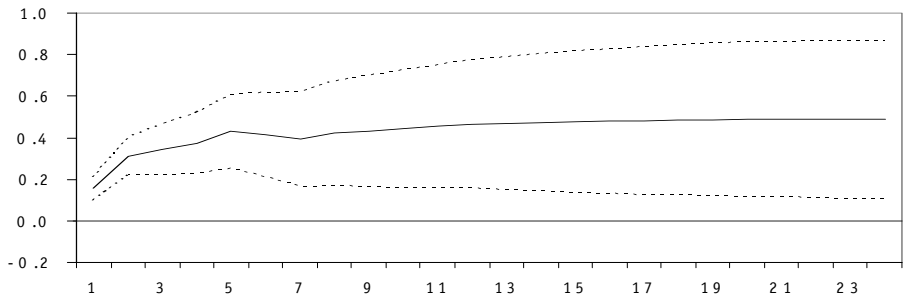


Figure 1 tracks the pass-through of a shock in the exchange rate into import prices. Several features seem noteworthy: firstly, import prices react quickly to exchange rate

[8] As the sample size is sufficiently large, standard errors are calculated analytically, i.e. by applying asymptocically valid delta methods.

shocks. The pass-through amounts to 0.34 after three months. In the long run, which is defined as two years in the context of this study, the pass-through comes to 0.49. As it is indicated by the confidence bands, the responses are significantly different both from zero and one over the whole time horizon considered. Hence, the pass-through is substantial but incomplete. These findings are compatible with most empirical literature. Goldberg and Knetter (1997) find an average pass-through for shipments to the US of 0.5, and Hahn (2003) estimates a similar degree of pass-through for the Euro area. McCarthy (2000) points out that the pass-through into import prices is relatively small in Switzerland compared to other industrialized countries. Only Campa and Goldberg (2005) come to a fundamentally different conclusion: they claim the pass-through into import prices in Switzerland to be higher than in most other OECD-countries and virtually complete in the long run. This deviative results may partly be caused by different estimation techniques. Instead of impulse responses from VAR models, Campa and Goldberg (2005) simply take the estimated coefficients in linear regression models as a measure for the pass-through.

4.2 Pass-through into consumer prices

Figure 2: Pass-through of import prices into consumer prices

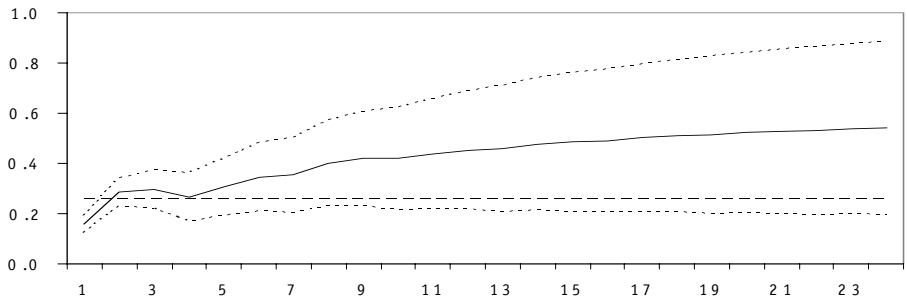
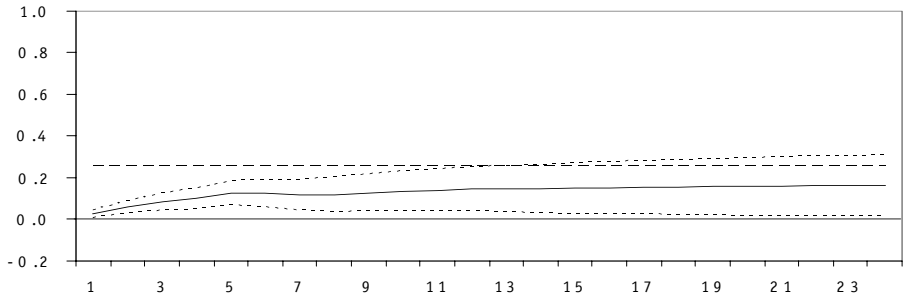


Figure 2 displays the the pass-through of import price shocks into consumer prices. Again, the pass-through takes place quite quickly and the responses are significantly different from zero for all periods. After three months, the pass-through amounts to 0.30 and after two years to 0.54. When interpreting these results, it is useful to consider the share of imported goods in the consumer price basket. In 2004, this share was roughly one quarter (25.8%), which is indicated by the horizontal dotted line in figure 2. If import price shocks were completely passed through along the distribution chain, the effect on total consumer prices should approximately equal this share. Note that this is a rough rule only, since it ignores possible effects of foreign shocks on prices of competing

domestic goods: domestic firms may have incentives to adjust their prices as a reaction to changes in prices for similar imported goods. Hence, it is not unplausible that the estimated pass-through exceeds the ratio of imported to total consumer goods, as it is the case in figure 2. In section 5.3, I will explicitely rule out this kind of effects on domestic prices by estimating the pass-through into a more narrow consumer price measure. For the time being, we note that the evidence of a strong pass-through of import prices into consumer prices is in line with the results in McCarthy (2000). Amstad and Fischer (2005), who use an event study approach, also find evidence that import price releases provide important information for consumer price inflation.

Figure 3: Exchange rate pass-through into consumer prices



Finally, the pass-through of exchange rate shocks into consumer prices is presented in figure 3. It amounts to 0.08 after nine months and increases to only 0.16 after two years. The pass-through is only borderline significant from zero in the longer run and it lies below the share of imported goods in the consumer price basket (which is again signalled by the horizontal dotted line). This evidence of weak and incomplete exchange rate pass-through into consumer prices stands basically uncontradicted in the literature. Nevertheless, there is some ambiguity concerning the degree of pass-through. McCarthy (2000) reports very small responses of consumer prices to exchange rate shocks for most industrialized countries and virtually no pass-through for Switzerland. Gagnon and Ihrig (2004), instead, acknowledge more or less the same degree of pass-through for Switzerland as in this paper.

5 Sensitivity analysis

Results from VAR models may highly depend on the specification of the underlying model. Therefore, I next examine the robustness of the estimated pass-through elasticities by submitting the baseline model to several modifications. The results from this

sensitivity analysis are documented as follows: figures and tables in Appendix B.1 and B.2 always comprise the lower and upper bound of all estimates from all model specifications and compare it with the baseline results. This should both give an impression of the range of estimates and of the location of the baseline results within that range. Sections 5.1 and 5.2 discuss the alternative model specifications and the respective impacts on estimated impulse responses. Furthermore, in section 5.3, I investigate to what extent the conclusions change, when I use a more narrow consumer price measure.

5.1 Alternative data sets

The robustness of the baseline results with respect to the information set is tested by estimating two so-called parsimonious models.[9] The first of these models comprises the vector $y^1 = [\Delta ex, \Delta ipi, gap]$ of endogenous variables together with the exogenous variable $x_t = \Delta cpiw$. This model exclusively focusses on the pass-through of exchange rate shocks into import prices. To this aim, money and consumer prices are excluded from the analysis. Foreign consumer prices are still considered in order to control for foreign price changes. The output gap remains part of the model, as the pricing behaviour of a foreign exporter may depend on demand conditions in the importing country. The impulse responses from this model specification lie slightly below the baseline results. In figure 14 and table 2 (panel 1) in Appendix B, they represent the lower bound of all estimates. The deviations from the baseline results are, however, small.

The second parsimonious model is represented by the vector $y^2 = [\Delta ipi, gap, \Delta m, \Delta cpi]$ of endogenous variables. It examines the pass-through of import price shocks into consumer prices, only. Hence, both the exchange rate and foreign consumer prices are omitted. This parsimonious specification yields stronger pass-through estimates than the baseline model. In fact, the parsimonious model produces the upper bound of all estimates in figures 15 and table 3 (panel 1). The differences in the results from the baseline and the parsimonious specification are more substantial than in the case of the pass-through of the exchange rate into import prices.

5.2 Alternative identification schemes

Identification by means of the Choleski decomposition of the covariance matrix Σ is only unique up to the ordering of the variables in the system. Consequently, the same is true for the orthogonalized impulse responses. In this section, I apply two alternative

[9] In this section, identification is achieved in accordance with the baseline model. In section 5.2, I will adopt different identification schemes to both the baseline and the parsimonious models.

identification strategies both to the full and the parsimonious models.

The first alternative is straightforward. The variables of the baseline system are simply reordered as follows[10]

$$gap_t \rightarrow \Delta ex_t \rightarrow \Delta ipi_t \rightarrow \Delta m_t \rightarrow \Delta cpi_t \tag{5}$$

Identification is then achieved as described in section 3.2, i.e. by applying a Choleski decomposition of the covariance matrix Σ. Note that the only difference to the baseline case consists in the position of the output gap. Here, the output gap precedes the exchange rate and import prices, thereby accounting for the fact that the appropriate position of the output gap is somewhat controversial in the context at issue (see the discussion in section 3.2). This alternative identification does, however, not yield substantially different results. In the case of the exchange rate pass-through into import prices, the estimated responses are marginally stronger than those in the baseline model. They provide the upper bound in figure 14. When it comes to the pass-through into consumer prices (both of exchange rate and import price shocks), the results are virtually indistinguishable from those of the baseline model. Thus, the ordering of the output gap is of little importance for the pass-through estimates. This is likely to be due to weak contemporaneous correlations between the output gap and the exchange rate and import prices, respectively.

As a second alternative, I calculated *generalized* impulse responses. This concept was advanced in Koop et al. (1996) and applied to VAR models in Pesaran and Shin (1998). Unlike traditional impulse responses, this concept does not require orthogonalization of the shocks, and is invariant to the ordering of the variables. Again, I assume the economy to be represented by the reduced form model (1) introduced in section 3.2. Given $D(L)$ is invertible, i.e. $D(L)^{-1} = C(L)$, this is equivalent to the vector moving average representation $y_t = C(L)\varepsilon_t = \sum_{i=0}^{\infty} C_i \varepsilon_{t-i}$.[11] According to Pesaran and Shin (1998), the generalized impulse response function of y_t at horizon n is then defined by

$$GI_y(n, \delta, \Omega_{t-1}) = E(y_{t+n} \mid \varepsilon_t = \delta, \Omega_{t-1}) - E(y_{t+n} \mid \Omega_{t-1}) = C_n \delta \tag{6}$$

It can be seen from (6) that generalized impulse responses are independent of the known history of the economy up to time $t-1$ (Ω_{t-1}), but depend on the composition of shocks δ. Hence, the choice of the hypothesized vector of shocks δ is central to the properties of the impulse response function. The traditional approach of orthogonalized impulse responses surrounds the choice of δ by using the Choleski decomposition of Σ (see section 3.2). The alternative approach of generalized impulse responses uses (6) directly, but

[10] In the parsimonious models, the reordering is carried out accordingly.

[11] Again, deterministic terms are suppressed in this vector moving average representation.

instead of shocking all elements of ε_t, only the $j-th$ element is shocked, and the effects of other shocks are integrated out using an assumed or historically observed distribution of the errors. We then have

$$GI_y\left(n, \delta_j, \Omega_{t-1}\right) = E\left(y_{t+n} \mid \varepsilon_{jt} = \delta_j, \Omega_{t-1}\right) - E\left(y_{t+n} \mid \Omega_{t-1}\right) = C_n \delta_j \tag{7}$$

Assuming that the $m \times 1$ vector ε_t has a multivariate normal distribution, Koop et al. (1996) derive

$$E\left(\varepsilon_t \mid \varepsilon_{jt} = \delta_j\right) = \left(\sigma_{1j}, \sigma_{2j}, \ldots \sigma_{mj,}\right)' \sigma_{jj}^{-1} \delta_j = \Sigma e_j \sigma_{jj}^{-1} \delta_j,$$

where e_j is an $m \times 1$ vector with unity at its $j-th$ place and zero elsewhere. Therefore, the $m \times 1$ vector of (unscaled) generalized responses of y_{t+n} to a shock δ_j in the $j-th$ equation at time t is given by

$$GI_y\left(n, \delta_j, \Omega_{t-1}\right) = \left(\frac{C_n \Sigma e_j}{\sqrt{\sigma_{jj}}}\right)\left(\frac{\delta_j}{\sqrt{\sigma_{jj}}}\right) \tag{8}$$

When interpreting the results, it is important to note that orthogonalized responses, obtained by Choleski decomposition of Σ, and generalized responses coincide for impulses (shocks) to the first variable in the VAR. Consequently, as the exchange rate was ordered first in the baseline model, generalized responses of import and consumer prices to exchange rate shocks equal the baseline (orthogonalized) responses. Generalized responses of consumer prices to import price shocks, by contrast, are somewhat stronger than in the baseline case.

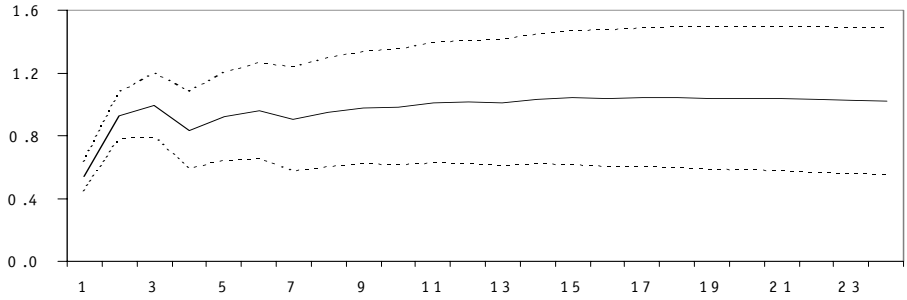
5.3 Alternative consumer price measure

Only about one quarter of all goods and services included in the consumer price basket are imports. Hence, estimated impulse responses of total consumer prices have no straightforward interpretation, i.e. responses significantly below one do not necessarily reflect an incomplete pass-through. In section 4.2, I suggested to use the share of imports in total consumer prices as criterion for the assesment of the strength of pass-through. This, however, does not fully solve the problem, as it is not clear how domestic competitors adjust their pricing behavior in reaction to changes in prices of competing imported goods. In order to circumvent such problems, I next estimated the pass-through of foreign shocks into consumer prices of imported goods and services only.[12]

Figure 4 (and table 5 in Appendix B.2) displays the cumulated responses of imported consumer price inflation to shocks in import prices. The pass-through is again remarkably fast and strong: after three months, it already amounts to 0.99. Hence, the pass-through

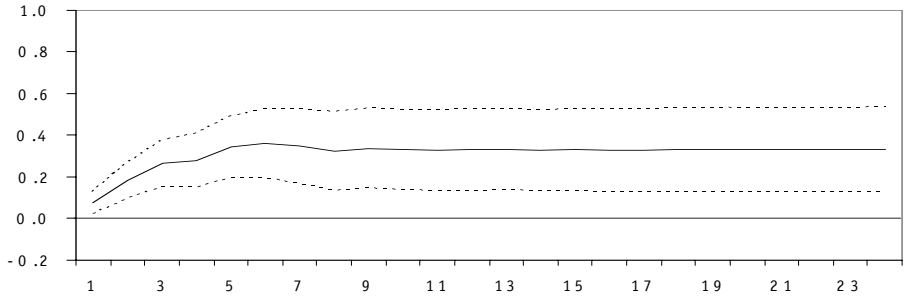
[12] Note that for this type of estimates, money is excluded from the empirical model.

Figure 4: Pass-through of import prices into imported consumer prices



is virtually complete within one quarter. This confirms the results in section 4.2, where evidence for a strong pass-through of import prices into consumer prices was found.

Figure 5: Exchange rate pass-through into imported consumer prices



The transmission of exchange rate shocks is displayed in figure 5 (and table 6 in Appendix B.2). Again, the estimated responses of imported consumer prices are stronger than those of total consumer prices. The degree of pass-through is 0.27 after three months and 0.33 after two years. Confidence bands indicate that the pass-through is significantly different from both zero and one over the whole horizon. This indicates that the exchange rate pass-through into imported consumer prices is substantial, but incomplete.

6 Changes in the degree of pass-through

A robust stylized fact of the 1990s is that the degree of the exchange rate pass-through decreased in many countries. Gagnon and Ihrig (2004) find a decline in the exchange rate pass-through into consumer prices in the vast majority of examined industrialized countries, including Switzerland. Bailliu and Fujii (2004) document similar findings for a

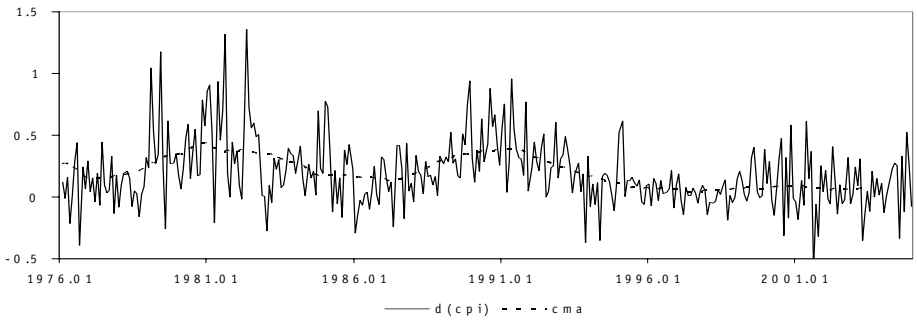
panel of eleven industrialized countries. One potential explanation for a decrease in the pass-through into consumer prices is the enhanced commitment of many central banks to keep inflation low. In a low-inflation environment, firms are less likely to pass along cost shocks (e.g. exchange rate or import price shocks) to consumers, because they expect countervailing pressure by the central bank.

This section aims to shed more light on the specific case of Switzerland. Firstly, the consumer price inflation series is investigated for structural breaks. As there is evidence for a shift towards lower and more stable inflation in the early nineties, I secondly carry out a sub-sample analysis and test for significance of changes in pass-through elasticities before and after the change in the inflation environment.[13]

6.1 Selection of sub-sample periods

The solid line in figure 6 marks month-on-month growth of consumer prices for the time period between 1976 and 2004. In order to enhance legibility, a centered moving average of this series is added as dotted line. The visual inspection of the figure indicates a change in the inflation environment somewhere in the first half of the 1990s. Both the mean and the variance of inflation seem to have decreased as compared to previous years.

Figure 6: Changes in the inflation environment



This visual evidence shall be supported by a more formal investigation. To this end, consumer price inflation is modelled as a simple univariate autoregressive process of the following form

$$\Delta cpi_t = c + \sum_{j=1}^{6} \beta_j \Delta cpi_{t-j} + \varepsilon_t \tag{9}$$

The lag length in the autoregressive process is set to six in order to ensure compatibility

[13] The tests for significance of changes in the degree of pass-through are carried out in the baseline model.

with the specification of the VAR models above. In addition, six lags proved to be sufficient to yield serially uncorrelated residuals ε_t. Model (9) is then examined for structural breaks, i.e. for changes in the parameter vector $\theta = \{c, \boldsymbol{\beta}\}$. As there is no strong prior for the precise location of the breakpoint, I use a test strategy that allows for a single but unknown change point. This test strategy comprises three steps:[14]

First, I consider the standard Wald test of structural change at a given change point πT, where T is the sample size and π is a given point in the interval $(0, 1)$.[15] Under the null hypothesis of no structural break at πT, the test statistic and its distribution are

$$\xi_T(\pi) = \left(\widehat{\theta}_1 - \widehat{\theta}_2\right)' \left[V\left(\widehat{\theta}_1\right) + V\left(\widehat{\theta}_2\right)\right]^{-1} \left(\widehat{\theta}_1 - \widehat{\theta}_2\right) \overset{H_0}{\sim} \chi^2_7 \tag{10}$$

with $\widehat{\theta}_1$ being the vector of parameter estimates in the regression covering data $t = 0, \ldots, T\pi - 1$ and $\widehat{\theta}_2$ the respective vector resulting from the regression from $t = T\pi, \ldots, T$. $V\left(\widehat{\theta}_1\right)$ and $V\left(\widehat{\theta}_2\right)$ are the covariance matrices of the estimated parameters.

Next, I allow for an unknown $\pi \in \Pi$, where Π is a pre-specified subset of $[0, 1]$. I then perform successive Wald tests for all potential change points in interval Π. Finally, the change point π^* that maximes the Wald statistics over all possible change points $\pi \in \Pi$ is chosen, i.e.

$$\pi^* = \underset{\pi \in \Pi}{\arg\max}\, \xi_T(\pi)$$

Note that testing for a structural change with unknown change point does not fit into the standard testing framework, i.e. the successive Wald statistics $\xi_T(\pi)$ for all $\pi \in \Pi$ do no longer follow the standard χ^2_7-distribution in (10). The reason is that π is now treated as a parameter and not as given. This complicates things, as π only appears under the alternative hypothesis but not under the null. Andrews (1993) provides asymptotically valid critical values for the following test statistic

$$\xi^*_T(\pi) = \sup_{\pi \in \Pi} \xi_T(\pi) \tag{11}$$

The critical values depend on the choice of Π. Instead of using the full interval $\Pi = (0, 1)$, Andrews (1993) suggests to use a restricted interval in order to ensure reasonable power properties.[16] In our case, the sample covers 347 data points from 1976.02 to 2004.12. I apply an interval $\Pi = [0.15, 0.85]$, i.e. I test for an unknown structural break between 1980.05 and 2000.08. The solid line in figure 7 displays successive Wald test statistics $\xi_T(\pi)$ for $\pi T \in [1980.05, 2000.08]$. The maximum of $\xi_T(\pi)$ is labelled with a black dot.

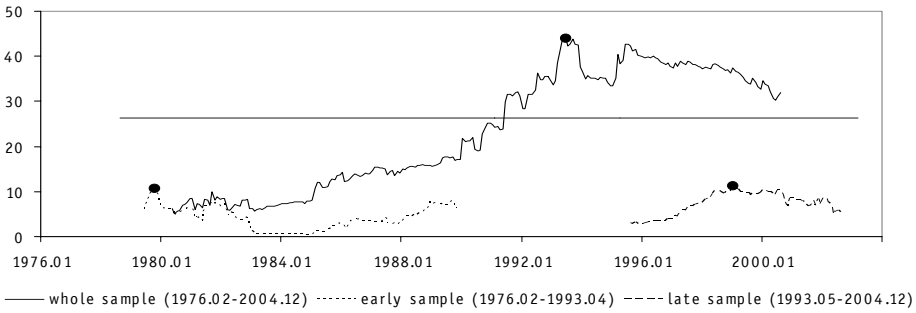
[14] The notation in this paragraph closely follows Andrews (1993).

[15] Wald tests are applied instead of standard Chow tests (F-tests), as, in large samples, the former are valid whether or not the underlying model is heteroscedastic (see for instance Greene, 2003).

[16] Using the full interval results in a test with strong concern for power against alternatives of a change point near zero or one, but low power against alternatives of change points in the rest of the interval.

It occurs at date 1993.06. The null hypothesis of no structural break in 1993.06 is clearly rejected, as the test statistic lies far above the one percent critical value according to Andrews (1993), which is represented by the horizontal line in figure 7.

Figure 7: Test for structural change with unknown change point



On account of the above results, I decided to split the sample in mid 1993. The analysis in the next session is then based on an *early sample* (running from 1976.02 to 1993.04) and a *late sample* (1993.05 to 2004.12). The consumer price series was methodologically revised by the Swiss Federal Statistical Office in 1993.05, which made it natural to pick this date for the splitting of the sample instead of 1993.06.[17] Note that the mean of consumer price inflation decreases substantially from the *early* to the *late sample* (from 0.27 to 0.07). The same is true for the standard deviation (0.29 to 0.19). Hence, we may interpret it as a shift towards lower and more stable inflation. Furthermore, no evidence for a significant break within the two sub-samples is detected. This is indicated by the two dotted lines in figure 7, which both lie clearly below the one percent critical value.

6.2 Impulse responses in sub-samples

Figures 8 through 10 compare the pass-through estimates in the two sub-samples. We observe a decrease for all three definitions of the pass-through and for nearly all horizons. Only the pass-through of import prices into consumer prices increased slightly in the very short run. In the longer run, however, this pass-through is about three times lower in the *late sample* as compared to the *early sample*. The exchange rate pass-through into consumer prices even becomes virtually zero in the late sample. Compared to that, the decrease of the exchange rate pass-through into import prices is rather moderate.

[17] As may be seen in figure 7, the null of no structural break is rejected already from mid 1991 onwards. I take this as indication that the structural change in consumer prices is not only due to the methodological revision of consumer price index in 1993.05.

Figure 8: Changes in the exchange rate pass-through into import prices

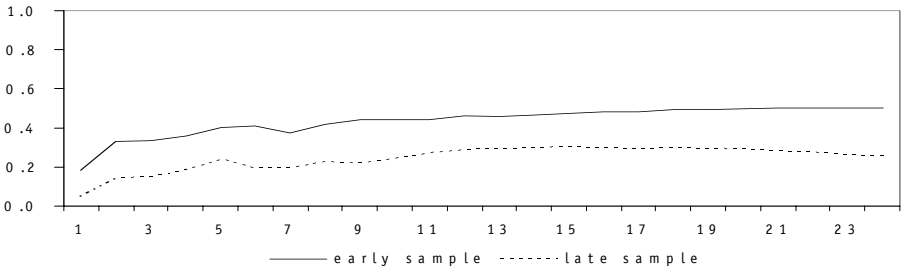


Figure 9: Changes in the pass-through of import to consumer prices

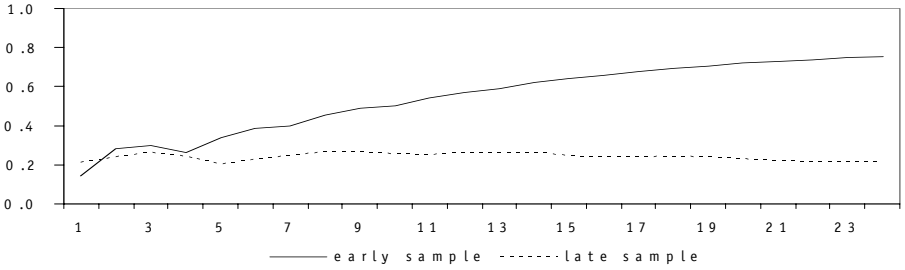
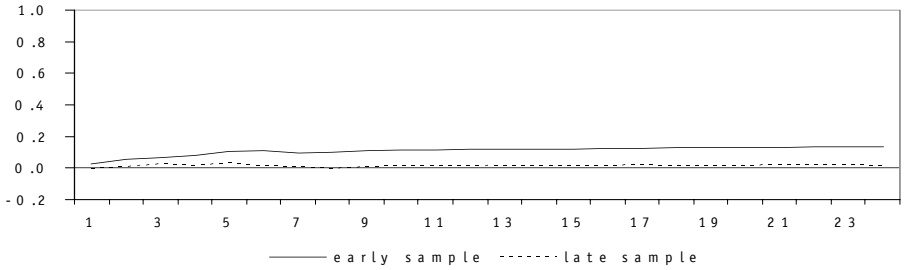


Figure 10: Changes in exchange rate pass-through into consumer prices



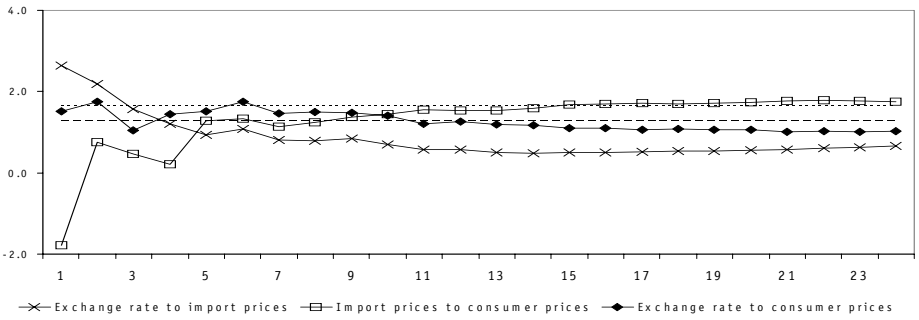
In order to assess whether the decreases in pass-through are statistically significant, I further applied a simple test strategy. Impulse responses are non-linear functions of the coefficients of the underlying VAR. These coefficients are estimated by *ordinary least squares* and thus asymptotically normal distributed. Hence, by means of delta methods one can show that impulse responses are asymptotically normal, too. We can then set up a simple test statistic D_s on the difference between the means of two independent, normally distributed variables (with different variances) at time horizon s.[18]

$$D_s = \left(\widehat{\psi}_{s,1} - \widehat{\psi}_{s,2}\right) / \left(\sqrt{\widehat{\sigma}_{s,1}^2 + \widehat{\sigma}_{s,2}^2}\right) \overset{H_0}{\sim} N(0,1)$$

The mean estimates ($\widehat{\psi}_{s,1}$, $\widehat{\psi}_{s,2}$) are the cumulated impulse response coefficients in the two sub-samples at time horizon s. The standard deviation coefficients ($\widehat{\sigma}_{s,1}$, $\widehat{\sigma}_{s,1}$) are again calculated analytically, by means of asymptotically valid delta methods.

The test statistics are presented in figure 11. Horizontal dotted lines denote the five and ten percent critical values for one-sided tests. The results are rather conclusive. The decrease in the exchange rate pass-through into import prices is statistically significant only in the very short run. For a time horizon of 4 months and more, the differences are statistically insignificant. Quite the opposite is true for the pass-through of import prices into consumer prices. As mentioned above, it even slightly increased in the short run. At a horizon of five months and more, however, we observe a significantly lower pass-through in the *late sample*. Finally, the decrease in the exchange rate pass-through into consumer prices is (at least borderline) significant for all horizons between four and twelve months. To sum up, the pass-through into consumer prices has indeed weakened in the 1990s, and this decrease did coincide with a shift in the inflation environment.

Figure 11: Mean comparison tests



[18] Strictly speaking, this test strategy is only valid asymptotically. In our case, however, the sample sizes are large enough to ensure credibility of the results.

7 Conclusions

As compared to other empirical studies on the pass-through issue, the approach of this paper features several aspects that are noteworthy. First, I explicitely focus on the Swiss case, rather than carrying out a cross-country analysis. This allows to consider specific features of the Swiss economy. Second, the data set comprises monthly data. Using monthly data seems adequate, as this frequency does better account for real-world price level stickiness. As a consequence, the analysis is likely to uncover short-run pass-through dynamics that remain hidden in quarterly data. This is of particular interest for monetary policy authorities, which depend on information that is relevant for short-term inflation forecasts. Third, the degree of pass-through is estimated by means of impulse response functions from VAR models. As such evidence may highly depend on the specification of the empirical model, I apply a battery of robustness tests, including different information sets, identification schemes and consumer price measures. Fourth, a thorough investigation of changes of pass-through mechanisms over time is carried out, thereby giving special attention to the possible role of the overall inflation environment as a determinant of the degree of pass-through into consumer prices.

The empirical investigation yields several interesting results. Evidence from a *full-sample* analysis, covering data from 1976.02 through 2004.12, suggests that exchange rate changes are passed along quickly into import prices. In the long run, the respective pass-through is substantial, but incomplete. Furthermore, the transmission of import price shocks into consumer prices is surprisingly strong. When looking at consumer prices of imported goods and services only, it is virtually complete in the long run. These findings are important when interpreting the weak exchange rate pass-through into consumer prices. In fact, the transmission of exchange rate changes into consumer prices seems to be blocked primarily by rigid import prices (i.e. by the incomplete exchange rate pass-through into import prices). On the other hand, there is no evidence for a dampening effect of production or distribution processes, through which imported goods have to go before being consumed.

The conclusions change, however, when results from a *sub-sample* analysis are considered. This perspective reveals that the magnitude of the pass-through at all stages has decreased in the 1990s. Whereas this decrease is relatively limited (and not statistically significant) for the exchange rate pass-through into import prices, it is particularly pronounced for the transmission of import price shocks into consumer prices. As a consequence, the exchange rate pass-through into consumer prices becomes virtually zero. Moreover, it is shown that the decrease in the degree of pass-through into consumer prices coincides with a change in the inflation environment, i.e. a shift towards lower

and more stable consumer price inflation. This finding corresponds to a recent strand in the pass-through literature, notably represented by Taylor (2000), which claims that the degree of pass-through into consumer prices is dependent on the monetary policy regime.

This paper is purely empirical in nature. Nevertheless, the empirical model is deliberately set up in the spirit of the new open economy macroeconomic theory. Hence, the above findings may be useful for further research endeavours. In particular, they may contribute to both the construction of appropriate theoretical models that allow for incomplete pass-through, as well as the evaluation of such models with respect to their ability to fit the Swiss data.

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A Data appendix

A.1 Definitions

Exchange rate (EX): Nominal effective exchange rate of the Swiss franc versus 24 trading partners. The weights correspond to the export shares of the individual countries. Index: 1977.11 = 100. Inverted (i.e. a rising value indicates a depreciation of the Swiss franc). Not seasonally adjusted. Source: Swiss National Bank.[19]

Import prices (IPI): Import prices at the docks (exclusive value added tax). Index: 2003.05 = 100. Seasonally adjusted by means of the Census-X-12 procedure. Source: Swiss Federal Statistical Office.

Gross domestic product (GDP): Monthly real GDP. In million Swiss francs. Seasonally adjusted (Census-X-12). The series is calculated in two steps. Firstly, quarterly GDP according to the *ESVG95* (available from 1980 onwards) is linked with a discontinued GDP series from the former *Nationale Buchhaltung.* Secondly, the resulting series is transformed into a monthly series by means of the Chow-Lin procedure (Chow and Lin, 1971). This approach assumes a linear relationship between the unobservable series of interest (here: monthly GDP) and other series with more frequent recording (related series). Related series are chosen in the spirit of Cuche and Hess (1999), who suggest to take indicators for the expenditure side of GDP. Accordingly, exports of goods (to proxy for total exports), retail sales (for private consumption) and imports of investment goods (for both total imports and business investment) are used. Sources: State Secretariat for Economic Affairs (quarterly GDP), Federal Customs Administration (exports, imports), Swiss Federal Statistical Office (retail sales), own calculations (monthly GDP).

Output Gap (gap): Deviation of real GDP from its Hodrick-Prescott trend (λ = 14400). Source: own calculations.

Money (M): Broad money M3. In million Swiss francs. Seasonally adjusted (Census-X-12). Source: Swiss National Bank.

Consumer prices (CPI): Consumer price index: 2000.05 = 100. Seasonally adjusted (Census-X-12). Source: Swiss Federal Statistical Office.

Foreign consumer prices (CPIW): Weighted average of foreign national consumer price indices. The weights correspond to those applied to the effective exchange rate. The CPIW series is calculated indirectly by dividing the nominal effective exchange rate of the Swiss franc through the real effective exchange rate, and multiplying it with Swiss consumer prices. Index: 1977.11 = 100. Seasonally adjusted (Census-X-12). Source: Swiss National Bank and own calculations.

[19] For details, see Fluri and Müller (2001)

A.2 Figures

Figure 12: Data in log levels

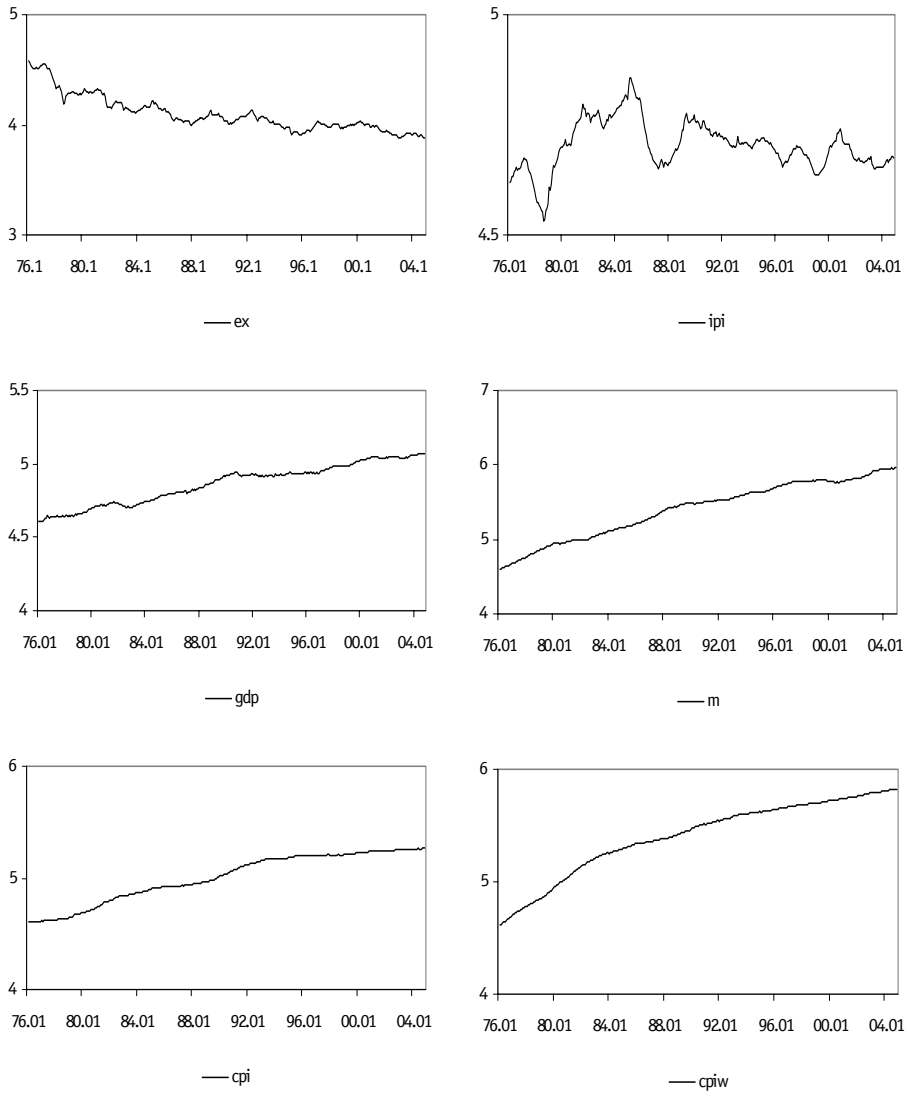
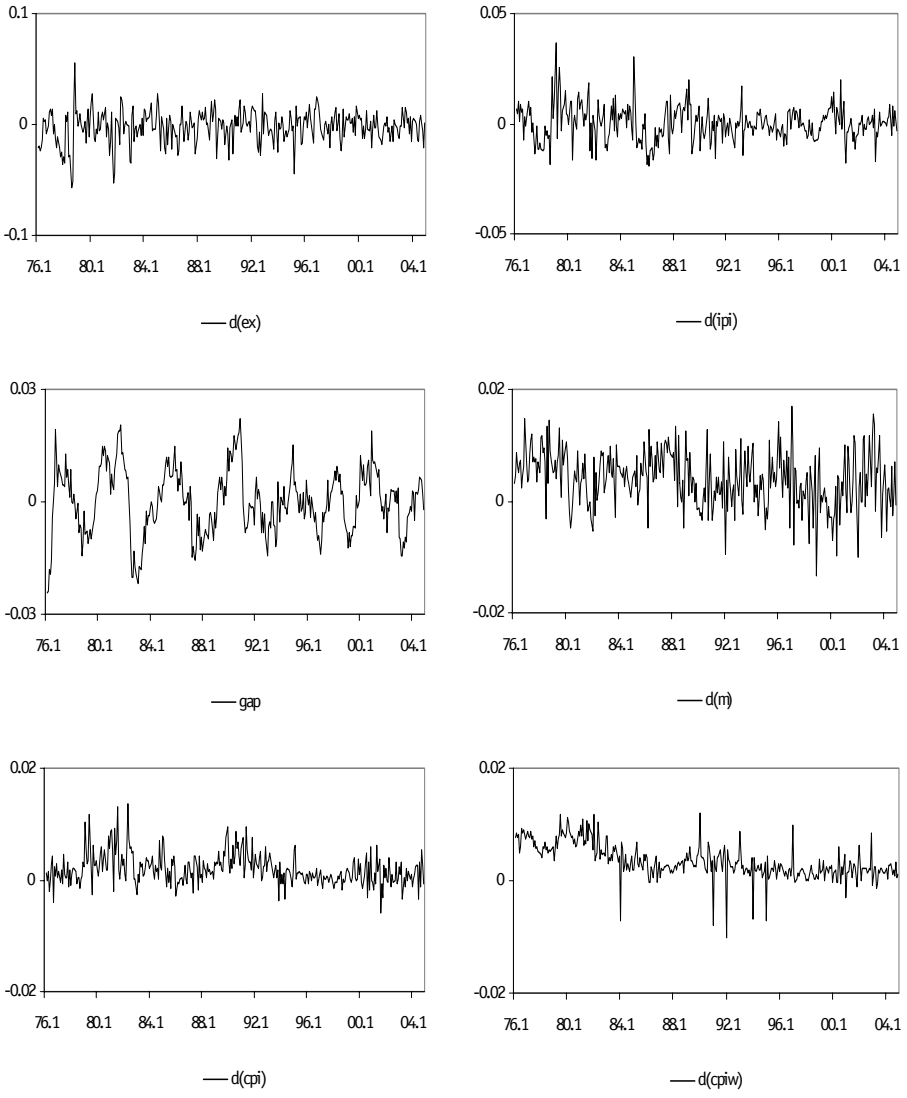


Figure 13: Data in log differences



B Results appendix

B.1 Figures

Figure 14: Range of exchange rate pass-through into import prices

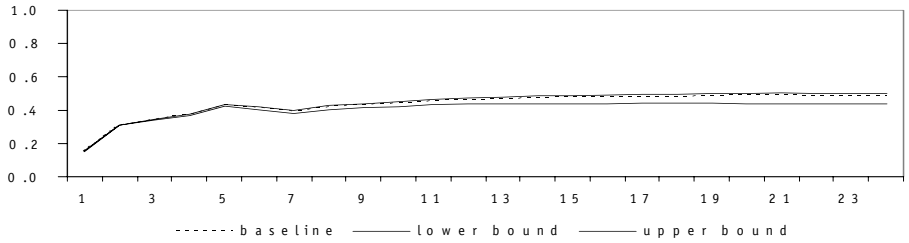


Figure 15: Range of pass-through of import prices into consumer prices

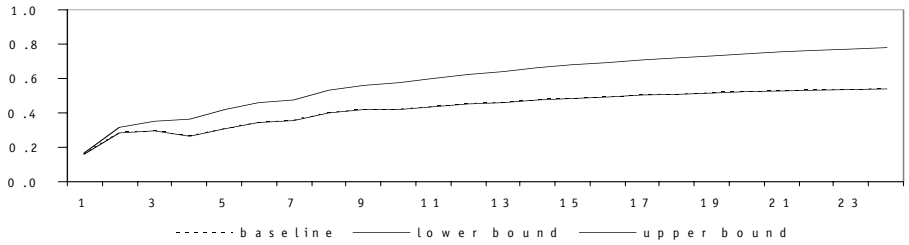
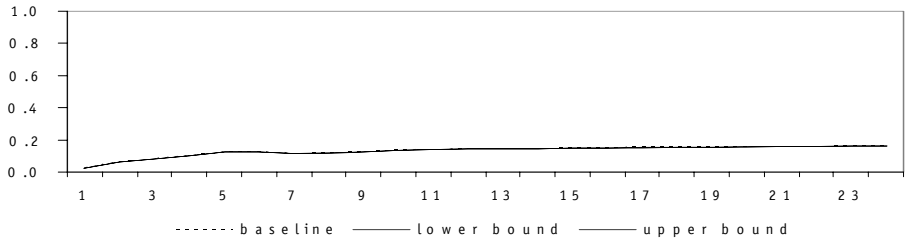


Figure 16: Range of exchange rate pass-through into consumer prices



B.2 Tables

B.2.1 Models including total consumer prices

Table 2: Exchange rate pass-through into import prices

Panel 1: Whole sample period (1976.02 - 2004.12)			
	baseline	lower bound	upper bound
1	0.16	0.15	0.16
3	0.34	0.34	0.35
6	0.41	0.40	0.42
9	0.43	0.42	0.44
12	0.47	0.44	0.47
24	0.49	0.44	0.50
Panel 2: High inflation period (1976.02 - 1993.04)			
1	0.18	0.18	0.19
3	0.33	0.33	0.39
6	0.41	0.41	0.48
9	0.44	0.44	0.50
12	0.46	0.46	0.52
24	0.50	0.47	0.54
Panel 3: Low inflation period (1993.05 - 2004.12)			
1	0.05	0.04	0.05
3	0.15	0.14	0.15
6	0.20	0.19	0.20
9	0.22	0.18	0.23
12	0.29	0.21	0.30
24	0.26	0.21	0.27

reported estimates are accumulated impulse responses

Table 3: Pass-through of import prices into consumer prices

Panel 1: Whole sample period (1976.02 - 2004.12)			
	baseline	lower bound	upper bound
1	0.16	0.16	0.17
3	0.30	0.30	0.35
6	0.35	0.35	0.46
9	0.42	0.42	0.56
12	0.45	0.45	0.62
24	0.54	0.54	0.78
Panel 2: High inflation period (1976.02 - 1993.04)			
1	0.14	0.14	0.14
3	0.30	0.30	0.31
6	0.39	0.39	0.42
9	0.49	0.48	0.50
12	0.57	0.53	0.58
24	0.75	0.67	0.75
Panel 3: Low inflation period (1993.05 - 2004.12)			
1	0.21	0.20	0.21
3	0.26	0.25	0.27
6	0.23	0.20	0.24
9	0.27	0.21	0.27
12	0.26	0.21	0.27
24	0.22	0.18	0.22

reported estimates are accumulated impulse responses

Table 4: Exchange rate pass-through into consumer prices

Panel 1: Whole sample period (1976.02 - 2004.12)			
	baseline	lower bound	upper bound
1	0.03	0.03	0.03
3	0.08	0.08	0.08
6	0.13	0.13	0.13
9	0.13	0.13	0.13
12	0.14	0.14	0.14
24	0.16	0.16	0.16
Panel 2: High inflation period (1976.02 - 1993.04)			
1	0.03	0.03	0.03
3	0.06	0.06	0.06
6	0.11	0.11	0.11
9	0.11	0.11	0.11
12	0.12	0.12	0.12
24	0.13	0.13	0.13
Panel 3: Low inflation period (1993.05 - 2004.12)			
1	0.00	0.00	0.00
3	0.02	0.02	0.03
6	0.01	0.01	0.01
9	0.00	0.00	0.00
12	0.01	0.01	0.01
24	0.02	0.02	0.02

reported estimates are accumulated impulse responses

B.2.2 Models including imported consumer prices

Table 5: Pass-through of import prices into imported consumer prices

Panel 1: Whole sample period (1976.02 - 2004.12)			
	baseline	lower bound	upper bound
1	0.54	0.54	0.55
3	0.99	0.99	1.12
6	0.96	0.96	1.24
9	0.98	0.98	1.26
12	1.01	1.01	1.29
24	1.02	1.02	1.28
Panel 2: High inflation period (1976.02 - 1993.04)			
1	0.54	0.51	0.54
3	1.09	1.09	1.14
6	1.08	1.08	1.29
9	1.11	1.11	1.29
12	1.21	1.21	1.33
24	1.26	1.26	1.42
Panel 3: Low inflation period (1993.05 - 2004.12)			
1	0.56	0.54	0.65
3	0.77	0.77	0.90
6	0.82	0.81	0.84
9	0.87	0.77	0.87
12	0.89	0.76	0.89
24	0.55	0.53	0.57

reported estimates are accumulated impulse responses

Table 6: Exchange rate pass-through into imported consumer prices

Panel 1: Whole sample period (1976.02 - 2004.12)			
	baseline	lower bound	upper bound
1	0.08	0.08	0.08
3	0.27	0.27	0.27
6	0.36	0.36	0.36
9	0.34	0.34	0.34
12	0.33	0.33	0.33
24	0.33	0.33	0.34
Panel 2: High inflation period (1976.02 - 1993.04)			
1	0.10	0.10	0.10
3	0.28	0.28	0.29
6	0.40	0.40	0.41
9	0.35	0.35	0.35
12	0.32	0.32	0.33
24	0.34	0.34	0.35
Panel 3: Low inflation period (1993.05 - 2004.12)			
1	0.03	0.03	0.04
3	0.11	0.11	0.12
6	0.04	0.03	0.04
9	0.07	0.07	0.07
12	0.02	0.02	0.03
24	0.01	0.01	0.02

reported estimates are accumulated impulse responses