Seminar paper
Applied Macroeconometrics - Vector Autoregression Models

A structural VAR analysis of the Phillips curve and monetary policy transmissions in the Euro area

Tim Lüdiger
Antoniusstr. 40
48151 Münster
tim@luediger-net.de

University of Münster
Institute of Econometrics and Economic Statistics
Dr. Andrea Beccarini

Contents

List of Figures

List of Tables

List of Abbreviations

ADF	Augmented Dickey Fuller
AIC	Akaike Information Criterion
ARCH	Autoregressive Conditional Heteroskedasticity
CINF	Core Inflation
ECB	European Central Bank
EUR	Euro
EURIBOR	Euro Interbank Offered Rate
EXR	Exchange Rate
FEVD	Forecast Error Variance Decomposition
FPE	Final Prediction Error
GDP	Gross Domestic Product
HQ	Hannan-Quinn Information Criterion
LM	Lagrange Multiplier
NKPC	New Keynesian Phillips Curve
SIC	Schwarz Information Criterion
SPF	Survey of Professional Forecasters
U.S.	United States (of America)
VAR	Vector Autroregression
VECM	Vector Error Correction Model

1 Introduction

The Phillips curve plays a central role in analysing business fluctuations and understanding monetary policy. Central banks use the Phillips curve concept to analyze prices and forecast inflation. A particularly interesting question from a macroeconometric point of view is how inflation and monetary policy impulses affect other macroeconomic variables and interact with each other. Since the seminal paper of Sims (1980) these dynamics have been extensively explored in the literature using Vector Autoregressive Models (VAR). VAR models contain a set of variables including their lagged values such that all variables contemporaneously affect each other and are all treated endogenously. This paper aims to understand the dynamics of the inflation rate and monetary policy impulses in the Euro area using a Phillips curve framework.

Galí and Gertler (1999) found a hybrid version of the New Keynesian Phillips Curve (NKPC) to be a good description of inflation in the U.S. and the Euro area. In this hybrid NKPC framework inflation dynamics are described as a function of lagged values of inflation itself, expected or future inflation and a measure of marginal costs whereas the original NKPC is purely forward-looking. The model is also characterized by nominal rigidities such as sticky prices in the short-run. Despite the theoretical appealingness of the model it has been criticized, e.g., regarding the question of how to weight the forward-looking and backward-looking inflation components in the model Galí, Gertler, and David López-Salido (2005). Furthermore, Fanelli (2008) points out that the single agent behavior on the national level of the members of the Euro area is blurred when using aggregated data due to the heterogeneity of the member states. In this paper however, I aim to understand monetary policy impulses from the European Central Bank (ECB) affecting the entire Euro area and therefore focusing on the dynamics in the Euro area as a whole.

The idea is to incorporate a hybrid version of the NKPC into a VAR system that models the interaction between main macroeconomic variables in the Euro area. In order to analyze and interpret the reactions of the variables in the model to single variable shocks, structural shocks have to be identified by restricting the model. Therefore, several restriction methods have been proposed to the literature to enable structural interpretations of the model dynamics. They can be categorized into sign restrictions, short-run restrictions, long-run restrictions and a combination of the latter two. In this paper I will make use of a combination of short-run and long-run restrictions to identify the model.

In structural VARs including at least a real measure of output, prices and a short-run interest rate, a monetary tightening often leads to a counterintuitive increase in prices. This is known in the literature as *prize puzzle*. Economic theory, intuition and empirical evidence suggest that prices should fall after the monetary interest rate has been increased. The VAR literature however, discussed various ways to overcome the prize puzzle. Sims (1986), e.g., suggests to include further variables in the model with forward-looking behavior such as commodity prices. Giordani (2004) proposes that the inclusion of a measure of the output gap is an adequate remedy to the puzzle. Other economists propose certain set of short-run restrictions and long-run neutrality restrictions as a remedy (Blanchard and Quah, 1989; Quah and Vahey, 1995; Kim and Roubini, 2000). In this VAR analysis of the Euro area both forward-looking variables and short-run and long-run restriction are included to identify the model and solve the prize puzzle.

The structural VAR analysis is structured as follows: After describing and displaying the data used for this analysis I will focus on the integration properties of the variables employed in the model using unit-root tests. Then, a theoretical structural VAR model is presented to set up the set of equations describing the model dynamics. The variables are then tested for their cointegration relations using the Johansen procedure. The fit of the model specification is tested for ARCH-effects and autocorrelation in the residuals. In order to allow structural inference the model is identified using a set of overidentifying short-run and long-run zero restrictions. Eventually, with the estimates of this model impulse response functions and Forecast Error Variance Decomposition (FEVD) are computed and analyzed.

2 Theoretical considerations

This paper investigates the dynamics of inflation, monetary policy and their relations to the business cycle. The original Phillips curve has been subject to criticism and changes throughout time. The most important specifications of the Phillips curve can be categorized in the Traditional, New Keynesian and a hybrid Phillips curve. In the traditional Phillips curve model inflation is defined by lagged values of inflation expectations and a measure of excess demand. The New Keynesian Phillips curve is described by a function of future expected inflation and a measure of marginal costs which indicates the flexibility of prices. This specification is purely forward-looking and assumes rational expectations and price stickiness as developed by Calvo (1983). The higher the coefficient on the marginal cost measure, the more flexible are prices and the faster they adjust. The hybrid version of the NKPC for that matter combines the forward-looking and backward-looking components of the traditional and the New Keynesian Phillips curve.

Several models proposed in the literature that deal with the analysis of inflation and monetary policy comprise an IS-equation, a Phillips curve and a monetary policy rule (L. Svensson, 1999; Judd and Rudebusch, 1998). This paper additionally takes the dynamics of a forward-looking variable and an open economy variable into account, namely expected inflation and the nominal exchange rate respectively.

In the hybrid version of the Phillips curve both inflation expectations and lagged values of realized inflation are included. The idea has been developed by Galí and Gertler (1999) assuming that not all firms in the economy are able to adjust prices optimally and therefore some firms´ price setting behaviour is simply formed through adaptive expectations.

The inflation dynamics in the following VAR model are based on a hybrid version of the NKPC, hence, amongst other variables both inflation and inflation expectations and their lagged values are included in the specification. The lagged values of inflation represent the share of firms that cannot adjust their prices instantaneously or put differently, the share of firms that form adaptive inflation expectations via backward-looking behavior.

Instead of assuming rational expectations for the forward-looking component of the model, I use survey-based inflation expectations. This brings the advantage for the empirical model that no theory-based assumptions are necessary and the data reflects real inflation expectations. This way it does not require the assumption that economic agents actually use all of the available information to form their expectations but the information set which is used is already part of the survey values. The inclusion of inflation expectations is based on the idea of self-fulfilling expectations. Therefore, economic agents´ expectations play a role in shaping future economic outcomes such that their expectations become consistent with the actual behavior of market participants (see Hamilton and Whiteman (1985)).

In addition, inflation in this model´s Phillips curve is driven by a measure of economic slack for which the output gap is incorporated into the model. In empirical applications the output gap is usually defined as the percentage deviation of actual output from potential output. The output gap measures how efficiently resources are utilized in an economy given the current state of the economy. In the following I will refer to the output gap as positive if output exceeds potential output and as negative if output is below its potential. If the output gap is zero it is closed and actual output matches potential output.

An output gap can be caused by shocks on either the demand or the supply side of the economy. These shocks are modeled by using stochastic error terms in the output gap equation. In case of a positive output gap induced by a positive demand shock aggregate demand increases and firms will employ more labor in order to meet the extra demand in the short-run. Due to the higher labor demand firms have to increase real wages to induce a higher labor supply. Production costs can also increase due to the utilization of capital over the optimal level. Higher costs then lead to increasing prices given a constant markup of prices over costs. Due to these price pressure mechanisms the output gap positively affects inflation. In the long-run the capital stock is unchanged and output eventually returns to its potential level, hence, the output gap is closed(Fisher, Mahadeva, and Whitley, 2014).

Alternatively, a negative output gap can be the result of a positive supply shock. Due to the initial lack of demand firms will not instantaneously increase output. Thus, they will employ less labor leading to lower costs causing disinflationary pressure. This disequilibrium is assumed to be offset by interaction of the monetary authorities encouraging spendings to accommodate an increase in output (Fisher, Mahadeva, and Whitley, 2014).

Furthermore, a short-term interest rate which is supposed to be set by the monetary authority, hence the ECB, is included in the model. Including the interest rate sets up the IS-curve in the VAR model since output represented by the output gap is now linked to the interest rate (Giordani, 2004). The interest rate equation can be interpreted as monetary policy rule executed by the ECB. The monetary authorities are assumed to set the interest rate after observing current inflation and its past values, the output gap and the exchange rate and based on inflation expectations. The interest rate movements that cannot be considered a reaction of the monetary authorities to the current economic state are modeled by a monetary policy shock. Brissimis and Magginas (2006) states that these shocks could reflect changes in the preferences of the monetary authorities, e.g., a shift in the reaction function.

Lastly, the nominal exchange rate given by U.S. Dollar per EUR is included in the model for two reasons. Firstly, the prices of imported goods have a direct impact on domestic prices and the consumer price index, hence, on inflation. Also, the current account and therefore the aggregated demand side of the economy is directly affected by exchange rate fluctuations (Woo, 1984; L. E. Svensson, 2000). Hence, both inflation and the output gap are directly affected by exchange rate fluctuations. Secondly, in order to identify the VAR model it has to be considered that the information set given to all economic agents and especially the ECB only comprises the variables that are included in the VAR model. The exchange rate yields additional information for the central bank. Monetary policy not only affects the economy via the interest rate channel but also via an exchange rate channel (Ball, 1998). Therefore, the exchange rate is included as a proxy for international economic activity. Also, the exchange is considered a forward-looking measure next to the expected inflation in this model. In conclusion the VAR model comprises a Phillips curve, an output gap equation describing the IS-curve, a monetary policy rule, an inflation expectations equation and an exchange rate equation.

3 Data

3.1 Data description

The variables used in this model are the core inflation rate π, expected future inflation π^e, an output gap measure $\hat{y}$, a short-term interest rate i and the exchange rate expressed as U.S. Dollar per Euro. I use quarterly data for the time period from the launch of Euro coins and banknotes in 2002:Q1 until 2021:Q4. All data is aggregated for the 19 countries that form the Economic and Monetary Union of the European Union as of 01.01.2015. The time series are not seasonally adjusted.

The core inflation rate π is the annualized quarterly percentage change in the harmonized consumer price index from Eurostat. The index excludes changes in the prices of energy, food, alcohol and tabacco. This way the model abstracts from high volatility in the headline inflation caused by, e.g., shocks to oil prices.

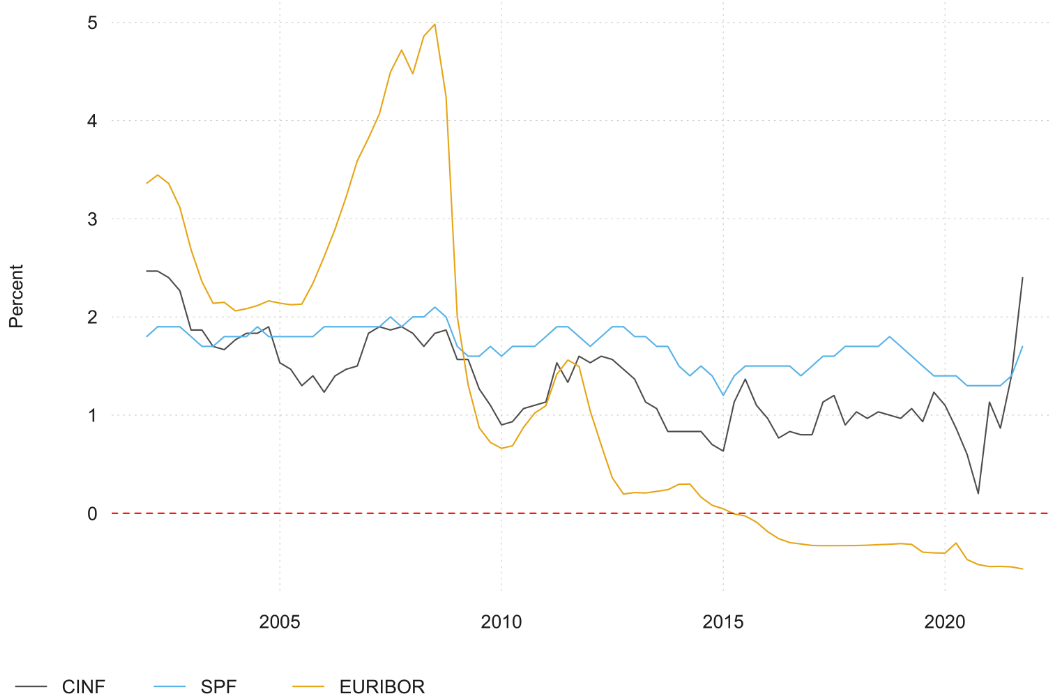


Figure 1: Core inflation (CINF), Expected inflation (SPF) and the Euribor rate (EURIBOR) for the Euro-area.

Expected inflation is measured by the two-year ahead inflation forecast from the Survey of Professional Forecasters (SPF) that is published each quarter by the European Central Bank (ECB). The underlying definition of the percentage change in the harmonized consumer price index matches the one used for the core inflation measure π. The inflation expectations do not exhibit strong fluctuations and are close to the ECB´s target inflation rate of 2%. The two-year ahead forecast was chosen based on the assumption that economic agents do not immediately adjust their behavior if inflation fluctuates in the short-run. Behavioral adjustments, e.g., the re-negotiation of wage contracts is presumably based on a medium-term forecast.

The interest rate used in this model is the 3-month Euribor rate which is denoted by i. The Euribor rate is not directly set by the ECB but largely mirrors the trajectory of the main financing operations. Furthermore, the Euribor rate allows to analyze the dynamics of monetary policy when the interest rate turns negative which has essentially characterized past years´ monetary policies. The main financing operation which is directly set by the ECB, however, never went below zero. Figure 1 shows the core inflation rate, expected inflation and the Euribor rate and also displays the period of a negative interest rate. The Euribor rate turns negative after 2015:Q2.

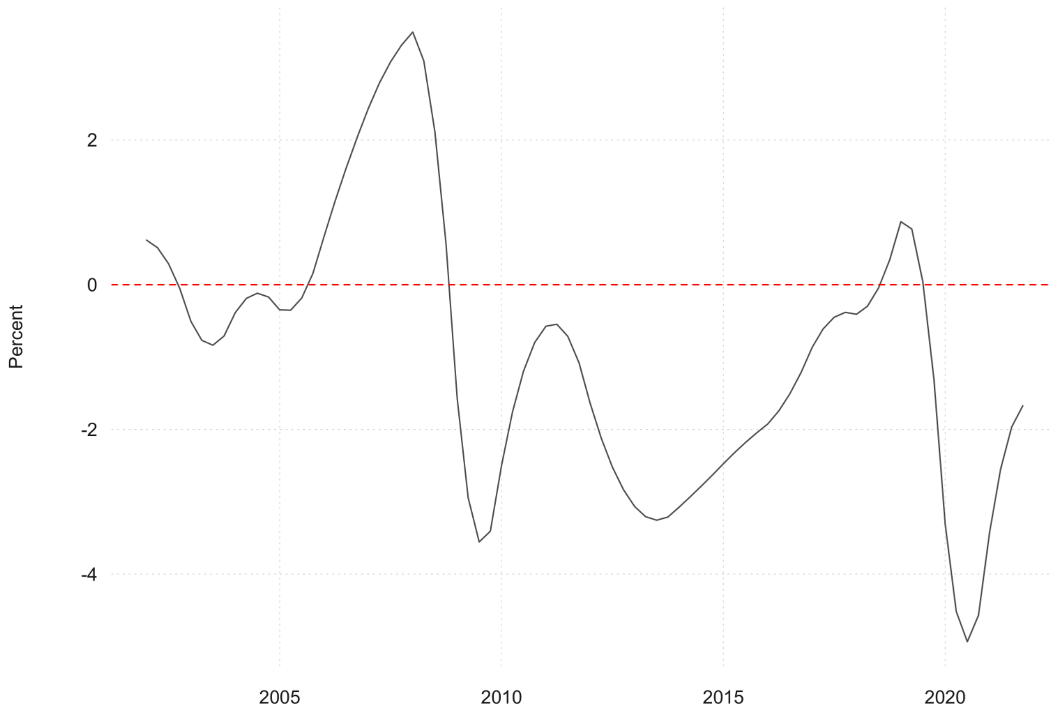


Figure 2: Output gap measure for the Euro-area.

Since the output gap cannot be directly observed I use estimates from the International Monetary Fund for $\hat{y}$. The output gap is defined as the share of the actual Gross Domestic Product (GDP) of the difference between actual and potential GDP. However, output gap measures are only available annually, thus, the annual series of the output gap data has to be adapted for quarterly use. This is achieved via temporal disaggregation of the low-frequency output gap series using the Chow-Lin method without an indicator which creates a new higher-frequency time series that is consistent with the original estimates of the output gap (Chow and Lin, 1971). This has the advantage over a simple interpolation that the average of the quarterly values of the output gap still match the annual estimates of the International Monetary Fund. The transformed output gap is shown in figure 2 where the dashed red line denotes the zero line where the output gap is closed.

The exchange rate e is measured by the quarterly averages of the nominal exchange rate expressed as U.S. Dollar in Euro. Although the exchange rate has usually been omitted in the vast literature of structural VARs it can be useful to include it into the analysis of monetary policy for various reasons. Clarida, Galí, and Gertler (1998) find that the exchange rate indeed plays a role in the process of setting monetary policy in industrialized countries. In addition to that, Cologni and Manera (2008) argue

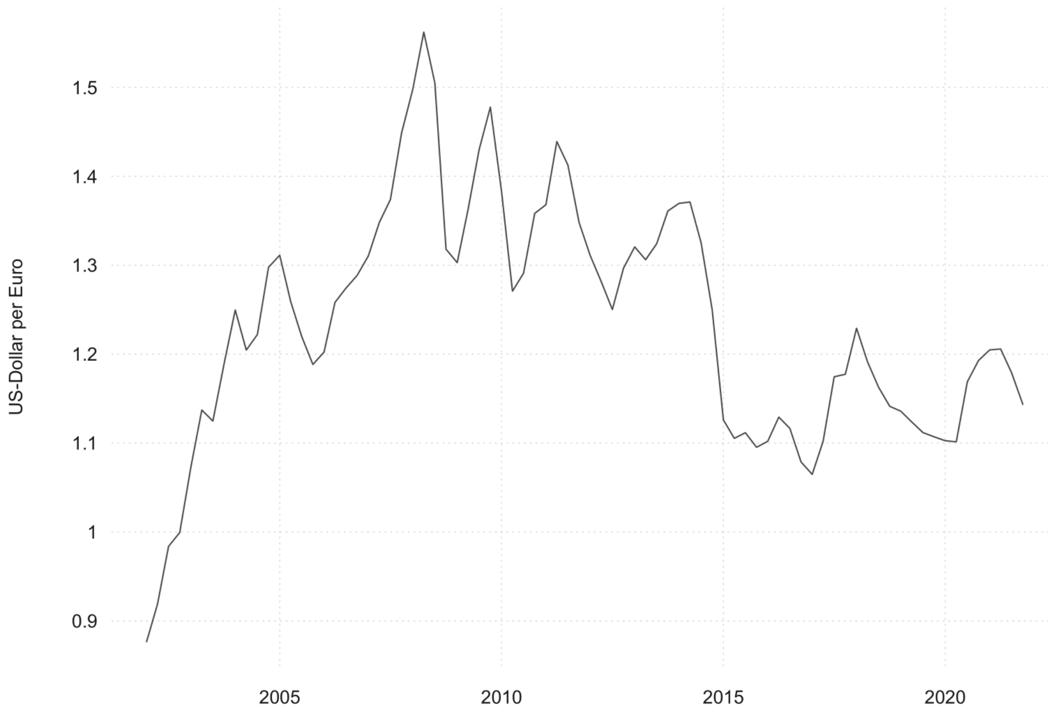


Figure 3: Nominal exchange rate denoted as U.S.-Dollar per Euro.

that monetary policy shocks will be mirrored in the innovations of the exchange rate due to monetary authorities targeting the exchange rate. Also, Brissimis and Magginas (2006) argue that in order to solve the prize puzzle it even is a necessary condition to include forward-looking variables. Therefore, including the exchange rate provides a better rational to the information available to the monetary authorities. Apart from the exchange rate all variables are expressed in percentages. The trajectory of the exchange rate in U.S. Dollar per Euro is presented in figure 3.

3.2 Unit-root testing

In order to correctly specify the model and circumvent spurious regression results I am investigating the integration and cointegration properties of all variables. To check for the existence of unit-roots in the underlying processes of the series an ADF-test was conducted for all variables first in levels and then in first differences. A constant and a trend were included in the ADF-regression for the inflation, the exchange rate and the interest rate. For inflation expectations only a constant was included in the specification and for the output gap and for all variables in first differences no deterministic terms were included. The ADF specifications include lags in first

ADF-test				*Critical Values*		
Variable	Deterministics	Lags	Test value	1 pct	5 pct	10 pct
$\hat{y}$	none	2	-1.6055	-2.6	-1.95	-1.61
$\Delta\hat{y}$	none	1	-6.3784***	-2.6	-1.95	-1.61
π	constant, trend	3	-3.3292	-4.04	-3.45	-3,15
$\Delta\pi$	none	3	-3.9481***	-2.6	-1.95	-1.61
π^e	constant	1	-2.5461	-3.51	-2.89	-2.58
$\Delta\pi^e$	none	0	-7.2003***	-2.6	-1.95	-1.61
i	constant, trend	1	-3.1266	-4.04	-3.45	-3.15
Δi	none	0	-4.5155***	-2.6	-1.95	-1.61
e	constant, trend	2	-3.0052	-4.04	-3.45	-3.15
Δe	none	1	-6.8779***	-2.6	-1.95	-1.61

Notes: *** - H_0 rejected at the 1% level.

Table 1: ADF-test for variables in levels and first differences.

differences up to the highest statistically significant lag. The results of the ADF-test including the deterministic terms and the critical values are presented in table 1. The ADF-test does not reject the Null hypothesis of a unit-root for the level variables but does reject the unit root hypothesis for first differenced variables at the 5% level.[1] Hence, I conclude all variables have a unit root and are integrated of order one ($I(1)$).

4 Econometric framework

4.1 A structural cointegrated VAR model

Since all variables in the model are assumed to be $I(1)$, i.e., stationary in first differences, I set up a structural Vector Error Correction Model (VECM) to model the dynamics of inflation and monetary policy impulses in the Euro area. The construction of the empirical model starts with a standard VAR(p) model in reduced form

$$y_t = A_1 y_{t-1} + ... + A_p y_{t-p} + \Lambda D_t + u_t, \tag{4.1}$$

where y_t is a $K \times 1$ vector of variables, which in this case is given by $y_t = \begin{pmatrix} \hat{y} & \pi & \pi^e & i & e \end{pmatrix}^\top$, D_t is a vector of deterministic terms like a constant and trend and $A_1, ..., A_p$ are coefficient matrices of dimension $K \times K$ for p lags included in the VAR. Λ is the coefficient matrix associated to D_t. The $K \times 1$ vector u_t, representing the reduced form disturbances, is an unobservable zero mean white noise process with non-singular covariance matrix Σ_u.

Subtracting y_{t-1} from both sides of the reduced form VAR(p) representation (4.1)

[1] The unit-root tests were computed by the **urca** package in **R**.

and rearranging the terms yields the VECM representation

$$\Delta y_t = \Pi y_{t-1} + \Gamma_1 \Delta y_{t-1} + ... + \Gamma_{p-1} \Delta y_{t-p+1} + \Lambda^+ D_t + u_t. \tag{4.2}$$

where

$$\Pi \coloneqq -(I_K - A_1 - ... - A_p) \tag{4.3}$$

and

$$\Gamma_i \coloneqq -(A_{i+1} + ... + A_p),\ i = 1, ..., p-1. \tag{4.4}$$

The Δ represents the first differences operator. Since Δy_t is assumed to be stationary, so must be the right-hand side of equation (4.2). y_{t-1} is the only non-stationary variable in equation (4.2) which implies that Πy_{t-1} is required to be stationary (Kilian and Lütkepohl, 2017). In cointegrated models Π is a $K \times K$ coefficient matrix with reduced rank $r = rank(\Pi) < K$ and can be decomposed as $\Pi = \alpha\beta\prime$, where α and β are $K \times r$ matrices that contain the loading coefficients and the cointegration vectors, respectively. The cointegration vectors determine the long-run relationship between the variables in the model and the loading matrix can be interpret as adjustment speed of the variables towards the long-run equilibrium. Furthermore, $\Gamma_1, ..., \Gamma_{p-1}$ are again $K \times K$ coefficient matrices that determine the short run dynamics of the model.

Typically, researchers are interested in the effect that certain shocks, e.g., a monetary policy shock has on other macroeconomic variables. These shocks have to be exactly identified by imposing additional structure on the model based on economic theory in order to give further analysis, e.g., impulse response functions and variance decomposition economic interpretations. The resulting models are called structural VAR or if applied on cointegrated models structural VECM.

The covariance matrix Σ_u of the reduced form VECM may not be a diagonal matrix, hence, the elements of u_t are likely to be contemporaneously correlated which is why isolated shocks to the elements of u_t are not common in practice (Lütkepohl, 2005). The structural shocks that allow for an economic interpretation are assumed to be uncorrelated. To identify the structural shocks from the reduced form residuals a matrix B has to be set up such that

$$u_t = B\epsilon_t \text{ with } \epsilon_t \sim \mathcal{N}(0, I_K), \tag{4.5}$$

where ϵ_t denotes the $K \times 1$ vector of structural shocks. Hence, $\Sigma_u = B\Sigma_\epsilon B\prime = BB\prime$. However, due to the symmetry of Σ_u and the normalization of the structural variances only $K(K+1)/2$ equations are identified through these relation such that at least $K(K-1)/2$ additional relations are needed to fully identify B. This can be achieved by imposing sufficient zero restrictions on B (Lütkepohl, 2005). It might, however, be challenging to find sufficient zero restriction on the contemporaneous impact matrix B. Therefore, it is interesting to also impose restrictions on the long-run relations between the variables. The Granger representation theorem (Johansen, 1995) tells us that the VECM from 4.2 has the vector moving-average representation

$$y_t = \Xi \sum_{i=1}^{t} (u_i + \Lambda D) + \sum_{j=0}^{\infty} \Xi^* (u_{t-j} + \Lambda D) + y_0^* \tag{4.6}$$

where

$$\Xi = \beta [\alpha'_\perp (I_N - \sum_{i=1}^{p-1} \Gamma_i) \beta_\perp]^{-1} \alpha'_\perp. \tag{4.7}$$

$\alpha'_\perp$ and $\beta_\perp$ denote the orhtogonal complements of α and β. Furthermore, Ξ has reduced rank $(K - r)$, where r represents the number of cointegration relationships. The initial values are contained in y_0^* and $\sum_{j=0}^{\infty} \Xi^* (u_{t-j} + \Lambda D)$ is a stationary process such that the expression will converge to zero for j $\rightarrow \infty$. Therefore, the long-run effects are solely captured by $\Xi \sum_{i=1}^{t} (u_i + \Lambda D)$. The reduced form disturbances u_t can now be replaced by $B\epsilon_t$ such that the long-run effects of structural shocks ϵ_t can be written as ΞB. Long-run restrictions can be imposed by setting elements of ΞB to zero.

4.2 Cointegration analysis and diagnostic tests

Since all variables are assumed to be $I(1)$ I investigate possible cointegration relations to include additional information concerning the long-run characteristics of the time series into the model. The number of cointegration relations, hence the rank of Π, is estimated by using both the trace test and the eigenvalue test from the Johansen procedure (Johansen, 1995). Because most of the time series have trending behavior a linear trend and a constant are included in the underlying VAR(p) specification. The lag order of the underlying VAR is set to two in accordance with information criteria. The AIC, HQ and FPE information criterion suggested an optimal lag length of two whereas the SIC suggested only to include one lag when the maximal lag length is set to $p = 6$. However, I found one lag to be too restrictive and therefore included two. Since the time series are not seasonally adjusted the VECM estimated by the Johansen procedure includes seasonal dummy variables to account for economic fluctuations.

The results of the Johansen cointegration test are shown in table 2 including the critical values. Both the trace test and the eigenvalue test reject the Null hypothesis of no cointegration relationship at the 1% level. Also, both tests reject the Null hypothesis of the cointegration rank being smaller or equal to 1 but neither rejects the hypothesis of at most 2 cointegration relations at the 5% level. Hence, I conclude that there are 2 cointegration relations between the variables and that the long-run coefficient matrix Π is of reduced rank $r = 2$.

Furthermore, I argue that the reduced form cointegrated VAR model including two lags in first differences, seasonal dummies, a trend term and a constant in the cointegration relation yields good results in terms of the absence of ARCH effects

Johansen cointegration test								
	Test statistic	*Critical values*			Test statistic	*Critical values*		
H_0	Trace	10 pct	5 pct	1 pct	Eigenvalue	10 pct	5 pct	1 pct
$r = 0$	120.56***	83.20	87.31	96.58	51.04***	34.75	37.52	42.36
$r \leq 1$	69.52**	59.14	62.99	70.05	32.44**	29.12	31.46	36.65
$r \leq 2$	37.08	39.06	42.44	48.45	16.33	23.11	25.54	30.34
$r \leq 3$	20.75	22.76	25.32	30.45	11.12	16.85	18.96	23.65
$r \leq 4$	9.63	10.49	12.25	16.26	9.63	10.49	12.25	16.26

Notes: *** , ** - H_0 rejected at the 1% or 5% level respectively.

Table 2: Johansen cointegration test

and autocorrelation in the residuals. Therefore, a number of misspecification tests are performed. The autocorrelation of the residuals is tested using a multivariate Ljung-Box portmonteau-test up to the p^th lag. The existence of ARCH-effects is tested by the multivariate Lagrange multiplier test. The results in table 3 show that the Null hypothesis of no autocorrelation in the residuals cannot be rejected at the 5% significance level. Also, the multivariate LM test results in p-values above the 5% level suggesting that there is no conditional heteroskedasticity present. I conclude that the model specification is a good description of the data.[2]

Diagnostic tests	Q^*_{14}	Q^*_{16}	$\text{MARCH}_{LM}(5)$	$\text{MARCH}_{LM}(6)$
Test statistic	340.6	374.64	1095	1080
Asymptotic distribution	χ^2_{305}	χ^2_{355}	χ^2_{1125}	χ^2_{1350}
p-value	0.07843	0.227	0.7337	1

Notes: Q^*_p - multivariate Ljung-Box portmonteau test up to the $\text{p}^{th} lag$
$\text{MARCH}_{LM}(p)$ - multivariate LM test for ARCH up to the $\text{p}^{th} lag$

Table 3: Residual autocorrelation and ARCH tests.

4.3 Identification strategy

In order to identify the orthogonal structural shocks additional structural restrictions have to be imposed on the model. Otherwise it would not be possible to precisely determine what, e.g., the consequences of a single variable shock are since it would be correlated to other disturbance terms. In the VAR literature mainly four sets of restrictions are used, namely short-run restrictions, long-run restrictions, a combination of these two and sign restrictions. I impose a combination of short- and long-run restrictions on the model motivated by several proposals made in the VAR literature.

[2]The cointegration and diagnostic test statistics were computed using the **vars** package in **R** (Pfaff, 2008).

Both types of restrictions are usually imposed by setting elements of the contemporaneous impact matrix B and the long run impact matrix ΞB to zero. The contemporaneous effects of the structural errors are captured in matrix B as stated in equation (4.8). This can be achieved by imposing a recursive structure via a Choleski-decomposition on the B matrix as, e.g., put to use in Sims (1980). However, although this method solves the identification problem and is prominently used in the literature (see, e.g., Eichenbaum and Evans (1995); Christiano, Eichenbaum, and Evans (1999)), I argue that a recursive structure would not fit the theoretical considerations of this model. Therefore, I choose a non-recursive identification scheme for this model. Other non-triangular identification schemes are also proposed in the literature (see, e.g., Kim and Roubini (2000) and Vlaar (2004)).

$$\begin{pmatrix} u_{\hat{y}} \\ u_{\pi} \\ u_{\pi^e} \\ u_i \\ u_e \end{pmatrix} = \begin{pmatrix} * & 0 & 0 & 0 & * \\ * & * & * & * & 0 \\ 0 & * & * & * & * \\ 0 & * & * & * & * \\ * & * & * & * & * \end{pmatrix} \begin{pmatrix} \epsilon_{\hat{y}} \\ \epsilon_{\pi} \\ \epsilon_{\pi^e} \\ \epsilon_i \\ \epsilon_e \end{pmatrix} \tag{4.8}$$

Equation (4.8) shows the zero restriction imposed on the B matrix. Note that the asterisks denote unrestricted parameters that are free to be estimated. $u_{\hat{y}}$, u_{π}, u_{π^e}, u_i and u_e denote the disturbances of the reduced-form equations and $\epsilon_{\hat{y}}$, ϵ_{π}, ϵ_{π^e}, ϵ_i and ϵ_e denote orthogonal structural shocks to the model consisting of a shock in aggregate demand or supply, an inflationary shock, a shock to inflation expectations, a monetary policy shock and an exchange rate shock.

In this specification inflation, inflation expectations and the interest rate are assumed to not affect the output gap contemporaneously. Output therefore only reacts sluggishly to changes in prices and their expectations. Re-negotiations of labor contracts and production adjustments due to firms´ own expectations are assumed to take place only in the long-run but not instantaneously. Based on a decision delay argument the interest rate does not affect output in the short-run either because investment decisions are assumed to take time. The nominal exchange rate however, is assumed to affect output contemporaneously because of its impact on the current account. The exchange rate thus controls for changes in import and export activity.

Although the exchange rate will eventually affect inflation it is not assumed to have a contemporaneous impact on it. Goldberg and Knetter (1997) argue that the pass-through of the exchange rate to the inflation rate is relatively slowly over time. The other variables are not restricted in their effect on inflation in the short-run leaving it to the model how quickly prices will be adjusted.

The short-run interest equation is assumed to represent a monetary policy rule such that the monetary authorities set the interest rate after observing inflation, the exchange rate and taking inflation expectations into account. However, the output gap is excluded from this monetary feedback rule based on information delays as also reasoned in Kim and Roubini (2000) and Sims and Zha (2006). According to this argument the monetary authorities are assumed to be able to observe the values for the aforementioned variables within a quarter, but not the output gap. This is plausible since data on GDP is not available within a quarter but data on inflation rates and exchange rates are available monthly or even daily respectively. The same reasoning applies to the inflation expectation equation.

The exchange rate in this model is included to represent systematic reactions of the monetary regimes to fluctuations in the worldwide state of the economy as argued by Kim and Roubini (2000). They also argue that major economies as G-7 countries are concerned with how a depreciation of their currency will affect domestic inflation rates, hence, monetary policy reacts to exchange rate changes.

Similar to the models in Kim and Roubini (2000) and Peersman and Smets (2001) the exchange rate is considered a forward-looking variable and therefore is contemporaneously affected by all other variables in the model.

In total there are six zero restrictions imposed on B, however, at least $K(K-1)/2 = 10$ restrictions are required to fully identify the structural shocks. Therefore, additional restrictions are placed on the long-run impact matrix.

$$\Xi B = \begin{pmatrix} 0 & 0 & * & 0 & * \\ 0 & * & * & 0 & * \\ * & * & * & * & * \\ * & * & * & * & * \\ * & * & * & * & * \end{pmatrix} \tag{4.9}$$

As discussed before, the output gap is assumed to be closed in the long-run. Based on the reasoning of Quah and Vahey (1995) the core inflation in this model is interpreted as the component of measured headline inflation that does not have a long-run impact on the output gap. This is consistent with a vertical long-term Phillips curve as predicted by, e.g., Fischer (1977) or Taylor (1980). Therefore, the core inflation rate is identified as output neutral in the long-run. This restriction matches the theoretical assumption that the output gap is closed in the long run Vlaar (2004). Furthermore, I assume that both demand and supply shocks may have persistent but not permanent effects on the output gap. Given sticky prices both shocks affect prices via the output gap. Depending on the degree of stickiness which is endogenously determined in this model, the output gap reacts relatively slow or quick to these shocks but closes eventually.

As in theoretical New-Keynesian models the monetary policy shock is restricted to only have short-run effects on real variables such as the output gap and inflation in this model (see, e.g.,Krusec (2010); Clarida, Galí, and Gertler (1998); Vlaar (2004)).

Krusec (2010) argues that this identification step remedies the prize puzzle in a relatively simple VAR model. I adapt this idea of money neutrality in the long-run next to the inclusion of forward-looking variables in the model to solve the puzzle. Inflation expectations are assumed to have a long-run effect on all variables. Adjustments for labor contracts or prices are presumably not always feasible in the short-run. Economic agents therefore re-negotiate wage contracts or change prices in the medium to long-run according to their expectations. Eventually, also the exchange rate feeds through to the inflation rate in the long-run.

Considering all the above restrictions the model happens to be overidentified by one restriction. To test whether this overidentifying assumption impairs the structural analysis a Likelihood-ratio test for overidentification is conducted. The test statistic is 1.2 producing a χ^2-value of 0.3, thus, the Null hypothesis of no overidentifying restriction cannot be rejected and all restrictions remain in the identification specification.

Firstly, the reduced-form variance-covariance matrix Σ_u is estimated using Maximum Likelihood Estimation methods. Given the estimates of Σ_u and the restrictions from equations (4.8) and (4.9) the contemporaneous impact matrix B and the long-run impact matrix ΞB can be estimated.[3] The estimates for the contemporaneous impact matrix are

$$B = \begin{pmatrix} 0.191239 & 0 & 0 & 0 & -0.100814 \\ 0.006724 & 0.08245 & 0.19438 & -0.5532 & 0 \\ 0 & -0.01581 & 0.02522 & -0.04457 & -0.057145 \\ 0 & 0.15225 & -0.02994 & 0.03360 & -0.122937 \\ 0.007085 & 0.02096 & -0.01507 & -0.03295 & 0.001453 \end{pmatrix} \tag{4.10}$$

and for the long-run impact matrix

$$\Xi B = \begin{pmatrix} 0 & 0 & -0.700358 & 0 & -0.27142 \\ 0 & 0.04817 & 0.089532 & 0 & 0.03247 \\ 0.01160 & -0.01430 & -0.001056 & -0.05007 & -0.02145 \\ 0.02596 & 0.27435 & -0.323102 & -0.11207 & -0.18651 \\ 0.01423 & 0.01424 & -0.008518 & -0.06144 & 0.03060 \end{pmatrix} \tag{4.11}$$

Both impact matrices yield a reasonable economic interpretation in terms of the sign in front of the coefficients. All values that were initially restricted to zero are of course estimated to be zero in both matrices. It is challenging and tedious to interpret single coefficient estimates since the variables affect each other contemporaneously making the model more complex. To give structural interpretations to the model dynamics impulse response functions and forecast error variance decompositions are computed and analyzed in the next section of the paper.

[3] The estimates for the structural VECM as well as for the following Impulse response analysis and FEVD were computed via the **vars** package in **R** (Pfaff, 2008).

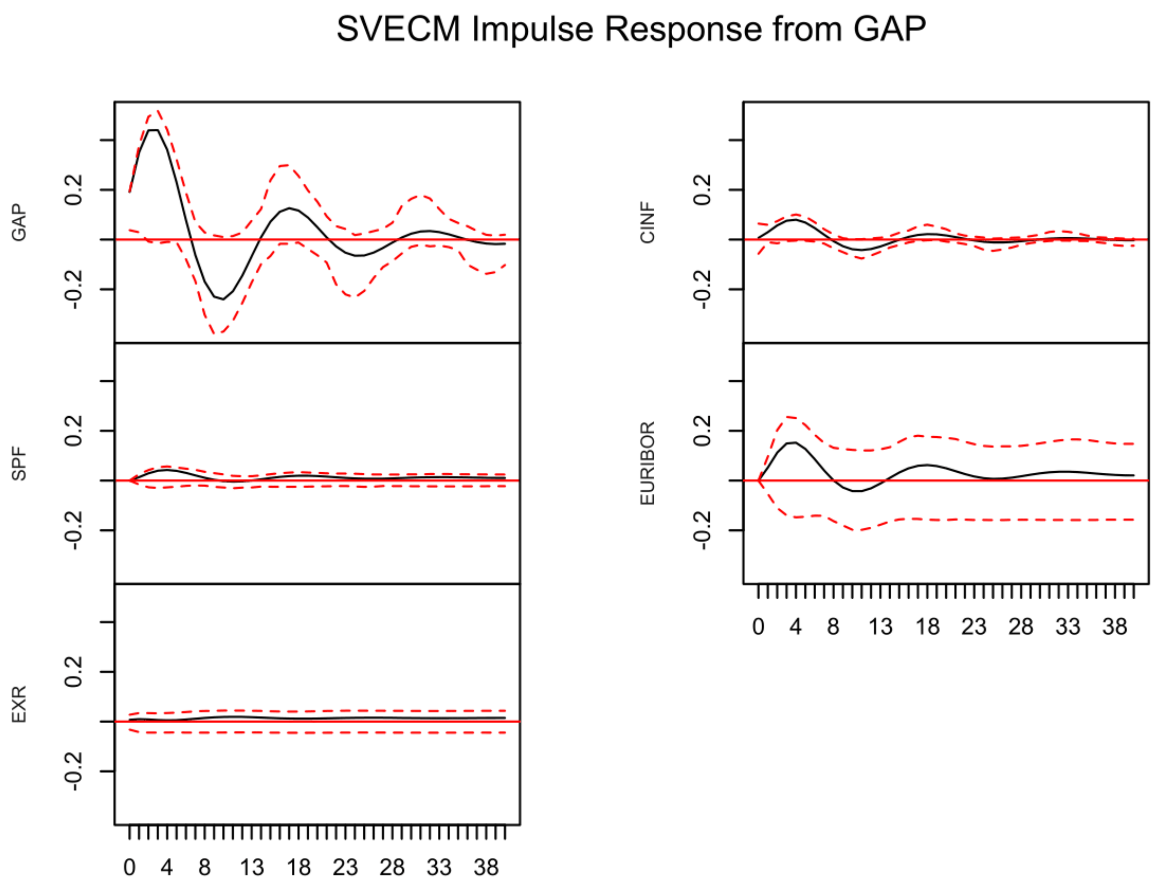
5 Structural analysis

5.1 Impulse response analysis

The analysis of the estimated coefficients becomes more tedious the more variables and lags are included. To better understand and interpret the dynamic effects and interactions of the variables in the model I compute the impulse responses of the variables. The impulse responses describe the dynamic adjustments of the entire system after a one standard deviation shock to one of the variables in the model. In order to capture both, the short-run and long-run dynamics the impulse responses are computed for a forecast horizon of 40 periods, thus 10 years. In the following visualizations the five variables are referred to as GAP (output gap), CINF (core inflation), SPF (inflation expectations), EURIBOR (Euribor interest rate) and EXR (exchange rate).

The responses of all five variables given an exogenous shock to the output gap equation are shown in figure 4. The output gap shock could be adequately described by an aggregated demand or aggregated supply shock Fisher, Mahadeva, and Whitley (2014). The output gap immediately increases with the shock and proceeds widening. This is in line with a demand shock causing an increase in output and thus a positive output gap. After one year the slope of the impulse response reverses until the output gap is closed again after two years and turns out to grow negative thereafter. This pattern repeats roughly every four years and reminds of the typical movements in the business cycle where economic expansion leads to a boom phase followed by a period of recession and depression eventually. The fluctuations grow continuously smaller and eventually converge to zero. This pattern can also be observed at the impulse responses of the inflation rate, expected inflation and the interest rate although not as strong.

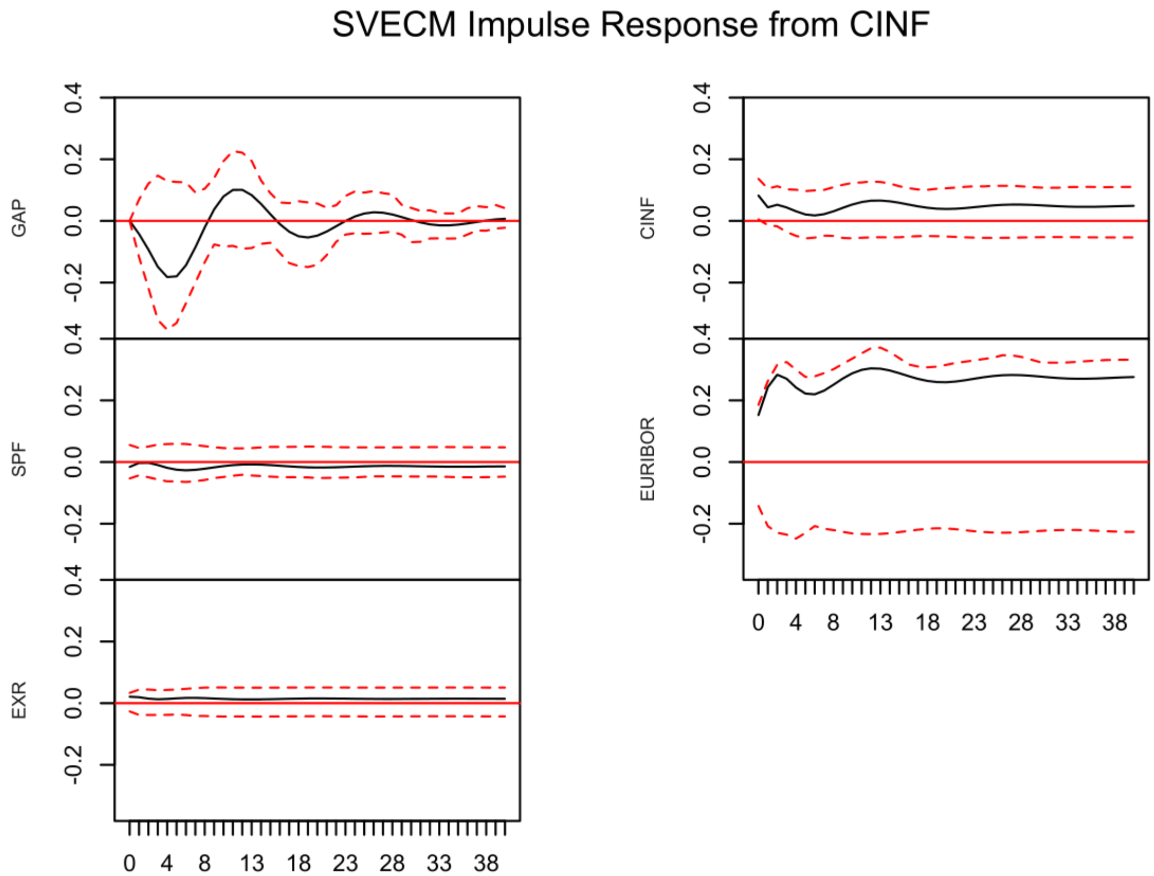
Both inflation and expected inflation increase with the output gap shock during the initial periods. This immediate and positive reaction of inflation can be interpreted as a reaction induced by price pressure since higher (wage) costs eventually lead to increasing prices as proposed in section 2. The inflation reaction shows greater fluctuations than the response for the inflation expectations which is more stable. The time series for expected inflation used to estimate the model does not exhibit strong fluctuations either. The low amplitude makes sense because the inflation expectations are medium-run expectations and agents would not immediately change their long-run forecast tremendously due to a single shock. Agents might in that regard stick to the inflation target of the ECB. The interest rate increases after the output gap shock. A possible explanation is that in order to prevent the economy from overheating and to reduce inflationary pressure induced by the increase in the output gap, the monetary authorities try to discourage further spending. By increasing the interest rate, the opportunity costs of money holding decrease, causing output to decrease too.



Note: The black line indicates the impulse response reaction, the red line is the zero line and the dashed red lines are confidence intervals (95% Bootstrap, 100 runs). The x-axis denotes the time dimension in quarters.

Figure 4: Impulse response functions given a shock to the output gap.

Figure 5 displays the impulse responses after an inflationary shock. The output gap follows a similar but reversed pattern as observed after the output gap shock. With the shock output decreases but slopes upwards again after four periods. Eventually, the output gap closes in the long-run since the amplitude of the fluctuations converges to zero. Again, this reminds of a typical business cycle movement. The inflation rate permanently increases with the shock at a relatively stable level. Only during the first six periods after the shock the inflation rate slightly declines before it increases again, yet it never reaches its original level. As expected, the monetary reaction function exhibits a relatively strong and immediate increase in the interest rate. Trying to avoid a further increase of the price level the interest rate also permanently rises above its initial level. Inflation expectations surprisingly slightly decrease after the shock but permanently remain close the initial level. This could possibly be explained by that inflation expectations anticipate the behavior of the central bank and therefore remain at their initial level close to the ECB´s target inflation. The exchange rate also unexpectedly increases slightly with an inflationary shock. One could have assumed a depreciation in the exchange rate due to higher prices causing the demand for Euro to decrease.



Note: The black line indicates the impulse response reaction, the red line is the zero line and the dashed red lines are confidence intervals (95% Bootstrap, 100 runs). The x-axis denotes the time dimension in quarters.

Figure 5: Impulse response functions given an inflationary shock.

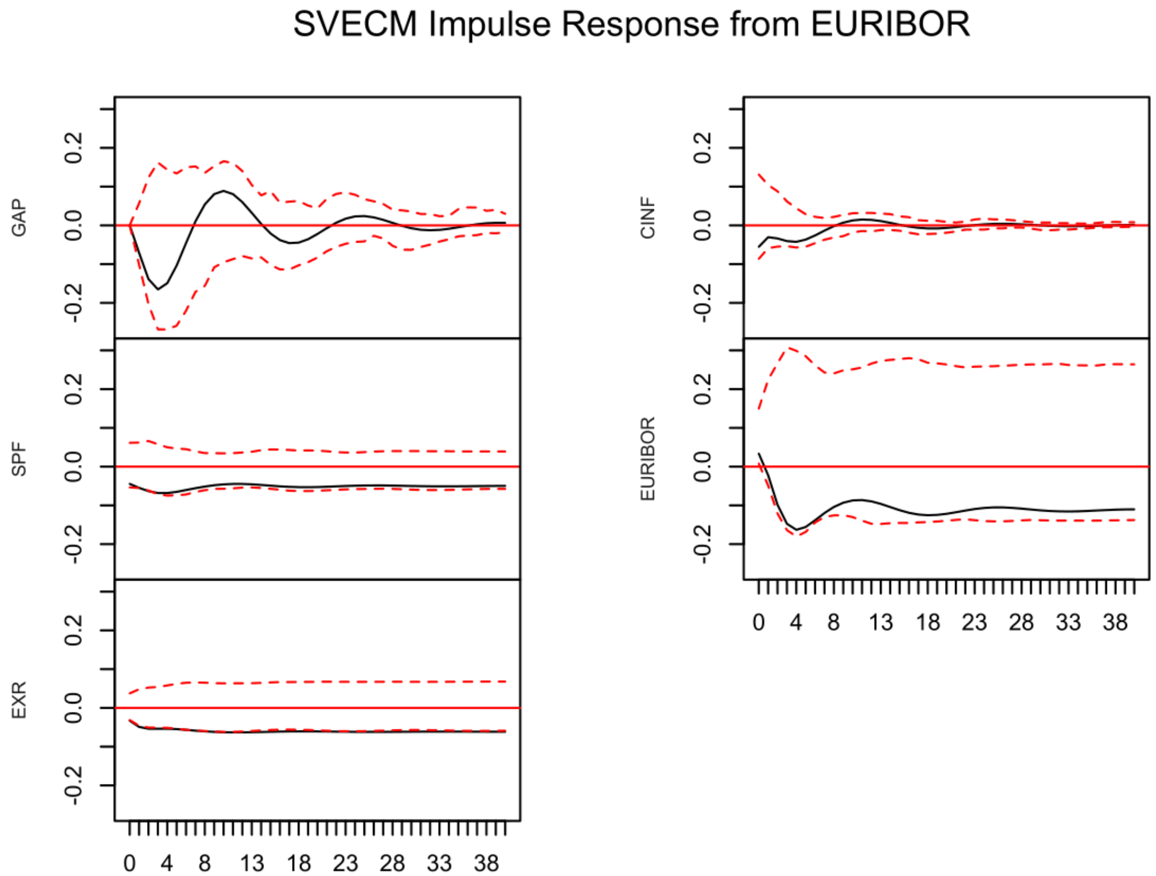
Figure 6 depicts the impulse response functions for a monetary policy shock. The shock could represent a contraction of the money base. The dynamics of the output gap are similar to the reaction after the inflationary shock. In this case the monetary contraction potentially discourages spending in the economy leading to a decrease in output and therefore a decline in the output gap. Again, the output gap follows the pattern observed after the inflationary shock. It starts with stronger fluctuations around the zero line in a four-year interval that eventually decrease. In the long-run, the output gap converges against its initial level. The inflation rate immediately drops with the monetary contraction. Only after eight periods inflation returns to its initial level. Thereafter, inflation slightly increases perhaps due to the simultaneously incline in the output gap inducing price pressure which leads to higher prices. In the long-run the monetary policy shock has no impact on the inflation rate which is in line with the assumptions implied in the identification scheme. This shows that the chosen identification strategy is capable of solving the price puzzle. A monetary contraction does not lead to an increase in prices but to an immediate decrease in the price level eventually returning to the initial level. The interest rate slightly increases with the inflationary shock but sharply declines after the second period. It then again follows the fluctuation pattern that is also visible for the output gap, however, permanently remains at a lower level. This strong reaction potentially reflects the central bank´s goal to avert the downward trend of the inflation rate in the euro area.

The exchange rate immediately falls after the monetary policy shock quickly finding a new equilibrium below the initial value. This depreciation of the euro is a rather unexpected result. The vast VAR literature including the exchange rate suggest that after an interest rate shock the domestic currency appreciates since it has become more attractive for foreign agents to invest in the domestic currency (Kim and Roubini, 2000; Peersman and Smets, 2001; Cologni and Manera, 2008). However, the interest rate also remains at a lower level in the long-run compared to pre-shock state.

The dynamics of the system given a shock to inflation expectations is shown in figure 7. A shock to inflation expectations could arise due to a worldwide increase in oil prices or extreme economic situations like the COVID-19 pandemic since these scenarios are not endogenously modeled. Although, e.g., energy prices are not included in the core inflation measured employed in this model, they still might feed through to prices. Since the production of goods and services more or less relies on energy, higher energy costs eventually pass-through to the core inflation (see Cologni and Manera (2008)).

With the expectation shock the output gap decreases and although it exhibits some fluctuations over time it never returns to the initial value but converges towards a lower new equilibrium. The inflation rate increases as expected with the shock in expectations. Economic agents try to adjust, e.g., wage contracts which in return increases prices to a new equilibrium above the initial value. This relates to the hypothesis of self-fulfilling expectations as agents drive up inflation with their actions which are in return motivated by an expected increase in inflation. The inflation expectations itself only increase slightly with the shock and nearly remain identical to the original values. Agent´s expectations are evidently quite stable possibly due to the reliability of the central bank´s inflation target.

The monetary authorities react with a gradual decline in the interest rate after the shock. This is in line with the central bank´s target to keep inflation at its target rate. Hence, the ECB lowers the interest rate leading to a monetary contraction in

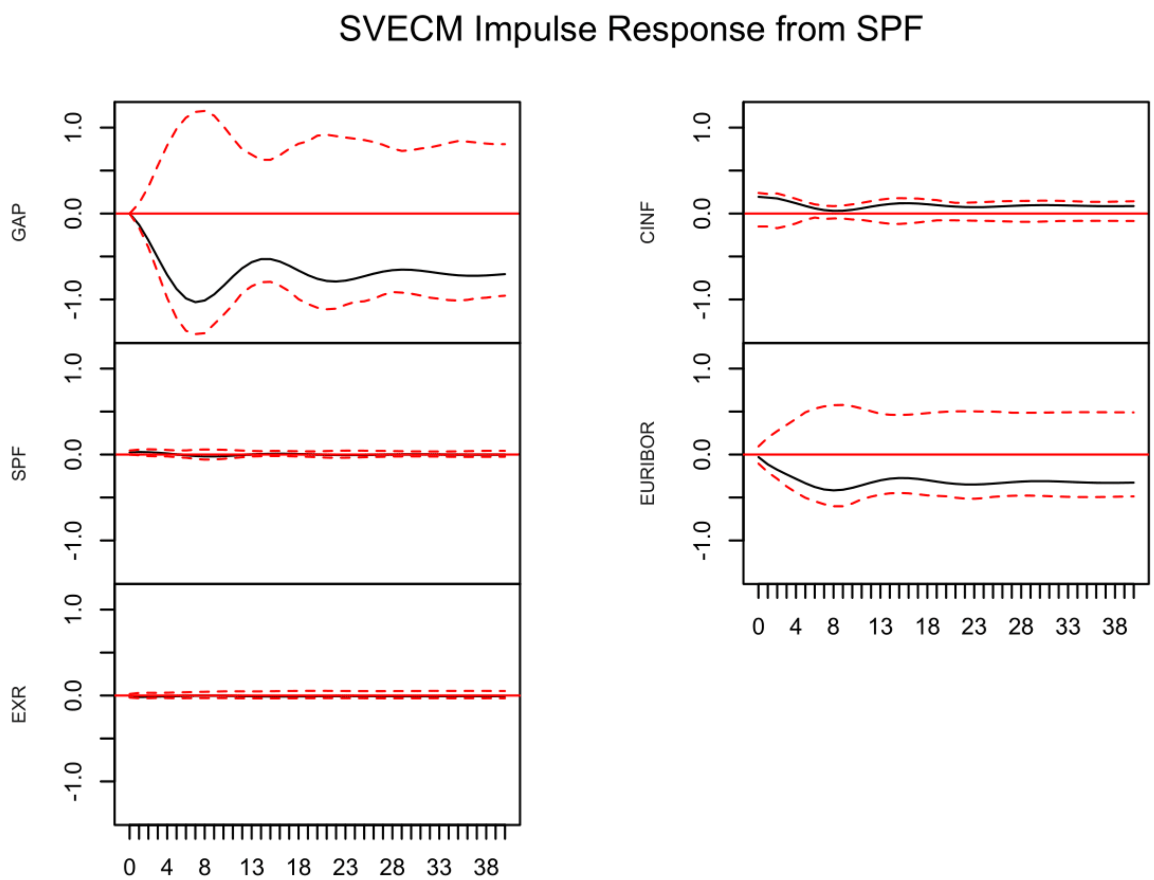


Note: The black line indicates the impulse response reaction, the red line is the zero line and the dashed red lines are confidence intervals (95% Bootstrap, 100 runs). The x-axis denotes the time dimension in quarters.

Figure 6: Impulse response functions given a monetary policy shock.

order to induce disinflationary pressure. The inflation rate indeed declines during the first two years. After that, both inflation and the interest rate slightly increase before they converge towards their new equilibrium. The monetary policy rate permanently remains at a lower level. Also, the nominal exchange rate does not exhibit strong fluctuations or changes after the shock.

Lastly, figure 8 displays the impulse functions after a shock to the nominal exchange rate. The output gap immediately drops with the shock and permanently remains at a level below the initial value. An appreciation of the exchange rate implies higher relative prices for foreign purchases and therefore decreases the demand of domestic goods, hence it leads to a fall in exports.

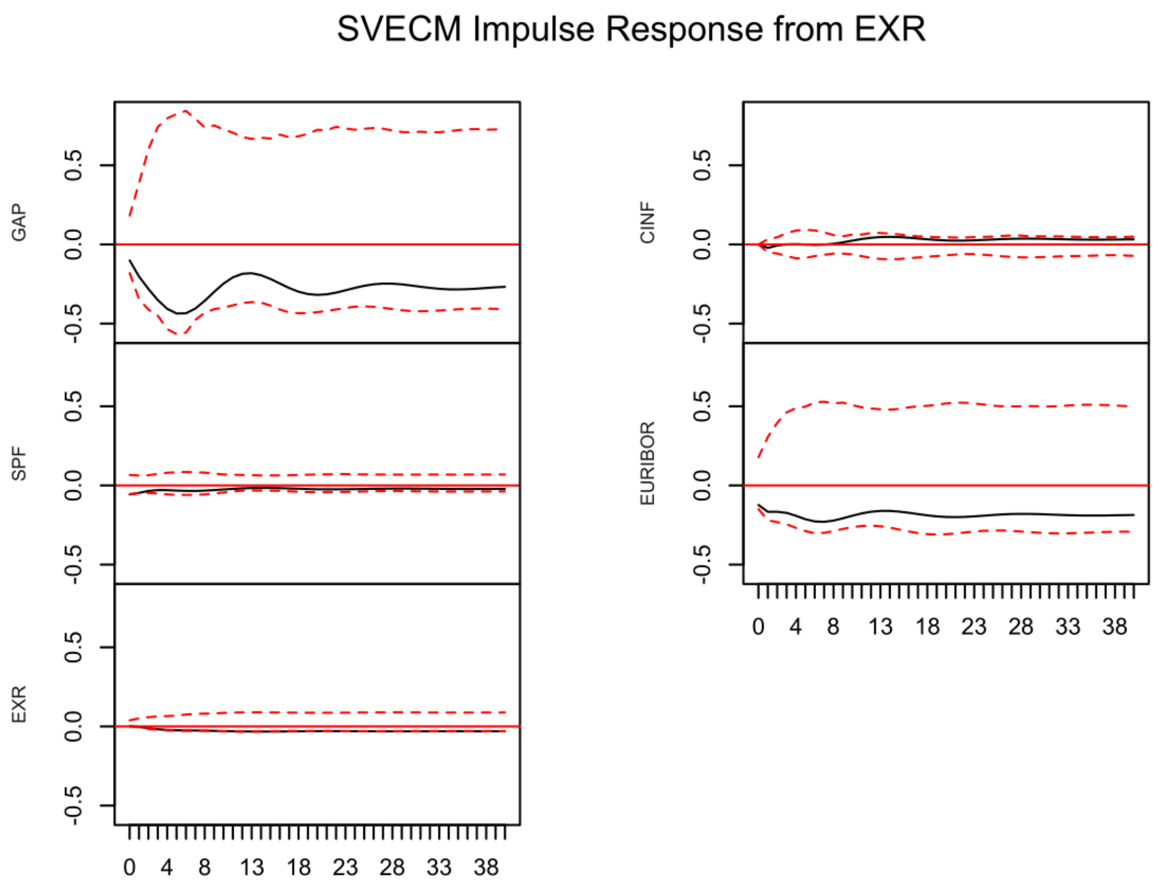


Note: The black line indicates the impulse response reaction, the red line is the zero line and the dashed red lines are confidence intervals (95% Bootstrap, 100 runs). The x-axis denotes the time dimension in quarters.

Figure 7: Impulse response functions given a shock to inflation expectations.

5.2 Forecast error variance decomposition

To evaluate the importance of the single shocks for the variables I computed the forecast error variance decomposition for the output gap, the inflation rate and the monetary policy equation as these three determine the key variables of interest in this model. The following tables show the FEVD for these variables, for the h-period ahead forecasts accounted for by the structural shocks $\epsilon_{\hat{y}}$, ϵ_{π}, ϵ_{π^e}, ϵ_i and ϵ_e. The forecasts errors are presented for up to the 40^{th}-period since the forecast errors slowly converge to a stable path at this horizon. The FEVD describes to what extent the aforementioned shocks explain the variations of the affected variable over time. It describes the contributions of the single shocks to a variable to the forecast error variance or mean squared error Lütkepohl (2005).



Note: The black line indicates the impulse response reaction, the red line is the zero line and the dashed red lines are confidence intervals (95% Bootstrap, 100 runs). The x-axis denotes the time dimension in quarters.

Figure 8: Impulse response functions given an exchange rate shock.

Table 4 lists the forecast error variance decomposition for the output gap. During the initial periods the variations in the output gap are almost solely explained by shocks in the exchange rate and demand shocks or supply shocks respectively. The importance of demand and supply shocks decreases quickly within the first ten quarters whereas shocks to inflation expectations explain increasingly more of the output gap variance. This is in line with the expectation that inflation expectations only affect output after some time since adjustments to output are delayed due to re-negotiations of contracts and re-planning of firms. After forty quarters almost only inflation expectations and the exchange rate play a role for the variance of the output gap. The forecast error variance decomposition for the inflation rate is presented in table 5. Surprisingly, demand and supply shocks barely affect the inflation rate during the initial periods. The inflation rate dynamics are rather driven by inflation

h	$\epsilon_{\hat{y}}$	ϵ_{π}	ϵ_{π^e}	ϵ_i	ϵ_e
1	0.78	0.00	0.00	0.00	0.22
2	0.68	0.01	0.07	0.02	0.22
3	0.56	0.02	0.18	0.04	0.21
4	0.43	0.03	0.30	0.04	0.20
5	0.32	0.03	0.42	0.03	0.20
6	0.23	0.03	0.52	0.03	0.19
7	0.17	0.03	0.60	0.02	0.18
8	0.13	0.02	0.66	0.02	0.17
9	0.11	0.02	0.70	0.01	0.16
10	0.10	0.02	0.72	0.01	0.15
15	0.09	0.02	0.75	0.01	0.13
20	0.08	0.01	0.76	0.01	0.14
25	0.06	0.01	0.78	0.01	0.14
30	0.05	0.01	0.80	0.01	0.13
40	0.04	0.01	0.81	0.01	0.13

Table 4: Forecast error variance decomposition of the output gap.

h	$\epsilon_{\hat{y}}$	ϵ_{π}	ϵ_{π^e}	ϵ_i	ϵ_e
1	0.00	0.14	0.79	0.06	0.00
2	0.01	0.10	0.84	0.05	0.01
3	0.03	0.09	0.83	0.04	0.00
4	0.06	0.09	0.80	0.04	0.00
5	0.09	0.08	0.78	0.05	0.00
6	0.11	0.08	0.76	0.05	0.00
7	0.12	0.08	0.75	0.05	0.00
8	0.12	0.08	0.75	0.05	0.00
9	0.11	0.08	0.75	0.05	0.00
10	0.12	0.09	0.74	0.05	0.00
15	0.11	0.14	0.68	0.04	0.03
20	0.09	0.14	0.70	0.03	0.04
25	0.08	0.15	0.70	0.03	0.05
30	0.07	0.16	0.69	0.03	0.06
40	0.06	0.16	0.70	0.02	0.06

Table 5: Forecast error variance decomposition of inflation.

expectations. Also in the long-run inflation expectation shocks determine the major part of the variance of inflation, permanently between 69% - 84%. The interest rate shocks only play a little role for the inflation rate as they explain only 6% initially and are slowly declining to 2% in the long-run. Inflationary shocks explain a larger portion of inflation´s variance ;between 9% and 16%. These results support the hypothesis of self-fulfilling inflation expectations since ϵ_{π}^{e} explains a large portion of inflation´s forecast error variance. Lastly, the forecast error variance decomposition

h	$\epsilon_{\hat{y}}$	ϵ_{π}	ϵ_{π^e}	ϵ_i	ϵ_e
1	0.00	0.57	0.02	0.03	0.37
2	0.02	0.57	0.10	0.01	0.30
3	0.05	0.53	0.15	0.04	0.23
4	0.07	0.47	0.20	0.07	0.20
5	0.08	0.40	0.25	0.08	0.19
6	0.08	0.35	0.30	0.09	0.19
7	0.07	0.31	0.35	0.08	0.19
8	0.06	0.29	0.39	0.08	0.19
9	0.05	0.28	0.42	0.07	0.18
10	0.04	0.27	0.44	0.06	0.18
15	0.03	0.31	0.45	0.05	0.16
20	0.02	0.32	0.44	0.06	0.16
25	0.02	0.31	0.45	0.06	0.16
30	0.02	0.32	0.45	0.06	0.16
40	0.01	0.32	0.45	0.06	0.16

Table 6: Forecast error variance decomposition of the monetary policy interest rate.

for the monetary policy interest rate is shown in table 6. The major part of the forecast error variance in the initial period is explained by inflationary shocks with 57%. The share of inflationary shocks explaining the interest rate decreases over time but still constitutes a major part of the forecast variance with 32% after ten years. The monetary reaction is hence largely influenced by the inflation rate. This follows the reasoning that the central bank follows an inflation target and adjusts the interest rate accordingly. Moreover, exchange rate shocks take up the next largest share after inflationary shocks. After seven periods however, inflation expectations explain the largest part of the dynamics of the monetary policy rate with 35% increasing up to 45% after ten years.

The output gap, inflation rate and the monetary policy interest rate are all widely affected by inflation expectations at least in the medium to long-run. Interest rate shocks and demand and supply shocks both fade in the long-run and affect neither of the three variables anymore. Demand and supply shocks, however, play a crucial role for the dynamics of the output gap in the short-run.

6 Concluding Remarks

In this paper I set up a structural VECM to assess output, inflation and monetary policy in the Euro area. The analysis is based on a hybrid version of the New Keynesian Phillips curve which includes both past lags of inflation and inflation expectations. For the empirical model however, expectations are not based on theoretical assumptions but on survey data. I also incorporate a measure of the output gap into the Phillips curve. All variables have shown to be integrated of order one ($I(1)$). The Johansen procedure suggests two cointegration relations between the variables. The structural identification strategy is mainly based on decision delay arguments in the short-run and long-run neutrality conditions.

In order to solve the prize puzzle I adapted several ideas from the VAR literature. Since my VAR model is based on a hybrid version of the New Keynesian Phillips curve it contains inflation expectations as a forward-looking variable as proposed by Sims (1980). The Phillips curve also employs the output gap in the model serving as a remedy to the puzzle according to Giordani (2004). Lastly, the structural shocks were not only identified via a recursive short-run ordering but by applying long-run neutrality conditions as proposed by Krusec (2010).

The impulse response analysis shows that according to the assumptions made the output gap is closed in the long-run. Demand and supply shocks, inflationary shocks and monetary shocks shocks do indeed affect the output gap in the short-run amplifying the fluctuations of the business cycle but have no long-run affect. An increase in the output gap induces inflationary pressures and also leads to an increase in the monetary policy rate. An inflationary shock also leads to an immediate increase in the monetary policy rate suggesting that the ECB tries to keep the inflation rate strictly at target. The impulse responses of the exchange rate after the structural shocks however, does not match economic intuition or the results of other models in the literature.

Finally, the FEVD shows that inflation expectations play a crucial role for the dynamics of inflation, the output gap and the monetary policy rate. The interest rate is largely determined by inflationary shocks emphasizing that the ECB focuses on inflation to set the monetary interest rate.

7 References

Ball, Laurence (1998). *Policy Rules for Open Economies*. NBER Working Papers 6760. National Bureau of Economic Research, Inc. URL: https://ideas.repec.org/p/nbr/nberwo/6760.html.

Blanchard, Olivier and Danny Quah (1989). "The Dynamic Effects of Aggregate Demand and Supply Disturbances". In: *American Economic Review* 79(4), pp. 655–73.

Brissimis, Sophocles and Nicholas S. Magginas (2006). "Forward-looking information in VAR models and the price puzzle". In: *Journal of Monetary Economics* 53(6), pp. 1225–1234.

Calvo, Guillermo A. (1983). "Staggered prices in a utility-maximizing framework". In: *Journal of Monetary Economics* 12(3), pp. 383–398. ISSN: 0304-3932. DOI: https://doi.org/10.1016/0304-3932(83)90060-0. URL: https://www.sciencedirect.com/science/article/pii/0304393283900600.

Chow, Gregory C. and An-loh Lin (1971). "Best Linear Unbiased Interpolation, Distribution, and Extrapolation of Time Series by Related Series". In: *The Review of Economics and Statistics* 53(4), pp. 372–375. ISSN: 00346535, 15309142. URL: http://www.jstor.org/stable/1928739.

Christiano, Lawrence J., Martin Eichenbaum, and Charles Evans (1999). "Chapter 2 Monetary policy shocks: What have we learned and to what end?" In: vol. 1. Handbook of Macroeconomics. Elsevier, pp. 65–148. DOI: https://doi.org/10.1016/S1574-0048(99)01005-8. URL: https://www.sciencedirect.com/science/article/pii/S1574004899010058.

Clarida, Richard, Jordi Galí, and Mark Gertler (1998). "Monetary policy rules in practice: Some international evidence". In: *European Economic Review* 42(6), pp. 1033–1067. ISSN: 0014-2921. DOI: https://doi.org/10.1016/S0014-2921(98)00016-6. URL: https://www.sciencedirect.com/science/article/pii/S0014292198000166.

Cologni, Alessandro and Matteo Manera (2008). "Oil prices, inflation and interest rates in a structural cointegrated VAR model for the G-7 countries". In: *Energy Economics* 30(3), pp. 856–888. ISSN: 0140-9883. DOI: https://doi.org/10.1016/j.eneco.2006.11.001. URL: https://www.sciencedirect.com/science/article/pii/S0140988306001393.

Eichenbaum, Martin and Charles Evans (1995). "Some Empirical Evidence on the Effects of Shocks to Monetary Policy on Exchange Rates". In: *The Quarterly Journal of Economics* 110(4), pp. 975–1009.

Fanelli, Luca (2008). "Testing the New Keynesian Phillips Curve Through Vector Autoregressive Models: Results from the Euro Area*". In: *Oxford Bulletin of Economics and Statistics* 70(1), pp. 53–66.

Fischer, Stanley (1977). "Long-Term Contracts, Rational Expectations, and the Optimal Money Supply Rule". In: *Journal of Political Economy* 85(1), pp. 191–205. ISSN: 00223808, 1537534X. URL: http://www.jstor.org/stable/1828335.

Fisher, Paul G., Lavan Mahadeva, and John D. Whitley (2014). "The output gap and inflation-experience at the Bank of England". In.

Galí, Jordi and Mark Gertler (1999). "Inflation dynamics: A structural econometric analysis". In: *Journal of Monetary Economics* 44(2), pp. 195–222. ISSN: 0304-3932. DOI: https://doi.org/10.1016/S0304-3932(99)00023-9. URL: https://www.sciencedirect.com/science/article/pii/S0304393299000239.

Galí, Jordi, Mark Gertler, and J. David López-Salido (2005). "Robustness of the estimates of the hybrid New Keynesian Phillips curve". In: *Journal of Monetary Economics* 52(6). The econometrics of the New Keynesian price equation, pp. 1107–1118. ISSN: 0304-3932. DOI: https://doi.org/10.1016/j.jmoneco.2005.08.005. URL: https://www.sciencedirect.com/science/article/pii/S0304393205000760.

Giordani, Paolo (2004). "An alternative explanation of the price puzzle". In: *Journal of Monetary Economics* 51(6), pp. 1271–1296. ISSN: 0304-3932. DOI: https://doi.org/10.1016/j.jmoneco.2003.09.006. URL: https://www.sciencedirect.com/science/article/pii/S0304393204000686.

Goldberg, Pinelopi Koujianou and Michael M. Knetter (1997). "Goods Prices and Exchange Rates: What Have We Learned?" In: *Journal of Economic Literature* 35(3), pp. 1243–1272. ISSN: 00220515. URL: http://www.jstor.org/stable/2729977.

Hamilton, James D. and Charles H. Whiteman (1985). "The observable implications of self-fulfilling expectations". In: *Journal of Monetary Economics* 16(3), pp. 353–373. ISSN: 0304-3932. DOI: https://doi.org/10.1016/0304-3932(85)90041-8. URL: https://www.sciencedirect.com/science/article/pii/0304393285900418.

Johansen, Soren (1995). *Likelihood-Based Inference in Cointegrated Vector Autoregressive Models*. Oxford University Press.

Judd, John P. and Glenn Rudebusch (1998). "Taylor's rule and the Fed, 1970-1997". In: *Economic Review*, pp. 3–16.

Kilian, Lutz and Helmut Lütkepohl (2017). *Structural Vector Autoregressive Analysis*. Themes in Modern Econometrics. Cambridge University Press. DOI: 10.1017/9781108164818.

Kim, Soyoung and Nouriel Roubini (June 2000). "Exchange rate anomalies in the industrial countries: A solution with a structural VAR approach". In: *Journal of Monetary Economics* 45(3), pp. 561–586.

Krusec, Dejan (Mar. 2010). "The "price puzzle" in the monetary transmission VARs with long-run restrictions". In: *Economics Letters* 106, pp. 147–150. DOI: 10.1016/j.econlet.2009.04.027.

Lütkepohl, Helmut (Jan. 2005). *The New Introduction to Multiple Time Series Analysis*. ISBN: 978-3-540-40172-8. DOI: 10.1007/978-3-540-27752-1.

Peersman, Gert and Frank Smets (2001). *The monetary transmission mechanism in the euro area: more evidence from VAR analysis*. Working Paper Series 91. European Central Bank.

Pfaff, Bernhard (July 2008). "VAR, SVAR and SVEC models: implementation within R package vars". In: *Journal of Statistical Software* 27. DOI: 10.18637/jss.v027.i04.

Quah, Danny and Shaun P. Vahey (1995). "Measuring Core Inflation". In: *The Economic Journal* 105(432), pp. 1130–1144. ISSN: 00130133, 14680297. URL: http://www.jstor.org/stable/2235408.

Sims, Christopher A. (1980). "Macroeconomics and Reality". In: *Econometrica* 48(1), pp. 1–48. ISSN: 00129682, 14680262. URL: http://www.jstor.org/stable/1912017.

Sims, Christopher A. (1986). "Are forecasting models usable for policy analysis?" In: *Quarterly Review* 10(Win), pp. 2–16.

Sims, Christopher A. and Tao Zha (Apr. 2006). "Does Monetary Policy Generate Recessions?" In: *Macroeconomic Dynamics* 10(2), pp. 231–272.

Svensson, Lars (June 1999). "Inflation targeting as a monetary policy rule". In: *Journal of Monetary Economics* 43(3), pp. 607–654.

Svensson, Lars E.O. (2000). "Open-economy inflation targeting". In: *Journal of International Economics* 50(1), pp. 155–183. ISSN: 0022-1996. DOI: https://doi.org/10.1016/S0022-1996(98)00078-6.

Taylor, John (1980). "Aggregate Dynamics and Staggered Contracts". In: *Journal of Political Economy* 88(1), pp. 1–23.

Vlaar, Peter (2004). "Shocking the eurozone". In: *European Economic Review* 48(1), pp. 109–131.

Woo, Wing T. (1984). "Exchange Rates and the Prices of Nonfood, Nonfuel Products". In: *Brookings Papers on Economic Activity* 15(2), pp. 511–536.