Modelling Monetary Transmission in Switzerland with a Structural Vector Error Correction Model

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November 2006

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Abstract

This paper examines the transmission of monetary policy in Switzerland using a structural vector error correction model (SVECM) that includes real money, real output, a long and short-term interest rate, inflation and the exchange rate as endogenous variables; and a foreign interest rate and oil prices as exogenous variables. The SVECM takes account of five cointegrating relations that are interpreted as capturing money demand, the real interest rate, the term spread, uncovered interest parity and an aggregate-demand schedule. After identifying a monetary policy shock, the model is used for impulse-response analysis. We find that including money in the model eliminates the price puzzle often found in the VAR literature. Moreover, it produces monetary policy shocks that are about three times smaller and much less persistent as in versions of the model without money. In addition, the long-run structure imposed by cointegration leads to a quicker return to equilibrium after a shock.

Keywords: Monetary transmission, structural vector error correction model

JEL classification: E40, C32

1 Introduction

In recent years, monetary aggregates have in many central banks increasingly lost their significance in the setting of monetary policy. This is reflected by the fact that most central banks have abandoned monetary targeting. Furthermore, in theoretical models monetary policy is typically described by an interest-rate rule like that proposed by Taylor (1993), which assumes that the central bank reacts to deviations of inflation and output from target. However, other central banks, in particular the Swiss National Bank (SNB) and the European Central Bank (ECB), continue to attach considerable significance to monetary developments.

Moreover, a number of authors have argued that the transmission process of monetary policy from interest rates to inflation and output may not be captured fully unless money is explicitly taken into account. First, if money supply is not infinitely elastic with respect to the interest rate, the money stock may play an independent role in the transmission of monetary policy (von Hagen 2004). Nelson (2003) argues that money is important in the transmission mechanism because it serves as a proxy for the whole spectrum of yields, summarizing the effect of multiple channels of transmission of monetary policy. Furthermore, Nelson (2002, 2003) shows that in a model in which money demand and investment depend on a long-term interest rate, transmission via the money-demand relation amplifies the effect of changes in the stock of money on aggregate demand.

Empirical work has focussed on the interest rate as the monetary policy instrument and most analyses of the transmission mechanism do not include a measure of the money stock.[1] Leeper and Roush (2003), however, show that including money in a structural vector autoregressive (SVAR) system for the United States results in a significantly greater estimate of the impact of monetary policy on output. Cushman and Zha (1997) interpret the contemporaneous relations in a SVAR model with money for Canada as money-demand and money-supply functions and find that this identification reduces the price and the exchange-rate puzzle.[2] Kim and Roubini (2000) obtain the same result in a similar model for the G7 countries.

This paper investigates the role of monetary aggregates in the transmission of interest-rate changes to output and inflation in Switzerland. Switzerland is of partic-

[1] See Christiano, Eichenbaum and Evans (1999) for a survey.

[2] Many papers in the SVAR literature have found that a monetary tightening is associated with an increase in the price level (the price puzzle) and an impact depreciation in the exchange rate (the exchange-rate puzzle), see Kim and Roubini (2000).

ular interest since monetary aggregates have played a prominent role in the monetary policy of the SNB since the mid-1970s. After the breakdown of the Bretton-Woods System in 1973 the SNB started to target M1 in 1975.[3] While this policy was successful in quickly bringing down inflation after the first oil-price shock, the continuing appreciation of the Swiss franc soon caused concerns. In October 1978 the SNB decided to suspend the monetary target and temporarily declared an exchange-rate target for 1979 to stop the appreciation of the Swiss Franc. Of course, this had consequences for money supply, and M1 rose by 23 percent in the last quarter of 1978. In 1979 the SNB was able to absorb part of this excess liquidity but, nevertheless, M1 growth exceeded its previous target value by a wide margin, leading inflation to rise above 7 percent in 1981. In 1980 an annual monetary target was again set, this time for M0. After experiencing instability in the year-to-year growth rate of M0, the strategy was reoriented in 1991 towards medium-term target paths for M0 over a period of five years. Continuing stability problems with M0 due to financial innovation lead the SNB to announce a new monetary policy framework in 2000, which is based on a three-year conditional inflation forecast, a definition of price stability as headline consumer-price inflation of below 2 percent per year and the three-month LIBOR as the operating target. Nevertheless, monetary aggregates retain an important role in the new framework as they are seen to provide information on the medium to long-term development of inflation (Jordan, Peytrignet and Rich 2001).

The paper is structured as follows. The next section provides a brief overview of the existing empirical studies on monetary transmission in Switzerland. Most of the literature for Switzerland focusses on SVAR models that include only a small number of variables and neglect the openness of the Swiss economy. Section 3 discusses the data and their time-series properties. Since we find that all macroeconomic variables can be considered as nonstationary, we use a cointegrating model that is discussed in Section 4. Section 4 also presents the results from the empirical analysis of the long-run model. We find five cointegration vectors that are interpreted as money demand, a real interest rate, a term spread, uncovered interest parity and an aggregate-demand schedule. The restrictions implied by this interpretation are not rejected by the data. In Section 5 we impose an economic structure on the covariance matrix of the residuals and identify a monetary policy shock from the interaction of money demand and supply. We find that including money when modeling the transmission mechanism in Switzerland eliminates the price puzzle that otherwise

[3] Peytrignet (1999) surveys the experience with monetary targeting in Switzerland.

would be present. Moreover, disregarding money results in monetary policy shocks that are almost three times as large and much more persistent than in the full model. The restrictions implied by the long-run cointegrating relations produce a quicker return of the impulse responses to equilibrium. Finally, Section 6 concludes.

2 Related Literature

SVAR models have been widely used to investigate the transmission of monetary policy shocks to macroeconomic variables. In these models, restrictions are imposed on the residual-covariance matrix of a reduced-form vector autoregression (VAR) to provide an economic interpretation of the shocks. In contrast to VAR models, which leave the long-run relations between the economic variables unrestricted, a vector error correction (VEC) model imposes also restrictions on the long-run relations. As in SVAR models, a full structural identification of the covariance matrix can be added. If the model is fully identified, the usual impulse-response, variance-decomposition and historical decomposition analyses can be performed.

SVEC analyses of monetary policy effects have been conducted for several countries, including the euro area (Vlaar and Schuberth 1998; Coenen and Vega 2001; Vlaar 2004), Germany (Hubrich and Vlaar 2004; Brüggemann 2003) and the United Kingdom (Dhar, Pain, and Thomas 2000; Garrat et al. 2003). Baltensperger, Jordan and Savioz (2001) estimate a SVEC model for Switzerland, though the focus of their analysis is on the model's ability to forecast inflation.

Table 1 provides an overview of SVAR and SVEC studies for Switzerland. Baltensperger, Jordan and Savioz (2001) estimate a SVEC model comprising nominal M3, real gross domestic product (GDP), the GDP deflator and the government bond yield. Imposing a long-run money demand function and using a Choleski decomposition to identify monetary policy shocks, they find that the residuals from the long-run money demand equation help forecast inflation. The studies by Jordan et al. (2002), Kugler and Rich (2002) and Kugler and Jordan (2004) are based on structural VAR models estimated in differences, comprising M1, GDP, the consumer price index (CPI) and the 3-month interest rate. They use long and short-run restrictions and find plausible reactions of the variables in the model to a monetary policy shock. Kugler et al. (2005) use long-run identifying restrictions only, but are able to generate the same impulse responses to a monetary policy shock. Natal (2002, 2004) extends the analysis by considering foreign variables. He also includes money and interprets the contemporaneous interactions as reflecting money-supply and demand shocks. In contrast to this paper, he does not identify long-run relations between the variables. Since VAR models contain many parameters, the imposition of restrictions coming from economic theory seems desirable. In this paper we therefore impose long-run restrictions and include foreign variables that appear important, providing a more complete analysis of the transmission mechanism in Switzerland than the previous studies.

3 Data

We choose 1976 as the starting date for the empirical analysis since the SNB was only able to pursue an independent monetary policy after the break-down of the Bretton-Woods system in 1973. Though a monetary target was announced already for 1975, the shift to a new regime and the first oil-price shock occurring at that time caused considerable instability of the economy as evidenced by large swings in macroeconomic variables. After accounting for necessary lags, the estimation runs from the first quarter of 1976 to the second quarter of 2006. The first step in the construction of the model is the choice of variables.[4] Since our focus is on the impact of money on the transmission of monetary policy, we pay particular attention to the choice of the monetary aggregate. Money can be defined in many ways. In empirical work on the Swiss economy particular attention has been given to M2 and M3.[5] While both money-demand relations appear to have been stable, M2 velocity seems to be more closely related to swings in the short-term interest rate than M3. We therefore include M2 and deflate money with the CPI.

In addition to the monetary aggregate, we consider the three-month LIBOR rate, r^s, as the monetary policy instrument. Moreover, we include variables involved in the monetary transmission process. These are real GDP, y, the rate of CPI inflation, π, and the 10-year government bond yield, r^l. Since Switzerland is a small open economy, the nominal effective exchange rate of the Swiss Franc, e, is also included. Furthermore, we consider the price of oil (in US dollar), p^{oil}, and the German interest rate, r^*, as exogenous variables.

Economic theory suggests a number of cointegrating relations among these vari-

[4] A detailed description of the data can be found in the appendix.

[5] Gerlach-Kristen (2001) provides a detailed overview of money-demand studies for Switzerland. Fischer and Peytrignet (1991) investigate an aggregate corresponding to the current definition of M2 and find a stable money-demand function. Peytrignet and Stahel (1998) find stable money-demand equations for both M2 and M3 in Switzerland, though they prefer M3 on empirical grounds.

ables. First, we expect to find a money-demand function, linking money, output and the interest rate. Second, the Fisher parity relationship implies that the real interest rate is stationary in the long run. Third, the expectations theory of the term structure suggests that the term spread is stationary. Fourth, if the change in the exchange rate is stationary, the domestic interest rate should be cointegrated with the foreign interest rate. Finally, there could exist an aggregate-demand relation between deviations of output from trend and real interest and exchange rates.

Figure 1 and 2 present the variables in levels and first differences. To obtain preliminary evidence on the existence of cointegrating relations, we always plot two variables together. Thus, Figure 1 shows interest rates and the rate of inflation. The first panel illustrates that the domestic three-month rate is closely associated with changes in the quarterly rate of inflation. The plot of the first differences on the right-hand side of the figure conveys that quarterly inflation is much more volatile than the interest rate but that the volatility of inflation has declined since the 1990s. The long and the short rate also exhibit the same swings though the plot of the first differences reveals that the long rate fluctuates much less. Finally, the domestic short-term rate moves in the same way as, but is generally below, the German interest rate. The first differences of the series confirm that the comovement between both rates is even closer than for the other series. From the first panel of Figure 2 it is evident that real M2 and real GDP share the same trend over the sample period though real M2 has been more volatile. Real M2 exceeded its long-run trend in the late 1970s, whereas in the early 1990s, and to a lesser extent around 2000, the money stock fell below its trend. These deviations are reflected in shifts in M2 velocity, which is defined as the logarithm of nominal GDP to M2. The second panel shows that velocity is closely correlated with the short-term interest rate. The last panel in Figure 2 shows the effective exchange rate of the Swiss franc and the oil price. The exchange rate shows a downward trend, especially in the first part of the sample. The oil price is dominated by the large increase at the time of the second oil-price shock. Though the movements in the oil price are likely to have had some impact on the rate of inflation, it is clearly visible that this series does not share common features with any of the other series in the model.

3.1 Unit Root Tests

It is important to first investigate the time-series characteristics of the data since they have implications for the econometric methodology used and for what long-run cointegrating relations one would expect to find between the variables. We therefore perform Augmented Dickey Fuller (ADF) tests, allowing for up to four lags. From Figures 1 and 2 it is apparent that e_t, m_t, y_t, and p_t^{oil} trend over time whereas inflation and interest rates do not appear to do so. The regressions in levels therefore include a trend and an intercept for the former group of variables and an intercept only for the latter group. All ADF regressions applied to the first differences include an intercept. Entries in italics show the lag length that was selected by the Akaike criterion (AIC). The sample period runs from 1976Q1 to 2006Q2 for all tests.

In establishing the unit-root properties of the variables we first check whether their first differences are in fact stationary.[6] The ADF test results for the first differences, which are reported in the upper panel of Table 2, reject the presence of unit roots in all the series, except for real M2 when three lags are included in the regression. Since the AIC favors the inclusion of four lags for both series and this gives a clear indication of stationarity, we proceed with the assumption that all the first differences are stationary.

Turning to the level of the variables, the ADF-test results in the bottom panel of Table 2 suggest that the unit-root hypothesis cannot be rejected in all the variables, with the exception of real M2, when the order of augmentation indicated by the AIC is used. All other augmentation orders of the ADF test, however, indicate nonstationarity and since the results for the first differences of M2 were less decisive than for the other series, we regard M2 as a unit-root process as well. The only other series for which the ADF test rejects nonstationarity is inflation if no or one lag is included. Since the AIC criterion chooses two lags and this points to nonstationarity we regard inflation as $I(1)$.

To conclude this section, we interpret the unit-root tests as indicating that all series under consideration can be regarded as nonstationary variables.

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[6] The unit-root tests applied to the levels of the data are only valid if the first differences are stationary.

4 The Long-Run Empirical Model

4.1 Methodology

The starting point for the empirical analysis is the reduced form of an unrestricted VAR model with p lags,

$$\mathbf{z}_t = \sum_{i=1}^{p} \mathbf{\Phi}_i \mathbf{z}_{t-i} + \mathbf{a}_0 + \mathbf{a}_1 t + \mathbf{u}_t, \tag{1}$$

where $\mathbf{z}_t = \{\mathbf{x}_t, \mathbf{x}_t^*\}$ is a $m \times 1$ vector of m_x endogenous variables, $\mathbf{x}_t$, and m_{x^*} exogenous variables, $\mathbf{x}_t^*$, that are integrated of order 1, $I(1)$; $\mathbf{a}_0$ denotes a vector of constants and $\mathbf{a}_1$ a vector of trend coefficients. The residuals, $\mathbf{u}_t$, are distributed normally with mean zero and covariance matrix $\mathbf{\Sigma}$, $\mathbf{u}_t \sim N(\mathbf{0}, \mathbf{\Sigma})$. The endogenous variables in the model, $\mathbf{x}_t = \{\pi_t, y_t, m_{2t}, r_t^s, r_t^l, e_t\}$, are inflation, real output, real M2, the short-term interest rate, the long-term interest rate and the exchange rate. The exogenous variables, $\mathbf{x}_t^*$, include the foreign interest rate, r_t^*, and the oil price, p_t^{oil}.

In contrast to SVAR models, in a SVEC model the long-run relations between the variables in the system are also specified. If cointegration between the variables in $\mathbf{z}_t$ is present, the VAR model in equation (1) can be rewritten in error-correction form,

$$\Delta \mathbf{z}_t = -\mathbf{\Pi} \mathbf{z}_{t-1} + \sum_{i=1}^{p-1} \mathbf{\Gamma}_i \Delta \mathbf{z}_{t-i} + \mathbf{a}_0 + \mathbf{a}_1 t + \mathbf{u}_t, \tag{2}$$

where the matrix $\mathbf{\Pi}$ is a $m \times m$ matrix of long-run multipliers and the matrices $\{\mathbf{\Gamma}_i\}_{i=1}^{p-1}$ contain the short-run responses. Switzerland is a small, open economy and can therefore be assumed to have no influence on neither foreign interest rates nor oil prices. The system therefore can be split into a conditional model for the endogenous variables, $\Delta \mathbf{x}_t$, and a marginal model for the exogenous variables, $\Delta \mathbf{x}_t^*$ (see Pesaran, Shin and Smith 2000). We partition the error term $\mathbf{u}_t$ into $\mathbf{u}_t = (\mathbf{u}'_{xt}, \mathbf{u}'_{x^*t})'$ and write the covariance matrix of $\mathbf{u}_t$ as

$$\mathbf{\Sigma} = \begin{pmatrix} \mathbf{\Sigma}_{xx} & \mathbf{\Sigma}_{xx^*} \\ \mathbf{\Sigma}_{x^*x} & \mathbf{\Sigma}_{x^*x^*} \end{pmatrix},$$

so that $\mathbf{u}_{xt}$ is given by

$$\mathbf{u}_{xt} = \mathbf{\Sigma}_{xx^*} \mathbf{\Sigma}_{x^*x^*}^{-1} \mathbf{u}_{x^*t} + \boldsymbol{\upsilon}_t,$$

where $\boldsymbol{\upsilon}_t \sim iid(0, \mathbf{\Sigma}_{xx} - \mathbf{\Sigma}_{xx^*} \mathbf{\Sigma}_{x^*x^*}^{-1} \mathbf{\Sigma}_{x^*x})$ is uncorrelated with $\mathbf{u}_{x^*t}$ by construction. In addition, the parameter matrices $\mathbf{\Pi}$, $\mathbf{\Gamma}_i$ and the vectors $\mathbf{a}_0$, $\mathbf{a}_1$ are partitioned conformably with $\mathbf{z}_t = (\mathbf{x}'_t, \mathbf{x}^{*\prime}_t)'$ as $\mathbf{\Pi} = (\mathbf{\Pi}'_x, \mathbf{\Pi}'_{x^*})'$, $\mathbf{\Gamma}_i = (\mathbf{\Gamma}'_{xi}, \mathbf{\Gamma}'_{x^*i})'$, $i = 1, ..., p-1$, $\mathbf{a}_0 = (\mathbf{a}'_{x0}, \mathbf{a}'_{x^*0})'$ and $\mathbf{a}_1 = (\mathbf{a}'_{x1}, \mathbf{a}'_{x^*1})'$. By assuming that the process $\{\mathbf{x}^*_t\}_{t=1}^{\infty}$ is weakly exogenous with respect to the parameters in the matrix $\mathbf{\Pi}$, we have $\mathbf{\Pi}_{x^*} = \mathbf{0}$. This means that the information available from the model for $\Delta\mathbf{x}^*_t$ is redundant for efficient conditional estimation of the parameters in the model for $\Delta\mathbf{x}_t$.[7]

If the model includes an unrestricted linear trend, in general there will be quadratic trends in the level of the variables when the model contains unit roots. To avoid this, the trend coefficients are restricted, see Pesaran, Shin and Smith (2000) and Garratt et al. (2006). Under the restricted trend coefficients the conditional model for the endogenous variables then can be written as

$$\Delta\mathbf{x}_t = -\mathbf{\Pi}_x\mathbf{z}_{t-1} + \mathbf{\Lambda}\Delta\mathbf{x}^*_t + \sum_{i=1}^{p_x-1}\mathbf{\Psi}_i\Delta\mathbf{z}_{t-i} + \mathbf{c}_0 + \mathbf{c}_1 t + \boldsymbol{\upsilon}_t, \tag{3}$$

and the marginal model for the exogenous variables as

$$\Delta\mathbf{x}^*_t = \sum_{i=1}^{p_{x^*}-1}\mathbf{\Gamma}_{x^*i}\Delta\mathbf{z}_{t-i} + \mathbf{a}_{x^*0} + \mathbf{u}_{x^*t}, \tag{4}$$

where the parameter matrices in the conditional model are now related to the original VEC model in equation (2) by $\mathbf{\Lambda} \equiv \mathbf{\Sigma}_{xx^*}\mathbf{\Sigma}^{-1}_{x^*x^*}$, $\mathbf{\Psi}_i \equiv \mathbf{\Gamma}_{xi} - \mathbf{\Sigma}_{xx^*}\mathbf{\Sigma}^{-1}_{x^*x^*}\mathbf{\Gamma}_{x^*i}$, $i = 1, ..., p-1$ and $\mathbf{c}_0 \equiv \mathbf{a}_{x0} - \mathbf{\Sigma}_{xx^*}\mathbf{\Sigma}^{-1}_{x^*x^*}\mathbf{a}_{x^*0}$,. The restrictions on the trend appear in the coefficients $\mathbf{c}_1$ where $\mathbf{c}_1 \equiv \mathbf{a}_{x1} - \mathbf{\Sigma}_{xx^*}\mathbf{\Sigma}^{-1}_{x^*x^*}\mathbf{a}_{x^*1} \equiv \mathbf{\Pi}_x\boldsymbol{\gamma}$, and $\boldsymbol{\gamma}$ is an $m \times 1$ vector of free coefficients (see Garratt et al. 2006, p. 138).

When there are r cointegrating relations among the variables $\mathbf{z}_t$, the matrix $\mathbf{\Pi}_x$ has rank $r < m$ and can be written as

$$\mathbf{\Pi}_x = \boldsymbol{\alpha}_x\boldsymbol{\beta}', \tag{5}$$

where $\boldsymbol{\alpha}_x$ $(m_x \times r)$ is a matrix of loading coefficients and $\boldsymbol{\beta}$ $(m \times r)$ is a matrix of long-run coefficients.[8] The null hypothesis of no cointegration is investigated by testing the rank of $\mathbf{\Pi}_x$.

4.2 Results for the long-run model

To estimate the long-run relations between the variables it is sufficient to consider the conditional model in equation (3). By contrast, investigation of the dynamic

[7] The restrictions $\mathbf{\Pi}_{x^*} = \mathbf{0}$ also imply that the variables $\mathbf{x}^*_t$ are $I(1)$ and not cointegrated.

[8] We speak of loading coefficients instead of error-correction coefficients because these pertain to the reduced form and cannot be given an economic interpretation. By contrast, $\mathbf{A}_0\boldsymbol{\alpha}_x$ shows the structural error correction, see Section 5.

properties of the system requires an analysis of the marginal model in equation (4) as well, since the dynamic properties depend on the processes driving the exogenous variables.

Before estimating the model in equation (3), the number of lags, p_x, to be included in the estimation has to be selected.[9] To this end, different criteria for lag-length selection are computed under various assumptions regarding the number of cointegration relations. Table 3 shows the Akaike information criterion (AIC), the forecast-prediction error (FPE), the Hannan-Quinn criterion (HQ), the Schwarz information criterion (SIC) and the fractional marginal likelihood criterion (FML) for different lag lengths under the assumption of different rank for $\mathbf{\Pi}_x$. The AIC and the FPE select a specification with two lags and five cointegration vectors, the HQ favors one lag and five cointegration vectors, whereas the SC and the FML point to one lag and a rank of two. Since Kilian (2002) shows that overestimation of the lag length is less harmful than underestimation, we select $p_x = 2$.

The cointegration-test statistics are shown in Table 4. We find four relations that are significant at the 90% level. The fifth relation is significant only below the 90% level, but since the AIC, the FPE and the HQ pointed to rank five, we proceed under the assumption that there are five cointegrating relations between the variables in the system.[10]

To identify the cointegrating vectors in $\boldsymbol{\beta}$, one needs at least $r-1$ constraints on each cointegration vector. Economic theory helps us specify these restrictions.[11] We interpret the five cointegrating vectors as a long-run money-demand function (MD), a Fisher relation (FR) (i.e., a stationary relation between inflation and the real interest rate), a stationary term spread (TS), uncovered interest parity (UIP) and an aggregate-demand schedule (AD), relating deviations of output from trend to the long-term interest rate and the exchange rate:

$$\text{MD:}\ \ m_t - y_t - b_{10} - \beta_{14} r_t = \xi_{1t},$$

$$\text{FR:}\ \ r_t^s - \pi_t - b_{20} = \xi_{2t},$$

$$\text{TS:}\ \ r_t^s - r_t^l - b_{30} - b_{31} t = \xi_{3t},$$

[9] Estimation of the long-run relations was done with the program by Anders Warne for Matlab which is available under http://texlips.hypermart.net/svar/index.html.

[10] Dropping the aggregate-demand relation and imposing over-identifying restrictions on the four significant cointegrating vectors lead to implausible coefficient estimates

[11] Exactly identifying restrictions cannot be tested empirically and different exactly identifying restrictions do not alter impulse responses or variance decompositions, but over-identifying restrictions do.

$$\text{UIP:}\ \ r_t^s - r_t^* - b_{40} = \xi_{4t},$$

$$\text{AD:}\ \ y_t - b_{50} - b_{51}t - \beta_{55} r_t^l - \beta_{56} e_t = \xi_{5t}.$$

Imposing these restrictions on $\boldsymbol{\beta}$ results in the following matrix:

$$\boldsymbol{\beta}' = \begin{pmatrix} 0 & -1 & 1 & \beta_{14} & 0 & 0 & 0 & 0 \\ -1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & 0 & \beta_{55} & \beta_{56} & 0 & 0 \end{pmatrix},$$

which leaves only three parameters to be estimated freely. The estimated $\boldsymbol{\beta}$ parameters and the estimates of the trend coefficients are given in Table 5, together with their 90% bootstrapped confidence intervals. The coefficient β_{14}, which represents the semi-elasticity of money demand with respect to the interest rate, is negative and implies that real money demand decreases by 2.5 percent if the interest rate increases by one percentage point. However, one has to keep in mind that in a system containing several cointegrating vectors, also linear combinations of the cointegrating vectors lie in the cointegration space. Since one of the cointegrating vectors reflects the term spread, an equivalent representation of the system would be to restrict the money-demand relation to include the long rate only. This can be seen by multiplying $\boldsymbol{\beta}$ with a transformation matrix $\mathbf{R}$ of the following form:[12]

$$\mathbf{R} = \begin{pmatrix} 1 & 0 & -\beta_{14} & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix},$$

which shifts the interest elasticity to the long rate so that

$$\boldsymbol{\beta}'^{*} = \mathbf{R}\boldsymbol{\beta}' = \begin{pmatrix} 0 & -1 & 1 & 0 & \beta_{14} & 0 & 0 & 0 \\ -1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & 0 & \beta_{55} & \beta_{56} & 0 & 0 \end{pmatrix}.$$

The second and the fourth cointegrating vector involve no estimated parameters. The second cointegrating relation restricts the real short-term interest rate to be

[12] See Hoffman and Rasche (1996, p. 194) for a more detailed discussion.

stationary, while the third cointegrating vector reflects the spread between the short and the long interest rate. We include a trend in the term spread, which is estimated to have a numerically small but statistically significant coefficient, implying that the difference between short and long rate has increased over time.[13] Since both the real short-term rate and the term spread are stationary, this implies that the long-term rate is stationary as well, though the trend coefficient in the term spread introduces a declining trend in the long-term real rate. The fourth cointegrating vector represents long-run uncovered interest-rate parity and reflects the close integration of the Swiss economy with the financial markets in the euro area.

Since economic theory is less clear on what the last relation in the system should be, we started with an exact identification of the last cointegrating vector. The coefficient on oil prices, however, turned out to be insignificant, so that it was restricted to zero. We interpret the last relation as an aggregate-demand schedule, linking deviations of output from trend to the long-term interest rate and the exchange rate. The coefficient on the interest rate is significant and implies a reduction in output if the interest rate increases. Again, a similar reasoning to that in the case of the money-demand relation applies. Since the Fisher parity and the term spread are among the cointegrating relations, the coefficient on the long rate is not identified but can be shifted to the short rate or the rate of inflation by multiplying $\boldsymbol{\beta}$ with an appropriate transformation matrix. The estimate of the trend implies an average annual growth rate of GDP of 1.4 percent. The coefficient on the exchange rate, however, has the wrong sign, which may be due to problems distinguishing between changes in nominal and real exchange rates. Since the system is quite large already, it does not seem desirable to include further series in order to model output demand and the role of the exchange rate in more detail.

A likelihood ratio test of the 15 restrictions imposed on the cointegrating vector leads to a test statistic of 39.70, which is distributed asymptotically as $\chi^2(15)$ and rejected. However, the asymptotic critical values of the χ^2 distribution may not be valid in small samples (Gredenhoff and Jacobson 2001). Using bootstrapping to compute the empirical critical values leads to a p-value of 0.15 and thus a non-rejection of the restrictions on the cointegrating vectors.

Finally, Table 6 shows summary statistics for the estimated error-correction equations in the system. Serial correlation is absent except for the m_2 equation. The other tests do also not point to serious misspecification of the model. The adjusted

[13] Excluding the trend significantly deteriorates the fit of the system and leads to imprecisely estimated interest elasticities of money and output demand.

R^2 ranges from 0.16 for the output equation to 0.64 for the inflation equation, indicating that the model is able to explain a large part of the variation in the quarterly inflation rate.

5 A structural model for the short run

The analysis of the dynamic properties, through impulse-response analysis or forecast-error variance decomposition, of a SVEC system including exogenous $I(1)$ variables requires the conditional model for $\Delta \mathbf{x}_t$ in equation (3) together with the marginal model for $\Delta \mathbf{x}_t^*$ in equation (4). For the marginal model, a lag length of two, i.e. $p_{x^*} = 2$, is chosen as well, though in principle the lag length in the conditional and the marginal model can differ. The full system now can be written as

$$\Delta \mathbf{z}_t = -\boldsymbol{\alpha}\boldsymbol{\beta}' \mathbf{z}_{t-1} + \sum_{i=1}^{p-1} \boldsymbol{\Gamma}_i \Delta \mathbf{z}_{t-i} + \mathbf{a}_0 + \mathbf{a}_1 t + \mathbf{H}\boldsymbol{\zeta}_t, \tag{6}$$

with

$$\boldsymbol{\alpha} = \begin{pmatrix} \boldsymbol{\alpha}_x \\ \mathbf{0} \end{pmatrix}, \boldsymbol{\Gamma}_i = \begin{pmatrix} \boldsymbol{\Psi}_i + \boldsymbol{\Lambda}\boldsymbol{\Psi}_{x^*i} \\ \boldsymbol{\Psi}_{x^*i} \end{pmatrix}, \mathbf{a}_0 = \begin{pmatrix} \mathbf{c}_0 + \boldsymbol{\Lambda}\mathbf{a}_{x^*0} \\ \mathbf{a}_{x^*0} \end{pmatrix}, \mathbf{a}_1 = \begin{pmatrix} \boldsymbol{\Pi}_x \gamma \\ \mathbf{0} \end{pmatrix},$$

$$\boldsymbol{\zeta}_t = \begin{pmatrix} \boldsymbol{\nu}_t \\ \mathbf{u}_{x^*t} \end{pmatrix}, \mathbf{H} = \begin{pmatrix} \mathbf{I}_{mx} & -\boldsymbol{\Lambda} \\ \mathbf{0} & \mathbf{I}_{mx^*} \end{pmatrix}, Cov(\boldsymbol{\zeta}_t) = \boldsymbol{\Sigma}_{\zeta\zeta} = \begin{pmatrix} \boldsymbol{\Sigma}_{\nu\nu} & \mathbf{0} \\ \mathbf{0} & \boldsymbol{\Sigma}_{x^*x^*} \end{pmatrix},$$

where $\boldsymbol{\beta}$ is defined as in equation (5).

This system still can be written in the form of a reduced-form VAR like in equation (1), except that the restrictions from the long-run cointegrating relations, together with the assumption of exogeneity for the foreign variables, imply the following relations for the coefficient matrices in equation (1):

$$\begin{aligned} \boldsymbol{\Phi}_1 &= \mathbf{I}_m - \boldsymbol{\alpha}\boldsymbol{\beta}' + \boldsymbol{\Gamma}_i, \\ \boldsymbol{\Phi}_i &= \boldsymbol{\Gamma}_i - \boldsymbol{\Gamma}_{i-1}, \ \ i = 2, ..., p-1, \\ \boldsymbol{\Phi}_p &= -\boldsymbol{\Gamma}_{p-1}, \end{aligned} \tag{7}$$

and the error term, $\mathbf{u}_t$, is partitioned between the endogenous and the exogenous variables, $\mathbf{u}_t = \mathbf{H}\boldsymbol{\zeta}_t$. To identify the short-run structure of the SVEC model we start from the VAR representation of equation (6) and transform it into its structural form by specifying the contemporaneous relations between the variables,[14]

$$\mathbf{A}_0\mathbf{z}_t = \sum_{i=1}^{p} \widetilde{\mathbf{\Phi}}_i \mathbf{z}_{t-i} + \widetilde{\mathbf{a}}_0 + \widetilde{\mathbf{a}}_1 t + \boldsymbol{\varepsilon}_t, \tag{8}$$

where the structural shocks, $\boldsymbol{\varepsilon}_t$, are defined as $\boldsymbol{\varepsilon}_t = \mathbf{A}_0\mathbf{H}\boldsymbol{\zeta}_t$, and the structural parameters are linked to the reduced-form parameters by the following relations: $\widetilde{\mathbf{\Phi}}_i = \mathbf{A}_0\mathbf{\Phi}_i$, $\widetilde{\mathbf{a}}_0 = \mathbf{A}_0\mathbf{a}_0$ and $\widetilde{\mathbf{a}}_1 = \mathbf{A}_0\mathbf{a}_1$. SVAR models are generally estimated by decomposing the covariance matrix of the errors, $\mathbf{\Sigma}_{\zeta\zeta}$. The relationship between the covariance matrix of the reduced-form and the structural-form errors therefore is:

$$\mathbf{A}_0\mathbf{H}\mathbf{\Sigma}_{\zeta\zeta}\mathbf{H}'\mathbf{A}_0' = \mathbf{\Omega}.$$

Assuming that the structural shocks are uncorrelated provides $m(m-1)/2$ restrictions on $\mathbf{A}_0$, which leaves another $m(m-1)/2$ restrictions to be determined by economic theory.

Like in a SVAR, the impulse responses for the cointegrated SVEC model are derived from the moving-average representation of equation (8),

$$\mathbf{z}_t = \mathbf{b}_0 t + \mathbf{C}\sum_{j=1}^{t} \boldsymbol{\varepsilon}_j + \mathbf{C}^*(L)\boldsymbol{\varepsilon}_t + \mathbf{z}_0^*, \tag{9}$$

where $\mathbf{C} = \boldsymbol{\beta}_\perp(\boldsymbol{\alpha}_\perp'(\mathbf{I}_k - \sum_{i=1}^{p-1}\mathbf{\Gamma}_i)\boldsymbol{\beta}_\perp)^{-1}\boldsymbol{\alpha}_\perp')\mathbf{A}_0^{-1}$, $\mathbf{b}_0 = \mathbf{C}\widetilde{\mathbf{a}}_0 + \mathbf{C}_1^*\widetilde{\mathbf{a}}$, and $\mathbf{C}^*(L) = \sum_{j=0}^{\infty}\mathbf{C}_j^* L^j$ is an infinite-order polynomial in the lag operator with coefficient matrices $\mathbf{C}_j^*$ that go to zero as $j \to \infty$.[15] The term $\mathbf{z}_0^*$ includes all initial values. While $\mathbf{C}$ represents the long-run effects of the shocks to the system, the $\mathbf{C}_j^*$'s contain the transitory effects.

To identify the short-run structure in SVEC models, in the literature the shocks often are split into shocks having only permanent and shocks having only transitory effects.[16] Then the permanent shocks are identified using restrictions on the long-run

[14] The terminology in the SVAR/SVEC literature is sometimes ambiguous. In SVAR models restrictions on the covariance matrix that apply to the sum of the $\mathbf{\Phi}_i$ coefficients are often also called long-run restrictions. Here we use the term long-run identification for the constraints on $\boldsymbol{\beta}$, whereas identification of the short-run structure is concerned with the determination of the matrix $\mathbf{A}_0$.

[15] See Johansen (1995), Breitung, Brüggemann and Lütkepohl (2004) or Pesaran, Smith and Shin (2000) for a more detailed exposition. The matrices $\mathbf{C}_j^*$ are defined as $\mathbf{C}_j^* = \mathbf{C}_{j-1}^* + \mathbf{C}_j$, with $\mathbf{C}_i = (\mathbf{\Phi}_1\mathbf{C}_{i-1} + \mathbf{\Phi}_2\mathbf{C}_{i-2} + ... + \mathbf{\Phi}_p\mathbf{C}_{i-p})\mathbf{A}_0^{-1}$, for $i = 2, 3, ...$, $\mathbf{C}_0 = \mathbf{A}_0^{-1}$, $\mathbf{C}_1 = (\mathbf{\Phi}_1 - \mathbf{I}_m)\mathbf{A}_0^{-1}$ and $\mathbf{C}_i = 0$ for $i < 0$.

[16] See, e.g., King, Plosser, Stock, and Watson (1991), Vlaar and Schuberth (1999), Brüggemann (2003), Hubrich and Vlaar (2004), and Vlaar (2004).

multipliers of the system, whereas the transitory shocks are identified by interpreting the reduced-form residuals $\mathbf{u}_t$ as functions of the structural shocks, i.e., imposing restrictions on the matrix $\mathbf{A}_0^{-1}$.[17] Identifying the whole system with long-run restrictions only is not feasible as the existence of r cointegrating relations implies that r shocks can only have temporary impacts. Since our model contains six endogenous variables and five cointegrating relations, only one independent common trend remains and five shocks would have to be identified by restrictions on $\mathbf{A}_0^{-1}$. Alternatively, one can proceed as in the SVAR case obtain impulse-response functions for the SVEC model by restricting $\mathbf{A}_0$ directly, while taking into account that the coefficients in the moving-average representation of the model in equation (9) incorporate the restrictions from the long-run relations (Levtchenkova, Pagan and Robertson 1998, p. 521). In this approach, however, there is no necessary distinction between permanent and transitory shocks and it is likely that all shocks will have permanent components.

5.1 Results for the short-run identification

Since we want to perform the analysis in terms of an interpretation of money demand and money supply, we work directly with restrictions on $\mathbf{A}_0$ and do not make use of the distinction between permanent and transitory shocks. The assumption that some variables are exogenous with respect to the domestic variables, which is embodied in the matrix $\mathbf{H}$, helps achieving structural identification of the model. The matrix $\mathbf{A}_0$ therefore becomes block diagonal. For the exogenous variables we assume a recursive structure of $\mathbf{A}_{0x^*}$, restricting the oil price to not react contemporaneously to changes in the German interest rate.

$$\mathbf{A}_0 = \begin{pmatrix} \mathbf{A}_{0x} & \mathbf{0} \\ \mathbf{0} & \mathbf{A}_{0x^*} \end{pmatrix}$$

To identify $\mathbf{A}_{0x}$ we follow the literature estimating SVAR models that include money and interpret the interaction between the short-term interest rate and the money stock as reflecting money demand and money supply.[18] Inflation and output are regarded to be inertial, reacting only to their own disturbance within the quarter. For these variables therefore a triangular structure is assumed, which is common in the literature. Money demand is proposed to depend contemporaneously on output

[17] In the terminology of Amisano and Giannini (1997) this would be a C model.

[18] See Cushman and Zha (1997), Leeper and Roush (2003), Natal (2002).

and the short-term interest rate. Since the estimation had problems to converge, the short-run income elasticity of money demand was set to unity. This constraint, together with a second overidentifying restriction on the money supply equation, cannot be rejected by a likelihood-ratio test with a p-value of 0.11. In setting the short-term interest rate, monetary policy reacts contemporaneously to the real money stock and the exchange rate. The long-term interest rate and the exchange rate are included as information variables that are affected by all other variables during the current period. While the restriction that the long-term interest rate does not react contemporaneously to the exchange rate is problematic, a change in the ordering of the two variables does not affect the identification of the monetary policy shock. The same is true for the question whether inflation or output should be ordered first and the ordering of among the exogenous variables.

Table 7 shows the estimated $\mathbf{A}_{0x}$ matrix. The money-market equations are

$$\underset{}{r^s} - \underset{(0.45)}{0.41 m_2} - \underset{(0.11)}{0.05 e} = \varepsilon^{MS}$$

for the monetary policy shock, ε^{MS}, and

$$m_2 - y + \underset{(15.77)}{32.34 r^s} = \varepsilon^{MD}$$

for the money demand shock, ε^{MD}. As shown by the insignificant coefficients, there is little evidence that monetary policy has reacted systematically to the money stock or the exchange rate during the quarter. A possible explanation is that the SNB never targeted M2 but has focussed on M1 and M0. Though the SNB has reacted to sizable movements in the exchange rate, the fact that there is no significant reaction during the quarter is consistent with the results by Wasserfallen and Kürsteiner (1994).

After having fully identified the model, we can compute impulse responses. Figure 3 plots the mean of the bootstrapped impulse responses to a typical monetary policy shock, together with their bootstrapped 90% confidence intervals. After a shock the short-term rate rises by 0.25 basis points on impact. This has an almost equally sized effect on inflation in the next quarter, which returns to practically zero in the third and fourth quarter. This pattern is generally found in studies for Switzerland and is ascribed to the indexing of housing rents to the short-term interest rates. Thereafter, inflation decreases again and bottoms out after about 10 quarters. Output shows a positive reaction in the second quarter but then falls and displays the usual hump-shaped pattern. Again, this result matches with the reaction found by Kugler and Rich (2002), Jordan et al. (2002) and Kugler and Jordan (2004) in a smaller SVAR system. While the reactions of inflation and output agree with theory, the exchange rate depreciates on impact, so that the exchange-rate puzzle is present despite the inclusion of money in the model. The long-term interest rate shows a similar pattern as the short rate, but moves less. Finally, the foreign interest rate shows a significant but almost negligible reaction to a domestic monetary policy shock, which is consistent with Switzerland being small relative to Germany.

Overall, the model produces plausible reactions of the endogenous variables to a monetary policy shock. Unfortunately, the confidence bounds on the impulse reponses are wide so that most effects are insignificant after a few quarters. Bayesian estimation of the coefficients in the SVEC model would be a possible solution to this problem, but this is outside the scope of this paper.

5.2 Comparison with other models

To assess the results from the above model, we compare it to some alternative specifications. First, we compare our benchmark model to a SVEC model without money that retains the long-run structure. We now have 4 cointegration vectors, which we identify as before but without the money-demand relation. The $\mathbf{A}_{0x}$ matrix for the model without money is modified by deleting the row corresponding to M2 and the column defining the money-demand shock. Figure 4 compares the impulse responses to a monetary policy shock from the SVEC model without money to the benchmark model. The typical monetary policy shock now is about three times larger and much more persistent than in the benchmark specification. While the reaction of inflation remains the same during the first two quarters, the model displays a price puzzle thereafter, in the sense that inflation increases to almost 2 percent per annum. Also the rise in output after a monetary policy shock is much more persistent and it takes about 10 quarters until output falls below its initial level. The ony variables that improves is the reaction of the exchange rate, which now depreciates slightly on impact and appreciates thereafter. While we confirm the results by Cushman and Zha (1997) and Kim and Roubini (2000) that including money and modeling the money market explicitly helps eliminate the price puzzle in SVAR models, we are not able to improve on the reaction of the exchange rate to a monetary policy shock.

Second, we compare the impulse responses from both the benchmark model and the alternative model without money to another version that does not impose any restrictions on the long-run relations. The identification of the shocks remains the same as above. Figure 5 shows that the results from this exercise are comparable to the results presented in Figure 4. As one would expect, the main effect of imposing cointegration is that the impulse responses return to equilibrium much faster and stay closer to zero in the long run. Since in VAR studies it often takes implausibly long until the responses of the variables to the shocks die out, the imposition of a long-run structure helps making results more consistent with conventional wisdom.

Summing up, the SVEC model including M2 provides a plausible description of the monetary transmission process in Switzerland. Both the inclusion of money and the imposition of a long-run structure help making results more credible compared to alternative specifications of the model.

6 Conclusion

In this paper we study a SVEC model of the monetary transmission in Switzerland incorporating M2 and foreign variables. We find evidence for five cointegrating vectors that are interpreted as a money-demand function, a stationary real interest rate, a stationary term spread, uncovered interest parity and an aggregate-demand schedule. For M2 a unitary income elasticity of money demand is not rejected. We identify a monetary policy shock by interpreting the contemporaneous interactions between the variables in the system as a money-demand and a money-supply relation. Impulse-response analysis shows that including a measure of the money stock helps eliminating the price puzzle, but not the exchange rate puzzle, that are often found in the SVAR literature. Imposing restrictions on the long-run relations in the model results in a faster adjustment to equilibrium and influences impulse responses mainly at longer horizons. Overall, the model appears to provide a plausible description of the monetary transmission mechanism in Switzerland.

Further extensions of the model are desirable. If the model is to be used for forecasting its predictive ability needs to be assessed and compared with alternative model specifications. As modeling choices always imply a certain degree of arbitrariness, probability forecasts from a variety of equally plausible models would also seem to be an interesting area of research. Finally, the model can be used to evaluate scenarios conditional on different assumptions for the exogenous variables, such as the effect of oil-price shocks on the Swiss economy.

A Appendix: Data

The Swiss data are from the data base of the SNB. The price level is the consumer price index (CPI) with the base of December 2005 = 100. Inflation is measured as the quarterly change in the CPI since the SNB focusses on the CPI in its formulation of monetary policy. For the CPI an adjustment was made to overcome breaks due to new data collection procedures at the Federal Statistical Office. From 2000 on the CPI includes end-of-season sales. This introduces marked seasonality into the sub-index for clothing and footwear, as can be seen in Figure A.1.

Figure A.1: Price index for clothing and footwear

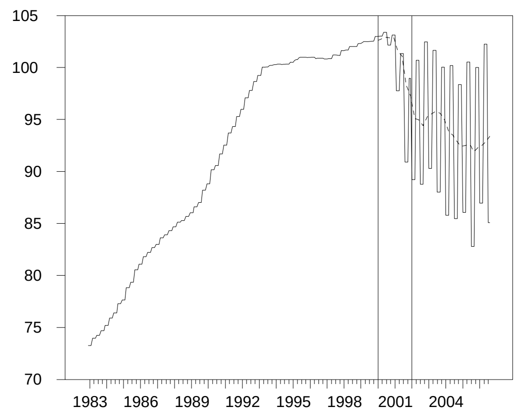
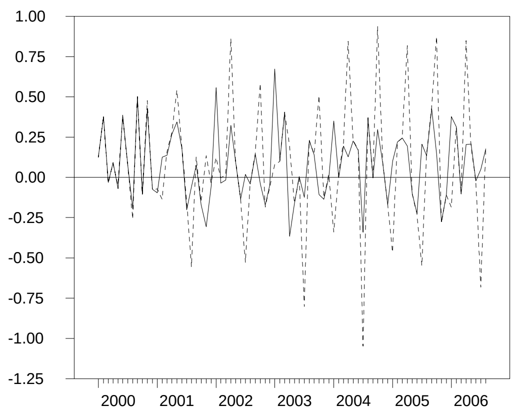


Figure A.2: Monthly inflation rate without (solid line) and with adjustment (dashed line) of the CPI



In addition, the data collection had been shifted from the end of the month to the beginning of the month in January 2002, which introduced another break into the series. We adjust for these changes by shifting the series by one month backward between January 2000 and January 2002, the period indicated by the vertical lines in Figure A.1. The resulting missing value is filled by inserting the December 2001 of the sub-index. The series is smoothed by computing a 12 month backward moving average. The smoothed sub-index is added to the CPI without clothing and footwear, using the weight of this subindex in the CPI.

Figure A.2 shows inflation computed from the original and the adjusted inflation series. Though the weight of the clothing-and-footwear subindex is less than 5% since 2000, it is clearly visible that the adjustment reduces the seasonal variability of the inflation rate since 2002 considerably.

M2 is in the definition of 1995 (excluding Liechtenstein) and includes cash, sight deposits and savings deposits. Real money is calculated by deflating M2 with the adjusted CPI. Output is the seasonally adjusted quarterly real gross domestic product (GDP) computed by the SECO (Secrétariat d'état à l'économie) from 1981 on. Quarterly output estimates before 1981 were interpolated from the official annual data by the SNB. The short-term interest rate is the end-of-month 3-month London Interbank Offered Rate (LIBOR) for Swiss francs, which is the operating target rate for the SNB. The long-term interest rate is the yield on 10-year government bonds. The foreign interest rate is the 3-month money market rate for Germany. All interest rates are expressed as $0.25 \ln(1 + R/100)$, where R is the interest rate measured in percent per annum, so that they are in the same unit of measurement as the quarterly inflation rate.

The effective nominal exchange rate is a trade-weighted average of the end-of-the month rates of Swiss franc against its 15 largest trading partners. These are (in the order of their importance) Germany, France, Italy, the United States, the United Kingdom, Austria, the Netherlands, Japan, Belgium, Spain, Sweden, Hong Kong, China, Ireland and Denmark. Trade data are from the Eidgenössische Zollverwaltung. Trade is defined as the sum of imports and exports from and to a specific country. The countries considered have an average share of at least 1% in total Swiss foreign trade during 1974 to 2006. Together, the countries account for about 82% percent of total Swiss foreign trade. For Ireland, Hong Kong and China, trade data were not available before 1988. For these countries, the trade shares were set to the January 1988 value for the period from 1974 to 1987. This avoids level effects that would otherwise appear if the trade weights for these countries were set to zero for the time where data are not available. The trade weights used in the aggregation are three-year moving averages of the trade share of the respective country in Switzerland's total trade with these 15 countries.

The oil price is the price of crude oil (Brent) in US dollar.

Monthly data for real money, the CPI, interest rates, the exchange rate and the oil price are aggregated into quarterly averages of monthly figures. Inflation is the quarterly difference of the logarithm of CPI.

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Tables and Figures

Table 1: Studies for Switzerland

Reference	Data	Method	Main findings
Baltensperger, Jordan, and Savioz (2001)	p^y, y, m_3, r^l, 1978Q1 to 1999Q2	SVECM with Choleski decomposition.	Residuals from long-run money demand function help forecast inflation.
Kugler and Rich (2002)	p, y, m_1, r^s, 1974Q1 to 2001Q4	SVAR in differences with long and short-run identifying restrictions.	Plausible reactions of macroeconomic variables to monetary policy shock.
Jordan, Kugler, Lenz, and Savioz (2002)	p, y, m_1, r^s, 1974Q1 to 2002Q4	SVAR in differences with long and short-run identifying restrictions.	Same results as Kugler and Rich (2002).
Natal (2002)	p^{oil}, y^*, p^*, r^*, m_1, s, cr, y, p, u, e, 1977M1 to 2000M9	Bayesian SVAR with money demand and supply.	No price and exchange rate puzzle.
Kugler and Jordan (2004)	p, y, m_1, r^s, 1974Q1 to 2002Q4	SVAR in differences with long and short-run identifying restrictions.	Same results as Kugler and Rich (2002).
Natal (2004)	p^{oil}, y^*, p^*, r^*, m_2, s, cr, y, p, u, e, 1976M1 to 2002M10	Bayesian SVAR with money demand and supply.	Similar results as Natal (2002).
Kugler, Jordan, Lenz and Savioz (2005)	p, y, m_1, r^s, 1974Q1 to 2002Q4	SVAR in differences with long-run identifying restrictions.	Same results as with long and short-run restrictions.

Note: p denotes the CPI, p^y the GDP deflator, y real GDP, m_1, m_2 and m_3 the respective monetary aggregate, r^s is the three-month Libor, r^l the 10-year government bond yield, p^{oil} the oil price, p^* the German producer price index, y^* German industrial production, r^* the German three-month interest rate; u denotes unemployment, s securities on banks' balance sheets, cr total credit, and e is the nominal exchange rate of the Swiss franc to the Euro (German mark before 1999).

Table 2: Unit root tests

				First Differences				
Lags	Δe	Δm_2	Δy	Δr^s	Δr^l	$\Delta \pi$	Δr^*	Δp^{oil}
0	*-8.53*	-6.56	*-9.91*	*-7.60*	*-6.85*	-15.30	*-6.67*	-8.76
1	-6.99	-5.82	-6.55	-6.26	-6.24	-11.56	-5.31	-8.18
2	-5.83	-4.27	-5.10	-5.64	-5.23	-8.67	-4.97	-5.39
3	-5.07	-2.82	-4.57	-5.33	-5.06	*-8.26*	-4.51	-5.57
4	-4.67	*-4.73*	-4.70	-4.93	-5.71	-6.83	-3.99	*-5.91*
				Levels				
Lags	e	m_2	y	r^s	r^l	π	r^*	p^{oil}
0	-3.03	-1.50	-1.88	-1.57	-1.99	-4.73	-1.15	-1.33
1	*-3.28*	-2.54	-2.07	*-2.41*	*-2.70*	-3.55	*-2.08*	-1.95
2	-3.21	-2.50	-2.36	-2.45	-2.61	*-2.87*	-2.30	-1.50
3	-3.24	-3.09	*-2.71*	-2.40	-2.72	-2.75	-2.25	*-2.11*
4	-3.25	*-4.74*	-2.85	-2.34	-2.59	-2.41	-2.36	-1.75

Note: The first column shows the number of lags included in the test. All regressions in first differences include an intercept, whereas the regressions in levels include a trend and an intercept for e, m, y, $y^*$and p^{oil}, and an intercept only for r^s, r^l, π, and r^*. The sample period runs from 1976Q1 to 2006Q2. Entries in italics denote the lag length selected by the AIC criterion. The 5% critical values are -3.45 for the tests including an intercept and a trend and -2.89 for models including a trend only. Entries in italics denote the lag length selected by the AIC criterion.

Table 3: Lag selection criteria

Lags	*Rank*	*AIC*	*log(FPE)*	*HQ*	*SC*	*FML*
1	6	-65.08	-65.08	-64.40	-63.41	-90.15
1	5	-65.06	-65.06	-64.44*	-63.53	-90.32
1	4	-65.01	-65.00	-64.44	-63.61	-90.42
1	3	-64.86	-64.86	-64.35	-63.61	-90.42
1	2	-64.78	-64.78	-64.38	-63.80*	-90.57*
1	1	-64.24	-64.24	-63.96	-63.54	-90.23
1	0	-63.55	-63.55	-63.38	-63.13	-89.70
2	6	-65.33	-65.31	-64.20	-62.54	-88.79
2	5	-65.39*	-65.37*	-64.31	-62.74	-89.03
2	4	-65.33	-65.31	-64.31	-62.82	-89.12
2	3	-65.23	-65.22	-64.27	-62.86	-89.16
2	2	-65.14	-65.14	-64.30	-63.05	-89.30
2	1	-64.91	-64.90	-64.17	-63.09	-89.25
2	0	-64.40	-64.40	-63.78	-62.87	-88.90
3	6	-65.14	-65.09	-63.56	-61.24	-87.04
3	5	-65.21	-65.16	-63.68	-61.45	-87.28
3	4	-65.15	-65.11	-63.68	-61.53	-87.37
3	3	-64.99	-64.96	-63.58	-61.51	-87.34
3	2	-64.91	-64.89	-63.61	-61.71	-87.48
3	1	-64.71	-64.69	-63.52	-61.79	-87.45
3	0	-64.27	-64.25	-63.19	-61.62	-87.15
4	6	-65.00	-64.88	-62.96	-59.98	-85.39
4	5	-65.05	-64.95	-63.07	-60.17	-85.62
4	4	-64.97	-64.88	-63.05	-60.23	-85.68
4	3	-64.86	-64.78	-63.00	-60.26	-85.69
4	2	-64.81	-64.74	-63.05	-60.49	-85.83
4	1	-64.67	-64.61	-63.03	-60.63	-85.86
4	0	-64.23	-64.18	-62.70	-60.47	-85.54

Note: Minimum values are represented by an asterisk. AIC: Akaike Information Criterion, FPE: Final Prediction Error, HQ: Hannan-Quinn Information Criterion, SC: Schwarz Information Criterion, FML: Fractional Marginal Likelihood Criterion. The endogenous variables are π, y, m_2, r^s, r^l and e; the exogenous variables r^* and p^{oil}. The sample period is 1976Q1 to 2006Q2.

Table 4: Test for cointegration

Rank	*Eigenvalue*	*Trace Statistic*	*Critical Value 90%*
1	0.493	246.55	137.00
2	0.356	163.64	105.24
3	0.299	109.93	77.21
4	0.242	66.54	53.16
5	0.154	32.81	35.45
6	0.097	12.46	15.91

Note: The endogenous variables are π, y, m_2, r^s, r^l and e; the exogenous variables r^* and p^{oil}. The sample period is 1976Q1 to 2006Q2. The system is estimated with two lags of the endogenous and the exogenous variables as well as a constant and a restricted linear trend.

Table 5: Coefficient estimates for overidentified β

Coefficient	*Point estimate*	*Lower 90% bound*	*Upper 90% bound*
β_{14}	10.09	0.84	18.31
β_{55}	8.47	1.86	19.47
β_{56}	0.17	0.09	0.62
b_{31}	4.16×10^{-5}	0.0000	0.0001
b_{51}	-3.15×10^{-3}	-0.0038	-0.0020

Note: The endogenous variables are π, y, m_2, r^s, r^l and e; the exogenous variables r^* and p^{oil}. The sample period is 1976Q1 to 2006Q2. The system is estimated with two lags of the endogenous and the exogenous variables as well as a constant and a restricted linear trend. The second and the third column show the 90% confidence bounds based on a parametric bootstrap with 999 replications. The overidentifying restrictions are not rejected with a LR test statistic of 39.74 and a bootstrapped p-value of 0.14.

Table 6: Specification tests for error correction equations

Variable	*LM*	*RESET*	*JB*	*ARCH*	$\overline{R}^2$
π	0.20	0.56	0.02	0.09	0.64
y	0.54	0.45	0.00	0.14	0.16
m_2	0.00	0.12	0.31	0.52	0.63
r^s	0.50	0.05	0.73	0.53	0.47
r^l	0.39	0.97	0.55	0.18	0.44
e	0.43	0.00	0.11	0.24	0.25

Note: The endogenous variables are π, y, m_2, r^s, r^l and e; the exogenous variables r^* and p^{oil}. The sample period is 1976Q1 to 2006Q2. The system is estimated with two lags of the endogenous and the exogenous variables as well as a constant and a restricted linear trend. LM is a Lagrange-multiplier test for 4^{th} order serial correlation, RESET is Ramsey's reset test of functional form, JB is the Jarque-Bera test for normality, and ARCH is a Lagrange-multiplier test for autoregressive conditional heteroscedasticity. Entries show p-values.

Table 7: Estimated $\mathbf{A}_{0x}$ matrix

	π	y	m_2	r^s	r^l	e
ε^1	1	0	0	0	0	0
ε^2	0.17 (0.26)	1	0	0	0	0
ε^{MD}	0	-1	1	32.34 (15.77)	0	0
ε^{MS}	0	0	-0.41 (0.45)	1	0	-0.05 (0.11)
ε^5	0.04 (0.02)	-0.02 (0.01)	0.003 (0.003)	-0.18 (0.03)	1	0
ε^6	-2.70 (1.10)	-0.46 (0.47)	-0.43 (0.67)	-1.87 (2.60)	3.64 (5.69)	1

Note: Asymptotic standard errors in parentheses. A likelihood ratio test of two overidentifying restrictions does not reject the restrictions with a test statistic of 4.46 and a p-value of 0.11.

Figure 1: Inflation and interest rates

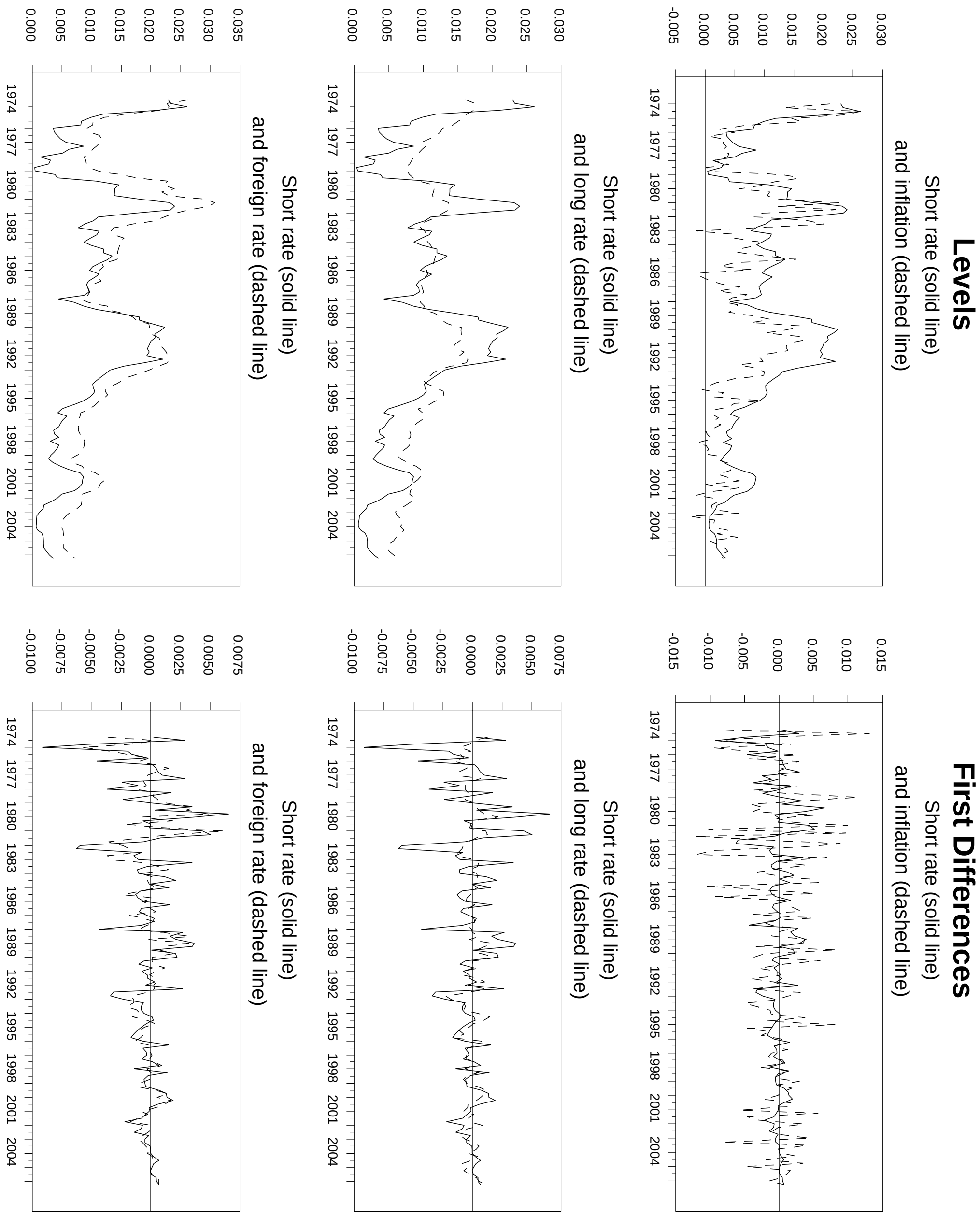

Figure 2: Money, output, exchange rate and oil price

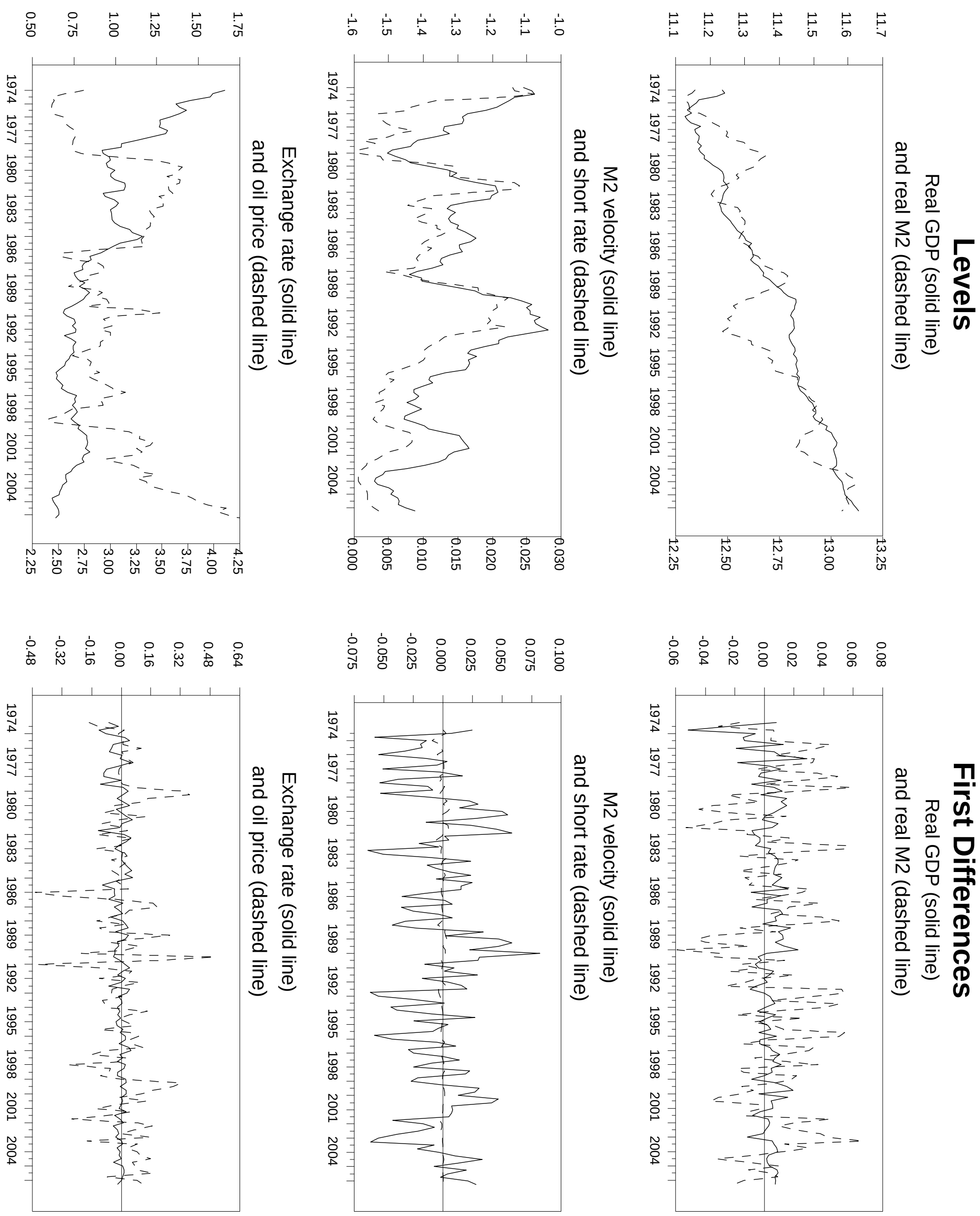

Figure 3: Mean impulse responses (solid line) to a monetary policy shock with 90% confidence bounds (dashed lines). Based on 1000 non-parametric bootstrap replications with β and the marginal-model parameters assumed fixed.

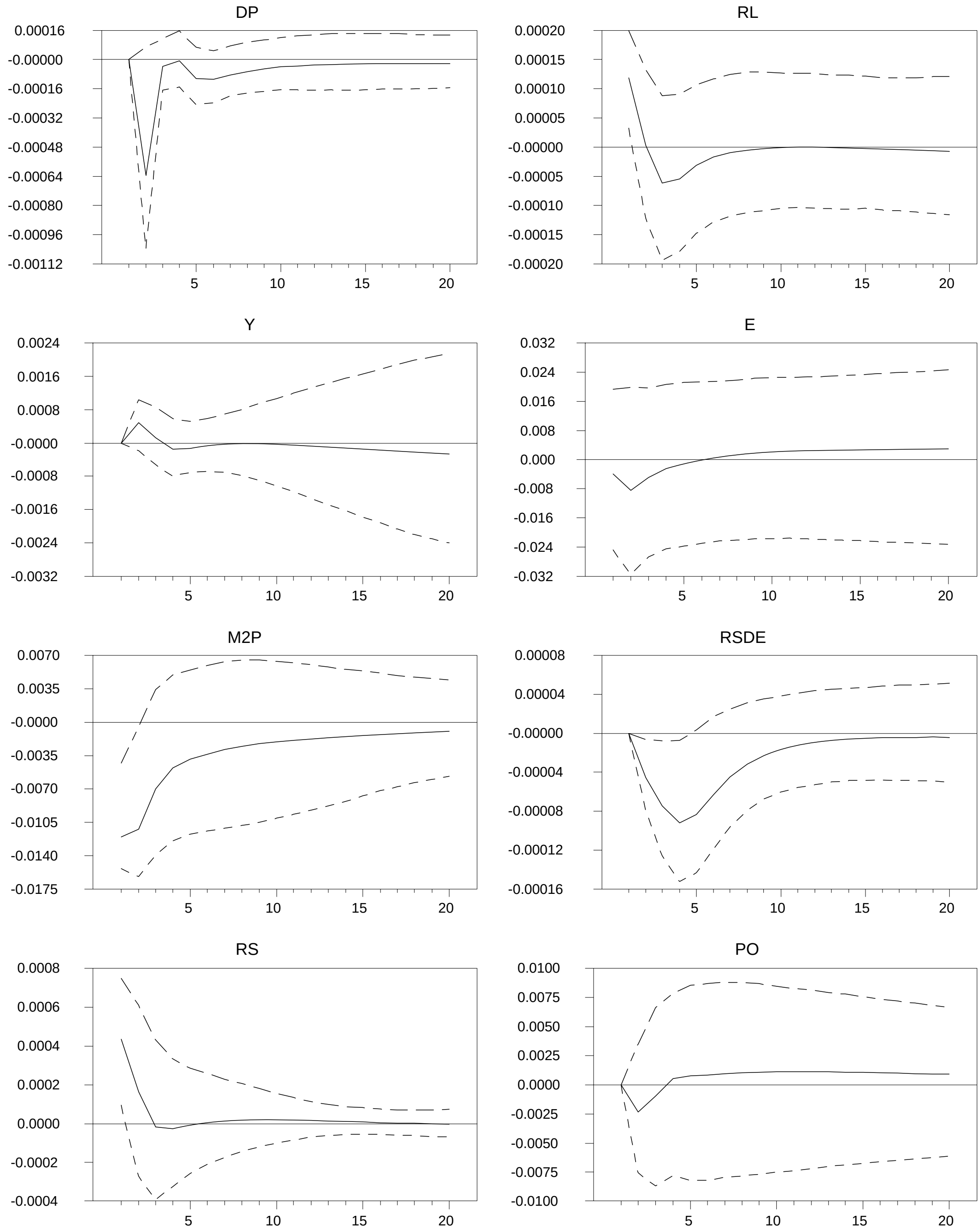

Figure 4: Impulse responses to monetary policy shock from SVEC with (solid line) and without (dashed line) money

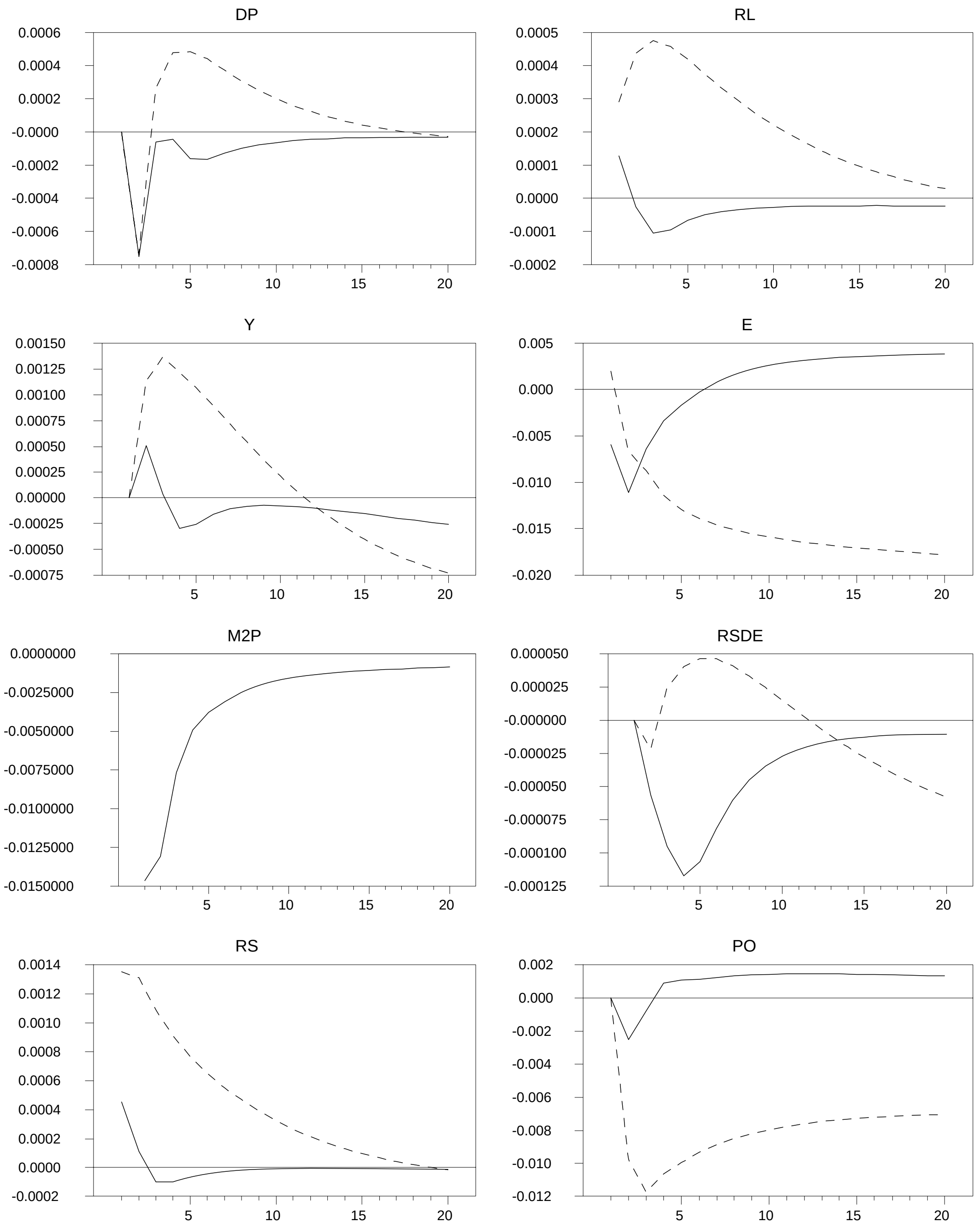

Figure 5: Impulse responses to monetary policy shock from SVAR with money (solid line) and without (dashed line)