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Structural changes in the euro area –

An evaluation of changes in the transmission mechanisms of monetary policy for selected economies

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Abstract:
In the recent decades, there have been major developments in the euro area: increased globalization, changes in the financial markets and a restructuring of the euro area economy during the transition to economic and monetary union (EMU). This empirical study analyzes the impacts of these developments – with a special focus on the transition to EMU – on the transmission mechanisms of monetary policy for selected Member States of the euro area (Germany, France, the Netherlands, Italy, Spain and Portugal). According to the Lucas critique, major changes in policy regimes can influence the dynamics of econometric models. Therefore, a time-varying vector autoregressive (TV-VAR) model is employed to test for and identify structural changes. The empirical study provides strong evidence for parameter instabilities during the observation period between 1990m1 (1992m1 for Germany) and 2007m12 for all countries. The identified changes in the transmission mechanisms seem to occur rather instantaneously and mostly around the period between stage two and three of the transition to EMU. Evidence on the effects of structural changes on the transmission mechanisms is mixed for the analyzed variables and countries. However, the empirical study provides suggestive evidence for changes in the evolution of changes in the short-term interest rate after the occurrence of a shock that appear to have become more persistent. Furthermore, a certain degree of convergence of the effects of monetary policy shocks can be observed for countries of the same type.

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Monetary policy, transmission mechanisms, EMU, TV-VAR model, unemployment, inflation

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Glossary

Countries and Regions

EMU	Economic and monetary union
EU	European Union
U.K.	United Kingdom
U.S.	United States

Economic terms

CPI	Consumer price index
EC	European Council; consists of the heads of state or government of the EU Member States
ECB	European Central Bank
EEC	European Economic Community; an international organization created by EU Member states that should bring about economic integration
EMI	European Monetary Institute; forerunner of the ECB
EMS	European Monetary System; established in 1979, most economies in the European Economic Community linked their currencies to prevent large fluctuations to one another
ERM	Exchange rate mechanism; was created in 1979 to reduce exchange rate variability and introduced fixed margins in which the currency exchange rates were supposed to fluctuate
ERM II	Exchange rate mechanism II; fixes the exchange rates of other EU currencies against the euro and only allows fluctuations within limits
ESCB	European System of Central Banks; consists of the ECB and national central banks of Member States of the EU
EUR	Euro
Eurosystem	Consists of the ECB and national central banks of Member States of the euro area
GATT	General Agreement on Tariffs and Trade; multilateral agreement regulating international trade by reducing tariffs and other trade barriers
GDP	Gross domestic product
HICP	Harmonized Index of Customer Prices; provides the official measure of consumer price inflation in the euro area

IFRS	International Financial Reporting Standards; designed to increase the international transparency and comparability of financial statements
M	Million
NBC	National central bank
OECD	Organization for Economic Co-operation and Development
SGP	Stability and Growth Pact; requires the Member States of the euro area to run their fiscal policies within the limits of government deficit and debt
TEU	Treaty on European Union; restructured the organization of the EU and defined convergence criteria
Transmission mechanisms	Describe the process by which monetary policy affects the general economy and especially the price level

Technical econometric terms

ADF test	Augmented Dickey-Fuller test; designed to test for the presence of a unit root in the process (Said and Dickey, 1984)
AIC	Akaike Information Criterion
AR model	Linear autoregressive model; univariate system that attempts to explain the evolution of a time series by its history
Cointegration	Refers to the long-run equilibrium relationship among a set of nonstationary variables implying that their stochastic trends must be linked (Enders, 2010)
FD	First differences; defined as the value of the function when evaluated at $t = t * +h$ minus the value of the function evaluated at $t = t*$
Identifying restrictions	Imposed restrictions on the causal structure of the variables in the multivariate system
LM test	In this study: Lagrange-multiplier test of Johansen (1995); test designed to test for remaining residual autocorrelation
NLS	Nonlinear least squares
OIR	Orthogonalized impulse response; allows to trace out the time path of the various shocks on the variables contained in the VAR system Enders (2010), accounts for interdependencies of the contemporaneous error terms by imposing identifying restrictions
Parameter constancy test	Tests the constancy of the dynamic behavior of a system
Parsimony	Attempts to emphasize sparseness of econometric models to prevent poorly estimation results caused by a reduction of the degrees of freedom (Enders, 2010)
Regimes switching model	Allows the dynamic behavior of a series to depend on a regime that occurs at a given point of time (Enders, 2010)

SBC	Schwarz Bayesian Information Criterion
Smooth transition	Framework that allows the parameters to change smoothly and continuously between different regressions
STAR model	Smooth transition autoregressive model; allows the autoregressive parameters to change smoothly and continuously between regimes depending on a transition variable (see Lin and Teräsvirta, 1994)
TV-VAR model	Time-varying vector autoregressive model; multivariate extension of the STAR model with time as the transition variable (see He et al., 2009)
Unidentified nuisance parameters	Problem of linearity testing in the TV-VAR framework; the model contains parameters that are not restricted under the null hypothesis of linearity and can contain any value
Unit root	Feature of a non-stationary series; series whose means and variances are not constant across time
VAR model	Linear vector autoregressive model; multivariate system with dynamic relationships between variables and their history while treating all variables symmetrically (Enders, 2010)

Main model parameters

$\mathbf{c}_{ij}$	Threshold parameters for equation $i = 1, ..., m$ and the number of change $j = 1, ..., k$; determine the locations of the changes between the two regimes
$\mathbf{D}_0$	Coefficient matrix; is related to system A that is associated with the extreme case $\mathbf{G}(t) = \mathbf{0}$ of the transition function
$\mathbf{D}_1$	Coefficient matrix; the combined effect $\mathbf{D}_0 + \mathbf{D}_1$ is related to system B that is associated with the extreme case $\mathbf{G}(t) = \mathbf{1}$ of the transition function
$\boldsymbol{e}_t$	Error vector
γ_i	Smoothness parameter for equation $i = 1, ..., m$; determines the speed of the change in the transition function
k	Number of changes, determine the functional form of the transition function
m	Number of equations
p	Lag order
$\boldsymbol{\phi}^i$	Intercept vector for regime i with $i = 1, 2$
$\boldsymbol{\Phi}_j^i$	Parameter matrix j with $j = 1, ..., p$ for regime i with $i = 1, 2$
t	Transition variable; time in the TV-VAR model
T	Sample horizon; number of observations

1 Introduction

During the last decades, the euro area has been subject to a number of global and area-wide structural changes that had impacts on the functioning of the participating economies. To begin with, a growing degree of globalization has brought a denser integration of international markets. Furthermore, there have been major changes in the financial markets such as the development of new products and changes in the supervisory regulations on the capital adequacy and reporting requirements of banks. One change that especially affected the euro area countries was the transition to economic and monetary union (EMU). This transition was implemented in three stages in July 1990, January 1994 and January 1999. These transition steps led to the introduction of a common currency and the implementation of a single monetary policy within the euro area. The focus of this thesis is placed on this transition. The three clearly cut transition stages can serve as a natural experiment (Meller and Nautz 2012) and can be compared to endogenously identified changes in the dynamics of the countries. With respect to the main goal of implementing a common monetary policy regime, this thesis analyzes the impacts of these structural changes on the transmission mechanisms of monetary policy – the process by which monetary policy affects the general economy and especially the price level – in an empirical analysis for selected economies. The analysis is conducted for six large economies of the euro area that can be classified by two categories: *type A countries* (containing Germany, France and the Netherlands) that met the Eurosystem's goal of price stability already at the start of the transition while *type B countries* (containing Italy, Spain and Portugal) had to implement major adjustments prior to stage three of the transition.

The idea that structural changes affect the dynamic structure of the economy dates back to Lucas (1976). The economist suggested to take these changes into account in econometric modeling. There is a huge stand of empirical literature that is concerned about the changes in the euro area and its impact on the dynamics of economic variables. However, most of the previous research focuses on specific factors and channels of the transmission mechanisms and has provided mixed evidence (Weber et al. 2009). Furthermore, empirical research on changes in the transmission mechanisms of monetary policy as a whole has been limited. The methodology applied in these studies relies mostly on exogenously determined break dates and instantaneous shifts. This thesis aims at contributing to this field of economic research.

The scope of the empirical study is placed on the identification whether and in how far structural changes in the euro had an impact on the transmission mechanisms for the selected countries. Furthermore, it is evaluated whether these effects were different for the identified two types of countries. For this purpose, the empirical study employs a different, recently developed multivariate framework that allows the coefficients to vary smoothly and continuously between extreme regimes across time without exogenously determining the break dates. This framework is called the time-varying vector autoregressive (TV-VAR) model. In contrast to studies in the early 2000s, the study benefits from sufficient data availability for both the pre-EMU and post-EMU era. Employing the specified framework, dynamics between the short-term interest rate (representing the monetary policy block), the unemployment rate (representing the real economy) and the inflation rate are analyzed for the time between January 1990 (1992 for Germany) and December 2007. The empirical results provide strong evidence for structural instabilites during the observed period for all countries under examination. There is evidence that the timing and the number of changes in the dynamics differ for the examined variables and countries. Furthermore, changes in the dynamics seem to occur rather instantaneously and mostly around the period between stage two and three of the transition to EMU. Evidence on the effects of structural changes on the transmission mechanisms is mixed, indicating that the changes in the dynamics seem to differ between the analyzed variables and countries. However, the empirical study provides suggestive evidence for changes in the evolution of changes in the short-term interest rate after the occurrence of a shock for all analyzed countries that appear to have become more persistent. Furthermore, the effects of monetary policy shocks seem to have converged to a certain degree for the countries of the same type.

The empirical study is organized as follows: Section 2 provides an overview of the theoretical background of the transmission mechanisms of monetary policy with a special focus on changes in the euro area during the transition to EMU. In section 3, existing empirical evidence concerning changes in specific factors and channels of the transmission mechanisms of monetary policy and the transmission mechanism as a whole is reviewed. Thereafter, section 4 presents the econometric framework of the TV-VAR model as well as the empirical specification procedure. Section 5 provides a detailed description of the data and its preliminary tests. Sections 6 and 7 present and a discuss the empirical findings, respectively. Finally, section 8 concludes.

2 Transmission mechanisms of monetary policy in the euro area

In order to analyze potential effects of structural changes in the euro area on dynamics of the participating economies, it is necessary to understand the main dynamics in the transmission mechanisms of monetary policy as well as the structural development that has taken place in the euro area in the last decades. Therefore, this section shall provide an overview of the theoretical background: Section 2.1 describes the transmission mechanisms of monetary policy in a simplified framework with a special focus on the euro area. Thereafter, section 2.2 provides an overview of the preparatory efforts in the run-up to the formation of the euro area as well as of the guidelines for the first decade. Finally, section 2.3 presents the monetary policy and macroeconomic situation for the objects of research in the subsequent empirical analysis.

2.1 Transmission mechanisms of monetary policy

Transmission mechanisms describe the process by which monetary policy affects the general economy and especially price level. These mechanisms contain a complex network of transmission channels. With respect to the simultaneous occurrence of shocks as well as technological and structural changes, a precise assessment of the effects of monetary policy is very difficult. Therefore, the main aspects of the transmission mechanisms of monetary policy[1] shall be described in the following in order to provide a theoretical background for the subsequent analysis. The presented framework is based on the theory of the monetarist transmission mechanisms. In the course of the following description, a special focus is placed on the euro area. The transmission mechanisms can be characterized to work at three simplified stages as presented in figure 2.1 (refer to Appendix A.1 for a more detailed chart).

Starting at the first stage, changes in the monetary policy will influence the money market conditions. This will have effects on the economy through four main channels: With respect to the consequences on their refinancing options, financial institutions will pass these changes in the money market conditions through to their customers – firms and households –

[1]Information are primarily based on the review in European Central Bank (2000b).

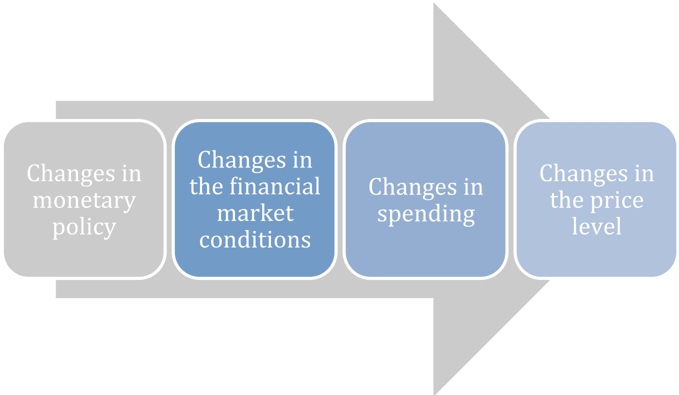

Figure 2.1: Simplified framework of transmission mechanisms of monetary policy

by changing bank credit and deposit rates[2] (the *interest rate channel*). Furthermore, changes in the market interest rates can influence asset prices that are determined as the value of their discounted future revenue stream, and hence can be either influenced by changes in the intertemporal discount rate or changes in the future revenue streams (the *wealth channel*). In addition, changes in the money market can potentially affect the credit availability in the credit markets when changes in the interest rate structure induce banks to shorten their supply of loans (the *credit channel*). Finally, the exchange rate will also be affected if the changes in the market interest rates will have influences on the nominal interest rate differentials in different currencies (the *exchange rate channel*). Since the uncovered interest parity condition[3] should hold, exchange rates will adjust.

Considering that prices will adjust only gradually, the previously described changes in the financial market conditions can lead to changes in nominal spending. Changes in the cost of capital can have effects the on investment decisions of firms – depending on the degree of capital intensity within the respective industry – and spending decisions of households on consumer durables (for instance, houses or cars). In addition, changes in the values of their assets can affect the wealth of the respective households. In how far this will affect overall spending will depend on the households' propensity to use this wealth to finance consumption as well as on whether these assets are held by a significant proportion of the population. Similar effects can also occur for firms and may indirectly influence firm spending if these appreciated assets are used as collateral in credit contracts. Changes in the credit availability may also play a role for the investment and spending decisions of firms and households, respectively. Furthermore, changes in the exchange rates will have effects on the terms of trade – the relationship of exports and imports – since the prices of domestic

[2]These adjustments will depend on the direction of the interest rate changes and the funding structure of the respective bank.

[3]The uncovered interest parity condition requires that investors should expect to obtain the same return on their investments in various currencies (Blanchard 2011).

products in foreign currency terms and foreign products in domestic currency terms are subject to changes.

The aforementioned changes will finally influence the price level in the long run. These inflationary pressures will work through the channels of import and domestic prices: Starting at the exchange rates, changes in import prices also will both influence consumer prices as well as producer prices, the latter ones by using imported intermediate goods in the production process that directly influences firm costs, and hence will be transferred to the end consumer. Furthermore, an increased demand will effect that the firms will produce above capacity in order to avoid the creation of bottlenecks in the economy. This will lead in the short run to an increased utilization of the labor force (for instance, by overtime and additional shifts) and wage pressures in the long run. As a consequence unit labor cost rises that will increase the cost of production and will also be transferred by the firms to the end customer in order to maintain their profitability. Both the increase in import prices and in domestic prices will finally affect the overall price level in the economy. How fast the changes in spending translate into changes in the overall price level depends mainly on the degree of nominal price rigidities and the overall flexibility of the economy. While econometric evidence (European Central Bank 2000b) suggests for the euro area that nominal price rigidities[4] have been comparable with the United States, the speed of adjustment of real wages to changes in unemployment has been much slower with reference to structural differences in the labor markets.[5] This in turn has a dampening effect on the adjustments of the overall price levels in the euro area with reference to the aforementioned price setting strategies of the firms.

Some other aspects should be mentioned that can largely influence the dynamic behavior of the transmission mechanisms. An important role plays the formation of expectations of various actors in the economy: If changes in monetary policy can be anticipated, changes in the financial market conditions will actually lead, rather than lag, the policy decisions. Furthermore, spending decisions of households and firms can be influenced if they take the general economic development into account during their decision process. Expectations do also directly influence price and wage-setting – the latter one since wages are negotiated in a forward-looking manner in the euro area –, and hence the overall price level. Moreover, the transmission mechanisms of monetary policy are subject to shocks outside the system. The current literature (European Central Bank 2010b) identifies three main developments in the

[4]Nominal price rigidities refer to the circumstance that prices are sticky because of, for instance, potential menu cost or imperfect information about the real market conditions.

[5]Structural differences are for instance the existence of labor unions and extensive labor law in the euro area versus a high degree of flexibility on the labor market in the United States (for instance, possibility of hiring and firing).

last decade that can have lead to major changes in the transmission mechanisms of monetary policy:

1. **Increased globalization:** One consequence of the globalization has been the increased degree of international trade changing the terms of trade. It has been argued that for this reason the relationships between the domestic macroeconomic variables may have changed worldwide.[6] Furthermore, this can have lead to a reduction of the dependency of domestic inflation on domestic output and therefore a reduction in the effectiveness of monetary policy (Weber et al. 2009).

2. **Changes in the financial markets:** During the last decade, major developments in the financial market have taken place including the expansion of securitization activities,[7] growing disintermediation of banks as well as changes in the supervisory regulations on the capital adequacy and reporting requirements of banks. These developments have increased the range of activities of financial market participants and can have lead to an accelerated pass-though of changes in the short-term interest rates to segments in the financial market such as bank rates and asset prices (European Central Bank 2010b).

3. **Transition to EMU:** The transition process to EMU may have had considerable influences on the structure of the euro area economy and therefore the transmission mechanisms of monetary policy. Its main changes included (a) the launch of the euro that eliminated exchange rates in the euro area and fixed other exchange rates in the EU within a band in ERM II, (b) the creation of a common central bank in charge of a single monetary policy within the euro area and (c) structural reforms of the labor and product markets that fostered the integration of the economies.[8]

The focus of this empirical study lies on analyzing potential structural changes of the transmission mechanisms during the transition to EMU.[9] To provide the necessary background, the next section gives a detailed overview of the preparatory efforts and structural changes in the run-up to the introduction of the euro and the implementation of a single monetary policy.

[6] See for instance, Galí and Gambetti (2009) and Giannone et al. (2008).

[7] Securitization refers to the financial practice of pooling assets, for instance issued loans, and selling interests in the pool to various investors. Banks have used this practice for instance as an opportunity to raise extra funds.

[8] An further explanation will be provided in section 2.2.

[9] However, the other aforementioned structural changes in the financial sector and the overall world economy should be kept in mind during the further analysis.

2.2 Transition to EMU

The euro area is an EMU of 17 out of 27 Member States of the European Union (EU) (see Appendix A.2.1 for an overview of the Member States of the euro area according to their accession date). The foundation for the transition to EMU was laid in Hanover, Germany, in June 1988 with the confirmation of the European Council (EC) to realize stepwise an EMU in the European Union (EU). The Delors Report (1989) recommended to implement the transition in three major stages (see A.3 for an overview):

The first stage started on July 1, 1990 when all restrictions regarding the movement of capital were abolished among Member States. Furthermore, cooperation between the national central banks of the Member States was increased with the objective to achieve price stability. In addition, a revision of the Treaty establishing the European Economic Community (1957; commonly referred to as the Treaty of Rome) was a necessary legal adjustment of the institutional structure for the implementation of later stages. The resulting Treaty on European Union (TEU; commonly referred to as the Treaty of Maastricht (1992)) restructured the organization of the EU and set up the convergence criteria that defined the criteria for the Member States of the EU to enter the third stage to EMU. The convergence criteria should provide an indication of stability and soundness of a Member States' public finances and were created to promote convergence of the future euro area countries during the time prior to the euro and the effectiveness of a common monetary policy. Figure 2.2 provides an overview of these criteria. The TEU was signed by the members of the European Council in Maastricht, the Netherlands, on February 7, 1992 and came into force on November 1, 1993.

The second stage started on January 1, 1994 in Frankfurt, Germany, with the establishment of the European Monetary Institute (EMI) as the forerunner of the European Central Bank (ECB). The EMI's task was not to conduct monetary policy in the EU but to strengthen cooperation and monetary policy coordination of the NBCs. Furthermore, the institute was responsible for the preparations of (1) the establishment of the European System of Central Banks (ESCB),[10] (2) the conduct of a single monetary policy, and (3) the creation of a single currency in the third stage. In December 1995, the EC decided that the new European currency unit should be named "euro" and that the transition to the common currency should start on January 1, 1999. The EC further adopted the Stability and Growth Pact (SGP) in June 1997 that constituted an agreement between the Member States of the EU ensuring budgetary discipline of the Member States as a complement to the convergence criteria.

[10]The ESCB consists of the ECB and the national central banks of the Member States of the European Union.

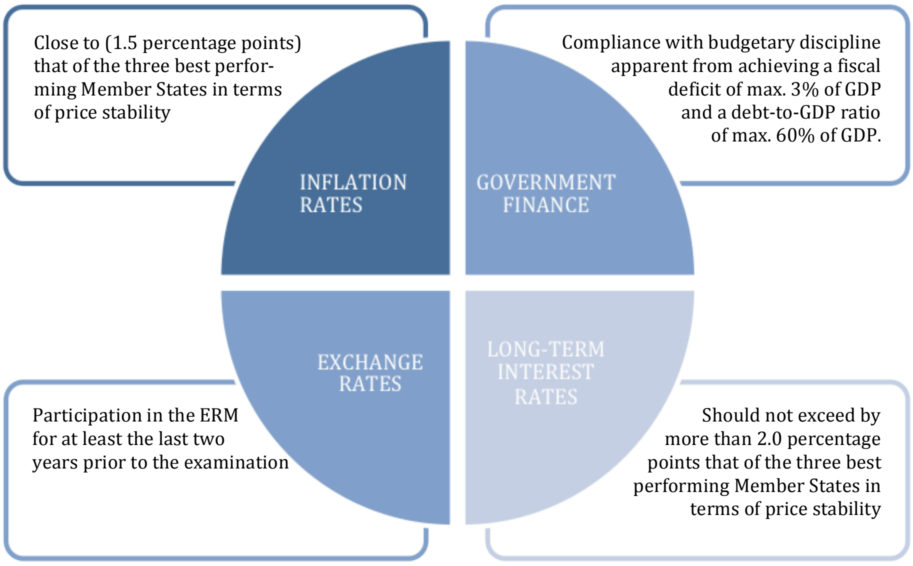

Figure 2.2: Convergence criteria

Under the SGP, the Member States were required to run their fiscal policies within the limits of government deficit (3% of GDP) and debt (60% of GDP). In case of a debt-to-GDP ratio higher than the reference value of 60%, they should aim at decreasing it at a sufficient pace for the purpose of maintaining stability in the EMU. Between 1994 and 1998, the Member States made preparatory efforts to meeting the convergence criteria and took steps towards economic policy convergence. On May 2, 1998, 11 out of (at that time) 15 Member States[11] met the convergence criteria, and hence were allowed to participate in the third stage of the EMU that would include the adoption of the euro on January 1, 1999. In June 1, 1998, the ECB was established and replaced the EMI.

Finally, the third stage to EMU lead to the largest changes for the participating Member States. These changes contained an (1) irrevocable fixing of exchange rates between the 11 Member States (December 31, 1998), (2) the introduction of the euro as the common currency, and (3) the introduction of a single monetary policy conducted under the responsibility of the Eurosystem (both January 1, 1999) that comprises of the ECB (deciding about the monetary policy) and the NCBs of the Member States (being responsible for applying the monetary policy decided by the ECB). Furthermore, the Exchange Rate Mechanism (ERM II) was set up on January 1, 1999. This regulation fixed the exchange rates of other EU currencies against the euro and only allowed fluctuations within limits. Its purpose was to prevent major exchange rate fluctuations that could lead to economic instability. It further should

[11] The remaining four countries did not join the euro area at this time for several reasons. The United Kingdom and Denmark are generally not obliged to join the EMU since they both secured an opt-out from having to introduce the euro: the former in the initial Maastricht Treaty negotiations, the latter in the Edinburgh Agreement in December 1992. Greece and Sweden did not fulfill the necessary criteria.

help non-euro countries to prepare themselves for the participation in the euro area. For the first three years, the euro was an invisible currency since it was only used for accounting purposes. This transition period ended on January 1, 2002 when euro cash was introduced and replaced the national currencies of the Member States of the euro area at fixed conversion rates.

Furthermore, two major guidelines should be mentioned that were influential for the development of the euro area in the first decade. In the Lisbon Agenda, set up in March 2000, the European Council set one guideline for the next decade: The EU should "become the most dynamic and competitive knowledge-based economy in the world by 2010 capable of sustainable economic growth with more and better jobs and greater social cohesion and respect for the environment" (European Council 2000). This guideline was set up to deal with low levels of productivity and stagnation of economic growth by introducing a set of interventions that included structural reforms in labor and product markets. Even though these objectives could not be reached completely, the reforms stipulated strong employment growth and low levels of unemployment prior to the financial crisis and – though not far reaching enough (European Central Bank 2005) – progress has been achieved in the integration of the Internal Market. The implemented Eurosystem set another guideline for the conduct of monetary policy: The primary objective of its monetary policy is to maintain price stability by keeping the increase in the Harmonized Index of Consumer Prices (HICP) at a level below 2% in the medium run.[12] This objective was set as price stability is considered to be the pre-condition to maintain high levels of economic growth and employment in the economy.[13]

2.3 Key countries of the empirical study

These changes during the transition to EMU had influenced on the economies of the Member States entering stage three of the transition to EMU to a varying extent depending on their prior policies and economic development. The subsequent empirical analysis shall provide further insights in the effects of the transition to EMU on the transmission mechanisms of monetary policy for different types of countries belonging to the euro zone. In the course of the analysis, the countries are classified with respect to the degree of adjustments necessary to meet the Eurosystem's objective of price stability: *Type A countries* are characterized by stable inflation rates prior to and after their accession of the euro area whereas *type B*

[12] As mentioned in section 2.1, this primary objective will influence the formation of expectations in the economy stabilizing in turn the price level additionally.

[13] Price stability contributes, for instance, by reducing inflation risk premia on interest rates or improving the transparency of the price mechanism that facilitates spending decisions by the economic agents.

countries had to implement major adjustments in the run-up to their accession (see Appendix A.3.1 for yearly inflation rate series of the Member States of the euro area). For each type, three countries are selected – meeting certain criteria[14] – that shall serve as the objects of research of the subsequent empirical study. A brief descriptive overview on the monetary policy and macroeconomic situation of these key countries shall be provided in the following.[15]

Type A countries

Germany Germany is the largest country of the Euro area with respect to several dimensions and one of the founding members of the European Monetary System (EMS). Since 1974, its national central bank (the Deutsche Bundesbank) has set targets for both inflation and monetary growth and had a special focus on fighting inflation probably due to Germany's historical experience (Clarida and Gertler 1997). The Bundesbank was successful to maintain both the level and the variation of the inflation rate at low rates in an international comparison. In the early 1990s, both an expansion and the reunification lead to accelerating inflation rates that were regulated by the Bundesbank by tightening its key rates for monetary growth. In economic literature, this step often has been regarded as the trigger of the ERM crisis in 1992-1993 (Buiter et al. 1998).[16] When assessing the fulfillment of the convergence criteria in 1998 as a prerequisite for the adoption of the euro, Germany fulfilled the necessary criteria at least roughly (refer to table A.1 for economic indicators) and became a member of the euro area.

France France is the second largest country of the Euro area. Since the late 1970s, the monetary policy conducted by the Banque de France had two primary objectives: (1) compliance to the ERM and (2) money supply growth targets. However, the money supply growth targets were often overshot and France experienced a period of high inflation. The inflation was partly caused by the French government engaging in fiscal expansion to boost output and employment. In 1984, the country entered a disinflation phase and both monetary and fiscal policies were conducted from then on in a way that aimed at rebuilding reputation. Since the 1990s, the exchange rate was steered within a much narrower band than required by the ERM. With reference to the convergence report by the European Monetary Institute (1998), France fulfilled all convergence criteria at the assessment in 1998.

[14]The following criteria have to be fulfilled: (1) The country shall belong to the Member States that initially accessed the euro area. (2) The country shall be a substantial part of the euro area (assessed by their fraction of euro area GDP as displayed in table A.1). (3) Sufficient and reliable data shall be available.

[15]Except noted otherwise, the main sources of the following discussion are Eleftheriou et al. (2006), the European Monetary Institute (1998), and Muscatelli et al. (2002).

[16]During the ERM crisis in 1992-1993, both the policy mix accompanying the reunification of Germany, as well as sizable asymmetries in the macroeconomic an political conditions of many European economies, generated strong tensions in the EMS. Speculative attacks on the European currencies as the lira and the pound accompanied these events (Buiter et al. 1998).

Netherlands The Netherlands represent a medium sized country of the Euro area. Prior to 1999, the De Nederlandsche Bank (DNB) determined its monetary policy under the main objective "to regulate the value of the Netherlands' currency in such a manner as will be most serviceable to the national wealth, while stabilising that value as much as possible" (De Nederlandsche Bank 2012).[17] In 1983, the Dutch guilder was linked to the German mark at an unchanged parity[18] within the ERM framework. The Netherlands' monetary policy thereby moved from a mixture of monetary and exchange rate targeting to reliance on the peg to the mark as a benchmark for monetary policy. This development was confirmed in the bilateral agreement between the two authorities in 1993 that was triggered by the consideration that – since most of the trade took place with Germany – it would be the best way to achieve price stability in the medium run (Hilbers 1998). At the assessment in 1998, the country fulfilled all convergence criteria except that for its debt-to-GDP ratio.

Type B countries

Italy Italy is the largest country of the EMU that had to adjust its inflation rates prior to the start of the third stage of EMU (see Appendix A.3.1 for the adjustment of the inflation rates). Italy's monetary authority, the Banca d'Italia, gained a certain degree of independence in 1981 and persued a flexible exchange rate policy while targeting inflation. With respect to their exchange rate policy, it was possible to maintain stability of the lira within the EMS and increase its credibility through the adoption of narrower bands of 2.25% in 1990. However, the previously successful disinflationary efforts were complicated in 1990 when the pace of disinflation slowed down. In addition, it had been discussed whether the high public debt would be compatible with the Maastricht criteria and not an obstacle for controlling inflation in the long run. During the ERM crisis of 1992-1993, the lira had to exit the ERM caused by speculative pressures on the currency. However, Italy was able to rejoin the ERM in November 1996. The economy fulfilled the convergence criteria in almost all dimensions except for its debt-to-GDP ratio at its assessment in 1998.[19]

Spain Spain represents the fourth largest country of the euro area and exhibited major adjustments of its inflation rates in the decade leading to the third stage of EMU. Spain has been a member of the European Community since 1986 when the Spanish central bank, the Banco de España, started focusing on exchange rate targeting, especially of the bilateral

[17]This main objective was formulated in 1948 in the Bank Act when the DNB was nationalized (De Nederlandsche Bank 2012). However, this formulation left room for interpretation whether the stabilization of the currency concerned its internal (price stability) or the external value (exchange rate stability) (Hilbers 1998).

[18]The guilder should not deviate more than 2.25% from the mark parity (Eleftheriou et al. 2006).

[19]However, there has been criticism that Italy improved its fiscal deficit by introducing the refundable "eurotax" in the year of assessment through the EMI (Besnard and Paul 2004).

nominal exchange rate against the German mark. In 1989, the Spanish peseta joined the EMS in order to formalize the exchange rate commitment and to increase credibility. This move was accompanied by a fiscal consolidation plan. In the early 1990s, the Spanish economic situation was difficult with respect to high rates of inflation and an extraordinarily high level of unemployment. Therefore, the Spanish central bank adopted direct inflation targeting in 1995 that lead to a decrease in both short- and long-term interest rates and a drop in the level of inflation. Spain became a member of the euro area in 1999 after fulfilling all convergence criteria at the assessment except for its debt-to-GDP ratio.

Portugal Compared to Italy and Spain, Portugal represents a smaller share of the euro area economy but had to implement larger adjustments for its inflation rates. With its accession to the EU in 1986, Portugal experienced a period of both fast economic growth caused by the large capital inflows through large EU transfers and private investors but also of high rates of inflation (Detragiache and Hamann 1999). In order to fight inflation, the escudo was pegged to a basket of European currencies in 1990 and monetary policy became more restrictive. However, inflation declined only gradually. In 1992, the escudo joined the ERM which lead to three separate devaluations in the following years. Following this, Portugal experienced a deep recession that both included a rise in unemployment and fiscal deficit but brought a decline of the overall inflation rate (Detragiache and Hamann 1999). At its assessment, Portugal could fulfill as Germany roughly the convergence criteria and became a member of the euro area (see European Monetary Institute 1998).

3 Existing empirical evidence

In light of these developments in the euro area, economic theory emphasizes that structural changes can influence the dynamic behavior of the economy. This effect was initially observed by Lucas (1976) and was tested for various international structural developments across time. An overview about the empirical literature in this area is provided in section 3.1. Furthermore, the impact of the three developments (1) increased globalization, (2) changes in the financial markets, and (3) the transition to EMU on the transmission mechanisms of monetary policy for the euro area has been widely analyzed. Section 3.2 summarizes this literature for the impact on specific factors and channels of the transmission mechanism as well as for the mechanism as a whole.

3.1 Lucas' critique and structural changes in history

> *"[G]iven that the structure of an econometric model consists of optimal decision rules of economic agents, and that optimal decision rules vary systematically with changes in the structure of series relevant to the decision maker, it follows that any change in policy will systematically alter the structure of econometric models."*
> (Lucas 1976, p. 41)

Lucas (1976) criticizes that most econometric models used for forecasting matters are backward-looking. If policy changes over time and if these changes can be anticipated by economic agents, they will modify their optimal decisions with respect to their level of information.[1,2] As a consequence, the dynamics in the economy will change, and hence also the structure of the representative econometric models. This results in imprecise forecasts when failing to recognize these changes in the econometric analysis. Lucas' (1976) notion of the inconstancy of the economy's dynamics during times of major policy changes is especially relevant in light

[1] Lucas (1976) distinguishes between policy changes that become known to the economic agents only gradually and those that were fully discussed and understood by the economic agents prior to the occurrence. The former case leads to an unsystematic transition to a new stable relationship of variables in the economy, in the latter one structural changes can be forecasted more precisely.

[2] In the same vein, Antal and Brazdik (2007) emphasize that the announcement of a change in the monetary policy regime will trigger an immediate change in the behavior of households and firms. This is caused by the incidence that households and firms also take future monetary policy regime into account when making decisions during the transitory period.

of the major structural developments in the euro area in the recent decades. Evidence for the likelihood of changes in the dynamics of the economy in times of structural changes in the economy was already earlier found in history when analyzing, for instance, the impact of monetary policy changes or of an earlier phase of globalization.

Changes in monetary policy and their effects on the real economy have been analyzed for many economies. The most prominent area of the scientific literature dealing with structural monetary policy changes concerns the U.S. in the late 1970s.[3] In this respect, previous research has come to different conclusions on the question whether changes in monetary policy with the appointment of Paul Volcker lead to significant changes in the transmission mechanisms, and hence a stabilization of the U.S. economy (among others Boivin and Giannoni 2006; Clarida et al. 2000; Cogley and Sargent 2001, 2005; Favero and Rovelli 2003) or not (see, for instance, Bernanke and Mihov 1998; Leeper and Zha 2003). Related research concerns the Asian economies where changes in monetary policy occurred in light of the Asian financial crisis 1997-1998. Empirical evidence suggests for China (Zhang and Clovis 2010) and other Asian economies (Gerlach and Tillmann 2012)[4] that changes in monetary policy have lead to a significant reduction in inflation persistence. Furthermore, a monetary policy shift in the U.K. after the departure from the ERM in 1992 has been analyzed. There has been evidence that this rapid change from exchange rate targeting to inflation targeting lead to more stability of both the nominal and real demand (King 1997) and a significant reduction in the volatility of the real interest rate (Reschreiter 2011).

The second wave of globalization started in the aftermath of World War II (Findlay and O'Rourke 2007). Among others, two major developments in this time affected the world economy: the liberalization of trade through the General Agreement on Tariffs and Trade (GATT) and improved technology that optimized the transportation system (see, for instance, Hummels 2007). These developments lead to a significant increase in international trade, and hence an integration of commodity, capital and labor markets (World Trade Organization 2008).

[3]The U.S. economy experience a period of high and volatile inflation as well as several severe recessions from the late 1960 until the early 1980s. It has been discussed whether the conduct of monetary policy or supply shock such as oil price shocks was the reason for the economic instabilities during these years (Clarida et al. 2000).

[4]Gerlach and Tillmann (2012) analyzes Asian countries whose central banks have adopted monetary policy frameworks that includes inflation targeting such as Korea, Indonesia, Thailand and the Philippines and finds a significant reduction in inflation persistence for countries who use inflation targeting but not elsewhere.

3.2 Impacts of structural changes in the euro area

Previous research on changes in the transmission mechanism of monetary policy in the euro area caused by the aforementioned three main developments has focused on different aspects of the transmission mechanisms. In doing so, it has come to several conclusions. In fact, “the existing empirical literature on possible changes in monetary policy transmission [...] is at best mixed” (Weber et al. 2009). The following subsections shall provide a comprehensive overview about existing empirical evidence for changes in the transmission machanisms of monetary policy regarding specific factors and channels[5] (subsection 3.2.1) and the mechanism as a whole (subsection 3.2.2).

3.2.1 Analysis of specific factors and channels

In the following, existing empirical evidence regarding impacts of the identified developments on different money market channels – specifically the interest rate channel, the credit channel and the exchange rate channel – and on the dynamics of economic activity and the inflation rate – represented by the Phillips curve – shall be reviewed.

Impacts on money market channels

Interest rate channel Overall, there has been controversial evidence for changes in the speed of the interest rate pass-through from policy rates to short- and long-term interest rates and capital market rates. Several potential reasons for an accelerated pass-though have been identified: van Leuvensteijn et al. (2008) find for selected euro area countries[6] that increased competition in the banking sector has lead to lower interest rate spreads for most loan market products, and hence a stronger transmission of money market interest rates.[7] Furthermore, Gropp et al. (2007) provide evidence that financial innovations, improving the ability of risk management, speed up the pass-through in those segments that are directly affected by those innovations. However, the interest rate pass-through can have also been weakened by globalization leading to a higher degree of international linkage of interest rates (e.g. the U.S. and German capital market, refer to Deutsche Bundesbank 2007),[8] and hence a decreased

[5]This classification is an extended version of Weber et al. (2009).

[6]van Leuvensteijn et al. (2008) analyze the countries Austria, Belgium, France, Germany, Italy, the Netherlands, Portugal and Spain.

[7]In the same vein, Mojon (2000) finds that competition between banks as well as from direct financing has an impact on the pass-through of interest rates from money market interest rates to bank credit and deposit rates.

[8]These cointegration relationships between the U.S. and the German interest rates could not be identified in studies starting prior to 1985; from the beginning of the 1990s – the period of financial market globalization – there has been evidence for remaining stable cointegration relationships (Deutsche Bundesbank 2007).

influence of national central banks on domestic rates (Weber et al. 2009). Evidence for this hypothesis is provided by Boivin et al. (2008) finding an overall reduction in the effects of monetary shocks on the long-term interest rate with the further integration of the euro area.

Credit channel The credit channel can be partitioned into the bank lending channel (the extent to which the banks are willing to supply loans) and the balance sheet channel (the influence of the interest rates on asset prices that are represented in the borrowers balance sheets). Regarding the bank lending channel, Altunbas et al. (2009) argue that increased use of securitization has lead to a decreased importance of the bank lending channel. They argue that this effect is caused by securitization providing the opportunity for banks of alternative funding that results in a lower degree of sensibility to monetary policy shocks.[9] Gambacorta and Marques-Ibanez (2011) find significant changes in the bank lending channel caused by developments including financial innovations. However, they argue that the provision of loans depends largely on the bank-specific characteristics such as bank capital, securitization activities or the amount of investment banking. Furthermore, regulatory changes in the financial markets can have effects on the bank lending channel. One regulatory change was the introduction of the International Financial Reporting Standards (IFRS).[10] Weber et al. (2009) note that these standards may support the bank lending channel with respect to its effect on bank capital through asset valuation. Further expected changes may occur through the introduction of new equity regulations for financial institutions (Basel III) coming into force in 2013 (Gambacorta and Marques-Ibanez 2011). The balance sheet channel affects both households and firms since changes in asset values will have consequences for the accessibility of loans with respect to the need of collateral in loan contracts, and finally consumption and investment decisions. Weber et al. (2009) describes that financial liberalization and innovation have eased the access of credit for borrowers (including both households and firms). It has been observed for several countries[11] that – while depending on the degree of credit liberalization – this has resulted in an altered spending and saving behavior for households increasing the consumption-to-income ratio (Muellbauer 2007). Although the increased accessibility to loans had a positive effect on the investment decisions of firms, the aforementioned introduction of the IFRS may have strengthened the balance sheet channel to a certain extent making firms more sensitive to monetary policy changes. Angelopoulou and Gibson (2009) provides evidence for the United Kingdom finding that firms show a greater investment sensitivity to cash flow during periods of tight monetary policy.

[9] However, Altunbas et al. (2009) also argue that securitization can not completely isolate the supply of loans from monetary policy shocks.

[10] The IFRS are designed to increase the international transparency and comparability of financial statements by requiring the assets and liability to be booked at market values or as a substitute – if market prices are not available – at the *fair value* (the amount at which the asset could be exchanged between knowledgeable, willing parties in an arm's length transaction).

[11] Muellbauer (2007) analyzes the influences of credit market liberalization for the U.S. and the U.K..

Exchange rate channel There seems to exist little recent empirical evidence regarding changes in the exchange rate channel (Weber et al. 2009) – possibly since the link between monetary policy and the exchange rate seems to be volatile (Angeloni and Ehrmann 2003) and empirical support for the existence of the uncovered interest parity appears to be weak (Calvo and Reinhart 2002). However, two developments should be mentioned: The creation of EMU including the elimination of intra-EMU exchange rates and the introduction of ERM II lead to a euro area that can be characterized as a "comparatively closed economy" (Weber et al. 2009). With the major fraction of trade taking place within the EMU, the area has become less open to international trade than the constituent countries (Angeloni and Ehrmann 2003). Furthermore, Boivin et al. (2008) provide some evidence for effects of monetary policy on exchange rates with countries outside the euro area. They claim that the effective real exchange rate[12] reacts more strongly to changes in monetary policy since the advent of the EMU. However, di Mauro et al. (2008) find that the impact of exchange rate changes on extra euro area export volumes of goods may have declined to a certain extent over time.[13] However, it remains unclear to which extent these contrary effects offset each other.

Impacts on the Phillips curve

The relationship between aggregate demand, the output gap and the overall price level can have been influenced by aforementioned three factors (globalization, changes in the financial markets and the transition to EMU). In the framework of the New Keynesian Phillips curve where inflation depends on expected inflation as well as on economic activity,[14] previous research has found two main developments (Weber et al. 2009):

Inflation persistence There has been mixed evidence for changes in the degree of inflation persistence – the tendency of inflation to converge slowly towards it long-run value after a shock (Angeloni et al. 2006) – in the euro area. While in long sample periods that cover multiple monetary policy regimes a substantial degree of inflation persistence could be identified (see, for instance, O'Reilly and Whelan 2005), this inflation persistence seems to reduce significantly once changes in the mean of inflation are allowed for (Altissimo et al. 2006). Furthermore, the latter authors note that these breaks in the mean of inflation may be related to changes in the monetary policy regimes with the start of stage three of the

[12] The effective real exchange rate denotes the real exchange rate between a country and its trading partners, computed as a weighted average of bilateral real exchange rates (Blanchard 2011).

[13] However, this decline was not found for all euro area countries and the differences in the degree of this decline between the euro area countries can possibly be explained by differing terms of trade (di Mauro et al. 2008).

[14] The methodology of the New Keynesian Phillips curve was mainly influenced by Clarida et al. (1999) and Blanchard and Galí (2007).

transition to EMU. This point of view is supported by more recent research finding a significant reduction of inflation persistence for the euro area as a whole since the implementation of a single monetary policy (see, for instance Beechey and Österholm 2009; Dias and Marques 2010; Meller and Nautz 2012).[15] According to Benati (2008), this reduced inflation persistence may be a result of an anchoring of inflation expectations leading to more effective monetary policy.

Price stickiness The sensitivity of inflation to changes in economic activity – measured by, for instance, the output gap or the unemployment rate – seems to have declined (Weber et al. 2009). This potential flattening of the Phillips curve has been observed for the euro area (Musso et al. 2009) as well as for other advanced economies (e.g. 16 OECD countries including the United States, Canada, Japan and Australia, see Borio and Filardo 2007). A possible explanation can be an increased degree of globalization leading to the integration of goods, factor and financial markets and weakening the link between the domestic output gap and inflation (refer to Deutsche Bundesbank 2007; Gnan and Valderrama 2006). However, Woodford (2007) argues that these developments should not be misinterpreted as an impairment of the national central bank's ability to control domestic inflation through national monetary policy.[16] Another strand of literature concerns the impact of changes in monetary policy on the relationship between inflation and economic activity (in line with Lucas (1976)). Especially for the United States, there has been extensive research regarding the tremendous changes in its inflation rates in the late 1970s and its influences on the U.S. economy finding that changes in monetary policy lead to a stabilization of the U.S. economy and changes in the dynamics of Phillips-type variables (see, for instance Boivin and Giannoni 2006; Cogley and Sargent 2001, 2005; Roberts 2006). Yet, there has been little and inconclusive evidence to which extent influences of globalization and changes in monetary policy have played a role in the euro area.[17] While Borio and Filardo (2007) provide evidence that the global output gap has become more important for domestic inflation in the euro area, Calza (2008) finds only little evidence that domestic consumer price inflation in the euro area can be either explained or predicted by global capacity constraints. Furthermore, Weber et al. (2009) argue that potential changes in the relationship between output and inflation in the euro area could be related to the regime shift in monetary policy caused by the creation of EMU.

[15] According Benati (2008) emphasizes that this fall in inflation persistence can differ among the euro area countries and finds weak evidence for Germany (possibly due to its consistently counter inflationary policy in the whole post-WWII period).

[16] This point of view is supported by Mishkin (2009).

[17] Hence, Weber et al. (2009) warns to overhasty reinterpret the existent evidence.

3.2.2 Analysis of the mechanism as a whole

The transmission mechanisms of monetary policy as a whole are a complex network with many co-existing and intertwined channels as described in section 2.1. Often, causes of structural changes are difficult to identify and to separate from other impacts if they occur simultaneously and are not independent of each other (Weber et al. 2009). Meller and Nautz (2012) argue that the implementation of a new monetary policy regime in the euro area during the transition to EMU might have been an obvious change in monetary policy and could be taken as an natural experiment. Since its creation, there have been few attempts to study the transmission mechanisms of monetary policy as a whole in the euro area and its changes during the transition to EMU. The existing studies differ with respect to data availability, methodology, and findings.

Most research conducted on the transmission mechanisms in the early years after the transition to EMU does not account yet for potential structural breaks that could have been caused by the implementation of a common monetary policy regime (see, for instance, Bruneau and De Bandt 2003; Mojon and Peersman 2001; van Aarle et al. 2003; van Els et al. 2003).[18] This is probably also caused by lacking data availability of the post-EMU period. The empirical research in this period indicates that euro area-wide adjustments to monetary policy shocks are found to be comparable to estimates for Japan and the U.S. (van Aarle et al. 2003). However, evidence is mixed comparing the size of these adjustments for Member States of the euro area, finding significant differences (van Aarle et al. 2003) as well as failing to do so (Mojon and Peersman 2001). Furthermore, convergence of the transmission mechanisms of monetary policy has been observed for euro area countries even prior to the start of EMU (Bruneau and De Bandt 2003).[19] This possibly explains the differing results in the aforementioned studies. Furthermore, the studies provide similar insights in the timing of these effects. Mojon and Peersman (2001) as well as van Els et al. (2003) find, for instance, negative effects of a monetary policy shock on output around one year after the shock and a gradual decline of the price level.

Further research was conducted that accounted for the possibility of one or more breaks in the transmission mechanisms both during the run-up to EMU and for a longer horizon including a post-EMU era. Ciccarelli and Rebucci (2006) analyze the question whether the preparation for EMU has already induced changes in the transmission mechanisms. For this purpose, they

[18] Bruneau and De Bandt (2003) account for a regime shift caused by the German reunification by allowing for time-varying intercepts with two regimes in their VAR specification.

[19] This has been found in an analysis for the euro area countries Germany and France (Bruneau and De Bandt 2003).

analyze the mechanisms for the four largest Member States of the euro area[20] and employ a structural VAR model with varying coefficients. They find that although the long-run cumulative effects of monetary policy shocks on output have significantly decreased[21] for these economies since 1991, existing cross-country differences do not seem to be affected during the preparation for EMU. Furthermore, there are a few studies that deal with changes in the transmission mechanisms in the euro area during the creation of EMU and the implementation of a single monetary policy. Boivin et al. (2008) place their focus on changes for key European economies[22] with the introduction of the euro in 1999.[23] They employ a factor-augmented VAR model that uses a large set of macroeconomic indicators for individual countries and enables to trace out effects of monetary policy shocks on many dimensions of the economy. For identifying potentials influences of different monetary policy regimes, the authors divide their sample in a benchmark sample and a post-EMU sample starting in January 1999. Boivin et al. (2008) find heterogeneity in the effects of monetary policy across countries before 1999 and a significantly greater homogeneity thereafter. Furthermore, they argue that the creation of the euro has triggered an overall reduction in the effects of monetary policy shocks. A similar issue is investigated by Weber et al. (2009) who place a focus on the effects on inflation and output for the aggregate euro area. For this purpose, the authors employ a standard VAR model for analyzing quarterly data over the period 1980 to 2006 and search for potential break dates. They provide significant evidence for a break around 1996 and possibly a second one around 1999. These breaks are implemented in the VAR model as instantaneous shifts in the dynamics of the system. Weber et al. (2009) find that the transmission mechanisms of monetary policy after 1998 are not significantly different from before 1996, but very different in the period in between. Further evidence is provided by Cecioni and Neri (2011). The authors utilize both structural VAR and dynamic general equilibrium models in an euro area-wide approach. Employing structural VAR analysis, the authors use a similar approach as Boivin et al. (2008) to identify differences in the effects of monetary policy shock on output and the price level by splitting the sample in January 1999. Cecioni and Neri (2011) do not find any significant differences in the transmission mechanisms over time with this procedure. However, employing a dynamic general equilibrium model[24] over the two subsamples, the authors are able to provide evidence for a more effective monetary policy in terms of its ability to stabilize the economy for the period after 1999.

[20] Ciccarelli and Rebucci (2006) analyze the countries Germany, France, Italy and Spain.
[21] The authors quantify this these effects with about 10 to 20%.
[22] Their analysis includes the countries Belgium, the Netherlands, Spain, Italy, France and Germany.
[23] Boivin et al. (2008) analyze quarterly data for the time between 1988 and 2007.
[24] A dynamic general equilibrium model aims to describe the behavior of the economy as a whole by analyzing the interactions of microeconomic decisions of, for instance, households, firms and governments.

3.3 Empirical challenge

Lucas (1976) criticizes that policy changes will alter the dynamic structure of the economy and shall therefore be taken into account in econometric modeling. This possible inconstancy in the economy's dynamics during times of major policy changes is specifically relevant in light of the aforementioned major structural developments in the euro area in the recent decades, namely (1) the increased globalization, (2) changes in the financial markets, as well as (3) the transition to EMU. Especially the transition to EMU constituted a major structural change with respect to the introduction of a single currency and monetary policy for the participating Member States that could be viewed as a natural experiment (Meller and Nautz 2012). Previous research on specific factors and channels has provided mixed evidence in how far these changes have influenced the real economy. Furthermore, there has been few research conducted yet that considered changes in the transmission mechanisms as a whole. The methodology applied in these studies relies mostly on exogenously determined break dates and instantaneous shifts. However, the methodology in the area of nonlinear VAR models has been further developed during the last years. In a similar vein as the study by Ciccarelli and Rebucci (2006), the subsequent analysis employs a new VAR framework that allows the coefficients to vary smoothly and continuously between different regimes across time. Thereby, this study tries to shed more light on the issue whether and how the transmission mechanisms as a whole have changed in the recent decades. The empirical analysis is conducted for selected Member States of the euro area that differ in their pre-EMU macroeconomic situation and monetary policy (as described in section 2.3). As the recent research conducted on this issue, the study benefits from sufficient data availability in both the pre-EMU and post-EMU era. Specifically, the study shall provide further insights in the following issues:

1. Did the structural changes in the euro area have an impact on the transmission mechanisms of monetary policy for the selected economies?
2. If so, when did these changes occur?
3. How can these changes be characterized and in how far are they dependent on the type of economy?

For answering these questions, the next section gives an overview about the methodological framework employed, section 5 provides information about the data used and section 6 presents the empirical results.

4 Methodology

In order to analyze in how far the transition to EMU has influenced the transmission mechanisms of monetary policy, a framework is needed that addresses the following issues: (1) an econometric model with time-varying parameters to measure potential influences of structural changes in monetary policy on the dynamics of the variables, and (2) a multivariate model to analyze the changing effects of monetary policy on the economy and especially on the price level.

Models with the possibility of time-varying parameters can be found in the area of *regime-switching models* that belong to the class of nonlinear time-series models. Regime-switching models allow the dynamic behavior of a series to depend on a regime that occurs at a given point of time (see Priestley 1980). The dynamic behavior could depend on, for instance, whether the economy is in an expansionary state or a recession or the type of policy that is conducted at a given point of time. In these cases, the mean, variance and (higher order moments) and/or autocorrelation of the series under examination can be different in different regimes. Assuming parameter constancy – one of the key assumptions of the Box-Jenkins methodology (Enders 2010) in linear models – when the structure of the data-generating process changes over time would lead to wrong inferences with respect to biased estimates. Hence, regime-switching models consider these structural changes and model the time series accordingly. Considering the convergence efforts and adjustments during the transition to EMU, this empirical study employs a model that allows for a *smooth transition*[1] between two extreme regimes. Initially, smooth transition models were developed for the the univariate case as smooth transition autoregressive (STAR) models. STAR models are the nonlinear alternative of linear AR models and allow the autoregressive parameters to change between the regimes dependent on a transition variable.[2] These models were largely influenced by Granger and Teräsvirta (1993) and Teräsvirta (1994) who developed an empirical specification procedure consisting of specification, estimation and evaluation as advised by Box and Jenkins (1970). Thereafter, Eitrheim and Teräsvirta (1996) enhanced the evaluation stage

[1] The idea of a "smooth transition" between regressions dates back to Bacon and Watts (1971), and is characterized by containing a continuous transition function that enables the parameters to change smoothly and continuously between different regimes dependent on a specific transition variable.

[2] Possible assumptions for the transition variable: For instance, it can be assumed to be a lagged endogenous variable y_{t-d} for a certain integer $d > 0$, an exogenous variable z_t as well as a linear time trend t (van Dijk et al. 2002) The idea to assume the parameters to change as a linear function of time in the transition function $F(t) = t$ as an alternative to constant parameters originated with Farley et al. (1975).

with specific misspecification tests. In order to be able to analyze the effects on the transmission mechanisms of monetary policy, the subsequent analysis utilizes a special case of the multivariate extension of the STAR model: the TV-VAR model. The TV-VAR model is characterized by a transition function that depends on time t as the transition variable and was discussed in He et al. (2009). The representation of the TV-VAR model is described in detail in the next section. Following that, section 4.2 provides a detailed explanation of the empirical specification procedure used in the subsequent analysis.

Throughout this study, vectors are denoted by lowercase boldface letters, matrices by uppercase boldface ones.

4.1 Representation of the basic TV-VAR model

Modifying the model proposed by He et al. (2009), the TV-VAR model for the multivariate time series $\mathbf{y}_t$ is given by

$$\mathbf{y}_t = (1 - \mathbf{G}(t)) \left(\boldsymbol{\phi}^1 + \sum_{i=1}^{p} \mathbf{\Phi}_i^1 \mathbf{y}_{t-i} \right) + \mathbf{G}(t) \left(\boldsymbol{\phi}^2 + \sum_{i=1}^{p} \mathbf{\Phi}_i^2 \mathbf{y}_{t-i} \right) + \boldsymbol{e}_t, \quad t = 1, ..., T \tag{4.1}$$

where $\mathbf{y}_t = (y_{1,t}, ..., y_{m,t})'$ is an $(m \times 1)$ random vector, $\boldsymbol{\phi}^i$, $i = 1, 2$ are $(m \times 1)$ constant parameter vectors, $\mathbf{\Phi}_i^1$ and $\mathbf{\Phi}_i^2$, $i = 1, ..., p$, are $(m \times m)$ parameter matrices, and $\boldsymbol{e}_t$ is an $(m \times 1)$ error vector. The $(m \times m)$ diagonal matrix of transition functions $\mathbf{G}(t) = diag\{G_1(t|\gamma_1, \mathbf{c}_1), ..., G_m(t|\gamma_m, \mathbf{c}_m)\}$ allows the parameters of the model to change smoothly and continuously from one extreme regime to the other as a function of the transition variable t. The diagonal elements $G_i(t|\gamma_i, \mathbf{c}_i), i = 1, ..., m$, are continuous transition functions, bounded between 0 and 1. The equation-specific transition functions are defined as the general kth-order logistic function:

$$G_i(t|\gamma_i, c_{ij}) = \left(1 + exp \left\{ -\gamma_i \prod_{j=1}^{k} (t - c_{ij}) \right\} \right)^{-1} \tag{4.2}$$

where $\gamma_i > 0$ and $c_{i1} \le c_{i2} \le ... \le c_{ik}$, for $i = 1, ..., m$. The transition variable is characterized as a linear time trend t. The parameters c_{ij} in equation (4.2) can be interpreted as the thresholds between the two regimes whereas the parameter γ_i determines the smoothness of the transition function.

Some special cases of the TV-VAR model should be mentioned. In case that $k = 1$, equation (4.2) becomes the simple logistic function. Figure 4.1 presents some examples of logistic

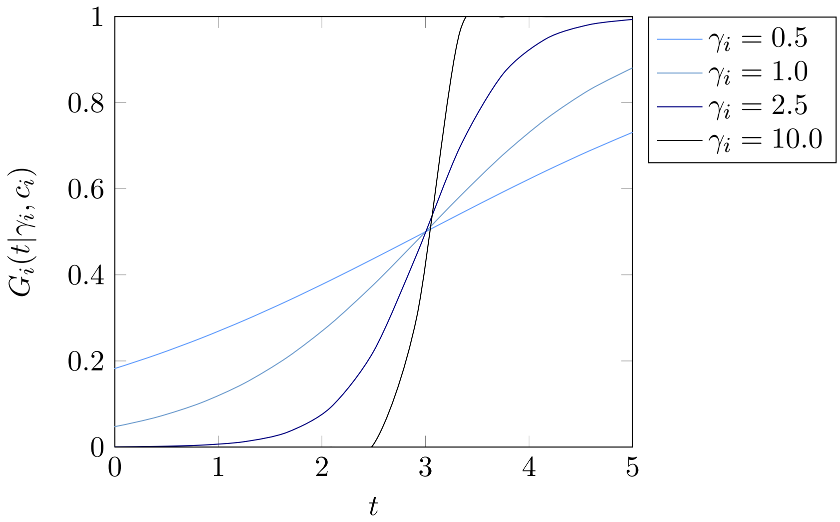

Figure 4.1: Logistic function $G_i(t|\gamma_i, c_i)$ for various values of the smoothness parameter γ_i and the threshold $c_i = 3$ (in case that $k = 1$)

functions for different values of the smoothness parameter γ_i, assuming $c_i = 3$. The change in $G_i(t|\gamma_i, c_i)$ becomes almost instantaneous with a single structural break approaching the indicator function $I(t > c_i)$ as $\gamma_i \to \infty$. In contrast, as $\gamma_i \to 0$, the function $G_i(t|\gamma_i, c_i)$ approaches the constant $\frac{1}{2}$ and equation (4.1) becomes a linear VAR model. For $\gamma_i > 0$, $i = 1, ..., m$, the parameters of equation (4.1) change smoothly and monotonically from $\mathbf{\Phi}_i^1$ to $\mathbf{\Phi}_i^2$ and from $\boldsymbol{\phi}^1$ to $\boldsymbol{\phi}^2$ as $\mathbf{G}(t)$ changes from a null to an identity matrix. The case of $k = 2$ represents a system in which the parameters first change in one direction and then start changing back towards their original values. Setting $k = 3$ identifies a more complicated change that can be non-monotonic. Appendix B.1 displays further examples of logistic functions for the orders $k = 2$ and $k = 3$. When $m = 1$, the system is characterized only by a single equation and the TV-VAR model collapses into the LSTAR model described in Lin and Teräsvirta (1994).

4.2 Empirical specification procedure

The empirical specification procedure is based on a data-based approach that was originally presented by Teräsvirta (1994) and further described in van Dijk et al. (2002). The approach follows Granger's (1993) recommendation to employ a "specific-to general" strategy[3] when modeling nonlinear time series models. This empirical study follows the following milestones of this approach that are modified to fit the multivariate TV-VAR framework:

[3]This strategy implies to begin with a simple model and extend it to a more complicated one if diagnostic checks indicate a inadequate model.

1. Specification of the linear VAR model of order p [VAR(p)] for the time series using an appropriate model selection criterion.
2. Testing the null hypothesis of linearity against the nonlinear alternative represented by the TV-VAR model.
3. Estimation of the parameters in the selected TV-VAR model.
4. Evaluation of the model using diagnostic checks and impulse response analysis.
5. Modification of the model (if necessary).

An overview of the methods used during the empirical analysis is provided in the following subsections.

4.2.1 Specification of the TV-VAR model

The first stage of the empirical specification procedure includes the specification of the TV-VAR model. For this purpose, a linear VAR model has to be specified that can be tested against the alternative nonlinear TV-VAR model. This includes the selection of an appropriate lenght of the vector autoregressive process, p, by employing information criteria such as the Akaike Information Criterion (Akaike 1974) or Schwarz Bayesian Criterion (Schwarz 1978) (AIC and SBC, respectively). The lag selection procedure should be accompanied by a test for residual autocorrelation of the VAR model such as the Lagrange-multiplier (LM) test presented in Johansen (1995). Remaining residual autocorrelation can be also a reason for rejecting the linearity hypothesis. Thereafter, the specification procedure determines to test the linear VAR model against the TV-VAR framework and – in case of rejection of the linear model – to determine the structure of the nonlinear TV-VAR model.

As aforementioned, this empirical study follows the strategy developed by He et al. (2009) for testing parameter constancy in a stationary linear VAR model against the alternative nonlinear TV-VAR model.[4] The author's preferred null hypothesis for testing parameter constancy in the framework containing equation (4.1) and (4.2) is

$$H_0 : \gamma_i = 0, \quad i = 1, ..., m, \tag{4.3}$$

representing a linear VAR model. However, they note that with this hypothesis, the nonlinear alternative will suffer from the problem of *unidentified nuisance parameters* meaning that the nonlinear TV-VAR model contains parameters that are not restricted under the

[4] This method is based on the parameter constancy test for univariate models against the alternative smooth transition regression (STR) model developed by Lin and Teräsvirta (1994).

null hypothesis and can contain any value (Franses and van Dijk 2000). As a consequence, standard asymptotic inference is not available since the likelihood ratio statistic tends to have a nonstandard distribution that is not known. However, this problem is circumvented by He et al. (2009) persuing the following strategy: The transition function is approximated by a first-order Taylor approximation about $\gamma_i = 0$ which results in the TV-VAR collapsing into the multivariate auxiliary regression that is linear in its parameters:[5]

$$\mathbf{y}_t = \mathbf{B}_0\mathbf{w}_t + \mathbf{B}_1\mathbf{w}_t t + ... + \mathbf{B}_k\mathbf{w}_t t^k + \boldsymbol{e}_t^* \tag{4.4}$$

where $\mathbf{B}_0$ is an $m \times (mp+1)$ coefficient matrix, $\mathbf{B}_i = \mathbf{\Gamma}\mathbf{B}_i^*$, $i = 1, ..., k$, are $m \times (mp+1)$ coefficient matrices such that $\mathbf{B}_i^* \neq 0$, $i = 1, ..., k$, and $\mathbf{\Gamma} = diag\{\gamma_1, ..., \gamma_m\}$. Furthermore, $\mathbf{w}_t = (1, y_{1,t-1}, ..., y_{1,t-p}, ..., y_{m,t-1}, ..., y_{m,t-p})'$ is an $(mp+1) \times 1$ vector.[6]

For the implementation, it is useful to rewrite equation (4.4) as

$$\mathbf{y}_t = \mathbf{B}\mathbf{z}_t + \boldsymbol{e}_t^* \tag{4.5}$$

where $\mathbf{z}_t = \mathbf{s}_t \otimes \mathbf{w}_t$ with $\mathbf{s}_t = (1, t, ..., t^k)'$ and $\mathbf{B} = (\mathbf{B}_0, \mathbf{B}_1, ..., \mathbf{B}_k)$ is an $(m \times (k+1)(mp+1))$ parameter matrix.

Hence, the hypothesis $\mathbf{\Gamma} = diag\{\gamma_1, ..., \gamma_m\} = \mathbf{0}$ can be replaced by the hypothesis

$$H_0' : \mathbf{B}_i = \mathbf{0}, \quad i = 1, ..., k, \tag{4.6}$$

that is, as the authors note, a linear hypothesis within a linear VAR model that can be tested using the asymptotic χ^2 distribution. He et al. (2009) provide a quasi maximum likelihood estimator of $\mathbf{B}$ to estimate the parameters in equation (4.4)

$$\mathbf{b}_T = vec(\hat{\mathbf{B}}_T) = ((\mathbf{Z}\mathbf{Z}')^{-1} \otimes \mathbf{I}_m)vec(\mathbf{Y}) \tag{4.7}$$

where $\mathbf{Y} = (\mathbf{y}_1, \mathbf{y}_2, ..., \mathbf{y}_T)$ and $\mathbf{Z} = (\mathbf{z}_1, \mathbf{z}_2, ..., \mathbf{z}_T)$. The authors advise to carry out the parameter constancy test for $k = 1, 2, 3$ and to compare the strenght of rejction (p-values) in order to retrieve initial information about the existence and type of parameter change that potentially has taken place. They suggest to carry out the test in three steps:

1. Fitting the linear VAR model by regressing $\mathbf{Y}$ on $\mathbf{W}_1$ where $\mathbf{W}_1 = (\mathbf{w}_1, \mathbf{w}_2, ..., \mathbf{w}_T)'$. Collection of the matrix of residuals $\hat{\mathbf{E}}_0$.

[5] Please refer to Appendix B.2 for the complete derivation of the simplified alternative model.

[6] The error term $\boldsymbol{e}_t^*$ comprises of $\mathbf{R}\left[\left(\boldsymbol{\phi}^2 + \sum_{i=1}^{p} \mathbf{\Phi}_i^2 \mathbf{y}_{t-i}\right) - \left(\boldsymbol{\phi}^1 + \sum_{i=1}^{p} \mathbf{\Phi}_i^1 \mathbf{y}_{t-i}\right)\right] + \boldsymbol{e}_t$ where $\mathbf{R}$ is the remainder matrix of the first-order Taylor approximation.

2. Fitting the nonlinear VAR model by regressing $\mathbf{Y}$ on $\mathbf{W}_2$ where $\mathbf{W}_2 = (\mathbf{s}_1 \otimes \mathbf{w}_1, \mathbf{s}_2 \otimes \mathbf{w}_2, ..., \mathbf{s}_T \otimes \mathbf{w}_T)'$. Collection of the matrix of residuals $\hat{\mathbf{E}}_1$.

3. Employing Rao's (1973) F-statistic to test for parameter constancy in the linear VAR model

$$F_{RAO}(k) = \left(\frac{1 - \Lambda^{\frac{1}{s}}}{\Lambda^{\frac{1}{s}}} \right) \frac{\delta s - \frac{1}{2}(mk-2)}{mw} \tag{4.8}$$

where $\Lambda = |\hat{\mathbf{E}}_1'\hat{\mathbf{E}}_1| / |\hat{\mathbf{E}}_0'\hat{\mathbf{E}}_0|$, is Wilk's lambda, $w = k(pm+1)$, $s^2 = (m^2w^2 - 4)/(w^2 + m^2 - 5)$, $\delta = T - (1 + pm) - \frac{1}{2}(m + w + 1)$ and the F_{RAO}-statistic (4.7) is approximately distributed as $F(mw, \delta s - \frac{1}{2}(mk-2))$ under the null hypothesis H_0.

In those cases where the null hypothesis of parameter constancy is rejected, the alternative TV-VAR model can be estimated. As a prerequisite, the nature of the parameter change and therefore the order k of the corresponding transition function $\mathbf{G}(t)$ has to be determined. Lin and Teräsvirta (1994) suggest a short sequence of nested tests that can be extended to the multivariate case. This study follows this methodology during the determination of the transition function. The nested tests are started assuming $k = 3$ and testing the hypothesis H_0' in equation (4.7). In the case of rejection, equation (4.4) shall be taken as the maintained model and the following hypothesis shall be tested:

$$H_{03} : \mathbf{B}_3 = \mathbf{0} \tag{4.9}$$

Rejection of hypothesis H_{03} provides evidence to choose $k = 3$ for the transition function described by equation (4.2). Otherwise, the procedure is to test

$$H_{02} : \mathbf{B}_2 = \mathbf{0} \quad | \quad \mathbf{B}_3 = \mathbf{0} \tag{4.10}$$

Again, in the case of rejection one should choose $k = 2$ for the transition function while when failing to reject one should test

$$H_{01} : \mathbf{B}_1 = \mathbf{0} \quad | \quad \mathbf{B}_2 = \mathbf{0}, \quad \mathbf{B}_3 = \mathbf{0}, \tag{4.11}$$

the original parameter constancy test with $k = 1$. Lin and Teräsvirta (1994) advise to carry out all of the tests to clarify the nature of the detected parameter change. When k is chosen, the system containing equations (4.1) and (4.2) can be estimated using nonlinear least squares (NLS). This procedure is explained in the next subsection.

4.2.2 Estimation of parameters

The subsequently presented estimation strategy follows Yang (2012). For the following considerations, it is beneficial to rewrite equation (4.1) as

$$\mathbf{y}_t = (\mathbf{1} - \mathbf{G}(t))\mathbf{\Phi}'_A\mathbf{x}_t + \mathbf{G}(t)\mathbf{\Phi}'_B\mathbf{x}_t + \boldsymbol{e}_t \tag{4.12}$$

where $\mathbf{\Phi}_A = (\boldsymbol{\phi}^1, \mathbf{\Phi}^1_1, ...\mathbf{\Phi}^1_p)'$ is a $(mp+1) \times m$ parameter matrix, $\mathbf{\Phi}_B = (\boldsymbol{\phi}^2, \mathbf{\Phi}^2_1, ...\mathbf{\Phi}^2_p)'$ is a $(mp+1) \times m$ parameter matrix, and $\mathbf{x}_t = (1, \mathbf{y}'_{t-1}, ..., \mathbf{y}'_{t-p})'$ is a $(mp+1) \times 1$ column vector. Furthermore, this equation can be in turn reparameterized as follows:

$$\begin{aligned}
\mathbf{y}_t &= \underbrace{\mathbf{\Phi}'_A}_{\mathbf{D}'_0}\mathbf{x}_t + \mathbf{G}(t)\underbrace{(\mathbf{\Phi}'_B - \mathbf{\Phi}'_A)}_{\mathbf{D}'_1}\mathbf{x}_t + \boldsymbol{e}_t \\
&= (\mathbf{D}'_0 + \mathbf{G}(t)\mathbf{D}'_1)\mathbf{x}_t + \boldsymbol{e}_t \\
&= \mathbf{\Psi}'_t\mathbf{D}'\mathbf{x}_t + \boldsymbol{e}_t
\end{aligned} \tag{4.13}$$

where $\mathbf{\Psi}_t = (\mathbf{I}_m, \mathbf{G}(t))'$ is a $2m \times m$ matrix and $\mathbf{D} = (\mathbf{D}_0, \mathbf{D}_1)$ is a $(mp+1) \times 2m$ parameter matrix.

In this framework, the parameters of $\boldsymbol{\theta} = \{\mathbf{D}, \mathbf{\Gamma}, \mathbf{C}\}$, where $\mathbf{\Gamma} = \{\gamma_1, ..., \gamma_m\}$ and $\mathbf{C} = \{c_{11}, ..., c_{1k},\ ..., c_{m1}, ..., c_{mk}\}$ with k denoting the order of the transition function and m denoting the number of equations in the system, have to be estimated. The estimation can be implemented utilizing nonlinear least squares estimators that are obtained by solving the optimization problem

$$\hat{\boldsymbol{\theta}} = \arg\min_{\theta} \sum_{t=1}^{T} (\mathbf{y}_t - \mathbf{\Psi}'_t\mathbf{D}'\mathbf{x}_t)'(\mathbf{y}_t - \mathbf{\Psi}'_t\mathbf{D}'\mathbf{x}_t). \tag{4.14}$$

Yang (2012) argues that it can be hard to find the optimum in practice with respect to the shape of function (4.14) that can be "rather flat", and therefore possess multiple local optima. He suggests to initialize the nonlinear optimization algorithm with good starting values for $\boldsymbol{\theta}$ that can be determined after conducting an initial grid search. For this purpose, the grid shall be constructed over $\mathbf{\Gamma}$ and $\mathbf{C}$. If these parameters are fixed, the model is linear in the parameters in $\mathbf{D}$, and hence $\mathbf{D}$ can be estimated conditionally on the set of parameters chosen in each point of the grid. This set of parameters $\mathbf{\Gamma}$ and $\mathbf{C}$ is chosen as starting values for the nonlinear optimization that yields in the smallest residual sum of squares $Q_T = \sum_{t=1}^{T}(\mathbf{y}_t - \mathbf{\Psi}'_t\mathbf{D}'\mathbf{x}_t)'(\mathbf{y}_t - \mathbf{\Psi}'_t\mathbf{D}'\mathbf{x}_t)$. Yang (2012) derives the NLS estimators for given $\mathbf{\Gamma}$ and $\mathbf{C}$ as

$$vec(\hat{\mathbf{D}})_{NLS} = (\mathbf{M}'\mathbf{M})^{-1}\mathbf{M}'vec(\mathbf{Y}') \tag{4.15}$$

$$\hat{\mathbf{\Omega}}_{NLS} = T^{-1}\hat{\mathbf{E}}'\hat{\mathbf{E}} \tag{4.16}$$

where $\mathbf{M} = (\mathbf{\Upsilon}_1, \mathbf{\Upsilon}_2, ..., \mathbf{\Upsilon}_T)'$ is a $Tm \times 2m(mp+1)$ matrix, $\mathbf{\Upsilon}_t = \mathbf{\Psi}_t \otimes \mathbf{x}_t$ is an $2m(mp+1) \times m$ matrix, $\hat{\mathbf{E}} = (\hat{\boldsymbol{e}}_1, \hat{\boldsymbol{e}}_2, ..., \hat{\boldsymbol{e}}_T)'$ is a $T \times m$ matrix, and $\hat{\mathbf{e}}_t = \mathbf{y}_t - \mathbf{\Psi}_t'\hat{\mathbf{D}}_{NLS}'\mathbf{x}_t$ is a column vector of residuals.

Furthermore, Yang (2012) argues that – since the error covariance matrix $\mathbf{\Omega}$ does not enter the objective function Q_T – the parameters can be estimated equation by equation which is equivalent to the estimation procedure in univariate STAR models. In the following procedure, the corresponding parameters in each equation i are denoted by $\mathbf{\Gamma}_i = \{\gamma_i\}$, $\mathbf{C}_i = \{c_{i1}, ..., c_{ik}\}$ and $\mathbf{D}_i$, and the residual sum of squares by $Q_{i,T}$. As previously mentioned, the estimation shall be carried out in two main steps:

1. In the first step, the starting values for the parameters $\mathbf{\Gamma}_i$ and $\mathbf{C}_i$ are determined. For this purpose the following algorithm can be employed:
   (a) Construction of a grid in the parameter space $\mathbf{\Gamma}_i$.
   (b) For each value in the grid over $\mathbf{\Gamma}_i$, construction of a grid with a zoom in the parameter space $\mathbf{C}_i$.
   (c) Estimation of the corresponding $\hat{\mathbf{D}}_{i,NLS}$ for each set of parameters $\mathbf{\Gamma}_i$ and $\mathbf{C}_i$ and construction of the corresponding residual sum of squares $Q_{i,T}$.
   (d) For each value of $\mathbf{\Gamma}_i$, selection of the set of parameters $\mathbf{C}_i$ that yields in the smallest $Q_{i,T}$.
   (e) Selection of $\mathbf{\Gamma}_i$ that yields in the smallest $Q_{i,T}$.
2. In the second step, the parameters can be estimated by using NLS. This can be performed iteratively until convergence is achieved by the following algorithm:
   (a) Given the NLS estimate for the parameter $\hat{\mathbf{D}}_{i,NLS}$, reestimation of $\mathbf{C}_i$ using equation (4.14).
   (b) Given $\mathbf{\Gamma}_i$ and the new values for $\mathbf{C}_i$, reestimation of the parameter matrix $\hat{\mathbf{D}}_{i,NLS}$ (as in step 1c).
   (c) In a final estimation round, reestimation of $\mathbf{\Gamma}_i$ and $\mathbf{C}_i$ using equation (4.14).

The special treatment of $\mathbf{\Gamma}_i$ in step 1 and 2 is caused by the potential difficulty to obtain precise estimates for $\mathbf{\Gamma}_i$ which would require many observations in the direct neighborhood of the timing of the structural breaks $\mathbf{C}_i$. Teräsvirta (1994) suggests the above mentioned estimation strategy to keep $\mathbf{\Gamma}_i$ fixed and estimate it only after the final specification has been found. The problem of imprecise estimates of $\mathbf{\Gamma}_i$ is especially relevant in the case when these parameters are large with respect to large changes in $\mathbf{\Gamma}_i$ leading then only to minor changes in the transition functions (see Franses and van Dijk 2000; van Dijk et al. 2002). However, the authors emphasize that high accuracy is necessary and insignificance of the estimate should not necessarily be interpreted as evidence against the presence of nonlinearity.

The grid with a zoom (refer to step 1b of the estimation algorithm) concerns the size of the grid that increases rapidly as the number of equations m and the number of possible breakdates k increase ($\lambda^{m(1+k)}$ with λ denoting the number of potential values for each parameter). Yang (2012) presents the solution to build a grid with a zoom. For each parameter, a moderate number of points are advised to be chosen to build the first grid. Thereafter, the subsequent smaller grids shall be constructed in the neighborhood of those parameters that yielded the lowest residual sum of squares in the previous round.

Both the division in the two steps of the algorithm as well as using a grid with a zoom for the determination of suitable starting values divide a complex optimization problem into smaller components that can be solved more easily. The main advantage of this approach is that it significantly reduces the number of iterations needed for solving the nonlinear estimation problem, saving computing time.

4.2.3 Evaluation

At the evaluation stage, two tests shall be performed that test for certain types of misspecifications of the previously estimated TV-VAR model. It shall be tested for serial correlation in the error process to determine whether there still are intertemporal dependencies in the error terms that were not captured by the specified model. Afterwards, a test for additional structural breaks in the TV-VAR model shall be conducted. Yang (2012) denotes that these tests can suffer from the problem of insufficient observations to adequately approximate the unknown finite sample null distributions of the tests. This is caused by the dimensionality of the VAR system with m equations, containing p lags for each of the variables and k potential breaks in the dynamics of the system which induces the huge data requirement. Yang (2012) refers to this problem as the “curse of dimensionality” and proposes as a potential solution to carry out the evaluation tests equation by equation. This empirical study follows this suggested approach. The procedures for conducting the misspecification tests follow Eitrheim and Teräsvirta (1996) for the univariate STAR models and will be described in the following.

Serial correlation in the error process

The first test aims to test for serial correlation in the error process after the estimation of the TV-VAR model. Failing to reject this hypothesis would mean that there are still intertemporal dependencies of the error terms existent that are not captured in the specified model and the sequence $\{\boldsymbol{e}_t\}$ does not behave as a white-noise process.[7] Eitrheim and Teräsvirta (1996) consider the following nonlinear univariate model with autocorrelated error:

$$y_t = \boldsymbol{\phi}_A' \mathbf{x}_t + G_i(t)(\boldsymbol{\phi}_B - \boldsymbol{\phi}_A)' \mathbf{x}_t + e_t \tag{4.17}$$

where

$$\begin{aligned} e_t &= \sum_{i=1}^{J} a_i e_{t-i} + \varepsilon_t \\ &= \mathbf{a}' \mathbf{e}_t^* + \varepsilon_t \end{aligned} \tag{4.18}$$

In 4.18, $\mathbf{a} = (a_1, a_2, ..., a_J)'$ is a $J \times 1$ parameter vector, J represents the lag length, $\mathbf{e}_t^* = (e_{t-1}, e_{t-2}, ..., e_{t-J})'$ is a vector of J lagged error vectors and $\varepsilon_t \sim n.i.d.(0, \Omega)$. The null hypothesis of no serial correlation in the error term sequence $\{e_t\}$ can be tested by

$$H_{0,s.c.} : a_1 = a_2 = ... = a_J = 0 \tag{4.19}$$

If one fails to reject the null hypothesis $H_{0,s.c.}$, the error process can be described as being white-noise and the parameters of the sequence y_t can be estimated consistently. This test can be performed using standard tests for serial correlation.[8]

Additional structural breaks

Thereafter, it shall be determined whether there are additional structural breaks in the univariate sequences $\{y_t\}$ that is not captured in the previously specified TV-VAR model. Following Eitrheim and Teräsvirta (1996) as well as Franses and van Dijk (2000), this diagnostic check is tested by specifying the alternative hypothesis of additional structural breaks as the presence of an additional regime. Hence, it shall be tested in this empirical study

[7] A *white-noise* process has the following characteristics: Each value in the sequence $\{e_t\}$ has a mean of zero, a constant variance, and is uncorrelated with all other realizations (Enders 2010).

[8] Employing standard tests is possible under the assumption that the process was consistently estimated.

whether the specified 2-regime model is sufficient to capture all structural breaks or whether a third regime should be considered, represented in an additive component such as

$$y_t = \boldsymbol{\phi}_A' \mathbf{x}_t + G_{i1}(t|\gamma_{i1}, \mathbf{c}_{i1})(\boldsymbol{\phi}_B - \boldsymbol{\phi}_A)' \mathbf{x}_t + G_{i2}(t|\gamma_{i2}, c_{i2})(\boldsymbol{\phi}_C - \boldsymbol{\phi}_B)' \mathbf{x}_t + e_t \tag{4.20}$$

where $\mathbf{x}_t = (1, \mathbf{y}_{t-1}', ...\mathbf{y}_{t-p})$, $\boldsymbol{\phi}_i$ with $i = A, B, C$ are $(mp + 1) \times 1$ coefficient matrices and $G_{ij}(t)$ with $j = 1, 2$ are specified as in 4.2 with $k = 1$. The null hypothesis can be formulated as $H_{0,s.b.} : \gamma_{i2} = 0$. Under the null hypothesis, Eitrheim and Teräsvirta (1996) assume that $\boldsymbol{\phi}_A, \boldsymbol{\phi}_B, \gamma_{i1}$ and $\mathbf{c}_{i1}$ can be consistently estimated by NLS. However, this test suffers under the same identification problem that was already discussed in the test for parameter constancy of the linear model in section 4.2.1. Hence, the authors proprose a similar solution to replace $G_{i2}(t|\gamma_{i2}, c_{i2})$ with its third-order Taylor series approximation about $\gamma_{i2} = 0$. After reparameterization that solves the identification problem, this results in

$$y_t = \mathbf{b}_0' \mathbf{x}_t + G_{i1}(t|\gamma_{i1}, \mathbf{c}_{i1})(\boldsymbol{\phi}_B - \boldsymbol{\phi}_A)' \mathbf{x}_t + \mathbf{b}_1' \mathbf{x}_t t + \mathbf{b}_2' \mathbf{x}_t t^2 + \mathbf{b}_3' \mathbf{x}_t t^3 + e_t^* \tag{4.21}$$

where $\mathbf{b}_j$, $j = 0, 1, 2, 3$ are functions of the parameters $\boldsymbol{\phi}_A, \boldsymbol{\phi}_C, \gamma_{i2}$ and c_{i2}. The null hypothesis of no additional structural breaks $H_{0,s.b.} : \gamma_{i2} = 0$ in turn becomes

$$H_{0,r.n.}' : \mathbf{b}_1 = \mathbf{b}_2 = \mathbf{b}_3 = \mathbf{0} \tag{4.22}$$

Eitrheim and Teräsvirta (1996) suggest to carry out the test of no additional structural breaks in three stages:

1. Estimation of the nonlinear univariate model under the null hypothesis of no additional structural breaks. Collection of the residuals $\hat{e}_t$ to compute the residual sum of squares $\mathbf{RSS}_0 = \hat{\boldsymbol{e}}_t' \hat{\boldsymbol{e}}_t$.

2. Estimation of the auxiliary regression of $\hat{e}_t$ on $(\hat{\mathbf{h}}, \hat{\mathbf{v}})$ where $\hat{\mathbf{h}}$ denotes the partial derivatives of the regression function with respect to the parameters in the 2-regime model $\boldsymbol{\phi}_A, \boldsymbol{\phi}_B, \gamma_{i1}$ and $\mathbf{c}_{i1}$, evaluated under the null hypothesis[9] and $\hat{\mathbf{v}}$ denotes a vector of the additional regressors $\hat{\mathbf{v}} = (\mathbf{x}_t' t, \mathbf{x}_t' t^2, \mathbf{x}_t' t^3)'$. Collection of the residuals $\hat{\xi}$ to compute the residual sum of squares $\mathbf{RSS}_1 = \hat{\boldsymbol{\xi}}' \hat{\boldsymbol{\xi}}$.

3. Computation of the test statistic

$$F_{LM} = \frac{(RSS_0 - RSS_1)/3mp}{RSS_1/(T - n - 3mp)} \tag{4.23}$$

[9] For further information regarding the derivation of the partial derivatives, refer to Eitrheim and Teräsvirta (1996) and Yang (2012) for the univariate and multivariate case, respectively.

The test statistic has an asymptotic F distribution with $3mp$ and $T-n-3mp$ degrees of freedom where n denotes the dimension of the gradient vector $\hat{\mathbf{h}}$.

Impulse response analysis

The properties of the estimated TV-VAR model will be evaluated using impulse response analysis. By means of impulse response analysis, the effects of the shocks ε_{it} with $i = 1, 2, ..., m$ on the evolution of the time series y_{it} with $i = 1, 2, ..., m$ can be evaluated (van Dijk et al. 2002). In a system where the dynamics of the variables change over time, the impulse responses will not be time-independent but rather depend on the history of the process.[10] Utilizing this idea, the empirical study employs a simplified framework that enables to derive conclusions about potential differences in impulse responses at extreme regimes at different points of time of the observation period. These regimes can be identified as[11]

$$\mathbf{O}_{A,i} = \mathbf{O}_i^1 + \mathbf{G}(t)\mathbf{O}_i^2, \quad i = 1, ..., p \tag{4.24}$$

$$\mathbf{O}_{B,i} = \mathbf{O}_i^1 + \mathbf{G}(t)\mathbf{O}_i^2, \quad i = 1, ..., p \tag{4.25}$$

with $\mathbf{G}(t) = diag\{G_1(t), G_2(t), ..., G_m(t)\}$ where $G_i(t) = \{0, 1\}$ for $i = 1, ..., m$.[12] Following Lütkepohl (2005), orthogonalized impulse responses (OIR) for the extreme systems are obtained from

$$\boldsymbol{\varphi}_{A,i} = \sum_{j=1}^{i} \boldsymbol{\varphi}_{A,i-j}\mathbf{O}_{A,j}, \quad i = 1, 2, ... \tag{4.26}$$

$$\boldsymbol{\varphi}_{B,i} = \sum_{j=1}^{i} \boldsymbol{\varphi}_{B,i-j}\mathbf{O}_{B,j}, \quad i = 1, 2, ... \tag{4.27}$$

with

$$\boldsymbol{\varphi}_{A/B,0} = \mathbf{I}_m\mathbf{S}^{-1} \tag{4.28}$$

where $\mathbf{S}$ denotes the matrix of contemporaneous effects. Identifying restrictions are described in Appendix B.3. The deviations of the asymptotic standard errors for the impulse responses are provided in Appendix B.4.

[10] Furthermore, the impulse responses will depend on the size of the shock Enders (2010).

[11] The identified coefficient matrices $\mathbf{D}_0 = (O^1, \mathbf{O}_1^1, \mathbf{O}_2^1, ..., \mathbf{O}_p^1)'$ and $\mathbf{D}_1 = (O^2, \mathbf{O}_1^2, \mathbf{O}_2^2, ..., \mathbf{O}_p^2)'$ are used for the impulse response analysis.

[12] For identifying the impulse responses, the extreme regimes are identified as follows. For each equation of the multivariate system, the extreme regime is identified with $G_i(t) = \{0, 1\}$ for a given point of time. This includes that different equations of the system can be at different extreme regimes at this point of time in this flexible framework. The diagonal of the transition function $\mathbf{G}(t)$ can contain in turn different combinations of zeros and ones.

5 Data

5.1 Data description

The time-varying framework is applied to a small monthly model of the economies for the selected Member States of the euro area. As the benchmark, a typical recursive linear VAR is used containing three variables: the inflation rate, the unemployment rate and the short-term interest rate. This approach enables to analyze the potential changes in the monetary transmission mechanism caused by structural changes during the transition to EMU. The subsequent empirical study follows Primiceri (2005) who uses the short-term interest rate as an indicator for monetary policy – the "policy block" –, and analyzes how the monetary policy actions affect the level of unemployment and the price level in particular – the "nonpolicy block". Furthermore, the choice of these variabels follows previous research that uses the same set of variables (see for instance, Altavilla and Ciccarelli 2007; Cogley and Sargent 2001, 2005; Primiceri 2005; Stock and Watson 2001). The analyzed period covers the time between January 1990 and December 2007. Data used are measured at monthly frequency (216 observations). The selection of the time span considers the first stage to EMU starting in 1990 and the financial crisis starting in the beginning of 2008. Following the suggestions of Schreiber and Wolters (2007), the analysis for Germany starts in January 1992 with respect to prior inconsistancies caused by the German reunification (reducing the German sample to 192 observations per variable). The inflation rate π_t is based on the monthly customer price index (CPI) (2005=100) that covers all goods and services for the respective country. It is constructed as the yearly difference of the log of the monthly CPIs: $\pi_t = log(p_t) - log(p_{t-12})$ where p_t denotes the CPI at time t. The CPIs are retrieved from the OECD StatExtracts database. Furthermore, the unemployment rate u_t is seasonally adjusted and represents the number of people unemployed as a percentage of the labor force that contains employed and unemployed people. Unemployed persons are defined as all persons aged 15 to 74 who are not employed during the reference week, have actively sought work during the past four weeks and are ready to start working immediately or within two weeks. The source for the unemployment rates is the Eurostat database. Finally, the short-term interest rate i_t is measured in percent per annum and displays the three month interbank offer rate. For euro area countries, the three month "European Interbank Offered Rate" is used from the date the country joined the euro area. The short-term interest rate is retrieved from the OECD StatExtracts database.

5.2 Data properties

Figures C.1 to C.6 display the time series of the aforementioned variables in levels for the respective Member States of the euro area. Visual inspection already provides some insights in the interactions of these variables that will be analyzed in detail in the further empirical study: (1) the yearly inflation rate and the short-term interest rate seem to move together over the course of time, (2) the unemployment rate seems to exert a behavior that is opposed to these movements and (3) with respect to changing means as well as changing variances the time series under examination do not appear to exert a stationary behavior but seem to meander in the fashion characteristic of a random walk process. Furthermore, table C.2 presents the summary statistics of the series under examination. It should be mentioned that the average inflation rates of type A countries are close to the ECB's primary objective of 2% for the observation period with a lower standard deviation than it can be observed for countries of type B. In how far the last assumption can be confirmed is evaluated by analyzing the statistical properties of the time series in augmented Dickey-Fuller (ADF) tests (Said and Dickey 1984). When implementing the ADF tests, potential heteroscedasticity is accounted for by using a modified test statistic that employs robust White's standard errors. Furthermore, the number of lags p included for the ADF tests are selected on the basis of the previously mentioned information criteria (AIC and SBC). After testing for remaining serial autocorrelation using the portmanteau test of Ljung and Box (1978), lags are added under the primary objective of the principle of parsimony when finding remaining serial autocorrelation. The heteroscedasticity robust ADF tests are conducted assuming a time trend and a constant for all variables and countries except for the inflation rates of the type A countries for which a constant but no time trend is assumed. The following equations considered by Said and Dickey (1984) are used to test for the presence of a unit root in the time series in levels:

$$\Delta y_t = a_0 + \gamma y_{t-1} + \sum_{i=2}^{p} \beta_i \Delta y_{t-i+1} + \varepsilon_t \tag{5.1}$$

$$\Delta y_t = a_0 + \gamma y_{t-1} + a_2 t + \sum_{i=2}^{p} \beta_i \Delta y_{t-i+1} + \varepsilon_t \tag{5.2}$$

where equation (5.1) includes an intercept term a_0, equation (5.2) includes both an intercept term and a linear time trend $a_2 t$, and y_t represents the respective variable under examination. The ADF test revolves around the null hypothesis $H_0 : \gamma = 0$ in equation (5.1) and the null hypothesis $H_0 : \gamma = 0$ ($\Rightarrow a_2 = 0$) in equation (5.2) under which the time series $\{y_t\}$

contains a unit root. Table C.3 reports the results for these tests. The null of a unit root can not be rejected at conventional significance levels for most of the series.[1] In fact, only for the inflation rate series $\{\pi_t\}$ of France, the null of a unit root can be rejected at the 10% significance level. However, the test statistics for the inflation rate series of the other type A countries, Germany and the Netherlands, are also close to rejecting the null hypothesis of a unit root. Thereafter, Engle-Granger cointegration tests (Engle and Granger 1987) are performed to test for cointegration of the series under examination.[2] If the null hypothesis of no cointegration can be rejected, the existing long-run equilibrium relationships between the variables will have to be accounted for in a further model specification, otherwise the model will be misspecified.[3] Table C.4 displays the results of these tests. The null hypothesis of no cointegration can not be rejected for any country.

It turns out that the time series are difference-stationary series and can be transformed into stationary series by taking first differences (reducing the samples to $T = 191$ and $T = 215$ for Germany and the other countries, respectively). Table C.5 displays the summary statistics of the differenced series $\{\Delta\pi_t\}$, $\{\Delta u_t\}$ and $\{\Delta i_t\}$. The plots of the differenced times series are presented in figures C.7 to C.12. Again, visual inspection provides the following preliminary insights: (1) the time series are consistent in meandering around zero over the observation period, (2) there seem to exist larger deviations in the short-term interest rate from the average level in the beginning of the second stage to EMU, and (3) these deviations lead to suspecting that heteroscedasticity has to be accounted for when performing the prelimary stationarity tests. For these reasons, the statistical properties of the aforementioned series are analyzed by heteroscedasticity robust ADF tests assuming no constant[4] and no time trend as represented in the following modified equation considered by Dickey and Fuller (1979):

$$\Delta^2 y_t = \gamma \Delta y_{t-1} + \sum_{i=2}^{p} \beta_i \Delta^2 y_{t-i+1} + \varepsilon_t \tag{5.3}$$

Table C.6 reports the results for testing the null hypotheses $H_0 : \gamma = 0$ for the estimated equations (5.3) where the number of lags p is chosen again by means of the aforementioned information criteria and remaining serial correlation is accounted for considering the primary objective of parsimony. The ADF tests indicate that the null of a unit root can be rejected at

[1] The indicated critical values for the significance levels are only approximate using robust standard errors. However, they are the same in large samples.

[2] Cointegration refers to the long-run equilibrium relationship among a set of nonstationary variables implying that their stochastic trends must be linked (Enders 2010).

[3] This is typically implemented by adding an error correction term in the VAR model. In this case, the variables react to stochastic shocks and to the previous period's deviation from the long-run equilibrium (Enders 2010).

[4] As reported in table C.5, the means of the differenced series are considerably close to zero. Furthermore, including the constant only leads to a loss of power in the performed Dickey-Fuller tests without providing any further explanatory support.

the 5% significance level for all and at the 1% significance level for most of the series $\{\Delta y_t\}$. Hence, these series are used as the basis for the subsequent analysis.

5.3 Identifying assumptions

To use the in chapter 4 described methodology for meaningful economic policy analysis, identifying assumptions are necessary that enable the identification of the structural VAR and hence the utilization of tools such as impulse response analyses. The identification scheme employed in this empirical study follows previous research. According to Bernanke and Blinder (1992), there are two possible timing assumptions that can be used for evaluating monetary policy effects: (1) monetary policy actions do have a contemporaneous effect on the real economy – suggesting that the policy variables should be ordered first – or (2) monetary policy actions affect the real economy only with a lag – suggesting that the policy variables should be ordered last in the VAR model. During the last decades, the standard assumption of previous research has been to model monetary policy variables last in VAR models. Hence, these variables are assumed not to have a contemporaneous effect on real economic variables which shall be an essential prerequisite for isolating monetary policy shocks (see for instance, Bernanke and Mihov 1998; Christiano et al. 1999; Primiceri 2005; Rotemberg and Woodford 1997). This empirical study will follow this approach and order the short-term interest rate – that represents an indicator of the monetary policy – last in the VAR model. Furthermore, it has been standard to assume that the inflation rate π_t is causally prior to the unemployment rate u_t implying that u_t does not have any contemporaneous effects on π_t (see for instance, Altavilla and Ciccarelli 2007; Primiceri 2005; Stock and Watson 2001). This suggested identifying assumption will also be followed in the subsequent analysis. Hence, the system can be identified by applying the standard Choleski decomposition to the structural VAR model with the previously described core variables in first differences in the following ordering: (1) the inflation rate $\Delta\pi_t$ (2) the unemployment rate Δu_t, and (3) the short-term interest rate Δi_t.

6 Empirical results

The empirical results obtained from the specification procedure of the TV-VAR model are presented in the following. To this day, no suitable code or software program is available that simplifies the implementation stage of the empirical specification procedure of the chosen model. Therefore, all major steps are implemented in MATLAB. The documentation of this implemented code is provided in Appendix E.

6.1 Specification

For specifying a linear VAR model that can be tested against the alternative nonlinear TV-VAR model, information criteria are employed to obtain insights in the potential lag structure. Testing the selected linear models for remaining residual autocorrelation, the employed LM tests (presented in Johansen 1995) indicate that a lag length as high as $p = 12$ is needed to capture the intertemporal dependencies between the variables. However, this will lead to a model that requires the estimation of more than 240 parameters. This incidence is mainly caused by the construction of the inflation rates. With respect to the central objective of parsimony in the Box-Jenkins model selection procedure (Box and Jenkins 1970), this approach has the weakness of reducing the degrees of freedom, and hence can result in poorly estimated coefficients (Enders 2010). Therefore, the difficulty is circumvented by choosing a restricted VAR model (Lütkepohl 2005). This model is characterized by restricting some of the parameter matrices $\mathbf{\Phi}_i$ with $i = 1, 2, ..., 12$ to zero matrices. The restrictions are chosen with respect to the objective of parsimony and yet considering the individual lag structures identified by the information criteria for the selected countries to find an identical specification for the six multivariate systems. It results in restricting the parameter matrices:

$$\mathbf{\Phi}_6 = \mathbf{\Phi}_7 = \mathbf{\Phi}_8 = \mathbf{\Phi}_9 = \mathbf{\Phi}_{10} = \mathbf{\Phi}_{11} = \mathbf{0} \tag{6.1}$$

leading to the specified linear model

$$\mathbf{y}_t = \boldsymbol{\phi} + \sum_{i=1}^{5} \mathbf{\Phi}_i \mathbf{y}_{t-i} + \mathbf{\Phi}_{12} \mathbf{y}_{t-12} + \mathbf{e}_t, \qquad t = 1, ..., T \tag{6.2}$$

Table D.1 provides the estimation results of the restricted linear VAR(12) model. As expected, there are highly significant dependencies of the inflation rate in first differences and its 12th lag. Furthermore, the time series of the inflation rates, unemployment rates and

Table 6.1: Specification: Parameter constancy tests for restricted linear VAR(12)

	Parameter constancy test			**Specification hypothesis**		
Country	$\mathbf{F_{RAO}(1)}$	$\mathbf{F_{RAO}(2)}$	$\mathbf{F_{RAO}(3)}$	$\mathbf{H_{03}}$	$\mathbf{H_{02}}$	$\mathbf{H_{01}}$
Type A countries						
Germany	0.098	0.003	0.000	0.0002		
France	0.316	0.028	0.017	0.0001		
Netherlands	0.180	0.009	0.001	0.0000		
Type B countries						
Italy	0.011	0.019	0.001	0.0000		
Spain	0.000	0.000	0.000	0.0013		
Portugal	0.266	0.096	0.004	0.0000		

short-term interest rates (all in first differences, $\Delta\pi_t, \Delta u_t$ and Δi_t, respectively) seem to be significantly dependent on their recent lags. This occurrence is observed for all countries except for type A countries in the differenced inflation rate series $\{\Delta\pi_t\}$. Moreover, the dynamics differ in terms of its direction for the analyzed series. While the differenced inflation rate series are mostly negatively dependent on their recent lags, the opposite is observed for the other two series, $\{\Delta u_t\}$ and $\{\Delta i_t\}$. The dependencies on lags of other variables vary with respect to the timing and the direction of the effects as well as their significance levels. In order to evaluate the appropriateness of the specified linear model, the residuals of the estimated model are tested for remaining residual autocorrelation. The results of the Lagrange-multiplier tests can be found in table D.2. Even though the 12th lag is included, the test statistics indicate that there still occurs residual autocorrelation for the countries Germany, the Netherlands and Italy. This should be kept in mind in the subsequent analysis with respect to its ability of leading to potentially biased estimates and standard errors. After the specification of the linear VAR model, the parameter constancy test developed by He et al. (2009) described in section 4.2.1 is applied to test against the alternative nonlinear TV-VAR model that allows the parameters to vary across time. The results of these tests are displayed in table 6.1. The null hypothesis $H_0' : \mathbf{B}_i = \mathbf{0}$ with $i = 1, ..., k$ can be rejected for each country assuming $k = 2, 3$ whereas it can not be rejected for France, the Netherlands and Portugal for $k = 1$. For each country, the strength of rejection (p-values) is largest for $k = 3$ which provides preliminary information about the type of parameter change as He et al. (2009) note. Therefore, $k = 3$ is chosen as the maintained model as specified in equation (4.4) that serves as the basis for the short sequence of nested tests. For each country, the hypothesis $H_{03} : \mathbf{B}_3 = \mathbf{0}$ is rejected at the 1% significance level. Hence, $k = 3$ is chosen to capture the nature of the parameter change in the multivariate system, and therefore the determined order of the transition function $\mathbf{G}(t)$.

6.2 Estimation

After the determination of the order of the transition function $\mathbf{G}(t)$ for the multivariate system, the nonlinear TV-VAR models can be estimated. For this purpose, this empirical study employs the in section 4.2.2 described estimation algorithm developed by Yang (2012) that advises to carry out the estimation of the nonlinear TV-VAR model equation by equation. The algorithm is initiated with starting values that determined by the aforementioned grid search with a zoom. The estimation results are obtained from the iterative estimation algorithm employing NLS. With respect to the previously determined order of the transition function, the algorithm is initially employed assuming three potential breaks in a system that allows for two different regimes. However, this procedure does not yield reliable results for all of the equations. An analysis of the initial estimation results suggests two main causes: Unreliable results often go along with break dates that are located close to each other. This can be an indication that a lower order of the equation-specific transition function is appropriate. Visual observation of the plotted series in figure C.7 to C.12 suggest a similar solution. For this reason, the order of the transition functions of these series is stepwise reduced to $k = 2$ and, if necessary, to $k = 1$. Another potential problem are break dates that are located in the beginning and the end of the sample. In these cases, estimation can be difficult if the observations do not suffice for a reliable estimation of the different systems. For solving this problem, the initial grid search is restricted at the beginning and the end of the sample.[1] These modifications yield reliable estimation results that are are displayed in the following tables and figures: Table D.3 displays the estimation results for the coefficient matrices $\mathbf{D}_0$ and $\mathbf{D}_1$ that indicate the dynamics between the specified variables in the different systems. With respect to the reparameterized equation (4.13) with $\mathbf{y}_t = (\mathbf{D}_0' + \mathbf{G}(t)\mathbf{D}_1')\mathbf{x}_t + \mathbf{e}_t$, the coefficient matrix $\mathbf{D}_0$ is related to system A that is associated with the extreme case $\mathbf{G}(t) = \mathbf{0}$ whereas the combined effect $\mathbf{D}_0 + \mathbf{D}_1$ is related to system B that is associated with the extreme case $\mathbf{G}(t) = \mathbf{1}$. Table D.4 presents the estimation results for the parameters in the equation-specific transition functions of the selected countries. Furthermore, the transition functions are visualized in figures D.1 to D.6. The results indicate that instabilities in the observation period differ between the analyzed variables and countries. This incidence is valid for the number of breaks as well as their timing. However, some estimation results seem to be consistent across the examined countries: The breaks seem to occur rather instantaneous with the transition taking place during a few months. The only exception can be identified for the dynamics of the differenced short-term interest rate of Spain that change during a period

[1] The restrictions were implemented as 10-25% of the sample dependent on the requirements of the respective series. This implementation was chosen under the consideration not to restrict any series more than necessary.

of more than five years (see figure D.5). Furthermore, most changes seem to have taken place around the period between stage two and three of the transition to EMU. This seems to be especially relevant for the differenced short-term interest rates. For this time series one break taking place in this period is identified for all countries. Furthermore, some of the structural changes coincide with the timing of the stages to EMU. The estimated system is assumed to be stationary.[2]

6.3 Evaluation

The maintained restricted TV-VAR models are tested for serial correlation in the error process as well as for additional structural breaks. The results of the diagnostic tests mostly suggest that the maintained models are adequate. Thereafter, impulse responses are analyzed to evaluate the properties of the estimated models.

Serial correlation in the error process

For testing the hypothesis of no serial correlation in the error process, standard tests are employed for each country-specific estimated equation. The results of these diagnostic tests are displayed in table D.5. The null hypothesis of no serial correlation in the error process $H_{0,s.c.}$ can not be rejected at any conventional significance level for most of the residual series. The Ljung-Box $Q(1)$, $Q(4)$, $Q(8)$ and $Q(12)$ statistics do not indicate in these cases that the autocorrelations of the residual series are significant. Exceptions are the residual series of the short-term interest rates of Italy and Portugal. The $Q(12)$ statistic indicates that the null hypothesis can be rejected at the 10% and 1% significance level, respectively. This might be an indication that a larger system is required to captured the true processes of these series.[3]

Additional structural breaks

Table D.5 displays the results for the tests of no additional structural breaks. The tests mostly fail to reject the null hypothesis of no additional structural breaks $H'_{0,s.b.}$ in the analyzed series with small differences between the two types of countries. For type A countries – containing Germany, France and the Netherlands – the specified structure of the restricted TV-VAR model seems to capture the existing nonlinearities well. The null of no additional structural breaks can not be rejected for any country-specific sequence $\{\Delta\pi_t\}, \{\Delta u_t\}$ or $\{\Delta i_t\}$ at any

[2] This assumption can be further verified by employing simulation methods as described in Yang (2012).

[3] As described in section 6.1, the linear system is restricted with respect to the central objective of parsimony in the Box-Jenkins model selection procedure (Box and Jenkins 1970). To solve the problem of remaining serial correlation in the error process shall be left to further research.

conventional significance level. In contrast, for type B countries – containing Italy, Spain and Portugal – the null hypothesis can not be rejected at the 5% significance level for any country-specific sequence $\{\Delta\pi_t\}, \{\Delta u_t\}$ or $\{\Delta i_t\}$. There might exist additional structural breaks for the differenced inflation rate series $\{\Delta\pi_t\}$ of Italy and the differenced unemployment rate series $\{\Delta u_t\}$ of Portugal.[4]

Impulse response analysis

One research objective of this empirical study is the characterization of changes in the transmission mechanisms of monetary policy for the selected countries. For this purpose, impulse response (IR) analysis is employed. In contrast to tests for Granger causality (Granger 1969) that test whether one time series is useful for improving the forecasting performance of another by means of F-tests,[5] IR analysis provides a more detailed picture about these interdependencies. By means of IR analysis, it is possible to trace out the effects of shocks in the monetary policy variable Δi_t on the evolution of the wider economy (here: $\Delta\pi_t$ and Δu_t). In the context of the multivariate framework that changes across time, IR analysis is conducted for the dynamics at the beginning and the end of the observation period. In doing so, potential changes in the effects of changes in monetary policy can be identified. Regarding necessary identifying assumptions, this empirical study follows the suggestions of prior research as formulated in section 5.3. It is assumed that the differenced inflation rate $\Delta\pi_t$ is causally prior to the differenced unemployment rate Δu_t which is in turn causally prior to the differenced short-term interest rate Δi_t. As a consequence, Δi_t does not have any contemporaneous effects on Δu_t and $\Delta\pi_t$. Furthermore, Δu_t does not have any contemporaneous effects on $\Delta\pi_t$.

Appendix D.4 displays the orthogonalized impulse response functions (OIRFs) for the estimated TV-VAR model with respect to an unexpected increase in changes of the short-term interest as well as their 95% confidence intervals. The OIRFs are provided for the dynamics at the beginning and the end of the observation period. For reasons of comparison, the impulse response functions (IRFs) for linear VAR model are also displayed.[6] Generally, it is observed that monetary policy shocks seem to have larger effects on the development of changes in the inflation rate than on that of changes in the unemployment rate in the short run. Furthermore, all series seem to approach their initial levels in the long run which can be

[4] For these series, different specifications with higher order transition functions were tested but did not solve the potential problem of additional structural breaks. A possible explanation could be that the selected time-varying framework does not capture the nature of nonlinearities well. Other frameworks (see, for instance, Primiceri 2005; Yang 2012, for similar models) could be employed in further research.

[5] This is the case when the lags of one variable enter into the equation for another variable (Enders 2010).

[6] The IRFs were chosen with respect to its ability of being better comparable with the OIRFs of the TV-VAR model. Since obtained from Stata that assumes $\{\varepsilon_t\}$ to have unit variance, OIRFs for the linear model would have been considerably smaller.

taken as an indication that the estimated systems are stable. For all of the analyzed countries, the OIRFs obtained from estimating the TV-VAR model show remarkable similarities with the IRFs obtained from the linear VAR model. In how far the OIRFs at the beginning or the end of the observation period are more similar to the IRFs seems to depend on the respective variables and countries. For the differing cases, the deviations of the OIRFs at the different points of time of the observation period from the "average" IRFs of the linear model also provide interesting insights. Comparing OIRFs at the beginning of the observation period with those at the end, the empirical results on changes in the transmission mechanisms seem to differ to some extent between the countries under examination. An analysis of the differences is provided in the following.

The results for **Germany** (refer to figures D.7 and D.8) indicate that the largest differences seem to have occurred in the dynamics of the changes in the unemployment rate Δu_t showing sizable negative effects after the shock. Furthermore, the persistence of the effects of the shock on changes of the short-term interest rate seems to have increased to a certain extent.[7] Similar effects can be observed for **France** (refer to figures D.10 and D.11). The OIRFs indicate that the largest development seem to have taken place for impulse responses on changes in the unemployment rate. While almost no short run effects can be found at the beginning of the observation period, significant and sizable short run effects can be identified later on. In addition, there might be an indication that the short term dynamics of differences in the short-term interest rate have become more persistent[8] The OIRFs of the **Netherlands** (refer to figure D.13 and D.14) indicate that significant changes seem to have taken place for all of the series $\{\Delta\pi_t\}, \{\Delta u_t\}$ and $\{\Delta i_t\}$. The short run effects on changes in the inflation rates seem to have reversed. In addition, there seems to occur a negative lasting effect on changes in the unemployment rate at the end of the observation period while no such effects are observed at the beginning. As already observed for Germany and France, the persistence of the impulse responses of the short-term interest rate seems to have increased significantly. For **Italy** (refer to figures D.16 and D.17), significant differences in the effects on the development of the differenced inflation rate are observed. While effects of an unexpected increase in changes of the short-term interest rate do not have any sizable effects at the beginning of the observation period, a positive effect can be observed at the end. These effects persist for about one year. In addition, the effects on the development of the differenced short-term interest rate also have become more persistent. The OIRFs of **Spain** (refer to figures D.19 and D.20) indicate an outstanding change in the effects of the shock on the evolution of the differenced inflation rate as well as the differenced short-term interest rate series: While a shock seems to

[7] While not completely significant, the OIRF seems to remain at positive levels for a long time after the shock has occurred.

[8] However, these short term effects are mostly not significant.

lead to major instabilities at the beginning of the observation period, the effects have become more stable at the end. Furthermore, the evolution of the short-term interest rate seems to have become more persistent with a significantly positive effect lasting for about one year. For **Portugal** (refer to figures D.22 and D.23), there seem to exist sizable differences in the impulse responses for all series. While the effects for the differenced short-term interest rate has become more persistent and positive, the effects for the differenced unemployment rate have deloped in the opposite direction. As observed for the other countries, the effects of an unexpected shock on the development of the differenced short-term interest rate seems to have become more persistent.

Comparing the OIRFs for the different countries, the effects of structural changes on the transmission mechanisms of monetary policy seem to be mixed. The changes in the dynamics seem to differ between the analyzed variables and countries. Regarding changes on the evolution of changes in the inflation rates, the empirical analysis provides evidence for no, increasing and decreasing effects comparing the OIRFs at the beginning and the end of the observation period. The effects of shocks on the evolution of the unemployment rate seem to have increased for some countries. However, one effect seems to have occurred for all of the countries under examination. The evolution of the differenced short-term interest rate seems to have become more persistent after the occurrence of a shock in changes of the short-term interest rate. For most of the analyzed countries, this effect is significant. It can be quantified to last for about six to twelve months. Furthermore, a certain degree of convergence of the effects of monetary policy shocks can be observed. However, this convergence seems to have taken place primarily among the countries of the same type.

7 Discussion

The empirical findings are discussed in the following in the context of existing empirical evidence and recent developments in the euro area.

The empirical study shall answer the question whether structural changes in the euro area – namely increased globalization, changes in the financial markets and especially the transition to EMU – had an impact on the transmission mechanisms of monetary policy for the selected economies. The study provides insights in this question by testing the hypothesis of parameter constancy in a multivariate framework that allows for smooth and continuous changes in the dynamics between two extreme regimes. The empirical results indicate strong evidence for several instabilities in the multivariate system.[1] Few studies that deal with a similar research objective have employed formal tests so far to identify structural instabilities in the linear multivariate systems. An exception is the study of Weber et al. (2009) who use different types of Chow tests to test for additional break dates during the observation period. The research findings of this empirical study are in line with these empirical results of Weber et al. (2009) who also find several break dates. In this respect, this empirical study is able to provide further empirical support for these instabilities by employing a more sophisticated framework than has been employed so far.

Analyzing the timing of changes in the transmission mechanisms of monetary policy, the empirical results indicate that the number of breaks as well as their location is dependent on the specific economic variables under examination. However, there is suggestive evidence that most of the instabilities occur around the period between stage two and three of the transition to EMU. This finding is reasonable considering the assumptions (refer to Boivin et al. 2008; Cecioni and Neri 2011)[2] and findings (Weber et al. 2009)[3] of prior research. In contrast to some of the earlier studies,[4] these results are obtained from utilizing a methodology that endogenously determines the timing of the breaks when fitting the data. Furthermore, as it was discussed in section 2.2, the largest changes of the transiton to EMU were introduced at the beginning of stage three including primarily the introduction of the euro as the common

[1] The results of the specification stage of the empirical specification procedure suggest $k = 3$ changes in the dynamics of the multivariate system between two regimes.

[2] The mentioned authors assume a break in the the dynamics in 1999.

[3] Weber et al. (2009) provide evidence for a break around 1996 and possibly a second one around 1999.

[4] This is especially relevant for research conducted by Boivin et al. (2008) as well as Cecioni and Neri (2011) who split the sample in 1999 to obtain a pre-EMU as well as a post-EMU sample.

currency and a single monetary policy under the responsibility of the Eurosystem. In the period between 1994 and 1998, the Member States made preparatory effort to meet the convergence criteria and took steps towards economic convergence. These developments were already observable in the initial time series (see figures C.1 to C.6) that indicated a convergence of the inflation and the short-term interest rates prior to the Member State's accession to the euro area.

Finally, the empirical study shall provide insights in the question how these changes in the transmission mechanisms of monetary policy can be characterized and in how far they are dependent on the type of economy. The empirical results suggest that the effects of structural changes on the transmission mechanisms differ between the analyzed variables and countries. These findings seem to emphasize the existing heterogeneity of the analyzed countries. Furthermore, they extend the early findings of Ciccarelli and Rebucci (2006) who provide evidence that existing cross-country differences do not have decreased over time.[5] For the effects of a shock on the evolution of changes in the inflation rate at the beginning and at the end of the observation period, no clear evidence can be provided for a specific direction of the changes if they occur at all. Furthermore, the effects of shocks on changes in the unemployment rate seem to have increased to some extent for some countries. These findings stand in contrast with the results obtained by Boivin et al. (2008) and Cecioni and Neri (2011) who provide evidence for a more effective monetary policy in terms of its better ability to stabilize the economy for the period after 1999. Furthermore, the empirical study provides suggestive evidence for changes in the evolution of the differenced short-term interest rate after the occurrence of a shock that appears to have become significantly more persistent for most of the countries under examination. This higher degree of persistence can be interpreted with respect to figures C.7 to C.12. These figures indicate that changes in the short-term interest rates have significantly reduced after the countries' accession to the euro area.[6] Hence, a shock on the changes of the short-term interest rates will remain for a longer period. The outlined findings suggest that potential developments are not clearly identifiable to be similar in terms of direction for countries belonging to the same type and different between the two type of countries. However, a certain degree of convergence can be observed among countries of the same type. This empirical finding coincides to a certain degree with findings of Boivin et al. (2008) who identify heterogeneity in the effects of monetary policy across the countries before 1999 and a significantly greater homogeneity thereafter.

[5] Ciccarelli and Rebucci (2006) analyze data for the time between 1981 and 1998.

[6] These reduced changes in the short-term interest rates are mainly caused by the creation of a common central bank in charge of a single monetary policy within the euro area. This can be also observed in figures C.1 to C.6.

8 Conclusion

During the last decades, the euro area has been subject to major structural changes. In the course of this study, the main changes are identified as a growing degree of globalization, major developments in the financial markets as well as the transition to EMU that took place in three stages in 1990, 1994 and 1999. The focus of the study is placed on this transition taking the clearly identifiable transition stages as a natural experiment as described in Meller and Nautz (2012). Research conducted on changes in the transmission mechanisms of monetary policy as a whole caused by these structural changes has been limited so far. Therefore, this empirical study aims at providing further insights in the impacts of the changes on the transmission mechanisms of monetary policy for selected Member States of the euro area (Germany, France, the Netherlands, Italy, Spain and Portugal). For this purpose, the study employs a recently developed methodology to identify changes in the dynamics of a structural VAR model that analyzes the dynamics between real economy variables (namely the inflation rate and the unemployment rate) and monetary policy variables (namely the short-term interest rate). The employed TV-VAR model allows the parameters to shift smoothly and continuously between two extreme regimes and for up to three changes between these regimes.

The empirical analysis provides several insights in the impact of these structural changes: Strong evidence is found for several instabilities during the observation period which is in line with the findings of previous research. Estimating the nonlinear TV-VAR model, several potential breaks can be identified. It is observed that the timing and the number of changes in the dynamics differ for the examined variables and selected countries. However, there is suggestive evidence that changes in the dynamics occur rather instantaneously and mostly in the period around stage two and three of the transition to EMU. These findings are reasonable considering the assumptions and findings of prior research. Furthermore, they are consistent with the fact that the largest changes of the transition were implemented at the beginning of stage three to EMU. Changes in the transmission mechanisms of monetary policy are analyzed by comparing the orthogonalized impulse response functions at the beginning and the end of the observation period. Evidence on the effects of structural changes on the transmission mechanisms seems to be mixed indicating that changes in the dynamics seem to differ between the analyzed variables and countries. These findings indicate a certain degree of heterogeneity of the selected countries. However, the empirical study provides suggestive evidence for changes in the evolution of the differenced short-term interest rate after the occurrence of a shock that appears to have become more persistent after the transition to EMU. Furthermore, a certain degree of convergence of the effects of monetary policy shocks can be observed. However, this convergence seems to have taken place primarily among countries of the same type. These findings are to some extent consistent with earlier findings of an increased homogeneity in the effects of monetary policy across countries of the euro area after 1999.

The presented findings should be interpreted in context with the methodology employed and the analytical difficulties that occurred during the implementation. The utilized nonlinear multivariate TV-VAR model has the strength that it is possible to formally test for nonlinearities in the dynamics of the linear system over the observation period. Furthermore, it enables to obtain insights in the timing of potential break dates that are determined endogenously. The clearly distinguishable regimes further enable to identify changes in the transmission mechanisms of monetary policy by comparing differences in the orthogonalized impulse response functions. However, the empirical study also has some limitations. During the specification of the model, it becomes obvious that a large system would be necessary to capture the main features of the data-generating process. Considering Yang's (2012) described "curse of dimensionality" the system is restricted in size to prevent a loss of power. Another limitation can be the necessary restrictions of the order of the transition functions for the individual equations as well as of the initial grid search to enable a reliable estimation of the systems. Considering these analytical uncertainties, the results should be considered with some caution. Furthermore, the empirical study is restricted in scope for the matters of feasibility and related to the problem of dimensionality. Therefore, certain dynamics are not considered in the multivariate system that can be of interest, for instance:

- interdependencies of the variables with longer lags; the diagnostic test for remaining serial correlation indicates that these interdependencies might exist; therefore they could be included in a further analysis that finds a solution for the "curse of dimensionality",
- exogenous variables that also could exert an influence on the analyzed dynamics; hence, the TV-VAR model could be augmented with external factors as considered by Boivin et al. (2008), and
- changes in the dynamics of the variables that could be described by more than two regimes; with respect to the identified high order of structural changes in the whole system, the TV-VAR framework could be extended to a higher order of regimes (see, for instance, Yang 2012).

This shall be left to further research.

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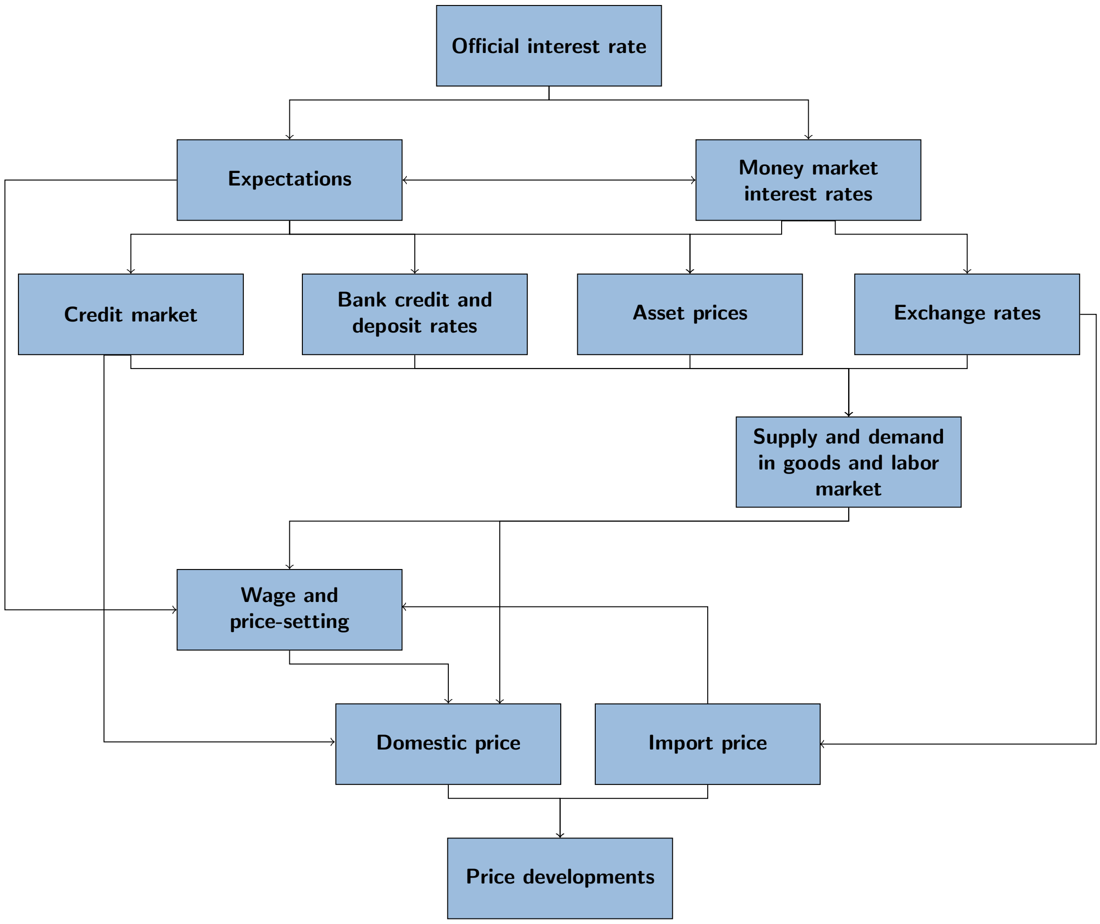
Appendix

A Transmission mechanisms of monetary policy in the euro area

A.1 Transmission mechanisms of monetary policy

Figure A.1: Transmission mechanisms of monetary policy

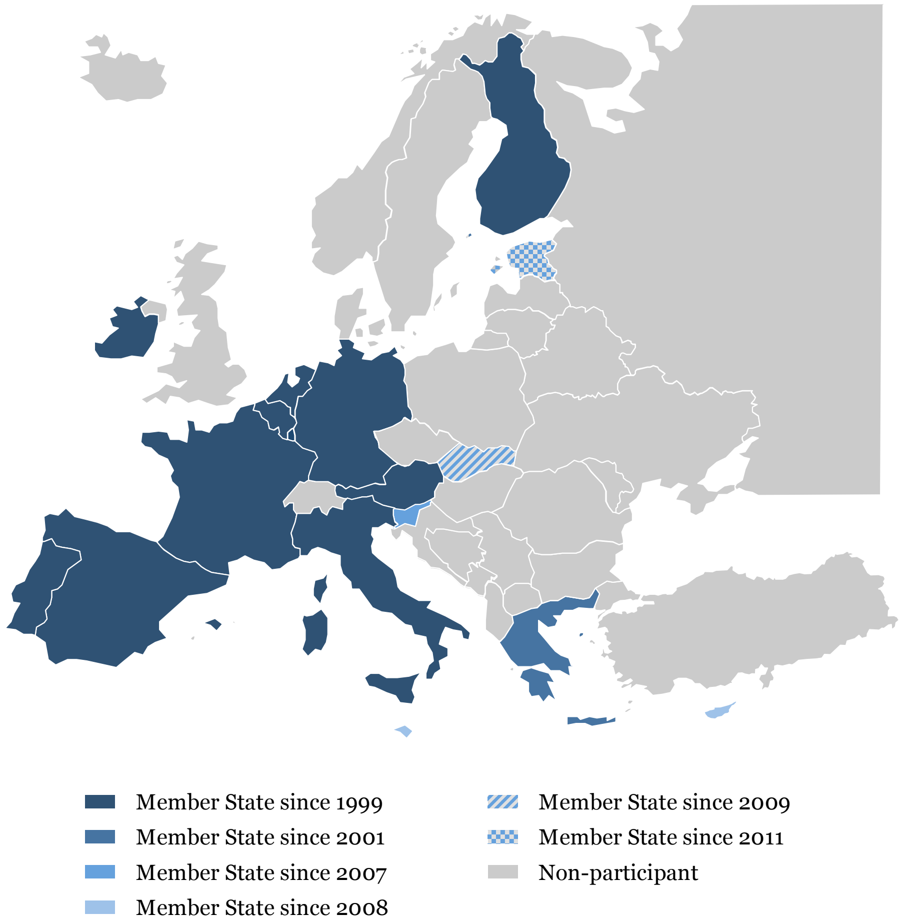


Source: Chart presented above is based on information retrieved from the official website of the European Central Bank (2012d).

A.2 Transition to EMU

A.2.1 Member States of the euro area

Figure A.2: Member States of the euro area

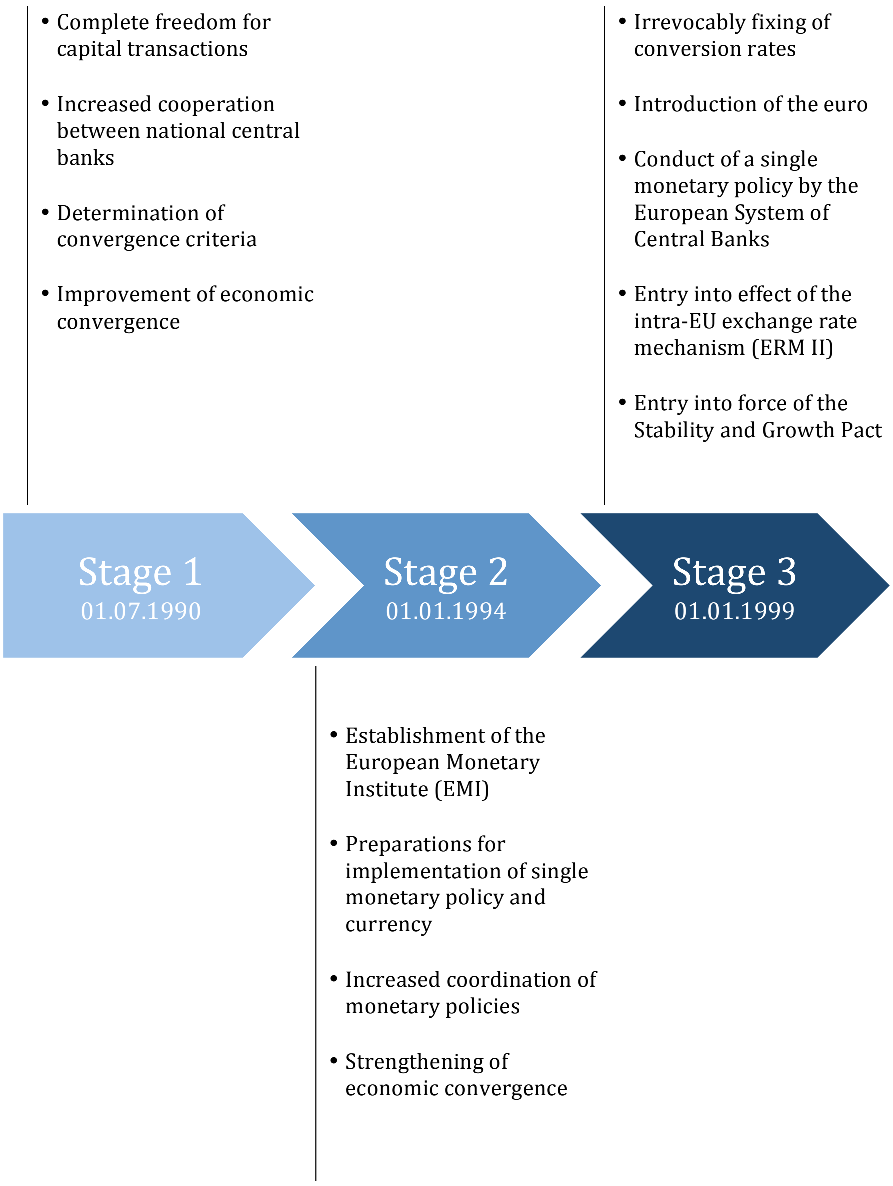


Notes: Figure presents Member States of the euro area according their accession date to the third stage of EMU. Country borders are displayed as of 2011.

Source: Information presented above were retrieved from the official website of the European Central Bank (2012c).

A.2.2 Three stages to EMU

Figure A.3: Three stages to EMU

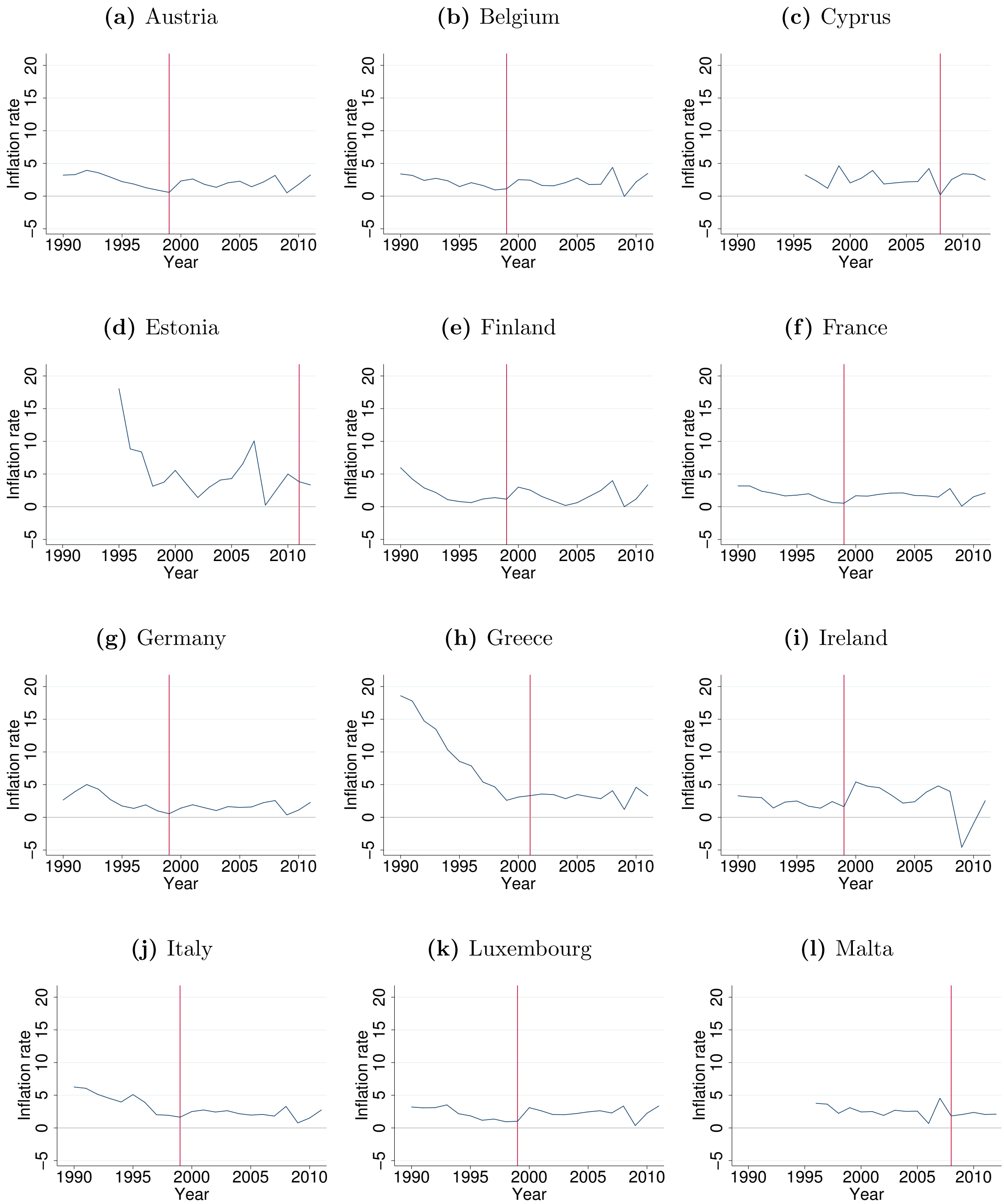


Source: Chart presented above is based on information retrieved from the official website of the European Central Bank (2012b).

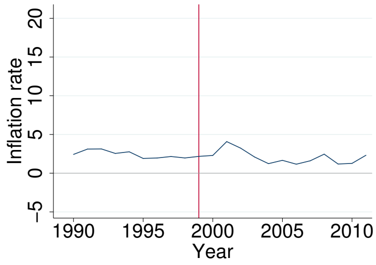
A.3 Key countries

A.3.1 Convergence of inflation rates

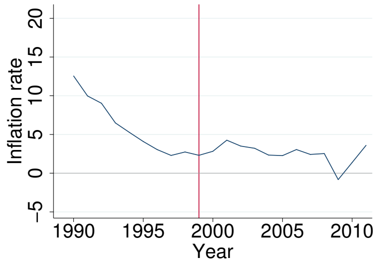
Figure A.4: Yearly time series of inflation rates for Member States of the euro area



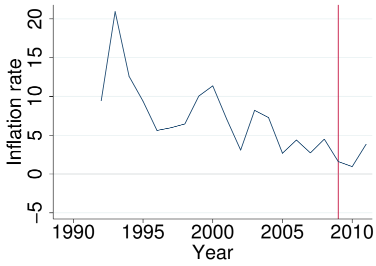
(m) Netherlands



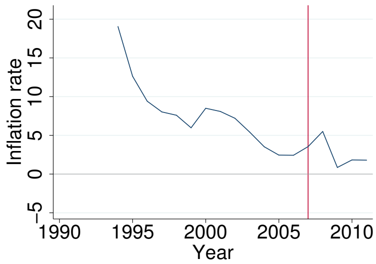
(n) Portugal



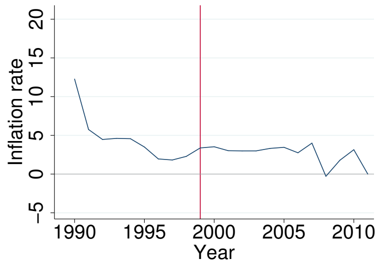
(o) Slovakia



(p) Slovenia



(q) Spain



Notes: Data are measured in percentages. The red line indicates the respective Member State's accession to the euro area. The inflation rate is constructed as the first difference of the log of the yearly customer price indices (CPIs) containing the full consumption basket for the respective countries. The time series of Slovenia does not display time series prior to 1994 that have been extraordinaryly high (1990: 187.50%; 1991: 76.47%; 1992: 113.12%; 1993: 27.58%).

Sources: OECD StatExtracts, AMECO database (data on Estonia, Cyprus and Malta).

A.3.2 Economic indicators for Member States of the euro area

Table A.1: Economic indicators for Member States of the euro area

Country	**Accession**	**Population**	**GDP** (in MEUR)	**Fraction total euro area GDP** (in %)	**HICP inflation** (in %)	**Fiscal deficit ratio** (in %)	**Debt-to-GDP ratio** (in %)	**Long-term interest rate** (in %)	**ERM membership**
Austria	1.1.1999	8,404,252	300,712	3.19	1.1	2.5	66.1	5.6	ERM 1995
Belgium	1.1.1999	10,951,266	369,836	3.92	1.4	2.1	122.2	5.7	ERM 1979
Cyprus	1.1.2008	839,751	17,761	0.19	2.0	1.5	65.3	4.2	ERM II 2005
Estonia	1.1.2011	1,340,194	15,951	0.17	-0.7	1.7	7.2	–	ERM II 2004
Finland	1.1.1999	5,375,276	189,368	2.01	1.3	0.9	55.8	5.9	ERM 1996
France	1.1.1999	65,048,412	1,996,583	21.18	1.2	3.0	58.0	5.5	ERM 1979
Germany	1.1.1999	81,751,602	2,592,600	27.51	1.4	2.7	61.3	5.6	ERM 1979
Greece	1.1.2001	11,309,885	215,088	2.29	2.0	1.6	104.4	6.4	ERM/ERM II 1998
Ireland	1.1.1999	4,480,858	156,438	1.66	1.2	0.9	66.3	6.2	ERM 1979
Italy	1.1.1999	60,626,442	1,580,220	16.77	1.8	2.7	121.6	6.7	ERM 1979
Luxembourg	1.1.1999	511,840	42,821	0.45	1.4	1.7	6.7	5.6	ERM 1979
Malta	1.1.2008	417,617	6,499	0.07	2.2	2.6	66.5	4.3	ERM II 2005
Netherlands	1.1.1999	16,655,799	601,973	6.39	1.8	1.4	72.1	5.5	ERM 1979
Portugal	1.1.1999	10,636,979	170,907	1.81	1.8	2.5	62.0	6.2	ERM 1992
Slovakia	1.1.2009	5,435,273	69,058	0.73	2.2	2.2	29.4	4.5	ERM II 2005
Slovenia	1.1.2007	2,050,189	36,172	0.38	2.3	1.8	29.1	3.8	ERM II 2004
Spain	1.1.1999	46,152,926	1,063,355	11.28	1.8	2.6	68.8	6.3	ERM 1989

Notes: Data on GDP and population refer to the year 2011. GDP is measured at market prices. Data on economic indicators of convergence refer to the convergence reports dated prior to the accession of the respective Member States to the Euro area. The reference value for the HICP inflation rate amounted to 2.7% for accession 1999, 2.4% for 2001, 2.6% for 2007, 3.0% for 2008, 3.2% for 2009 and 1.0% for 2011. The reference value for the long-term interest rate amounted to 7.8% for accession in 1999, 7.2% for 2001, 5.9% for 2007, 6.4% for 2008, 6.5% for 2009 and 6.0% for 2011.

Sources: Data on GDP and population was retrieved from Eurostat. Data on economic indicators of convergence was retrieved from the convergence reports of the European Monetary Institute and later the European Central Bank (refer to European Central Bank 2000a, 2002, 2004, 2006a,b, 2007, 2008, 2010a, 2012a; European Monetary Institute 1998).

B Methodology

B.1 Visualization of different orders of the logistic function

Figure B.1: Logistic function $G_i(t|\gamma_i, \mathbf{c}_i)$ for various values of the smoothness parameter γ_i and the threshold $c_{i1} = 1$ and $c_{i2} = 3$ (in case that $k = 2$)

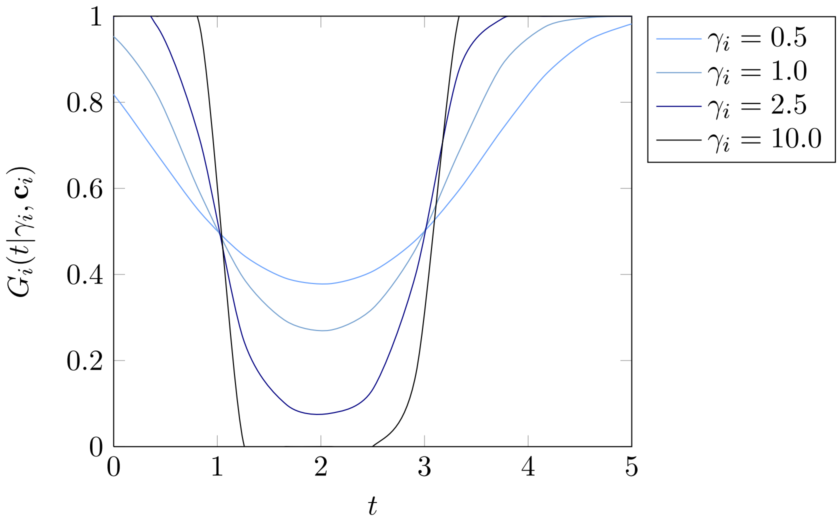
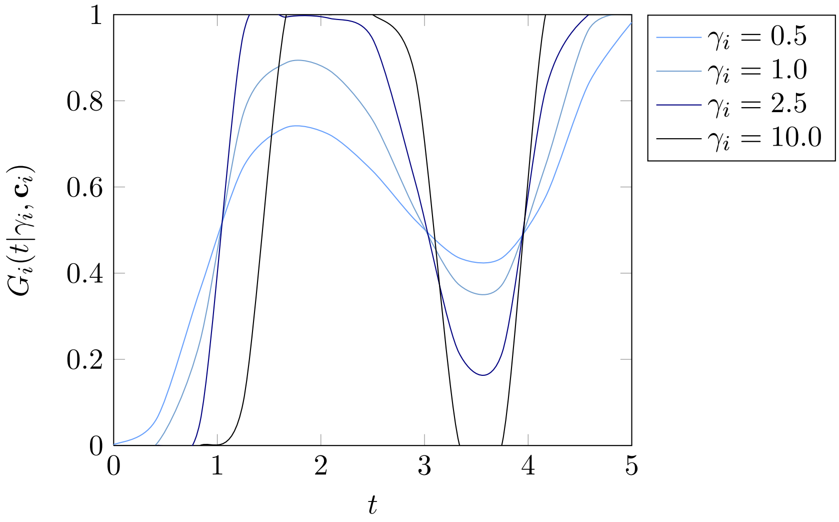


Figure B.2: Logistic function $G_i(t|\gamma_i, \mathbf{c}_i)$ for various values of the smoothness parameter γ_i and the threshold $c_{i1} = 1$, $c_{i2} = 3$ and $c_{i3} = 4$ (in case that $k = 3$)



B.2 Derivation of the simplified linear alternative in the parameter constancy test

He et al. (2009) replace $G(t|\gamma_i, \mathbf{c}_i)$ for notational convenience by $\tilde{G}(t|\gamma_i, \mathbf{c}_i) = G(t|\gamma_i, \mathbf{c}_i) - G(t|0, \mathbf{c}_i)$ for $i = 1, ..., m$, as it results in $\tilde{G}(t|0, \mathbf{c}_i) = 0$.

They further note, that $\tilde{G}(t|\gamma_i, \mathbf{c}_i)$ can be approximated by the first-order Taylor approximation about $\gamma_i = 0$:

$$\begin{aligned}
\tilde{G}(t|\gamma_i, \mathbf{c}_i) &= \tilde{G}(t|0, \mathbf{c}_i) + \left.\frac{\delta \tilde{G}(t|\gamma_i, \mathbf{c}_i)}{\delta \gamma_i}\right|_{\gamma_i=0} (\gamma_i - 0) + R_i \\
&= \left.\frac{\delta \left[\left(1 + exp\{-\gamma_i \prod_{j=1}^{k}(t - c_{ij})\}\right)^{-1} - \frac{1}{2} \right]}{\delta \gamma_i}\right|_{\gamma_i=0} \gamma_i + R_i \\
&= \left.\frac{exp\{-\gamma_i \prod_{j=1}^{k}(t - c_{ij})\} \prod_{j=1}^{k}(t - c_{ij})}{\left(1 + exp\{-\gamma_i \prod_{j=1}^{k}(t - c_{ij})\}\right)^2}\right|_{\gamma_i=0} \gamma_i + R_i \\
&= \frac{1}{4}\gamma_i \prod_{j=1}^{k}(t - c_{ij}) + R_i
\end{aligned} \tag{B.1}$$

where R_i is the remainder.

As a consequence, the transition function $\mathbf{G}(t) = diag\{G_1(t|\gamma_1, \mathbf{c}_1), ..., G_m(t|\gamma_m, \mathbf{c}_m)\}$ can be replaced by $\tilde{\mathbf{G}}(t) = diag\{\tilde{G}_1(t|\gamma_1, \mathbf{c}_1), ..., \tilde{G}_m(t|\gamma_m, \mathbf{c}_m)\}$. In order to clarify the following calculations, $\tilde{\mathbf{G}}(t)$ can be represented by the sum $\mathbf{A}(t) + \mathbf{R}$, where $\mathbf{A}(t) = diag\{\frac{1}{4}\gamma_1 \prod_{j=1}^{k}(t - c_{1j}), ..., \frac{1}{4}\gamma_m \prod_{j=1}^{k}(t - c_{mj})\}$ and $\mathbf{R} = diag\{R_1, ..., R_m\}$.

To arrive at the simplified linear alternative, He et al. (2009) substitute $\mathbf{G}(t)$ in equation (4.1) by $\tilde{\mathbf{G}}(t)$ being equal to $\mathbf{A}(t) + \mathbf{R}$:

$$
\begin{aligned}
\mathbf{y}_t &= \left(1-\tilde{\mathbf{G}}(t)\right)\left(\boldsymbol{\phi}^1+\sum_{i=1}^{p}\boldsymbol{\Phi}_i^1\mathbf{y}_{t-i}\right)+\tilde{\mathbf{G}}(t)\left(\boldsymbol{\phi}^2+\sum_{i=1}^{p}\boldsymbol{\Phi}_i^2\mathbf{y}_{t-i}\right)+\boldsymbol{e}_t\\
&=(1-\mathbf{A}(t)-\mathbf{R})\left(\boldsymbol{\phi}^1+\sum_{i=1}^{p}\boldsymbol{\Phi}_i^1\mathbf{y}_{t-i}\right)+(\mathbf{A}(t)+\mathbf{R})\left(\boldsymbol{\phi}^2+\sum_{i=1}^{p}\boldsymbol{\Phi}_i^2\mathbf{y}_{t-i}\right)+\boldsymbol{e}_t\\
&=\left(\boldsymbol{\phi}^1+\sum_{i=1}^{p}\boldsymbol{\Phi}_i^1\mathbf{y}_{t-i}\right)+\mathbf{A}(t)\left[\left(\boldsymbol{\phi}^2+\sum_{i=1}^{p}\boldsymbol{\Phi}_i^2\mathbf{y}_{t-i}\right)-\left(\boldsymbol{\phi}^1+\sum_{i=1}^{p}\boldsymbol{\Phi}_i^1\mathbf{y}_{t-i}\right)\right]\\
&\quad\underbrace{+\mathbf{R}\left[\left(\boldsymbol{\phi}^2+\sum_{i=1}^{p}\boldsymbol{\Phi}_i^2\mathbf{y}_{t-i}\right)-\left(\boldsymbol{\phi}^1+\sum_{i=1}^{p}\boldsymbol{\Phi}_i^1\mathbf{y}_{t-i}\right)\right]+\boldsymbol{e}_t}_{\boldsymbol{e}_t^*}\\
&=\left(\boldsymbol{\phi}^1+\sum_{i=1}^{p}\boldsymbol{\Phi}_i^1\mathbf{y}_{t-i}\right)+\mathbf{A}(t)\left[\left(\boldsymbol{\phi}^2+\sum_{i=1}^{p}\boldsymbol{\Phi}_i^2\mathbf{y}_{t-i}\right)-\left(\boldsymbol{\phi}^1+\sum_{i=1}^{p}\boldsymbol{\Phi}_i^1\mathbf{y}_{t-i}\right)\right]+\boldsymbol{e}_t^*
\end{aligned}
\tag{B.2}
$$

Rearranging terms yields:

$$\mathbf{y}_t=\mathbf{B}_0\mathbf{w}_t+\mathbf{B}_1\mathbf{w}_t t+...+\mathbf{B}_k\mathbf{w}_t t^k+\boldsymbol{e}_t^* \tag{B.3}$$

where $\mathbf{B}_0$ is an $m\times(mp+1)$ coefficient matrix, $\mathbf{B}_i=\boldsymbol{\Gamma}\mathbf{B}_i^*$, $i=1,...,k$, are $m\times(mp+1)$ coefficient matrices such that $\mathbf{B}_i^*\neq 0$, $i=1,...,k$, and $\boldsymbol{\Gamma}=diag\{\gamma_1,...,\gamma_m\}$. Furthermore, $\mathbf{w}_t=(1,y_{1,t-1},...,y_{1,t-p},...,y_{m,t-1},...,y_{m,t-p})'$ is an $(mp+1)\times 1$ vector.

The authors note that under H_0, $\mathbf{B}_0=[\boldsymbol{\phi}^1,\boldsymbol{\Phi}_1^1,...,\boldsymbol{\Phi}_p^1]$ and $\boldsymbol{e}_t^*=\boldsymbol{e}_t$, where the latter statement implies that the distributional properties of the error process are not affected when the null hypothesis is valid.

B.3 Identification

In order to identify the impulse responses, identifying restrictions have to be imposed on the estimated model which can be done by using the Choleski decomposition (Enders 2010). For this purpose, an ordering of the variables has to be assumed. The following derivations assume $m = 3$ equations in the VAR system. For instance, it can be assumed that y_{1t} is causally prior to y_{2t} that is in turn causally prior to y_{3t}. As a consequence, y_{2t} and y_{3t} do not have any contemporaneous effects on y_{1t}. Furthermore, y_{3t} does not have a contemporaneous effect on y_{2t}.

Assuming $s_{12} = s_{13} = s_{23} = 0$, the error terms can be decomposed as follows:

$$e_{1t} = \varepsilon_{1t} \tag{B.4}$$

$$e_{2t} = \varepsilon_{2t} - s_{21}\varepsilon_{1t} \tag{B.5}$$

$$e_{3t} = \varepsilon_{3t} - s_{31}\varepsilon_{1t} - s_{32}\varepsilon_{2t} \tag{B.6}$$

where $\varepsilon_{1t}, \varepsilon_{2t}$ and ε_{3t} can be characterized as white-noise processes.

Considering the following properties, the impulse responses can be identified:

$$E(\boldsymbol{e}_t'\boldsymbol{e}_t) = E\begin{pmatrix} e_{1t}^2 & e_{1t}e_{2t} & e_{1t}e_{3t} \\ e_{2t}e_{1t} & e_{2t}^2 & e_{2t}e_{3t} \\ e_{3t}e_{1t} & e_{3t}e_{2t} & e_{3t}^2 \end{pmatrix} = \begin{bmatrix} \sigma_1^2 & \sigma_{12} & \sigma_{13} \\ \sigma_{21} & \sigma_2^2 & \sigma_{23} \\ \sigma_{31} & \sigma_{32} & \sigma_3^2 \end{bmatrix} = \boldsymbol{\Sigma}_e \tag{B.7}$$

where $\sigma_{12} = \sigma_{21}$, $\sigma_{13} = \sigma_{31}$, and $\sigma_{23} = \sigma_{32}$. Furthermore,

$$\sigma_1^2 = E\left[\varepsilon_{1t}^2\right] = \sigma_{y_1}^2 \tag{B.8}$$

$$\sigma_2^2 = E\left[(\varepsilon_{2t} - s_{21}\varepsilon_{1t})^2\right] = \sigma_{y_2}^2 + s_{21}^2\sigma_{y_1}^2 \tag{B.9}$$

$$\sigma_3^2 = E\left[(\varepsilon_{3t} - s_{31}\varepsilon_{1t} - s_{32}\varepsilon_{2t})^2\right] = \sigma_{y_3}^2 + s_{31}^2\sigma_{y_1}^2 + s_{32}^2\sigma_{y_2}^2 \tag{B.10}$$

$$\sigma_{12} = E\left[(\varepsilon_{1t})(\varepsilon_{2t} - s_{21}\varepsilon_{1t})\right] = -s_{21}\sigma_{y_1}^2 \tag{B.11}$$

$$\sigma_{13} = E\left[(\varepsilon_{1t})(\varepsilon_{3t} - s_{31}\varepsilon_{1t} - s_{32}\varepsilon_{2t})\right] = -s_{31}\sigma_{y_1}^2 \tag{B.12}$$

$$\sigma_{23} = E\left[(\varepsilon_{2t} - s_{21}\varepsilon_{1t})(\varepsilon_{3t} - s_{31}\varepsilon_{1t} - s_{32}\varepsilon_{2t})\right] = -s_{32}\sigma_{y_2}^2 + s_{21}s_{31}\sigma_{y_1}^2 \tag{B.13}$$

and

$$E(\boldsymbol{\varepsilon}_t'\boldsymbol{\varepsilon}_t) = E\begin{pmatrix} \varepsilon_{1t}^2 & \varepsilon_{1t}\varepsilon_{2t} & \varepsilon_{1t}\varepsilon_{3t} \\ \varepsilon_{2t}\varepsilon_{1t} & \varepsilon_{2t}^2 & \varepsilon_{2t}\varepsilon_{3t} \\ \varepsilon_{3t}\varepsilon_{1t} & \varepsilon_{3t}\varepsilon_{2t} & \varepsilon_{3t}^2 \end{pmatrix} = \begin{bmatrix} \sigma_{y_1}^2 & 0 & 0 \\ 0 & \sigma_{y_2}^2 & 0 \\ 0 & 0 & \sigma_{y_3}^2 \end{bmatrix} = \boldsymbol{\Sigma}_\varepsilon \tag{B.14}$$

B.4 Derivation of the asymptotic standard errors of the impulse responses

With reference to Lütkepohl (2005), the asymptotic standard errors of the impulse response matrices can be obtained as the square roots of the diagonal elements of

$$\mathbf{L}_i \hat{\boldsymbol{\Sigma}}_{\hat{\alpha}} \mathbf{L}_i' / T \tag{B.15}$$

where T equals the number of observations.

Furthermore, $\mathbf{L}_i$ is obtained from

$$\mathbf{L}_i = \sum_{n=0}^{i-1} \mathbf{J}(\mathbf{O}')^{i-1-n} \otimes \boldsymbol{\varphi}_n \tag{B.16}$$

with $\boldsymbol{\varphi}_n$ denoting the impulse response matrix and

$$\mathbf{J} = (\mathbf{I}_m, \mathbf{0}, \mathbf{0}, \mathbf{0}, \mathbf{0}, \mathbf{0}) \tag{B.17}$$

where m equals the number of equations in the system, and

$$\mathbf{O} = \begin{pmatrix} \mathbf{O}_{i,1} & \mathbf{O}_{i,2} & \dots & \mathbf{O}_{i,p-1} & \mathbf{O}_{i,p} \\ \mathbf{I}_m & \mathbf{0} & \dots & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{I}_m & & \mathbf{0} & \mathbf{0} \\ \vdots & & \ddots & \vdots & \vdots \\ \mathbf{0} & \mathbf{0} & \dots & \mathbf{I}_m & \mathbf{0} \end{pmatrix} \tag{B.18}$$

with p denoting the lag order and $i = A, B$. Moreover, $\mathbf{O}_{ij}$, for $j = 1, ..., p$, denote the identified coefficient matrices for lag j considering system i as described in equations (4.24) and (4.25).

Finally, $\hat{\boldsymbol{\Sigma}}_{\hat{\alpha}}$ is characterized as

$$\hat{\boldsymbol{\Sigma}}_{\hat{\alpha}} = \boldsymbol{\Gamma}_Y(0)^{-1} \otimes \boldsymbol{\Sigma}_e \tag{B.19}$$

with

$$\boldsymbol{\Gamma}_Y(0) = \mathbf{Z}\mathbf{Z}'/T \tag{B.20}$$

where $\mathbf{Z} = (\mathbf{Z}_1, \mathbf{Z}_2, ..., \mathbf{Z}_T)$ is a $mp \times T$ matrix and $\mathbf{Z}_t = (\mathbf{y}_{t-1}', \mathbf{y}_{t-2}', ..., \mathbf{y}_{t-p}')'$ with $\mathbf{y}_t = (y_{1,t}, y_{2,t}, ..., y_{m,t})'$.

C Data

C.1 Data description

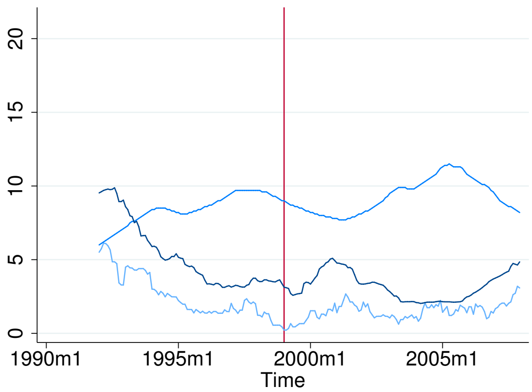
π_t	Inflation rate; the inflation rate is constructed as the yearly difference of the log of monthly customer price indices (CPIs) p_t [$\pi_t = log(p_t) - log(p_{t-12})$]. The CPI contains the full consumption basket for the respective countries. [*Source:* OECD StatExtracts]
$\Delta\pi_t$	Inflation rate (FD); the inflation rate in first differences is constructed as first difference of the inflation rates in levels [$\Delta\pi_t = \pi_t - \pi_{t-1}$].
u_t	Unemployment rate; the unemployment rate represents the number of people unemployed as a percentage of the labor force that contains employed and unemployed people. Unemployed persons are defined as all persons aged 15 to 74 who were not employed during the reference week, had actively sought work during the past four weeks and were ready to begin working immediately or within two weeks. The unemployment rate is seasonally adjusted. [*Source:* Eurostat]
Δu_t	Unemployment rate (FD); the unemployment rate in first differences is constructed as first difference of the unemployment rates in levels [$\Delta u_t = u_t - u_{t-1}$].
i_t	Short-term interest rate; the short-term interest rate is measured per annum and displays the three month interbank offer rate. From the date the country joined the eurozone, the rate displays the "European Interbank Offered Rate". [*Source:* OECD StatExtracts]
Δi_t	Short-term interest rate (FD); the short-term interest rate in first differences is constructed as first difference of the short-term interest rates in levels [$\Delta i_t = i_t - i_{t-1}$].

C.2 Data properties

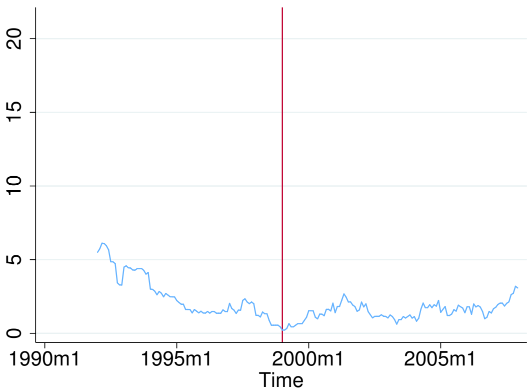
C.2.1 Time series in levels

Figure C.1: Plots of time series in levels: Germany

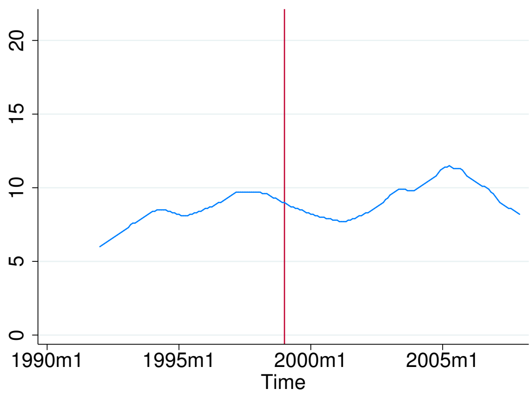
(a) Total



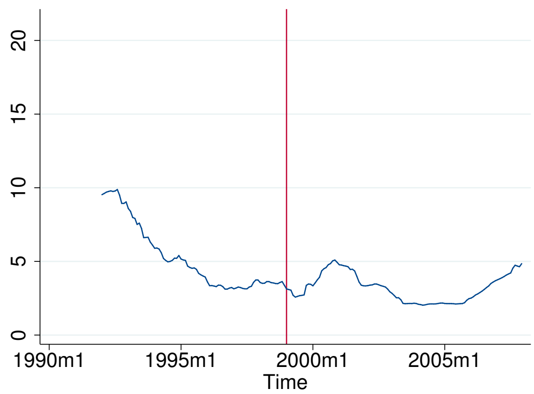
(b) Inflation rate



(c) Unemployment rate

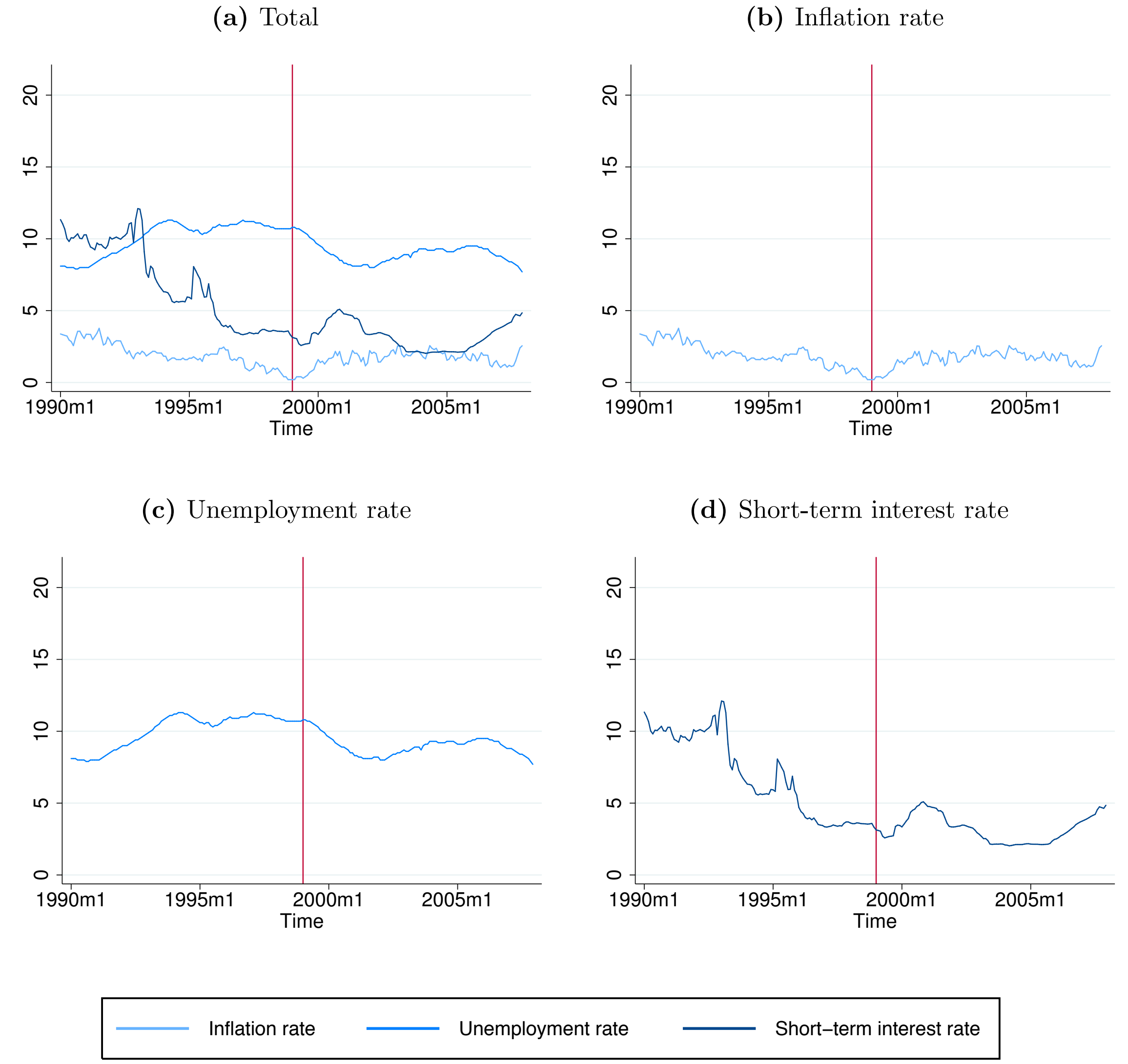


(d) Short-term interest rate



Notes: Data are measured in percentages and are at monthly frequency. The data basis for Germany starts in 1992m1 with respect to Germany's prior reunification.

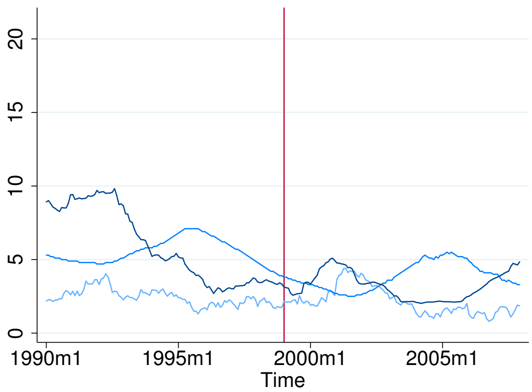
Figure C.2: Plots of time series in levels: France



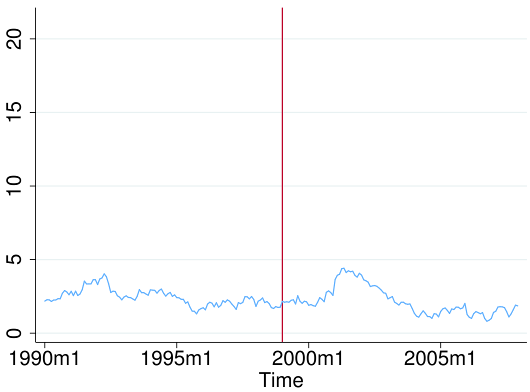
Notes: Data are measured in percentages and are at monthly frequency.

Figure C.3: Plots of time series in levels: Netherlands

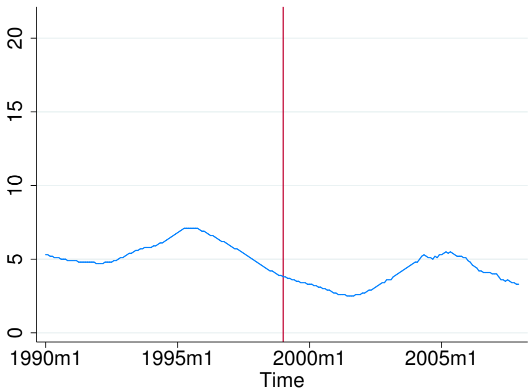
(a) Total



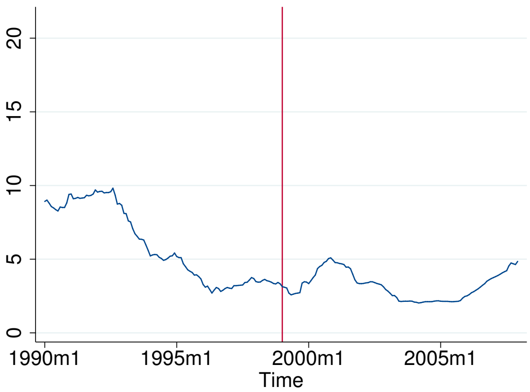
(b) Inflation rate



(c) Unemployment rate



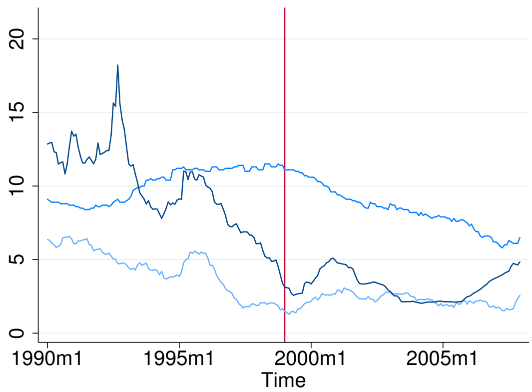
(d) Short-term interest rate



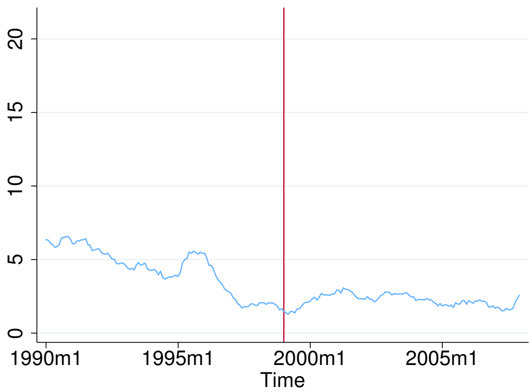
Notes: Data are measured in percentages and are at monthly frequency.

Figure C.4: Plots of time series in levels: Italy

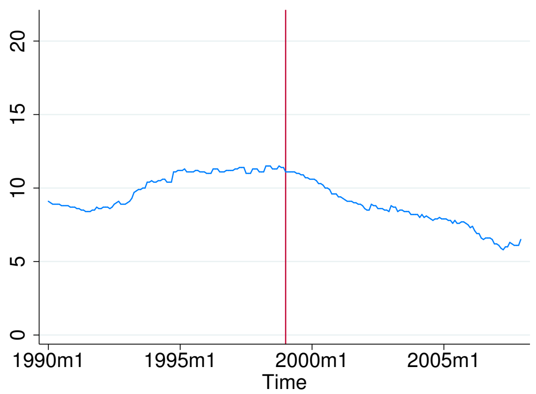
(a) Total



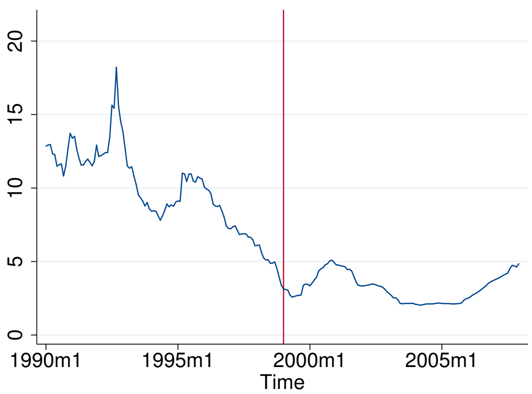
(b) Inflation rate

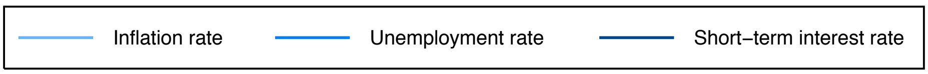


(c) Unemployment rate



(d) Short-term interest rate





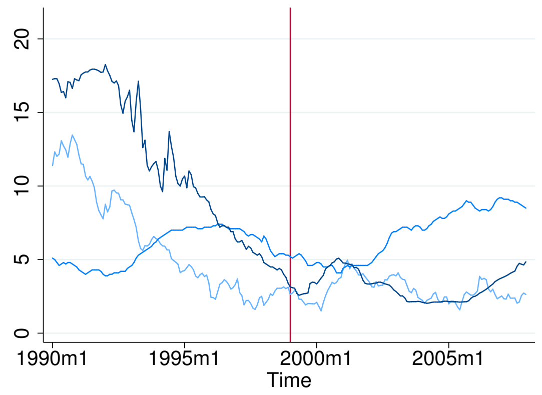
Notes: Data are measured in percentages and are at monthly frequency.

Figure C.5: Plots of time series in levels: Spain

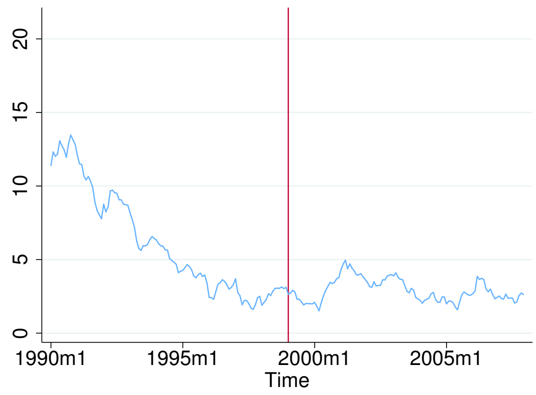
Notes: Data are measured in percentages and are at monthly frequency.

Figure C.6: Plots of time series in levels: Portugal

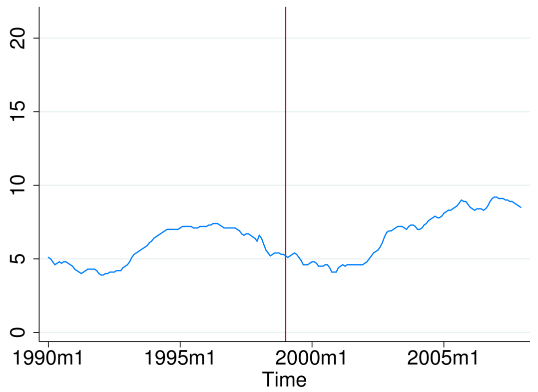
(a) Total



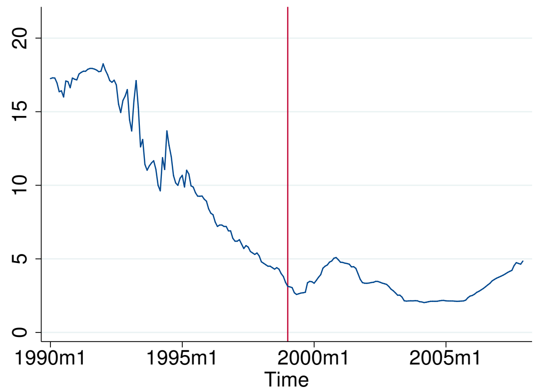
(b) Inflation rate



(c) Unemployment rate



(d) Short-term interest rate



Notes: Data are measured in percentages and are at monthly frequency.

Table C.2: Summary statistics for time series in levels

Variable	Mean	Std. Dev.	Min.	Max.	T
Type A countries					
Germany					
Annual inflation rate	1.96	1.20	0.22	6.12	192
Unemployment rate	8.91	1.17	6.00	11.50	192
Short-term interest rate	4.11	1.92	2.03	9.88	192
France					
Annual inflation rate	1.82	0.73	0.20	3.77	216
Unemployment rate	9.54	1.09	7.70	11.30	216
Short-term interest rate	5.06	2.81	2.03	12.10	216
Netherlands					
Annual inflation rate	2.30	0.78	0.81	4.41	216
Unemployment rate	4.69	1.22	2.50	7.10	216
Short-term interest rate	4.58	2.35	2.03	9.82	216
Type B countries					
Italy					
Annual inflation rate	3.28	1.54	1.29	6.58	216
Unemployment rate	9.30	1.57	5.80	11.50	216
Short-term interest rate	6.51	3.93	2.03	18.22	216
Spain					
Annual inflation rate	3.70	1.36	1.39	7.04	216
Unemployment rate	14.15	4.14	7.90	21.50	216
Short-term interest rate	6.49	4.25	2.03	15.60	216
Portugal					
Annual inflation rate	4.54	3.01	1.52	13.46	216
Unemployment rate	6.25	1.57	3.90	9.20	216
Short-term interest rate	7.32	5.40	2.03	18.25	216

Notes: Data are measured in percentages.

The following table reports the results of heteroscedasticity robust augmented Dickey-Fuller tests for the time series in levels. The number of lags is chosen by means of AIC and SBC information criteria:

Table C.3: Unit root tests for time series in levels

Variable	γ	**Robust Std. Err.**	$\mathbf{H_0 : \gamma = 0}$[1]	**p**	**T**	**Time trend**
Type A countries						
Germany						
Inflation rate	−0.057	0.023	$t = -2.52$	13	179	No
Unemployment rate	−0.009	0.005	$t = -1.91$	3	189	Yes
Short-term interest rate	−0.016	0.010	$t = -1.54$	4[1]	188	Yes
France						
Inflation rate	−0.062	0.023	$t = -2.72$*	13	203	No
Unemployment rate	−0.010	0.004	$t = -2.16$	4	212	Yes
Short-term interest rate	−0.022	0.020	$t = -1.08$	9	207	Yes
Netherlands						
Inflation rate	−0.056	0.023	$t = -2.43$	19	197	No
Unemployment rate	−0.009	0.004	$t = -2.25$	2	212	Yes
Short-term interest rate	−0.009	0.009	$t = -1.06$	14	202	Yes
Type B countries						
Italy						
Inflation rate	−0.016	0.013	$t = -1.22$	13	203	Yes
Unemployment rate	−0.011	0.007	$t = -1.66$	7	209	Yes
Short-term interest rate	−0.023	0.028	$t = -0.82$	16	200	Yes
Spain						
Inflation rate	−0.028	0.018	$t = -1.57$	14	202	Yes
Unemployment rate	−0.008	0.003	$t = -2.63$	4	212	Yes
Short-term interest rate	−0.013	0.012	$t = -1.08$	4	212	Yes
Portugal						
Inflation rate	−0.036	0.013	$t = -2.67$	14	202	Yes
Unemployment rate	−0.012	0.006	$t = -2.17$	7	209	Yes
Short-term interest rate	−0.002	0.012	$t = -0.11$	11	205	Yes

[1] Number of lags was chosen to account for remaining serial correlation.

Notes: Approximate significance levels for ADF tests with a constant but no time trend: −3.46 (1%), −2.88 (5%), −2.57 (10%). Approximate significance levels for ADF tests with a constant and a time trend: −3.99 (1%), −3.43 (5%), −3.13 (10%). Significance levels refer to empirical cumulative distribution of τ_μ and τ_τ, respectively, for non-robust standard errors and a sample size of $T = 250$ reported in Fuller (1976). In large samples, the significance levels for the ADF tests are the same using robust and non-robust standard errors. *** $p < 1\%$, ** $p < 5\%$, * $p < 10\%$.

The following table reports the results for the Engle-Granger cointegration tests for time series in levels:

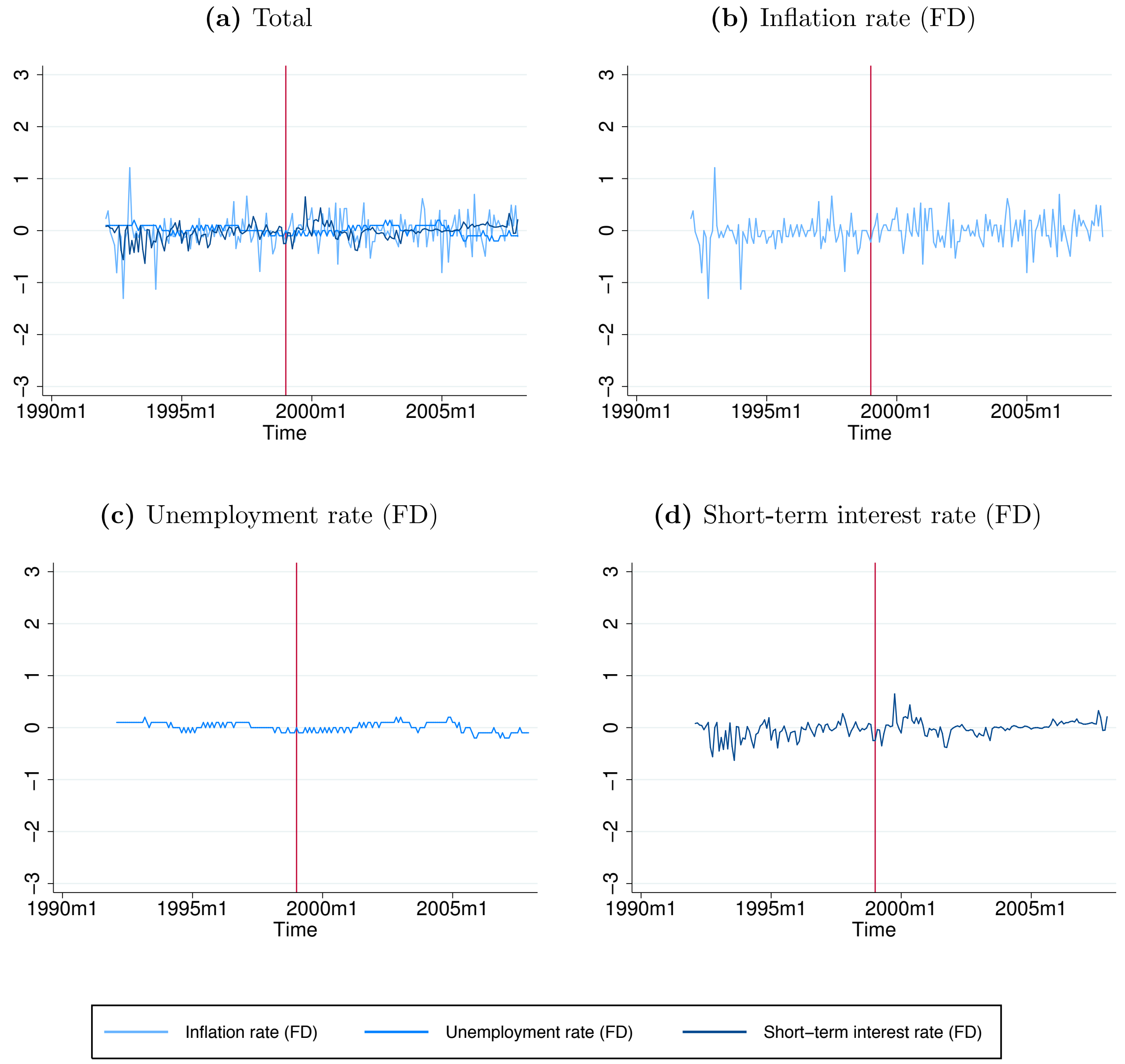
Table C.4: Cointegration tests for time series in levels

Dependent variable	**Test statistic**
Type A countries	
Germany	
Inflation rate	−3.152
Unemployment rate	−2.433
Short-term interest rate	−3.481
France	
Inflation rate	−2.719
Unemployment rate	−1.625
Short-term interest rate	−1.909
Netherlands	
Inflation rate	−2.271
Unemployment rate	−1.489
Short-term interest rate	−2.263
Type B countries	
Italy	
Inflation rate	−3.172
Unemployment rate	−1.354
Short-term interest rate	−3.014
Spain	
Inflation rate	−2.510
Unemployment rate	−1.736
Short-term interest rate	−2.640
Portugal	
Inflation rate	−2.775
Unemployment rate	−1.378
Short-term interest rate	−1.614

Notes: Table displays test statistics from cointegration tests for potential cointegrating relationships between the three variables for different dependent variables. The test statistics are obtained from testing the unit root hypothesis in the residual series using the ADF test with twelve augmentations and no constant and no trend which is the same as testing the null hypothesis of no cointegation. Critical values for the Engle-Granger cointegration test for three variables: −4.368 (1%), −3.785 (5%), −3.483 (10%). Critical values refer to a sample size of $T = 200$ as reported Enders (2010). *** $p < 1\%$, ** $p < 5\%$, * $p < 10\%$.

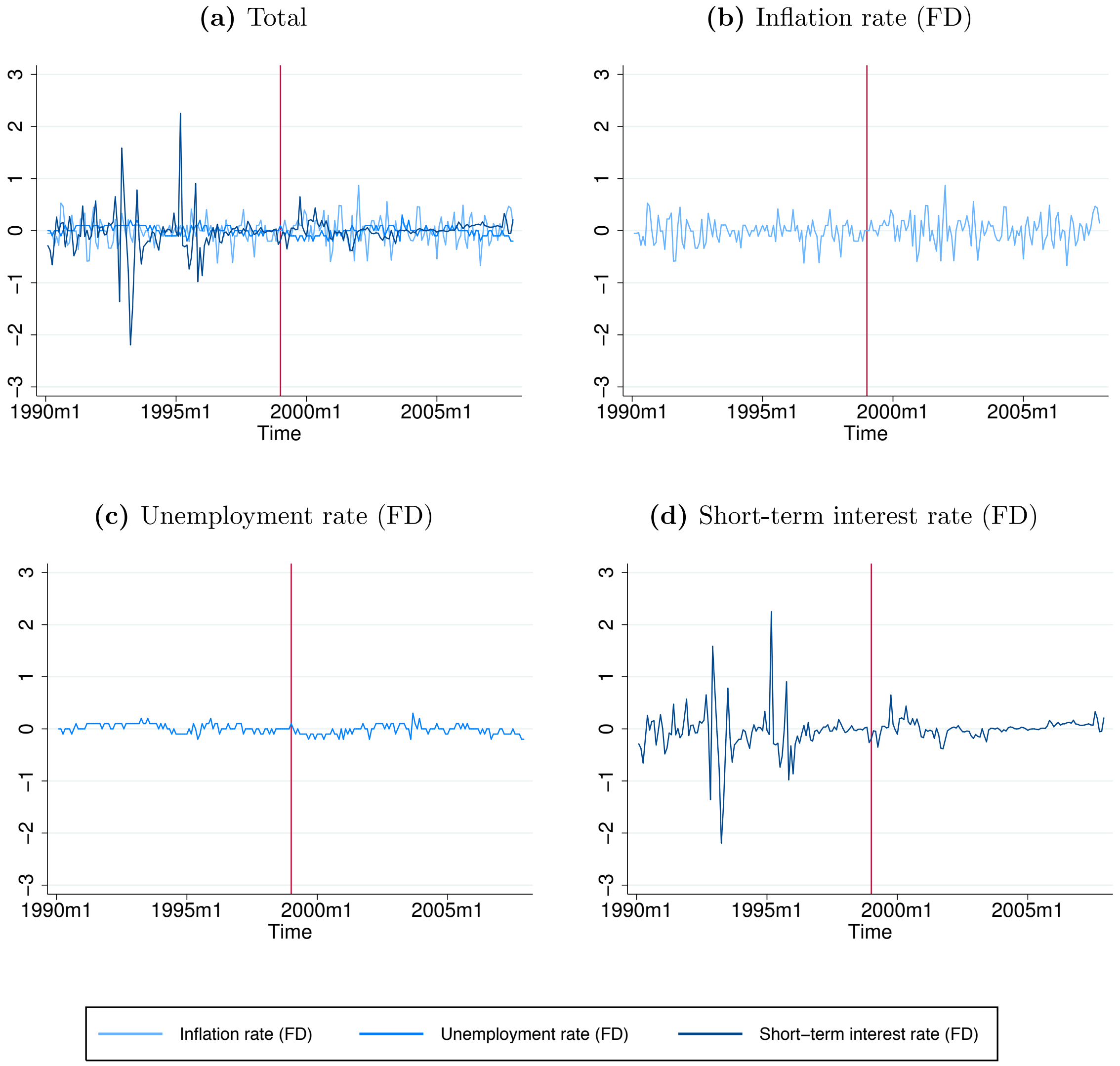
C.2.2 Time series in first differences

Figure C.7: Plots of time series in first differences: Germany



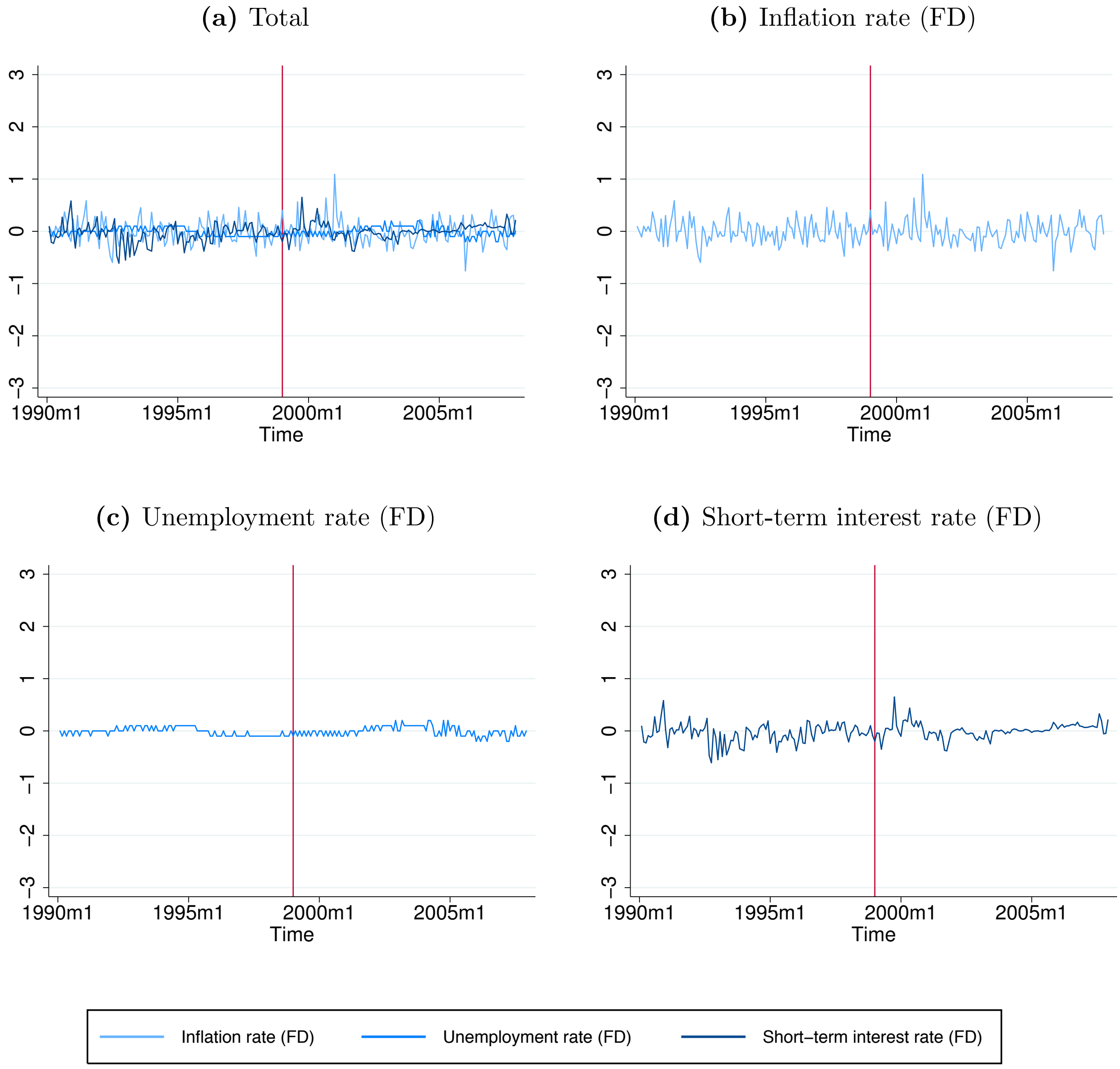
Notes: Data are measured in percentage points and are at monthly frequency. The data basis for Germany starts in 1992m1 with respect to Germany's prior reunification.

Figure C.8: Plots of time series in first differences: France



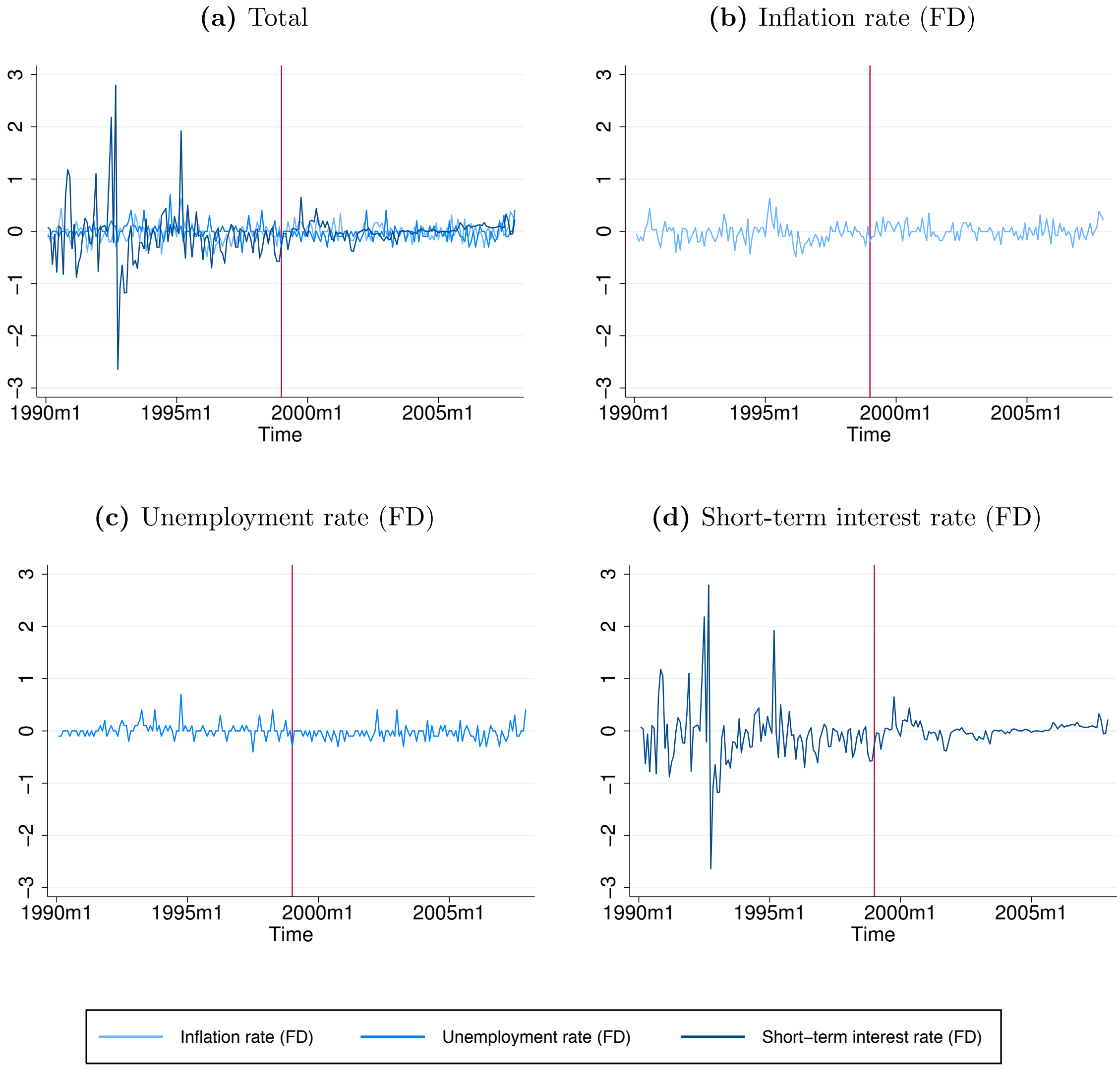
Notes: Data are measured in percentage points and are at monthly frequency.

Figure C.9: Plots of time series in first differences: Netherlands



Notes: Data are measured in percentage points and are at monthly frequency.

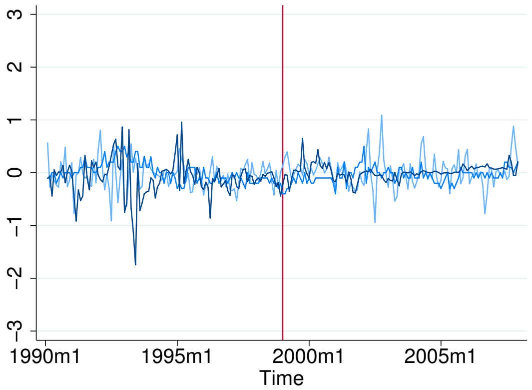
Figure C.10: Plots of time series in first differences: Italy



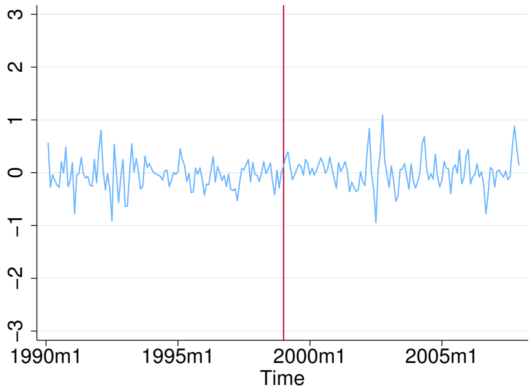
Notes: Data are measured in percentage points and are at monthly frequency.

Figure C.11: Plots of time series in first differences: Spain

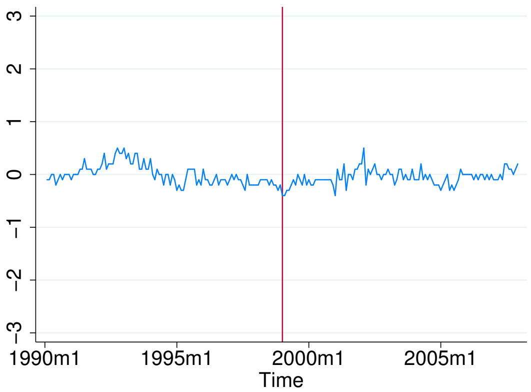
(a) Total



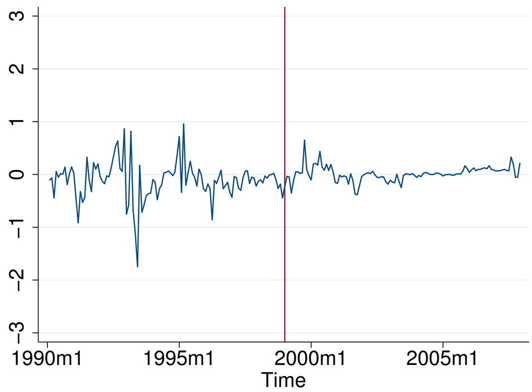
(b) Inflation rate (FD)

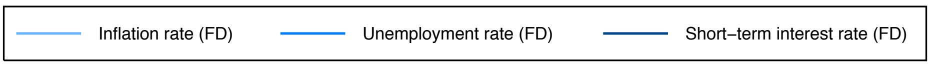


(c) Unemployment rate (FD)



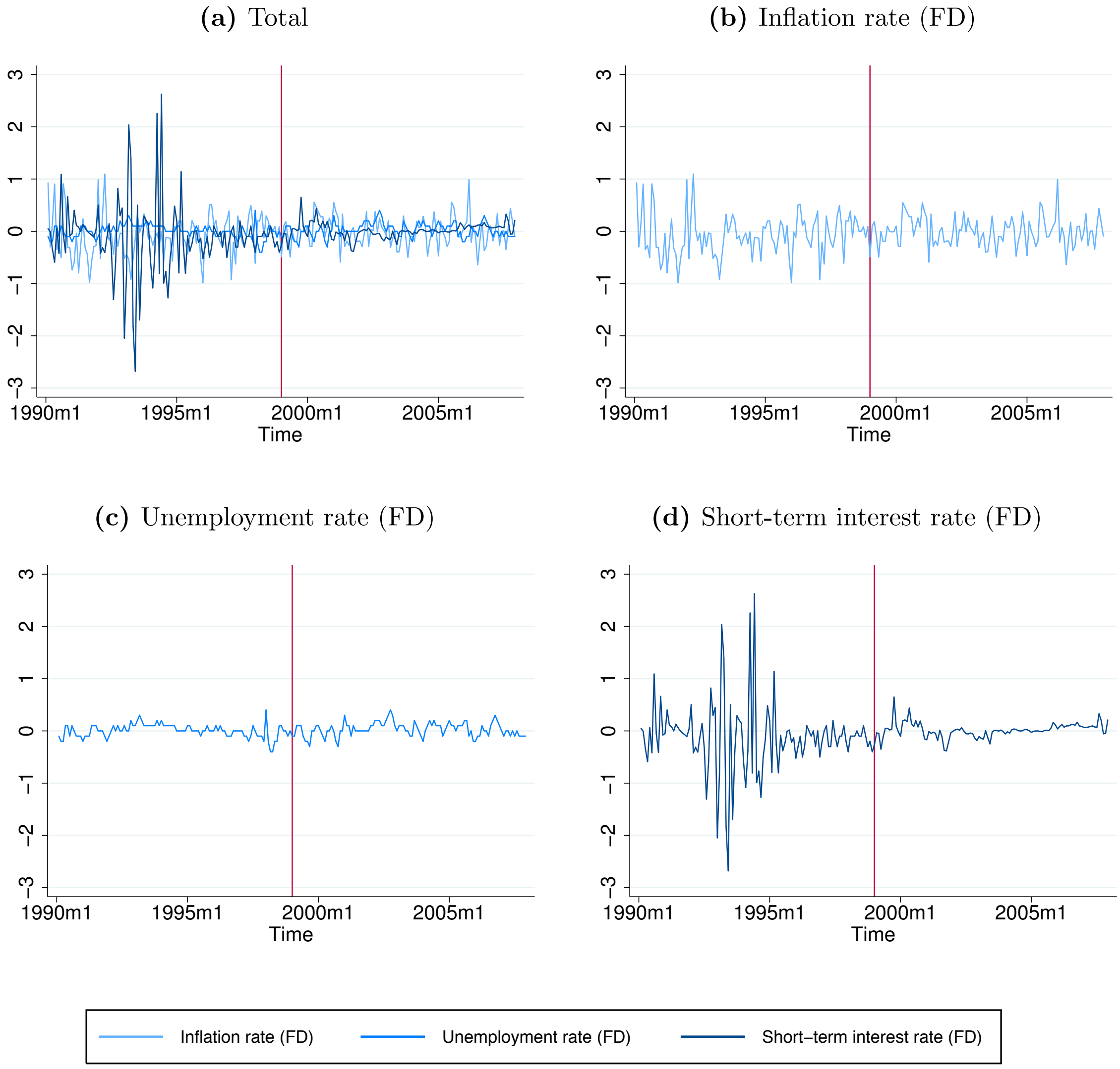
(d) Short-term interest rate (FD)





Notes: Data are measured in percentage points and are at monthly frequency.

Figure C.12: Plots of time series in first differences: Portugal



Notes: Data are measured in percentage points and are at monthly frequency.

Table C.5: Summary statistics for time series in first differences

Variable	Mean	Std. Dev.	Min.	Max.	T
Type A countries					
Germany					
Inflation rate (FD)	−0.01	0.30	−1.30	1.21	191
Unemployment rate (FD)	0.01	0.09	−0.20	0.20	191
Short-term interest rate (FD)	−0.02	0.16	−0.63	0.65	191
France					
Inflation rate (FD)	0.00	0.25	−0.67	0.87	215
Unemployment rate (FD)	0.00	0.09	−0.20	0.30	215
Short-term interest rate (FD)	−0.03	0.36	−2.19	2.25	215
Netherlands					
Inflation rate (FD)	0.00	0.23	−0.76	1.09	215
Unemployment rate (FD)	−0.01	0.09	−0.20	0.20	215
Short-term interest rate (FD)	−0.02	0.17	−0.61	0.65	215
Type B countries					
Italy					
Inflation rate (FD)	−0.02	0.17	−0.49	0.62	215
Unemployment rate (FD)	−0.01	0.14	−0.40	0.70	215
Short-term interest rate (FD)	−0.04	0.46	−2.64	2.79	215
Spain					
Inflation rate (FD)	−0.01	0.29	−0.94	1.09	215
Unemployment rate (FD)	−0.03	0.17	−0.40	0.50	215
Short-term interest rate (FD)	−0.05	0.29	−1.74	0.95	215
Portugal					
Inflation rate (FD)	−0.04	0.35	−0.98	1.09	215
Unemployment rate (FD)	0.02	0.13	−0.40	0.40	215
Short-term interest rate (FD)	−0.06	0.51	−2.68	2.63	215

Notes: Data are measured in percentage points.

The following table reports the results of heteroscedasticity robust augmented Dickey-Fuller tests for the time series in first differences. The number of lags is chosen by means of AIC and SBC information criteria.

Table C.6: Unit root tests for time series in first differences

Variable	γ	**Robust Std. Err.**	$\mathbf{H_0:\gamma=0}$[1]	**p**	**T**
Type A countries					
Germany					
Inflation rate (FD)	−1.076	0.240	$t=-4.49$***	12	179
Unemployment rate (FD)	−0.124	0.048	$t=-2.57$**	3	188
Short-term interest rate (FD)	−0.321	0.107	$t=-2.99$***	4	187
France					
Inflation rate (FD)	−1.219	0.295	$t=-4.13$***	12	203
Unemployment rate (FD)	−0.222	0.071	$t=-3.14$***	5[1]	210
Short-term interest rate (FD)	−0.645	0.169	$t=-3.83$***	7	208
Netherlands					
Inflation rate (FD)	−0.992	0.220	$t=-4.52$***	12	203
Unemployment rate (FD)	−0.153	0.069	$t=-2.22$**	6[2]	210
Short-term interest rate (FD)	−0.335	0.113	$t=-2.96$***	13	202
Type B countries					
Italy					
Inflation rate (FD)	−0.627	0.150	$t=-4.20$***	13	202
Unemployment rate (FD)	−0.620	0.162	$t=-3.84$***	6	209
Short-term interest rate (FD)	−0.707	0.335	$t=-2.11$**	12	203
Spain					
Inflation rate (FD)	−1.150	0.232	$t=-4.96$***	13	202
Unemployment rate (FD)	−0.131	0.062	$t=-2.11$**	6	209
Short-term interest rate (FD)	−0.365	0.137	$t=-2.67$***	4	211
Portugal					
Inflation rate (FD)	−0.819	0.234	$t=-3.50$***	13	202
Unemployment rate (FD)	−0.296	0.078	$t=-3.79$***	6	209
Short-term interest rate (FD)	−0.736	0.319	$t=-2.30$**	11	204

[1] Number of lags was chosen to account for remaining serial correlation.

Notes: Approximate significance levels for ADF tests without a constant or time trend: −2.58 (1%), −1.95 (5%), −1.62 (10%). Significance levels refer to empirical cumulative distribution of τ for non-robust standard errors and a sample size of $T = 250$ reported in Fuller (1976). In large samples, the significance levels for the ADF tests are the same using robust and non-robust standard errors. *** $p < 1\%$, ** $p < 5\%$, * $p < 10\%$.

D Empirical results

D.1 Specification

Table D.1: Specification: Estimation of restricted linear VAR(12)

Variable	**Country**					
	Germany	**France**	**Netherlands**	**Italy**	**Spain**	**Portugal**
Inflation rate (FD)						
L.Inflation rate (FD)	−.114*	.093	.006	.012	.282***	.127*
	(.065)	(.061)	(.065)	(.062)	(.065)	(.067)
L2.Inflation rate (FD)	.077	−.113*	−.064	.149**	−.124*	.025
	(.066)	(.060)	(.066)	(.061)	(.069)	(.066)
L3.Inflation rate (FD)	.019	.021	.004	.190***	−.004	.047
	(.064)	(.062)	(.066)	(.062)	(.070)	(.066)
L4.Inflation rate (FD)	−.173***	−.063	.075	.139**	−.113	−.022
	(.062)	(.060)	(.066)	(.063)	(.069)	(.067)
L5.Inflation rate (FD)	−.027	−.119**	−.082	.028	−.068	−.024
	(.062)	(.059)	(.066)	(.063)	(.066)	(.064)
L12.Inflation rate (FD)	−.380***	−.515***	−.402***	−.423***	−.379***	−.341***
	(.059)	(.061)	(.066)	(.063)	(.063)	(.062)
L.Unemployment rate (FD)	−.400	−.364*	−.327	−.173**	−.355**	−.255
	(.313)	(.190)	(.230)	(.072)	(.141)	(.200)
L2.Unemployment rate (FD)	.047	.096	−.292	−.038	.208	−.186
	(.323)	(.197)	(.230)	(.071)	(.150)	(.225)
L3.Unemployment rate (FD)	.579*	.097	.065	−.016	.186	.005
	(.349)	(.197)	(.248)	(.070)	(.152)	(.223)
L4.Unemployment rate (FD)	−.472	−.105	−.214	.131*	.155	−.111
	(.327)	(.195)	(.232)	(.071)	(.149)	(.225)
L5.Unemployment rate (FD)	.376	−.067	.074	.146**	−.284*	.109
	(.326)	(.198)	(.236)	(.072)	(.146)	(.199)
L12.Unemployment rate (FD)	−.217	−.268	.047	−.091	−.042	−.152
	(.244)	(.171)	(.215)	(.071)	(.123)	(.161)
L.Short-term interest rate (FD)	.116	−.025	−.078	.003	.119*	−.044
	(.132)	(.041)	(.107)	(.022)	(.067)	(.042)
L2.Short-term interest rate (FD)	.156	.011	−.118	.010	−.078	.007
	(.138)	(.041)	(.109)	(.022)	(.069)	(.043)
L3.Short-term interest rate (FD)	.022	.040	.148	.016	.086	.007
	(.134)	(.041)	(.107)	(.022)	(.066)	(.043)
L4.Short-term interest rate (FD)	−.145	−.130***	−.010	.011	.030	.016
	(.132)	(.042)	(.108)	(.021)	(.068)	(.041)
L5.Short-term interest rate (FD)	.195	.103**	.016	.013	−.051	−.039
	(.128)	(.042)	(.104)	(.021)	(.068)	(.041)
L12.Short-term interest rate (FD)	.271**	.023	−.009	.005	.021	−.032
	(.115)	(.039)	(.095)	(.021)	(.060)	(.042)
Constant	.001	−.009	−.014	−.013	−.019	−.047**
	(.018)	(.014)	(.016)	(.010)	(.019)	(.023)

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Table D.1: Specification: Estimation of restricted linear VAR(12) (cont'd)

Variable	**Country**					
	Germany	**France**	**Netherlands**	**Italy**	**Spain**	**Portugal**
Unemployment rate (FD)						
L.Inflation rate (FD)	.044***	.011	−.023	.021	−.013	.044*
	(.015)	(.023)	(.020)	(.061)	(.032)	(.023)
L2.Inflation rate (FD)	.007	.013	−.009	.022	.064*	.021
	(.016)	(.023)	(.020)	(.061)	(.034)	(.023)
L3.Inflation rate (FD)	−.003	.018	−.031	.029	−.025	−.033
	(.015)	(.023)	(.020)	(.061)	(.034)	(.023)
L4.Inflation rate (FD)	.018	−.011	.001	−.030	.028	−.026
	(.015)	(.022)	(.020)	(.062)	(.034)	(.023)
L5.Inflation rate (FD)	−.003	−.040*	−.024	.007	−.020	−.025
	(.015)	(.022)	(.020)	(.062)	(.032)	(.022)
L12.Inflation rate (FD)	−.024*	−.001	.001	.043	−.096***	.041*
	(.014)	(.023)	(.020)	(.062)	(.031)	(.021)
L.Unemployment rate (FD)	.258***	.229***	.054	.005	.340***	.543***
	(.074)	(.071)	(.069)	(.071)	(.069)	(.068)
L2.Unemployment rate (FD)	.438***	.278***	.358***	.169**	.314***	.118
	(.077)	(.073)	(.069)	(.070)	(.073)	(.077)
L3.Unemployment rate (FD)	.108	.179**	.150**	−.210***	.191**	−.180**
	(.083)	(.073)	(.075)	(.070)	(.074)	(.076)
L4.Unemployment rate (FD)	.051	.024	.008	.022	−.088	−.003
	(.078)	(.073)	(.070)	(.071)	(.073)	(.077)
L5.Unemployment rate (FD)	−.010	.044	.152**	.182**	.112	.112
	(.077)	(.074)	(.071)	(.071)	(.071)	(.068)
L12.Unemployment rate (FD)	−.014	.047	.068	.063	−.040	.089
	(.058)	(.064)	(.065)	(.070)	(.060)	(.055)
L.Short-term interest rate (FD)	−.036	−.001	−.028	−.037*	−.039	−.005
	(.031)	(.015)	(.032)	(.022)	(.033)	(.014)
L2.Short-term interest rate (FD)	.008	.007	.004	−.001	.003	−.007
	(.033)	(.015)	(.033)	(.022)	(.034)	(.015)
L3.Short-term interest rate (FD)	.006	−.029*	.020	.001	.074**	.003
	(.032)	(.015)	(.032)	(.022)	(.032)	(.015)
L4.Short-term interest rate (FD)	.010	−.003	−.035	−.028	−.009	−.005
	(.031)	(.016)	(.033)	(.021)	(.033)	(.014)
L5.Short-term interest rate (FD)	−.048	.016	−.018	−.041**	−.009	−.017
	(.030)	(.016)	(.031)	(.021)	(.033)	(.014)
L12.Short-term interest rate (FD)	−.024	.002	.019	−.021	.004	−.016
	(.027)	(.015)	(.029)	(.020)	(.029)	(.014)
Constant	−.004	−.002	−.003	−.011	−.003	.005
	(.004)	(.005)	(.005)	(.010)	(.009)	(.008)

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Table D.1: Specification: Estimation of restricted linear VAR(12) (cont'd)

Variable	**Country**					
	Germany	**France**	**Netherlands**	**Italy**	**Spain**	**Portugal**
Short-term interest rate (FD)						
L.Inflation rate (FD)	.023	.057	−.040	.183	.082	.034
	(.036)	(.103)	(.042)	(.195)	(.066)	(.114)
L2.Inflation rate (FD)	.034	−.058	.053	−.139	−.185***	.020
	(.037)	(.102)	(.043)	(.194)	(.071)	(.113)
L3.Inflation rate (FD)	.061*	−.039	.063	.277	.160**	.107
	(.036)	(.104)	(.043)	(.195)	(.072)	(.113)
L4.Inflation rate (FD)	.018	−.042	−.052	.227	.036	−.029
	(.035)	(.101)	(.043)	(.199)	(.071)	(.114)
L5.Inflation rate (FD)	.072**	−.002	.014	−.022	−.148**	.112
	(.034)	(.099)	(.043)	(.199)	(.068)	(.109)
L12.Inflation rate (FD)	−.000	−.203**	.025	.299	−.036	.089
	(.033)	(.103)	(.043)	(.199)	(.064)	(.105)
L.Unemployment rate (FD)	−.064	−.198	.150	−.080	.130	.142
	(.175)	(.320)	(.149)	(.228)	(.145)	(.341)
L2.Unemployment rate (FD)	−.219	−.185	−.157	−.105	.125	−.329
	(.181)	(.332)	(.150)	(.224)	(.154)	(.384)
L3.Unemployment rate (FD)	.140	−.441	−.142	−.010	−.230	−.202
	(.195)	(.332)	(.162)	(.222)	(.156)	(.381)
L4.Unemployment rate (FD)	−.248	−.767**	.043	−.142	−.013	.017
	(.183)	(.329)	(.151)	(.226)	(.153)	(.384)
L5.Unemployment rate (FD)	.073	.065	−.263*	.258	−.260*	−.113
	(.182)	(.334)	(.154)	(.227)	(.150)	(.340)
L12.Unemployment rate (FD)	−.021	.416	.130	.020	.115	.080
	(.136)	(.289)	(.140)	(.224)	(.127)	(.275)
L.Short-term interest rate (FD)	.309***	.173**	.336***	.070	.213***	−.036
	(.074)	(.069)	(.069)	(.070)	(.069)	(.071)
L2.Short-term interest rate (FD)	−.044	−.101	−.082	.188***	.112	−.139*
	(.077)	(.070)	(.071)	(.069)	(.071)	(.073)
L3.Short-term interest rate (FD)	.084	−.055	.141**	.070	.204***	−.179**
	(.075)	(.069)	(.070)	(.069)	(.068)	(.073)
L4.Short-term interest rate (FD)	.109	−.153**	.108	−.099	.113	.024
	(.074)	(.071)	(.071)	(.067)	(.070)	(.070)
L5.Short-term interest rate (FD)	.063	.094	.069	−.122*	−.037	.012
	(.072)	(.071)	(.067)	(.067)	(.070)	(.070)
L12.Short-term interest rate (FD)	−.035	.041	.061	.035	−.030	.025
	(.064)	(.067)	(.062)	(.065)	(.062)	(.072)
Constant	−.004	−.029	−.010	−.017	−.027	−.053
	(.010)	(.024)	(.010)	(.032)	(.019)	(.039)

Notes: Standard errors in parentheses. The number of observations for the estimations amounts to 179 and 203 for Germany and the other economies, respectively. *** $p < 1\%$, ** $p < 5\%$, * $p < 10\%$.

The following table provides measures to test for remaining serial correlation in the linear restricted VAR(12):

Table D.2: Specification: LM tests for restricted linear VAR(12)

Country	**LM(1)**	**LM(4)**	**LM(8)**	**LM(12)**
Type A countries				
Germany	0.109	0.093	0.711	0.007
France	0.507	0.032	0.064	0.353
Netherlands	0.054	0.911	0.342	0.058
Type B countries				
Italy	0.044	0.461	0.240	0.077
Spain	0.476	0.384	0.693	0.734
Portugal	0.009	0.287	0.171	0.120

Notes: Table displays p-values. For Germany, the indicated serial correlation considering up to 12 lags remained even when including up to 12 or 13 lags. In the case of France, the significant LM(4) and LM(8) statistics did not seem to be representative with respect to surrounding LM-test statistics.

D.2 Estimation

Table D.3: Estimation: Restricted nonlinear VAR(12)

Variable	Country											
	Germany		France		Netherlands		Italy		Spain		Portugal	
	D_0	D_1	D_0	D_1	D_0	D_1	D_0	D_1	D_0	D_1	D_0	D_1
Inflation rate (FD)												
L.Inflation rate (FD)	0.046***	-0.078***	-0.017***	0.154***	0.100***	-0.199***	0.112***	-0.180***	-0.397***	0.805***	0.163***	-0.182***
	(0.001)	(0.002)	(0.000)	(0.000)	(0.001)	(0.001)	(0.026)	(0.036)	(0.000)	(0.000)	(0.000)	(0.000)
L2.Inflation rate (FD)	0.064***	-0.113***	0.047***	-0.263***	-0.165***	0.108***	-0.048***	0.198***	-0.154***	0.085***	-0.015***	-0.079***
	(0.000)	(0.002)	(0.000)	(0.000)	(0.002)	(0.001)	(0.005)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
L3.Inflation rate (FD)	0.071***	0.075***	0.084***	-0.175***	-0.086***	0.052***	0.030	0.192***	0.110***	-0.311***	0.058***	-0.148***
	(0.000)	(0.004)	(0.000)	(0.000)	(0.003)	(0.001)	(0.034)	(0.031)	(0.000)	(0.000)	(0.000)	(0.000)
L4.Inflation rate (FD)	0.061***	-0.248***	-0.247***	0.381***	0.236***	-0.317***	-0.023**	0.153***	-0.349***	0.400***	-0.208***	0.302***
	(0.000)	(0.007)	(0.000)	(0.000)	(0.001)	(0.002)	(0.010)	(0.005)	(0.001)	(0.002)	(0.000)	(0.000)
L5.Inflation rate (FD)	0.007***	0.200***	-0.197***	0.085***	-0.157***	-0.011***	-0.207***	0.215***	-0.437***	0.394***	0.054***	-0.057***
	(0.000)	(0.007)	(0.000)	(0.000)	(0.001)	(0.001)	(0.003)	(0.007)	(0.001)	(0.001)	(0.000)	(0.000)
L12.Inflation rate (FD)	0.028***	-0.068***	-0.543***	0.117***	-0.349***	-0.144***	-0.383***	0.050	-0.507***	0.131***	-0.297***	-0.078***
	(0.000)	(0.002)	(0.000)	(0.000)	(0.004)	(0.004)	(0.048)	(0.062)	(0.001)	(0.001)	(0.000)	(0.000)
L.Unemployment rate (FD)	0.116***	-0.314***	-0.261***	-0.418***	-1.043***	1.003***	-0.488***	0.384***	-0.845***	0.477***	0.005***	-0.169***
	(0.006)	(0.080)	(0.000)	(0.001)	(0.007)	(0.009)	(0.050)	(0.059)	(0.001)	(0.002)	(0.000)	(0.000)
L2.Unemployment rate (FD)	-0.297***	0.487***	0.049***	0.072***	-1.267***	1.070***	0.438***	-0.485***	0.370***	-0.032***	-0.791***	0.593***
	(0.003)	(0.057)	(0.000)	(0.001)	(0.002)	(0.002)	(0.018)	(0.013)	(0.005)	(0.006)	(0.003)	(0.003)
L3.Unemployment rate (FD)	-0.190***	0.786***	-0.065***	0.405***	-0.072***	-0.026***	0.221***	-0.268***	-0.068***	0.414***	-0.153***	0.099***
	(0.003)	(0.011)	(0.000)	(0.000)	(0.007)	(0.005)	(0.040)	(0.038)	(0.002)	(0.003)	(0.004)	(0.004)
L4.Unemployment rate (FD)	-0.128***	-0.848***	-0.198***	-0.008***	-0.952***	1.020***	-0.089	0.280***	0.168***	-0.120***	0.534***	-0.521***
	(0.009)	(0.087)	(0.000)	(0.000)	(0.013)	(0.013)	(0.077)	(0.088)	(0.002)	(0.001)	(0.002)	(0.003)
L5.Unemployment rate (FD)	0.299***	-0.903***	-0.053***	-0.103***	0.871***	-0.947***	-0.256**	0.493***	-0.082***	-0.260***	-0.505***	0.585***
	(0.013)	(0.119)	(0.000)	(0.001)	(0.000)	(0.000)	(0.119)	(0.126)	(0.000)	(0.001)	(0.002)	(0.002)
L12.Unemployment rate (FD)	0.058***	0.111***	-0.335***	0.028***	-0.222***	0.355***	-0.393***	0.339***	-0.507***	0.510***	-0.174***	-0.021***
	(0.002)	(0.007)	(0.000)	(0.001)	(0.001)	(0.001)	(0.085)	(0.071)	(0.003)	(0.004)	(0.001)	(0.001)
L.Short-term interest rate (FD)	0.433***	-0.331***	-0.021***	0.082***	-0.185***	0.331***	-0.020***	0.083***	0.340***	-0.149***	-0.076***	0.193***
	(0.000)	(0.014)	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)	(0.003)	(0.000)	(0.002)	(0.000)	(0.001)
L2.Short-term interest rate (FD)	-0.099***	-0.202***	-0.016***	0.205***	-0.124***	-0.040***	-0.060***	0.090***	-0.226***	0.188***	-0.048***	0.185***
	(0.000)	(0.015)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.005)	(0.001)	(0.003)	(0.000)	(0.000)
L3.Short-term interest rate (FD)	0.050***	0.100***	0.022***	-0.013***	0.054***	0.185***	-0.009***	0.086***	0.053***	0.035***	-0.047***	0.073***
	(0.000)	(0.005)	(0.000)	(0.000)	(0.004)	(0.003)	(0.003)	(0.002)	(0.001)	(0.002)	(0.000)	(0.000)
L4.Short-term interest rate (FD)	0.057***	0.221***	-0.101***	-0.136***	-0.143***	0.146***	0.020***	-0.037***	0.065***	-0.010***	-0.057***	0.310***
	(0.001)	(0.007)	(0.000)	(0.000)	(0.001)	(0.002)	(0.003)	(0.001)	(0.001)	(0.002)	(0.000)	(0.000)
L5.Short-term interest rate (FD)	0.025***	0.152***	0.073***	-0.105***	-0.030***	0.014***	-0.002	0.078***	0.020***	-0.115***	-0.127***	0.070***
	(0.001)	(0.006)	(0.000)	(0.000)	(0.002)	(0.002)	(0.012)	(0.023)	(0.000)	(0.000)	(0.000)	(0.000)
L12.Short-term interest rate (FD)	0.057***	-0.082***	0.036***	-0.201***	-0.196***	0.214***	0.034***	-0.102***	-0.599***	0.715***	-0.050***	0.103***
	(0.001)	(0.011)	(0.000)	(0.000)	(0.001)	(0.000)	(0.008)	(0.007)	(0.001)	(0.000)	(0.000)	(0.000)
Constant	-0.001***	-0.031***	-0.024***	0.024***	0.033***	-0.053***	-0.064***	0.064***	-0.111***	0.126***	-0.147***	0.157***
	(0.000)	(0.001)	(0.000)	(0.000)	(0.001)	(0.001)	(0.002)	(0.003)	(0.000)	(0.000)	(0.000)	(0.000)

Continued on next page

Table D.3: Estimation: Restricted nonlinear VAR(12) (cont'd)

Variable	**Country**											
	Germany		**France**		**Netherlands**		**Italy**		**Spain**		**Portugal**	
	$\mathbf{D}_0$	$\mathbf{D}_1$	$\mathbf{D}_0$	$\mathbf{D}_1$	$\mathbf{D}_0$	$\mathbf{D}_1$	$\mathbf{D}_0$	$\mathbf{D}_1$	$\mathbf{D}_0$	$\mathbf{D}_1$	$\mathbf{D}_0$	$\mathbf{D}_1$
Unemployment rate (FD)												
L.Inflation rate (FD)	0.022***	0.004***	0.015***	0.047***	-0.027***	0.016***	0.125***	-0.098***	-0.187***	0.194***	-0.038***	0.067***
	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
L2.Inflation rate (FD)	-0.004***	-0.003***	0.022***	-0.012***	0.003***	-0.039***	-0.092***	0.166***	0.043***	-0.002***	0.079***	-0.080***
	(0.000)	(0.000)	(0.001)	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
L3.Inflation rate (FD)	-0.003***	-0.051***	-0.010***	0.068***	-0.017***	-0.043***	0.136***	-0.167***	-0.068***	0.039***	0.000***	-0.006***
	(0.000)	(0.000)	(0.001)	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
L4.Inflation rate (FD)	-0.007***	0.026***	-0.029***	0.008***	-0.012***	0.032***	-0.136***	0.090***	0.175***	-0.183***	-0.109***	0.107***
	(0.000)	(0.000)	(0.001)	(0.003)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
L5.Inflation rate (FD)	-0.027***	0.053***	0.018***	-0.109***	-0.012***	-0.039***	0.189***	-0.305***	-0.011***	-0.033***	-0.052***	0.008***
	(0.000)	(0.000)	(0.002)	(0.003)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
L12.Inflation rate (FD)	-0.016***	0.010***	0.033***	-0.052***	0.026***	-0.104***	0.071***	-0.002***	-0.128***	0.044***	0.101***	-0.088***
	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
L.Unemployment rate (FD)	0.193***	0.135***	0.248***	-0.064***	-0.035***	0.026***	0.078***	-0.193***	0.150***	0.190***	0.286***	0.275***
	(0.001)	(0.003)	(0.006)	(0.009)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.002)
L2.Unemployment rate (FD)	0.531***	-0.431***	0.370***	-0.220***	0.320***	-0.031***	0.087***	0.034***	0.119***	0.170***	0.127***	-0.018***
	(0.001)	(0.002)	(0.008)	(0.021)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.002)
L3.Unemployment rate (FD)	0.292***	-0.486***	0.069***	0.114***	0.294***	-0.270***	-0.461***	0.409***	0.225***	-0.084***	0.028***	-0.255***
	(0.000)	(0.002)	(0.019)	(0.030)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)	(0.000)
L4.Unemployment rate (FD)	-0.069***	0.328***	0.133***	-0.351***	0.261***	-0.413***	0.016***	0.012***	-0.333***	0.400***	0.025***	-0.093***
	(0.000)	(0.002)	(0.003)	(0.004)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.002)	(0.003)
L5.Unemployment rate (FD)	-0.166***	0.108***	0.062***	0.095***	0.110***	0.064***	0.113***	-0.041***	0.133***	-0.119***	-0.049***	0.223***
	(0.001)	(0.000)	(0.016)	(0.022)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)
L12.Unemployment rate (FD)	-0.046***	0.031***	-0.010***	0.210***	-0.100***	0.248***	0.177***	-0.240***	0.066***	-0.133***	0.601***	-0.575***
	(0.001)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.002)	(0.002)
L.Short-term interest rate (FD)	0.027***	-0.116***	0.017***	-0.125***	0.009***	-0.232***	-0.079***	0.107***	0.002***	-0.043***	-0.009***	0.022***
	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
L2.Short-term interest rate (FD)	-0.025***	0.178***	-0.014***	0.201***	0.028***	0.102***	-0.024***	0.052***	0.078***	-0.080***	-0.021***	0.011***
	(0.000)	(0.001)	(0.000)	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
L3.Short-term interest rate (FD)	0.062***	-0.266***	0.013***	-0.316***	-0.002***	-0.126***	-0.006***	0.039***	0.052***	0.025***	0.003***	-0.029***
	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)
L4.Short-term interest rate (FD)	-0.001***	0.116***	0.025***	-0.095***	0.001***	-0.148***	-0.056***	0.067***	-0.025***	0.003***	-0.008***	-0.038***
	(0.000)	(0.001)	(0.001)	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
L5.Short-term interest rate (FD)	-0.033***	-0.025***	0.001***	0.047***	-0.043***	0.024***	-0.029***	-0.030***	-0.043***	0.036***	-0.031***	-0.014***
	(0.000)	(0.000)	(0.000)	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
L12.Short-term interest rate (FD)	0.022***	-0.183***	0.007***	-0.086***	-0.013***	0.053***	-0.038***	0.062***	0.157***	-0.191***	-0.016***	-0.061***
	(0.000)	(0.001)	(0.000)	(0.016)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	0.019***	-0.060***	0.003***	-0.012***	-0.005***	0.004***	0.017***	-0.054***	-0.074***	0.077***	-0.039***	0.047***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Continued on next page

Table D.3: Estimation: Restricted nonlinear VAR(12) (cont'd)

Variable	**Country**											
	Germany		**France**		**Netherlands**		**Italy**		**Spain**		**Portugal**	
	$\mathbf{D}_0$	$\mathbf{D}_1$	$\mathbf{D}_0$	$\mathbf{D}_1$	$\mathbf{D}_0$	$\mathbf{D}_1$	$\mathbf{D}_0$	$\mathbf{D}_1$	$\mathbf{D}_0$	$\mathbf{D}_1$	$\mathbf{D}_0$	$\mathbf{D}_1$
Short-term interest rate (FD)												
L.Inflation rate (FD)	-0.033***	0.068***	0.151***	-0.037***	-0.067***	0.057***	0.296***	-0.268***	-0.046**	0.061	0.010***	0.011***
	(0.001)	(0.000)	(0.001)	(0.001)	(0.000)	(0.000)	(0.002)	(0.000)	(0.022)	(0.043)	(0.000)	(0.001)
L2.Inflation rate (FD)	-0.039***	0.081***	-0.254***	0.175***	0.131***	-0.061***	-0.243***	0.324***	-0.374***	0.419***	-0.078***	0.108***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.002)	(0.001)	(0.009)	(0.007)	(0.000)	(0.001)
L3.Inflation rate (FD)	0.195***	-0.157***	-0.156***	0.186***	0.317***	-0.389***	0.390***	-0.327***	0.205***	-0.220***	0.097***	-0.130***
	(0.003)	(0.005)	(0.001)	(0.001)	(0.000)	(0.000)	(0.012)	(0.014)	(0.004)	(0.014)	(0.000)	(0.000)
L4.Inflation rate (FD)	-0.064***	0.101***	0.102***	-0.231***	-0.030***	0.027***	0.563***	-0.654***	0.173***	-0.213***	-0.065***	0.063***
	(0.003)	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)	(0.010)	(0.025)	(0.015)	(0.012)	(0.000)	(0.000)
L5.Inflation rate (FD)	0.167***	-0.132***	-0.150***	0.026***	0.106***	-0.125***	-0.268***	0.127***	-0.362***	0.378***	0.076***	-0.151***
	(0.003)	(0.003)	(0.000)	(0.000)	(0.000)	(0.000)	(0.010)	(0.048)	(0.003)	(0.018)	(0.000)	(0.001)
L12.Inflation rate (FD)	0.129***	-0.171***	-0.417***	-0.084***	0.025***	-0.025***	0.476***	-0.380***	-0.020	0.020	0.196***	-0.163***
	(0.002)	(0.003)	(0.000)	(0.000)	(0.000)	(0.000)	(0.005)	(0.051)	(0.017)	(0.014)	(0.000)	(0.000)
L.Unemployment rate (FD)	-0.205***	0.317***	-0.132***	-0.144***	0.610***	-0.592***	-0.328***	0.423***	0.210***	-0.078	0.325***	-0.663***
	(0.003)	(0.004)	(0.001)	(0.001)	(0.000)	(0.000)	(0.002)	(0.025)	(0.023)	(0.070)	(0.002)	(0.001)
L2.Unemployment rate (FD)	-0.361***	0.042	0.059***	0.078***	-0.116***	0.014***	0.300***	-0.240***	0.025***	0.116***	-0.670***	0.888***
	(0.062)	(0.066)	(0.003)	(0.003)	(0.000)	(0.000)	(0.011)	(0.004)	(0.002)	(0.002)	(0.002)	(0.003)
L3.Unemployment rate (FD)	0.646***	-0.666***	0.672***	-0.594***	-0.494***	0.482***	-0.015	0.038***	-0.571***	0.519***	0.106***	-0.097***
	(0.014)	(0.020)	(0.002)	(0.002)	(0.000)	(0.000)	(0.011)	(0.009)	(0.019)	(0.022)	(0.006)	(0.006)
L4.Unemployment rate (FD)	-0.719***	0.637***	-0.785***	0.752***	-0.253***	0.312***	-0.348***	0.254***	0.333***	-0.467***	-0.655***	0.563***
	(0.021)	(0.024)	(0.002)	(0.002)	(0.001)	(0.001)	(0.012)	(0.032)	(0.017)	(0.012)	(0.003)	(0.005)
L5.Unemployment rate (FD)	-0.597***	0.715***	-0.527***	0.433***	-0.429***	0.144***	0.799***	-0.772***	-0.602***	0.548***	-0.390***	0.417***
	(0.027)	(0.024)	(0.005)	(0.005)	(0.000)	(0.000)	(0.005)	(0.009)	(0.006)	(0.015)	(0.003)	(0.011)
L12.Unemployment rate (FD)	0.191***	-0.222***	0.544***	-0.873***	0.057***	0.050***	-0.096***	0.171***	0.573***	-0.638***	-0.057***	0.234***
	(0.051)	(0.057)	(0.006)	(0.006)	(0.001)	(0.001)	(0.004)	(0.001)	(0.011)	(0.037)	(0.003)	(0.001)
L.Short-term interest rate (FD)	0.196***	0.321***	-0.052***	0.047***	0.204***	0.348***	0.071***	0.646***	0.163***	0.343***	-0.158***	0.701***
	(0.005)	(0.006)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.051)	(0.002)	(0.038)	(0.000)	(0.001)
L2.Short-term interest rate (FD)	-0.249***	0.077***	0.114***	-0.119***	-0.138***	-0.059***	0.149***	-0.408***	0.214***	-0.319***	-0.251***	0.085***
	(0.006)	(0.007)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.049)	(0.004)	(0.026)	(0.000)	(0.001)
L3.Short-term interest rate (FD)	0.038***	0.037***	0.015***	0.031***	0.103***	0.061***	0.067***	0.303*	0.134***	-0.027***	-0.265***	0.497***
	(0.003)	(0.006)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.172)	(0.001)	(0.003)	(0.000)	(0.003)
L4.Short-term interest rate (FD)	0.059***	0.124***	-0.148***	0.006***	0.088***	0.033***	-0.109***	-0.085	0.077***	0.133***	-0.087***	0.233***
	(0.006)	(0.010)	(0.000)	(0.000)	(0.000)	(0.000)	(0.003)	(0.270)	(0.003)	(0.025)	(0.000)	(0.005)
L5.Short-term interest rate (FD)	0.094***	-0.157***	0.075***	0.070***	0.062***	-0.092***	-0.158***	0.363***	-0.004	0.025***	-0.066***	0.036***
	(0.002)	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.114)	(0.005)	(0.001)	(0.000)	(0.004)
L12.Short-term interest rate (FD)	0.095***	-0.117***	-0.007***	0.075***	0.170***	-0.228***	0.041***	-0.041**	-0.002	0.015	-0.010***	-0.023***
	(0.007)	(0.013)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.018)	(0.012)	(0.073)	(0.000)	(0.003)
Constant	-0.003	0.007***	-0.037***	0.033***	-0.025***	0.026***	-0.033***	0.045***	-0.070***	0.068***	-0.194***	0.197***
	(0.002)	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.002)	(0.003)	(0.000)	(0.000)

Notes: Standard errors in parentheses. The number of observations for the estimations amounts to 191 and 215 for Germany and the other economies, respectively. *** $p < 1\%$, ** $p < 5\%$, * $p < 10\%$.

The transition function $\mathbf{G}(t) = diag\{G_1(t|\gamma_1, \mathbf{c}_1), ..., G_m(t|\gamma_m, \mathbf{c}_m)\}$ can be estimated equation-by-equation. The following table presents the parameter estimates for the equation-wise transition functions $G_i(t|\gamma_i, c_{ij}) = \left(1 + exp\left\{-\gamma_i \prod_{j=1}^{k}(t - c_{ij})\right\}\right)^{-1}$:

Table D.4: Estimation: Transition function **G**(t)

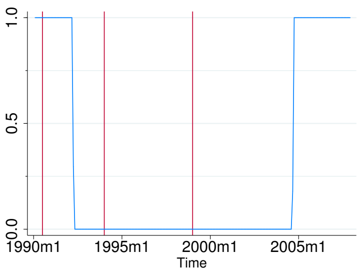
Variable	i	γ_i	$\mathbf{c}_{i1}$	$\mathbf{c}_{i2}$	$\mathbf{c}_{i3}$
Type A countries					
Germany					
Inflation rate (FD)	1	0.097***	26.940***	176.105***	
		(0.014)	(0.004)	(0.017)	
Unemployment rate (FD)	2	0.100***	73.006***	103.989***	157.001***
		(0.000)	(0.000)	(0.000)	(0.000)
Short-term interest rate (FD)	3	5.006	60.128***		
		(6.274)	(0.682)		
France					
Inflation rate (FD)	1	0.113***	26.834***	149.421***	
		(0.017)	(0.016)	(0.022)	
Unemployment rate (FD)	2	1.000***	65.001***	71.998***	153.327***
		(0.161)	(0.000)	(0.000)	(13.706)
Short-term interest rate (FD)	3	0.997***	57.698***		
		(0.068)	(0.131)		
Netherlands					
Inflation rate (FD)	1	1.000***	49.000***	127.135***	170.024***
		(0.100)	(0.000)	(0.687)	(1.990)
Unemployment rate (FD)	2	10.000***	127.980***		
		(1.066)	(0.002)		
Short-term interest rate (FD)	3	1.002***	93.913***		
		(0.022)	(0.020)		
Type B countries					
Italy					
Inflation rate (FD)	1	1.015***	51.288***		
		(0.384)	(1.786)		
Unemployment rate (FD)	2	1.000***	32.995***	105.948***	
		(0.009)	(0.000)	(0.000)	
Short-term interest rate (FD)	3	2.004	121.182***		
		(1.819)	(1.011)		
Spain					
Inflation rate (FD)	1	0.097**	37.992***	64.051***	80.550***
		(0.046)	(0.000)	(0.077)	(19.250)
Unemployment rate (FD)	2	1.001	56.204***	141.058***	
		(0.888)	(5.997)	(0.148)	
Short-term interest rate (FD)	3	0.119	92.873***		
		(0.083)	(13.183)		
Portugal					
Inflation rate (FD)	1	10.002***	81.548***		
		(2.011)	(0.008)		
Unemployment rate (FD)	2	1.002***	35.012***	101.082	
		(0.010)	(0.000)	(0.032)	
Short-term interest rate (FD)	3	1.992***	101.246 ***		
		(0.089)	(0.236)		

Notes: Standard errors in parentheses. *** $p < 1\%$, ** $p < 5\%$, * $p < 10\%$.

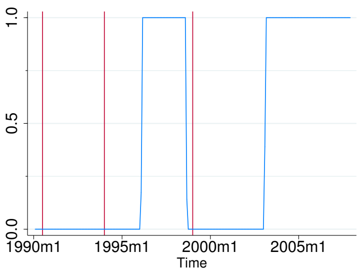
Type A countries

Figure D.1: Transition functions: Germany

(a) Inflation rate (FD)



(b) Unemployment rate (FD)



(c) Short-term interest rate (FD)

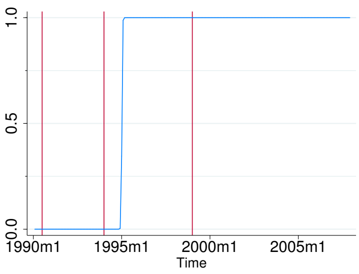
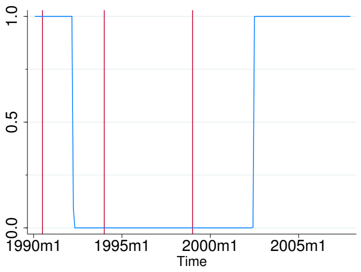
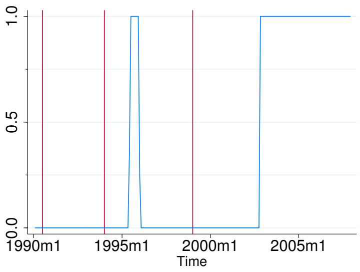


Figure D.2: Transition functions: France

(a) Inflation rate (FD)



(b) Unemployment rate (FD)



(c) Short-term interest rate (FD)

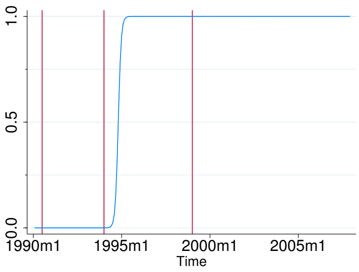
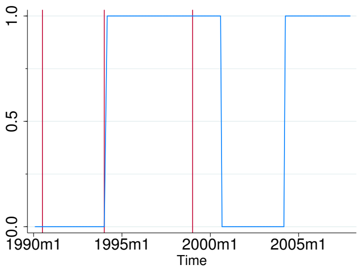
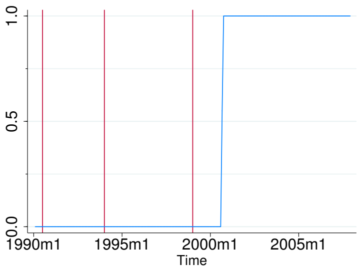


Figure D.3: Transition functions: Netherlands

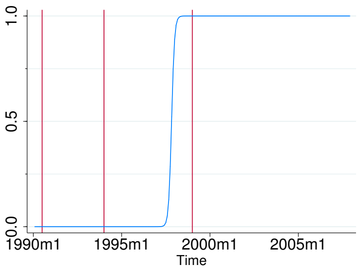
(a) Inflation rate (FD)



(b) Unemployment rate (FD)



(c) Short-term interest rate (FD)

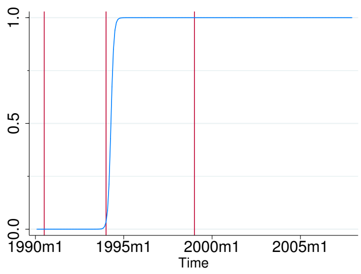


Notes: The red lines indicate the timing of the three stages to EMU (see figure A.3). A value of 0.0 in the transition function refers to system A, a value of 1.0 to system B.

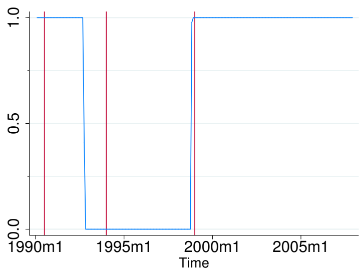
Type B countries

Figure D.4: Transition functions: Italy

(a) Inflation rate (FD)



(b) Unemployment rate (FD)



(c) Short-term interest rate (FD)

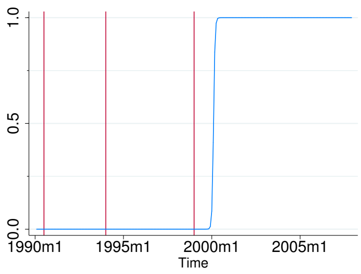
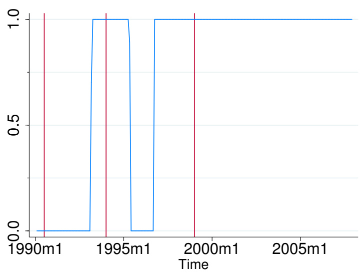
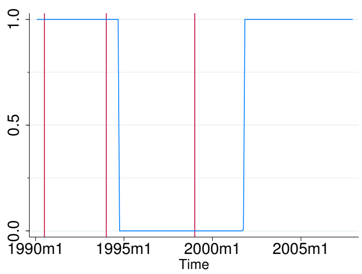


Figure D.5: Transition functions: Spain

(a) Inflation rate (FD)



(b) Unemployment rate (FD)



(c) Short-term interest rate (FD)

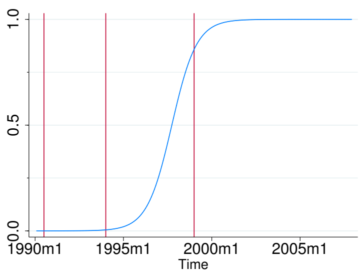
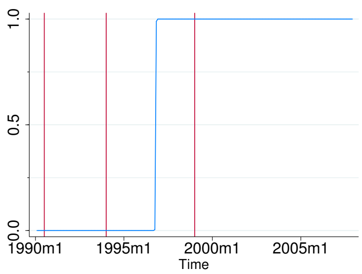
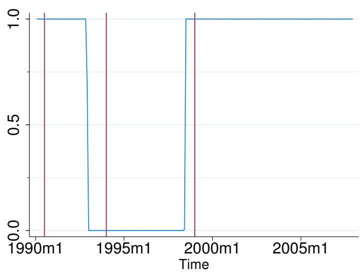


Figure D.6: Transition functions: Portugal

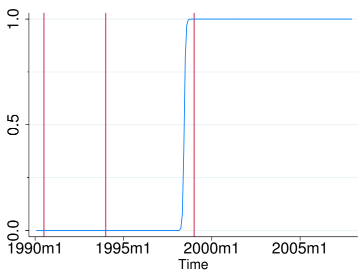
(a) Inflation rate (FD)



(b) Unemployment rate (FD)



(c) Short-term interest rate (FD)



Notes: The red lines indicate the timing of the three stages to EMU (see figure A.3). A value of 0.0 in the transition function refers to system A, a value of 1.0 to system B.

D.3 Evaluation

Table D.5: Evaluation: Restricted nonlinear VAR(12)

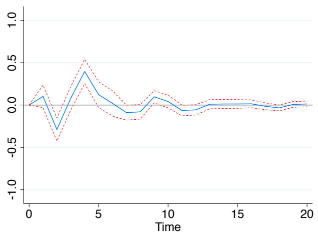
	Tests of no remaining serial correlation				Test of no additional structural breaks
Country	**Q(1)**	**Q(4)**	**Q(8)**	**Q(12)**	$\mathbf{H}'_{0,s.b.}$
Type A countries					
Germany					
Inflation rate (FD)	0.620	0.945	0.888	0.617	0.470
Unemployment rate (FD)	0.823	0.897	0.600	0.795	0.284
Short-term interest rate (FD)	0.739	0.940	0.995	0.990	0.214
France					
Inflation rate (FD)	0.583	0.619	0.727	0.471	0.123
Unemployment rate (FD)	0.911	0.692	0.278	0.429	0.649
Short-term interest rate (FD)	0.839	0.931	0.327	0.487	0.276
Netherlands					
Inflation rate (FD)	0.319	0.742	0.622	0.708	0.268
Unemployment rate (FD)	0.753	0.896	0.988	0.994	0.214
Short-term interest rate (FD)	0.779	0.935	0.309	0.105	0.698
Type B countries					
Italy					
Inflation rate (FD)	0.311	0.833	0.975	0.808	0.055
Unemployment rate (FD)	0.940	1.000	1.000	0.995	0.504
Short-term interest rate (FD)	0.824	0.994	0.664	0.072	0.713
Spain					
Inflation rate (FD)	0.828	0.950	0.964	0.939	0.411
Unemployment rate (FD)	0.788	0.830	0.671	0.677	0.869
Short-term interest rate (FD)	0.928	0.989	0.971	0.702	0.517
Portugal					
Inflation rate (FD)	0.481	0.704	0.974	0.637	0.102
Unemployment rate (FD)	0.876	0.841	0.368	0.566	0.080
Short-term interest rate (FD)	0.941	0.996	0.868	0.003	0.974

Notes: Table displays p-values.

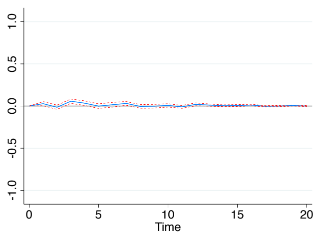
D.4 Impulse response analysis

Figure D.7: OIRFs at the beginning of the observation period: Germany

(a) $\Delta i_t \rightarrow \Delta \pi_t$



(b) $\Delta i_t \rightarrow \Delta u_t$



(c) $\Delta i_t \rightarrow \Delta i_t$

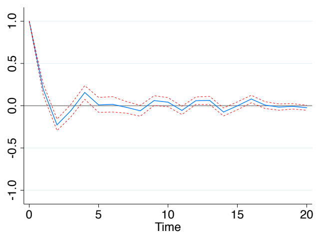
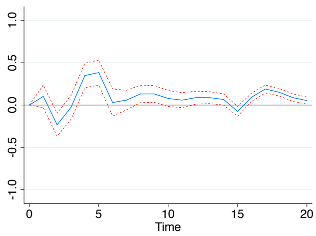
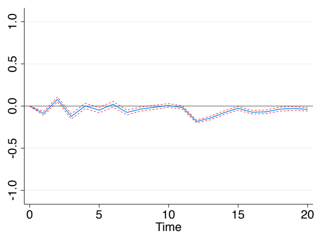


Figure D.8: OIRFs at the end of the observation period: Germany

(a) $\Delta i_t \rightarrow \Delta \pi_t$



(b) $\Delta i_t \rightarrow \Delta u_t$



(c) $\Delta i_t \rightarrow \Delta i_t$

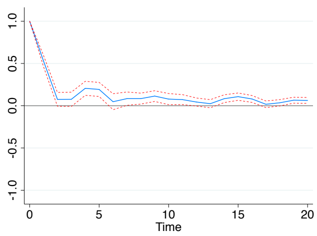
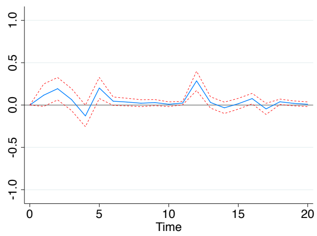
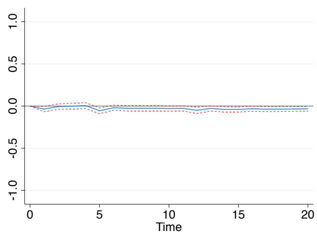


Figure D.9: Comparison with IRFs of the linear VAR model: Germany

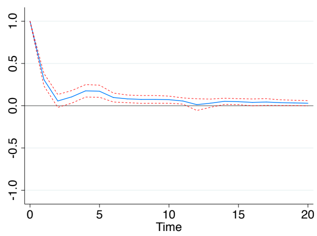
(a) $\Delta i_t \rightarrow \Delta \pi_t$



(b) $\Delta i_t \rightarrow \Delta u_t$



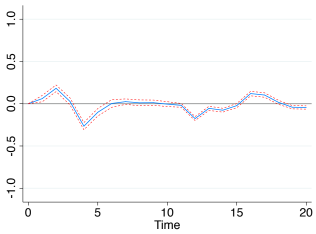
(c) $\Delta i_t \rightarrow \Delta i_t$



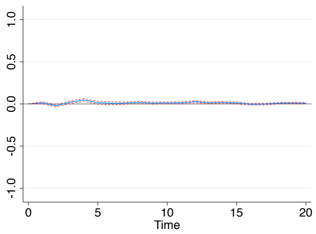
Notes: OIRFs at the beginning and the end of the observation period for the estimated TV-VAR model and IRFs for the linear VAR model (blue) with 95% confidence bands (red).

Figure D.10: OIRFs at the beginning of the observation period: France

(a) $\Delta i_t \rightarrow \Delta \pi_t$



(b) $\Delta i_t \rightarrow \Delta u_t$



(c) $\Delta i_t \rightarrow \Delta i_t$

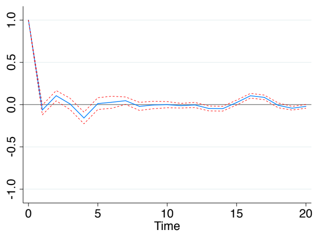
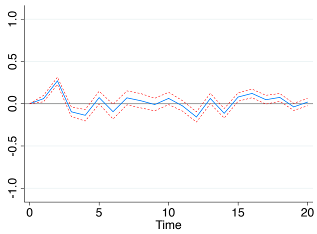
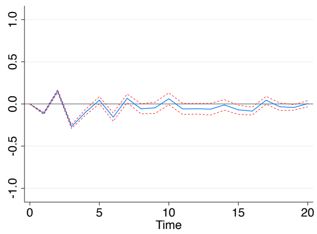


Figure D.11: OIRFs at the end of the observation period: France

(a) $\Delta i_t \rightarrow \Delta \pi_t$



(b) $\Delta i_t \rightarrow \Delta u_t$



(c) $\Delta i_t \rightarrow \Delta i_t$

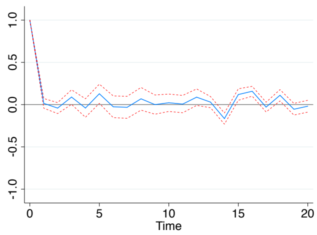
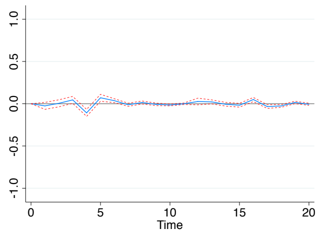
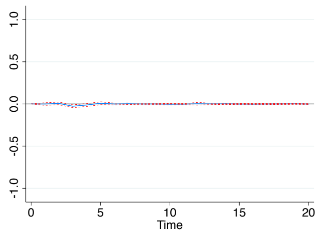


Figure D.12: Comparison with IRFs of the linear VAR model: France

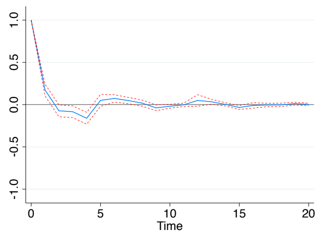
(a) $\Delta i_t \rightarrow \Delta \pi_t$



(b) $\Delta i_t \rightarrow \Delta u_t$



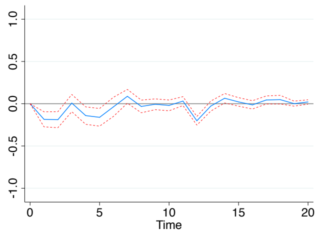
(c) $\Delta i_t \rightarrow \Delta i_t$



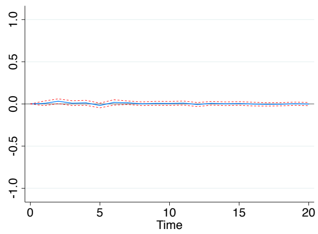
Notes: OIRFs at the beginning and the end of the observation period for the estimated TV-VAR model and IRFs for the linear VAR model (blue) with 95% confidence bands (red).

Figure D.13: OIRFs at the beginning of the observation period: Netherlands

(a) $\Delta i_t \rightarrow \Delta \pi_t$



(b) $\Delta i_t \rightarrow \Delta u_t$



(c) $\Delta i_t \rightarrow \Delta i_t$

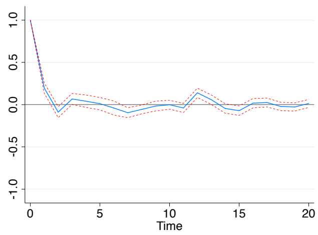
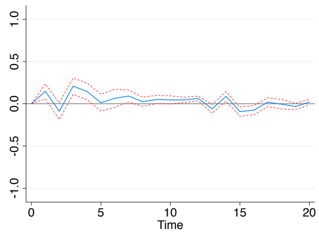
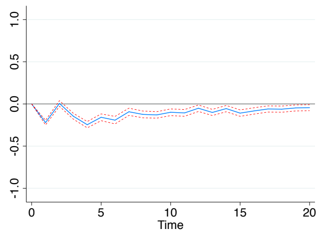


Figure D.14: OIRFs at the end of the observation period: Netherlands

(a) $\Delta i_t \rightarrow \Delta \pi_t$



(b) $\Delta i_t \rightarrow \Delta u_t$



(c) $\Delta i_t \rightarrow \Delta i_t$

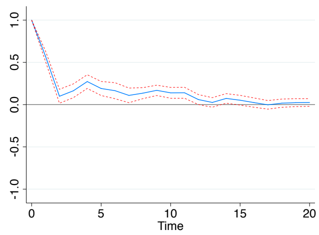
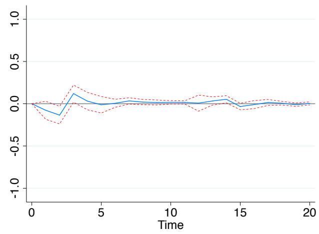
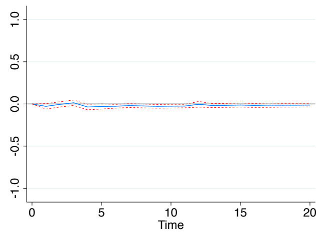


Figure D.15: Comparison with IRFs of the linear VAR model: Netherlands

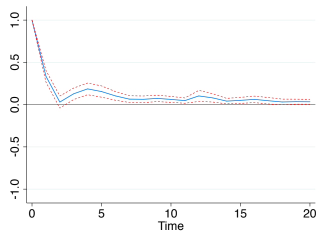
(a) $\Delta i_t \rightarrow \Delta \pi_t$



(b) $\Delta i_t \rightarrow \Delta u_t$



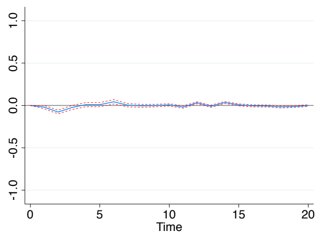
(c) $\Delta i_t \rightarrow \Delta i_t$



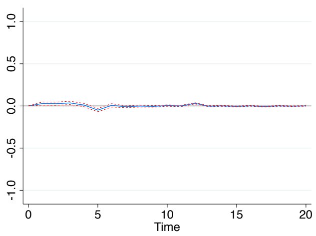
Notes: OIRFs at the beginning and the end of the observation period for the estimated TV-VAR model and IRFs for the linear VAR model (blue) with 95% confidence bands (red).

Figure D.16: OIRFs at the beginning of the observation period: Italy

(a) $\Delta i_t \rightarrow \Delta \pi_t$



(b) $\Delta i_t \rightarrow \Delta u_t$



(c) $\Delta i_t \rightarrow \Delta i_t$

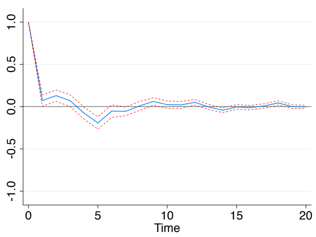
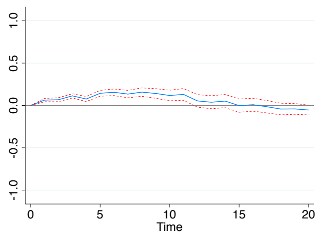
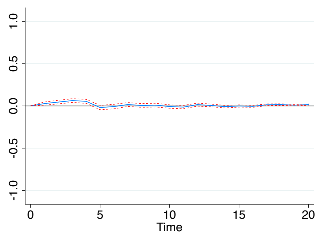


Figure D.17: OIRFs at the end of the observation period: Italy

(a) $\Delta i_t \rightarrow \Delta \pi_t$



(b) $\Delta i_t \rightarrow \Delta u_t$



(c) $\Delta i_t \rightarrow \Delta i_t$

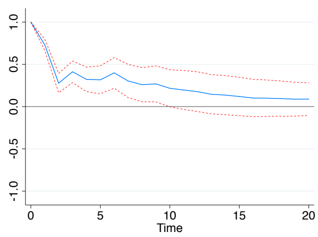
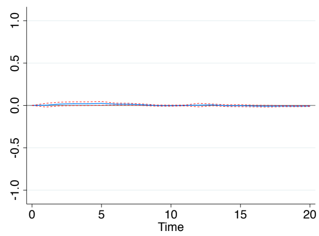
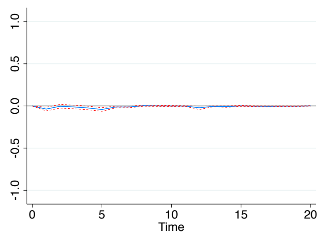


Figure D.18: Comparison with IRFs of the linear VAR model: Italy

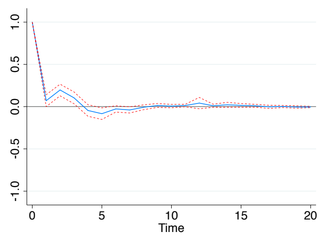
(a) $\Delta i_t \rightarrow \Delta \pi_t$



(b) $\Delta i_t \rightarrow \Delta u_t$



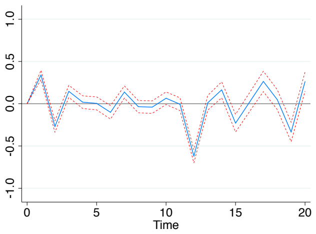
(c) $\Delta i_t \rightarrow \Delta i_t$



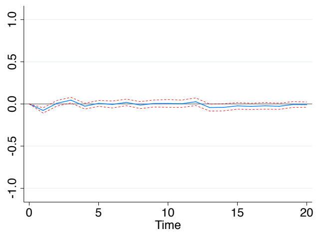
Notes: OIRFs at the beginning and the end of the observation period for the estimated TV-VAR model and IRFs for the linear VAR model (blue) with 95% confidence bands (red).

Figure D.19: OIRFs at the beginning of the observation period: Spain

(a) $\Delta i_t \rightarrow \Delta \pi_t$



(b) $\Delta i_t \rightarrow \Delta u_t$



(c) $\Delta i_t \rightarrow \Delta i_t$

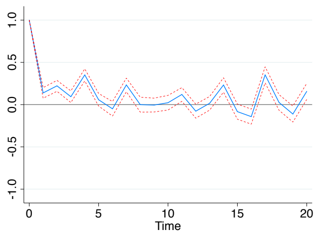
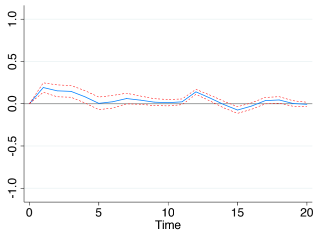
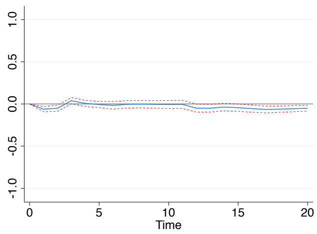


Figure D.20: OIRFs at the end of the observation period: Spain

(a) $\Delta i_t \rightarrow \Delta \pi_t$



(b) $\Delta i_t \rightarrow \Delta u_t$



(c) $\Delta i_t \rightarrow \Delta i_t$

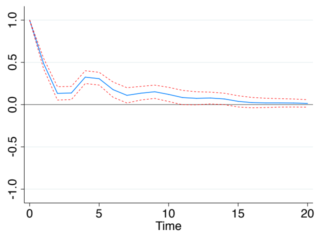
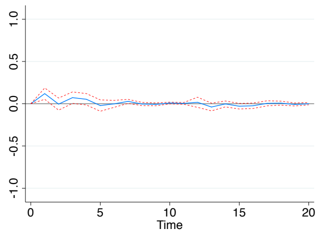
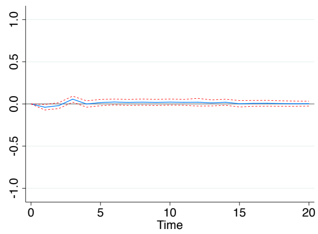


Figure D.21: Comparison with IRFs of the linear VAR model: Spain

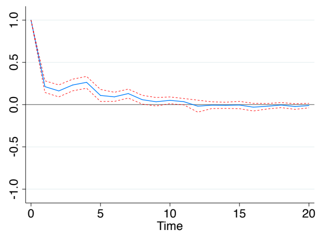
(a) $\Delta i_t \rightarrow \Delta \pi_t$



(b) $\Delta i_t \rightarrow \Delta u_t$



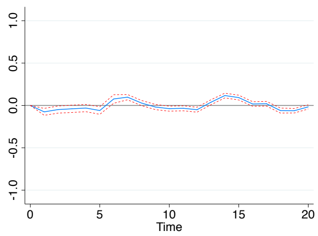
(c) $\Delta i_t \rightarrow \Delta i_t$



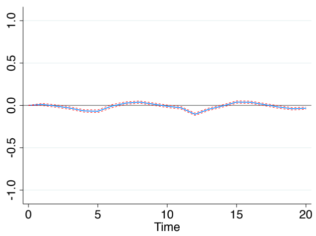
Notes: OIRFs at the beginning and the end of the observation period for the estimated TV-VAR model and IRFs for the linear VAR model (blue) with 95% confidence bands (red).

Figure D.22: OIRFs at the beginning of the observation period: Portugal

(a) $\Delta i_t \rightarrow \Delta \pi_t$



(b) $\Delta i_t \rightarrow \Delta u_t$



(c) $\Delta i_t \rightarrow \Delta i_t$

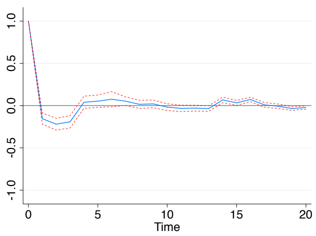
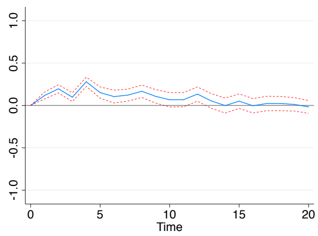
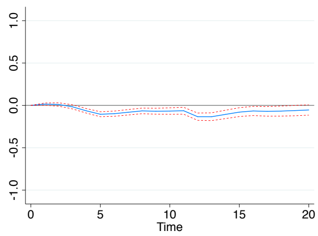


Figure D.23: OIRFs at the end of the observation period: Portugal

(a) $\Delta i_t \rightarrow \Delta \pi_t$



(b) $\Delta i_t \rightarrow \Delta u_t$



(c) $\Delta i_t \rightarrow \Delta i_t$

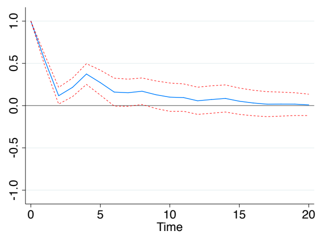
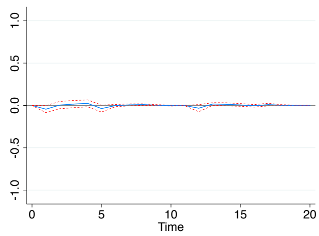
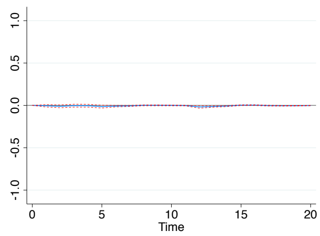


Figure D.24: Comparison with IRFs of the linear VAR model: Portugal

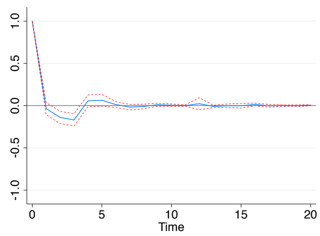
(a) $\Delta i_t \rightarrow \Delta \pi_t$



(b) $\Delta i_t \rightarrow \Delta u_t$



(c) $\Delta i_t \rightarrow \Delta i_t$



Notes: OIRFs at the beginning and the end of the observation period for the estimated TV-VAR model and IRFs for the linear VAR model (blue) with 95% confidence bands (red).

E MATLAB code

E.1 Specification

```
%% 5350 Thesis in economics
% Structural changes in the euro area -
% An evaluation of changes in the transmission mechanisms of monetary
% policy for selected economies

% Maximiliane Hoerl

% PARAMETER CONSTANCY TEST



clear all
format short

%% Parameters

m=3;                    % no. of variables
T=215;                  % no. of observations
p=[1,2,3,4,5,12];       % lags
nor=6;                  % no. of regressors


%% Data import

data= xlsread ('Portugal.xls', 'Portugal.csv', 'a1:d216');

t=data(:,1);            % time
dinf=data(:,2);         % inflation rates (FD)
dune=data(:,3);         % unemployment rates (FD)
dint=data(:,4);         % short-term interest rates (FD)


%% Fix matrices

% Y = (y_1,...,y_T)
Y=[dinf,dune,dint]';

% Vec(Y)
Yvec=[];
```

```
for j=1:T
    help1=Y(:,j);
    Yvec=[Yvec;help1];
end;


% I
I=eye(m,m);


% W = (w_1,...,w_T)
for j=p
    help=zeros(j,1);
    eval(['dinf_' num2str(j) '=[help;dinf(1:end-j)]']);
    eval(['dune_' num2str(j) '=[help;dune(1:end-j)]']);
    eval(['dint_' num2str(j) '=[help;dint(1:end-j)]']);

end;

W=ones(T,1);

for j=p
    W = [W, eval(['dinf_' num2str(j)])];
end;

for j=p
    W = [W, eval(['dune_' num2str(j)])];
end;

for j=p
    W = [W, eval(['dint_' num2str(j)])];
end;

W=W';

%% Test 1:

k=0;                    % order of transition function

%% Variable matrices

% S = (s_1,...,s_T)
S=[];
for j=1:T
    s_tilde=[];
    for i=1:k
        s_tilde=[s_tilde;j^i];
    end;
    s_tilde=[1;s_tilde];
    S=[S,s_tilde];
```

```
end;

% Z = (z_1,...,z_T)
s_length= k+1;
w_length= m*nor+1;

Z=[];
for j=1:T
    z_t=[];
    for i=1:s_length
        s_help=S(i,j);
        for l=1:w_length
            w_help=W(l,j);
            z_t=[z_t;s_help*w_help];
        end;
    end;
    Z=[Z,z_t];
end;


% B = (B_0,...,B_k)
H=((Z*Z')^-1)*Z;

[H_rows, H_columns]=size(H);

b_total=[];
for j=1:H_rows
    b_row_product=[];

    for i=1:H_columns
        b_help=H(j,i);
        b_new=b_help*I;
        b_row_product=[b_row_product,b_new];
    end;
    b_total=[b_total;b_row_product];
end;

b_T=b_total*Yvec;

B_rows=m;
B_columns=(k+1)*(m*nor+1);
B=[];

for j=1:B_columns
    B_c=[];
    for i= 1: B_rows
        B_determ=b_T((j-1)*B_rows+i,1);
        B_c=[B_c;B_determ];
    end;
    B=[B,B_c];
```

```
end;


% Estimation
Y_pred=B*Z;

% Prediction of error terms
epsilon1=Y-Y_pred;


%% Test 2:

k=3;                            % order of transition function

%% Variable matrices

% S = (s_1,...,s_T)
S=[];
for j=1:T
     s_tilde=[];
     for i=1:k
          s_tilde=[s_tilde;j^i];
     end;
     s_tilde=[1;s_tilde];
     S=[S,s_tilde];
end;

% Z = (z_1,...,z_T)
s_length= k+1;
w_length=m*nor+1;

Z=[];
for j=1:T
     z_t=[];
    for i=1:s_length
         s_help=S(i,j);
         for l=1:w_length
             w_help=W(l,j);
             z_t=[z_t;s_help*w_help];
         end;
    end;
    Z=[Z,z_t];
end;


% B = (B_0,...,B_k)
H=((Z*Z')^-1)*Z;

[H_rows, H_columns]=size(H);
```

```
b_total=[];
for j=1:H_rows
    b_row_product=[];

    for i=1:H_columns
        b_help=H(j,i);
        b_new=b_help*I;
        b_row_product=[b_row_product,b_new];
    end;
    b_total=[b_total;b_row_product];
end;

b_T=b_total*Yvec;

B_rows=m;
B_columns=(k+1)*(m*nor+1);
B=[];

for j=1:B_columns
    B_c=[];
    for i= 1: B_rows
        B_determ=b_T((j-1)*B_rows+i,1);
        B_c=[B_c;B_determ];
    end;
    B=[B,B_c];
end;


% Estimation
Y_pred=B*Z;

% Prediction of error terms
epsilon2=Y-Y_pred;


%% Parameter constancy test

w=k*(nor*m+1);
s2=(m^2*w^2-4)/(w^2+m^2-5);
s=s2^(0.5);
delta=T - (m*nor+1) - 0.5 *(m+w+1);

help1=epsilon2*epsilon2';
help0=epsilon1*epsilon1';

det1=det(help1);
det0=det(help0);

lambda=det1/det0;
```

```
% F_RAO statistic
F=( (1-(lambda^(1/s))) / (lambda^(1/s)) ) * ( (delta*s-0.5*(m*k-2)) / (m
    *w) );

% numerator degrees of freedom
df_num=m*w;

% denominator degrees of freedom
df_den=delta*s-0.5*(m*k-2);

% p-value
pval=1-fcdf(F,df_num,df_den);



% Results
Results=[k,F,df_num,df_den,pval];
```

E.2 Estimation

```
%% 5350 Thesis in economics
% Structural changes in the euro area -
% An evaluation of changes in the transmission mechanisms of monetary
% policy for selected economies

% Maximiliane Hoerl

% ESTIMATION ALGORITHM



clear all
format short

%% Parameters

m=3;                    % no. of variables
T=215;                  % no. of observations
p=[1,2,3,4,5,12];       % lags
nor=6;                  % no. of regressors


%% Data import

data= xlsread ('Portugal.xls', 'Portugal.csv', 'a1:d216');

t=data(:,1);                % time
dinf=data(:,2);             % inflation rates (FD)
dune=data(:,3);             % unemployment rates (FD)
dint=data(:,4);             % short-term interest rates (FD)


%% Fix matrices

% Y = (y_1,...,y_T)
Y=[dinf,dune,dint]';

% Vec(Y)
Yvec=[];
for j=1:T
    help1=Y(:,j);
    Yvec=[Yvec;help1];
end;


% I
I=eye(m,m);
```

```
% X = (x_1 ,... ,x_T)
for j=p
    help=zeros(j,1);
    eval(['dinf_' num2str(j) '=[help;dinf(1:end-j)]']);
    eval(['dune_' num2str(j) '=[help;dune(1:end-j)]']);
    eval(['dint_' num2str(j) '=[help;dint(1:end-j)]']);
end;

X=ones(T,1);

for j=p
    X = [X, eval(['dinf_' num2str(j)])];
end;

for j=p
    X = [X, eval(['dune_' num2str(j)])];
end;

for j=p
    X = [X, eval(['dint_' num2str(j)])];
end;

X=X';


%% Relevant equation

y=dune';


%% Determination of starting values

Final_solution=zeros(1,5);

% Variation of gamma_e = [0,0.01,0.1,1,10]
gamma_e=0.01;

for iteration=1:5

    if iteration==1
        c1=[20,60,100,140,180];
        c2=[20,60,100,140,180];
        c3=[20,60,100,140,180];
    elseif iteration==2
        if c1_e<21
            c1_e=21;
        end;
        if c2_e<21
```

```
            c2_e=21;
        end;
         if c3_e<21
            c3_e=21;
         end;
        c1=[c1_e-20,c1_e-10,c1_e,c1_e+10,c1_e+20];
        c2=[c2_e-20,c2_e-10,c2_e,c2_e+10,c2_e+20];
        c3=[c3_e-20,c3_e-10,c3_e,c3_e+10,c3_e+20];
    elseif iteration==3
          if c1_e<11
            c1_e=11;
        end;
        if c2_e<11
            c2_e=11;
        end;
         if c3_e<11
            c3_e=11;
         end;
        c1=[c1_e-10,c1_e-5,c1_e,c1_e+5,c1_e+10];
        c2=[c2_e-10,c2_e-5,c2_e,c2_e+5,c2_e+10];
        c3=[c3_e-10,c3_e-5,c3_e,c3_e+5,c3_e+10];
    elseif iteration==4
        if c1_e<5
            c1_e=5;
        end;
        if c2_e<5
            c2_e=5;
        end;
         if c3_e<5
            c3_e=5;
         end;
        c1=[c1_e-4,c1_e-2,c1_e,c1_e+2,c1_e+4];
        c2=[c2_e-4,c2_e-2,c2_e,c2_e+2,c2_e+4];
        c3=[c3_e-4,c3_e-2,c3_e,c3_e+2,c3_e+4];
    elseif iteration==5
        if c1_e<3
            c1_e=3;
        end;
        if c2_e<3
            c2_e=3;
        end;
         if c3_e<3
            c3_e=3;
         end;
        c1=[c1_e-2,c1_e-1,c1_e,c1_e+1,c1_e+2];
        c2=[c2_e-2,c2_e-1,c2_e,c2_e+1,c2_e+2];
        c3=[c3_e-2,c3_e-1,c3_e,c3_e+1,c3_e+2];
    end;

Solution=[0,0,0,0,10000];
```

```
for j1=1:5
    c1_e=c1(j1);

    for j2=1:5
        c2_e=c2(j2);

        for j3=1:5
            c3_e=c3(j3);

                M=zeros((m*nor+1)*2,1);

                for i=1:T
                    m1=gamma_e*(i-c1_e)*(i-c2_e)*(i-c3_e);
                    G_t=(1/(1+exp(-m1)));
                    psi_t=[1;G_t];
                    M_e1=X(:,i)*psi_t(1);
                    M_e2=X(:,i)*psi_t(2);
                    M_e=[M_e1;M_e2];
                   M=[M,M_e];
                end;

                M=M(:,2:end);

                M=M';

                vecD=(M'*M)^(-1)*M'*y';

                D=vecD';

                y_pred=D*M';
                Epsilon=y-y_pred;
                Epsilon2=Epsilon*Epsilon';


                if Epsilon2 < Solution(5)
                    D_opt=D;
                    Solution=[c1_e,c2_e,c3_e,gamma_e,Epsilon2];
                end;

        end;
    end;
end;

c1_e=Solution(1);
c2_e=Solution(2);
c3_e=Solution(3);

end;
```

```
%% Iterative estimation

c_ini=Solution(1,1:3);
D1=D_opt(1,1:(m*nor+1));
D2=D_opt(1,(m*nor+1)+1:end);
t=t';
options=optimset('Display','iter');

c_opt=fsolve(@nlsthesis2,c_ini,options,D1,D2,X,y,t,T,gamma_e);

c1_opt=c_opt(1);
c2_opt=c_opt(2);
c3_opt=c_opt(3);

c1_e=c_ini(1);
c2_e=c_ini(2);
c3_e=c_ini(3);

criterion=10^(-8);
count=0;

while abs(c1_opt-c1_e) > criterion || abs(c2_opt-c2_e) > criterion || abs(
    c3_opt-c3_e) > criterion

                count=count+1;

                c1_e=c_opt(1);
                c2_e=c_opt(2);
                c3_e=c_opt(3);


                M=zeros((m*nor+1)*2,1);
                for i=1:T
                    m1=gamma_e*(i-c1_e)*(i-c2_e)*(i-c3_e);
                    G_t=(1/(1+exp(-m1)));
                    psi_t=[1;G_t];
                    M_e1=X(:,i)*psi_t(1);
                    M_e2=X(:,i)*psi_t(2);
                    M_e=[M_e1;M_e2];
                    M=[M,M_e];
                end;

                M=M(:,2:end);

                M=M';

                vecD=(M'*M)^(-1)*M'*y';

                D=vecD';
```

```

                D1=D_opt(1,1:(m*nor+1));
                D2=D_opt(1,(m*nor+1)+1:end);
                c_ini=c_opt;

                c_opt=fsolve(@nlsthesis2,c_ini,options,D1,D2,X,y,t,T,gamma_e);



end;

Uni=ones(1,T);
G_opt=Uni./(Uni+exp(-gamma_e*(t-c_opt(1)).*(t-c_opt(2)).*(t-c_opt(3))));
eps=y-D1*X-(D2*X).*G_opt;
eps2=eps*eps';

Values_transition_function=[gamma_e,c_opt(1),c_opt(2),c_opt(3),eps2];


%% Final estimation round including gamma

x_0=[gamma_e,c_ini,D1,D2];              % 1x42 matrix
[x,fval,exitflag,output,grad,hessian] = fminunc(@nlsthesis4,x_0,options,X,y,t,T
    );

out_prod_grad=grad*grad';
C=(hessian^(-1))*out_prod_grad*(hessian^(-1));

standards=zeros(1,42);                  % standard errors for estimates
for i=1:42
    standards(i)=sqrt(C(i,i));
end;

% estimation results: coefficients and standard errors
Result=[x;standards];



function f = nlsthesis2(c_ini,D1,D2,X,y,t,T,gamma_e)
%This function takes the initial guess for c_ini and returns the optimal
%timing values
%

% Parameter extraction
c1=c_ini(1);
c2=c_ini(2);
c3=c_ini(3);

c1_v=c1*ones(1,T);
c2_v=c2*ones(1,T);
c3_v=c3*ones(1,T);
```

```
Uni=ones(1,T);

G_tn=Uni./(Uni+exp(-gamma_e*(t-c1_v).*(t-c2_v).*(t-c3_v)));
eps=y-D1*X-(D2*X).*G_tn;

% Definition of optimization function
f=2*eps;

end


function f = nlsthesis4(x_0,X,y,t,T)
%This function takes the initial guess for x_0 (c1,c2,c3 and dynamics)
%and returns the optimal values
%

% Parameter extraction
gamma_e=x_0(1);

c1=x_0(2);
c2=x_0(3);
c3=x_0(4);

c1_v=c1*ones(1,T);
c2_v=c2*ones(1,T);
c3_v=c3*ones(1,T);

B1=x_0(5:23);
B2=x_0(24:end);

Uni=ones(1,T);

G_tn=Uni./(Uni+exp(-gamma_e*(t-c1_v).*(t-c2_v).*(t-c3_v)));
eps=y-B1*W-(B2*W).*G_tn;

% Definition of optimization function
f=eps*eps';

end
```

E.3 Evaluation

E.3.1 Additional structural breaks

```
%% 5350 Thesis in economics
% Structural changes in the euro area -
% An evaluation of changes in the transmission mechanisms of monetary
% policy for selected economies

% Maximiliane Hoerl

% EVALUATION: ADDITIONAL STRUCTURAL BREAKS



clear all
format longG

%% Parameters

m=3;                        % no. of variables
T=215;                      % no. of observations
p=[1,2,3,4,5,12];           % lags
nor=6;                      % no. of regressors


%% Data import

data= xlsread ('France.xls', 'France.csv', 'a1:d216');

t=data(:,1);                    % time
dinf=data(:,2);                 % inflation rates (FD)
dune=data(:,3);                 % unemployment rates (FD)
dint=data(:,4);                 % short-term interest rates (FD)


%% Fix matrices

% Y = (y_1,...,y_T)
Y=[dinf,dune,dint]';

% Vec(Y)
Yvec=[];
for j=1:T
    help1=Y(:,j);
    Yvec=[Yvec;help1];
end;

```

```
% I
I=eye(m,m);


% X = (x_1,...,x_T)
for j=p
    help=zeros(j,1);
    eval(['dinf_' num2str(j) '=[help;dinf(1:end-j)]']);
    eval(['dune_' num2str(j) '=[help;dune(1:end-j)]']);
    eval(['dint_' num2str(j) '=[help;dint(1:end-j)]']);
end;

X=ones(T,1);

for j=p
    X = [X, eval(['dinf_' num2str(j)])];
end;

for j=p
    X = [X, eval(['dune_' num2str(j)])];
end;

for j=p
    X = [X, eval(['dint_' num2str(j)])];
end;

X=X';


%% Definition: equation and parameters

% relevant equation
y=dune';

% transition parameters
gamma=1.000;
c1=65.001;
c2=71.998;
c3=153.327;

% order of the transition function
k=3;


%% 1. Estimation of the nonlinear TV-VAR model
% under the null hypothesis of no additional structural breaks

M=zeros((m*nor+1)*2,1);

```

```
for  i=1:T
     m1=gamma*(i-c1)*(i-c2)*(i-c3);
     G_t=(1/(1+exp(-m1)));
     Psi_t=[1;G_t];
     M_e1=X(:,i)*Psi_t(1);
     M_e2=X(:,i)*Psi_t(2);
     M_e=[M_e1;M_e2];
    M=[M,M_e];
end;

M=M(:,2:end);
M=M';

Dvec=(M'*M)^(-1)*M'*y';
D=Dvec';

% Estimation
y_pred=D*M';
epsilon=y-y_pred;

% Residual sum of squares
RSS_0=epsilon*epsilon';


%% 2. Auxiliary regression
%  of residuals on (h,v)

% Determination of partial derivative matrix H
H=zeros(1,2*(m*nor+1)+1+k);

for  i=1:T

    % Derivatives with respect to D
          delta_D0=X(:,i)';
          m1=gamma*(i-c1)*(i-c2)*(i-c3);
          G_t=(1/(1+exp(-m1)));
          delta_D1=G_t*X(:,i)';


    % Derivatives with respect to Gamma
          D1=D(1:m*nor+1);
          D2=D(m*nor+2:end);
          D_mat_trans=[D1;D2];

          delta_g_gamma=G_t*(1-G_t)*(i-c1)*(i-c2)*(i-c3);
          delta_Psi_t=[0;delta_g_gamma];
          delta_gamma=delta_Psi_t'*D_mat_trans*X(:,i);


    % Derivatives with respect to C
```

```
            delta_g_c1=-G_t*(1-G_t)*gamma*(i-c2)*(i-c3);
            delta_Psi_t=[0;delta_g_c1];
            delta_c1=delta_Psi_t'*D_mat_trans*X(:,i);

            delta_g_c2=-G_t*(1-G_t)*gamma*(i-c1)*(i-c3);
            delta_Psi_t=[0;delta_g_c2];
            delta_c2=delta_Psi_t'*D_mat_trans*X(:,i);

            delta_g_c3=-G_t*(1-G_t)*gamma*(i-c1)*(i-c2);
            delta_Psi_t=[0;delta_g_c3];
            delta_c3=delta_Psi_t'*D_mat_trans*X(:,i);

      % Vectorization
      vec_delta_t=[delta_D0,delta_D1,delta_gamma,delta_c1,delta_c2,delta_c3];

      % Creation h
      H=[H;vec_delta_t];


end;

H=H(2:end,:);

H=H';


% Determination of additional regressors V

N=3;
S=[];
for j=1:T
      s_tilde=[];
      for i=1:N
            s_tilde=[s_tilde;j^i];
      end;
      S=[S,s_tilde];
end;


s_length= N;
x_length= m*nor+1;

V=[];
for j=1:T
      v_t=[];
     for i=1:s_length
          s_help=S(i,j);
          for l=1:x_length
               x_help=X(l,j);
               v_t=[z_t;s_help*x_help];
```

```
        end;
    end;
    V=[V,v_t];
end;

% Regression of residuals epsilon on (H,V)
Regressors=[H;V];

Dvec2=(Regressors*Regressors')^(-1)*Regressors*epsilon';

D_eps=Dvec2';

epsilon_pred=D_eps*Regressors;
xi=epsilon-epsilon_pred;

% Residual sum of squares
RSS_1=xi*xi';


%% 3. Calculation of test statistic F_LM

% n1: dimension of the gradient vector H
[n1,n2]=size(H);
m=3;
q=N*(m*nor);

% test statistic
F=((RSS_0-RSS_1)/q) / (RSS_1/(T-n1-q));

% degrees of freedom
df=q;
df2=T-n1-q;

pval=1-fcdf(F,df,df2);
Results=[F,pval];
```

E.3.2 Impulse response analysis

```
%% 5350 Thesis in economics
% Structural changes in the euro area -
% An evaluation of changes in the transmission mechanisms of monetary
% policy for selected economies

% Maximiliane Hoerl

% IMPULSE RESPONSE ANALYSIS



clear all
format short

%% Parameters

m=3;                        % no. of variables
T=215;                      % no. of observations
periods=20;                 % no. of periods
country='Portugal';         % country

% System (A=0, B=1)
G1=0;
G2=0;
G3=0;
version='A';                % system

%% Data import

T_help=T+1;

data= xlsread (strcat('D_',country,'.xls'),'Blatt1', strcat('a1:d',num2str(T_help)));
errors= xlsread (strcat('errors_',country,'.xls'), strcat('errors_',country,'.csv'), strcat('a1:d',num2str(T_help)));
raw_data= xlsread (strcat(country,'.xls'), strcat(country,'.csv'), strcat('a1:d',num2str(T_help)));


%% Variance-covariance matrix

Sigma=cov(errors);


%% Identification
%  Assumption: s12=s13=s23=0

```

```
s21=-Sigma(1,2)/Sigma(1,1);

s31=-Sigma(1,3)/Sigma(1,1);

sigma_y2=Sigma(2,2)-s21^2*Sigma(1,1);

s32=- (Sigma(2,3)-s21*s31*Sigma(1,1)) / sigma_y2;

% Matrix S
S=[1,0,0;s21,1,0;s31,s32,1];

Sneg1=S^(-1);


%% Coefficients

D0=data(:,2:19);
O1A=[D0(:,1),D0(:,7),D0(:,13)];
O2A=[D0(:,2),D0(:,8),D0(:,14)];
O3A=[D0(:,3),D0(:,9),D0(:,15)];
O4A=[D0(:,4),D0(:,10),D0(:,16)];
O5A=[D0(:,5),D0(:,11),D0(:,17)];
O12A=[D0(:,6),D0(:,12),D0(:,18)];


D1=data(:,21:end);
O1B=[D1(:,1),D1(:,7),D1(:,13)];
O2B=[D1(:,2),D1(:,8),D1(:,14)];
O3B=[D1(:,3),D1(:,9),D1(:,15)];
O4B=[D1(:,4),D1(:,10),D1(:,16)];
O5B=[D1(:,5),D1(:,11),D1(:,17)];
O12B=[D1(:,6),D1(:,12),D1(:,18)];

% Transition function
G=[G1,0,0;0,G2,0;0,0,G3];

% Time dependent coefficients
O1=O1A+G*O1B;
O2=O2A+G*O2B;
O3=O3A+G*O3B;
O4=O4A+G*O4B;
O5=O5A+G*O5B;
O12=O12A+G*O12B;


%% Impulse response matrices

Phi0=eye(m,m)*Sneg1;
Phi1=Phi0*O1;
Phi2=Phi1*O1+Phi0*O2;
```

```
Phi3=Phi2*O1+Phi1*O2+Phi0*O3;
Phi4=Phi3*O1+Phi2*O2+Phi1*O3+Phi0*O4;
Phi5=Phi4*O1+Phi3*O2+Phi2*O3+Phi1*O4+Phi0*O5;
Phi6=Phi5*O1+Phi4*O2+Phi3*O3+Phi2*O4+Phi1*O5;
Phi7=Phi6*O1+Phi5*O2+Phi4*O3+Phi3*O4+Phi2*O5;
Phi8=Phi7*O1+Phi6*O2+Phi5*O3+Phi4*O4+Phi3*O5;
Phi9=Phi8*O1+Phi7*O2+Phi6*O3+Phi5*O4+Phi4*O5;
Phi10=Phi9*O1+Phi8*O2+Phi7*O3+Phi6*O4+Phi5*O5;
Phi11=Phi10*O1+Phi9*O2+Phi8*O3+Phi7*O4+Phi6*O5;
Phi12=Phi11*O1+Phi10*O2+Phi9*O3+Phi8*O4+Phi7*O5+Phi0*O12;
Phi13=Phi12*O1+Phi11*O2+Phi10*O3+Phi9*O4+Phi8*O5+Phi1*O12;
Phi14=Phi13*O1+Phi12*O2+Phi11*O3+Phi10*O4+Phi9*O5+Phi2*O12;
Phi15=Phi14*O1+Phi13*O2+Phi12*O3+Phi11*O4+Phi10*O5+Phi3*O12;
Phi16=Phi15*O1+Phi14*O2+Phi13*O3+Phi12*O4+Phi11*O5+Phi4*O12;
Phi17=Phi16*O1+Phi15*O2+Phi14*O3+Phi13*O4+Phi12*O5+Phi5*O12;
Phi18=Phi17*O1+Phi16*O2+Phi15*O3+Phi14*O4+Phi13*O5+Phi6*O12;
Phi19=Phi18*O1+Phi17*O2+Phi16*O3+Phi15*O4+Phi14*O5+Phi7*O12;
Phi20=Phi19*O1+Phi18*O2+Phi17*O3+Phi16*O4+Phi15*O5+Phi8*O12;
Phi21=Phi20*O1+Phi19*O2+Phi18*O3+Phi17*O4+Phi16*O5+Phi9*O12;
Phi22=Phi21*O1+Phi20*O2+Phi19*O3+Phi18*O4+Phi17*O5+Phi10*O12;
Phi23=Phi22*O1+Phi21*O2+Phi20*O3+Phi19*O4+Phi18*O5+Phi11*O12;
Phi24=Phi23*O1+Phi22*O2+Phi21*O3+Phi20*O4+Phi19*O5+Phi12*O12;

% Shocks
sh=[0;0;1];

% IRFs
IRF=[];
for i=0:periods
    eval(['IR' num2str(i) '=Phi' num2str(i) '*sh']);
    eval(['IRF_help=IR' num2str(i)]);
    IRF=[IRF,IRF_help];
end;

IRF1=IRF(1,:);
IRF2=IRF(2,:);
IRF3=IRF(3,:);


%% Standard errors

% J
m=3;
nor=6;
I=eye(m,m);
Zero=zeros(m,m);
J=[I,Zero,Zero,Zero,Zero,Zero];

% O
O_first=[O1,O2,O3,O4,O5,O12];
```

```
O_second=zeros(1,m*nor);
for i=1:nor-1
      count=i;
    O_help=zeros(m,1);
    if i==1
        O_help=[O_help,I];
        for j=i+1:nor
            O_help=[O_help,Zero];
        end;
    end;
    if i>1 && i<nor
    for j=1:i-1
        O_help=[O_help,Zero];
    end;
    O_help=[O_help,I];
    for j=i+1:nor
        O_help=[O_help,Zero];
    end;
    end;
    O_help=O_help(:,2:end);
    O_second=[O_second;O_help];
end;

O_second=O_second(2:end,:);

O=[O_first;O_second];


% L
for i=1:periods
    L_sum=zeros(m*m,m*m*nor);
    for n=0:i-1
        L_help=J*((O')^(i-1-n));
        [L_rows, L_columns]=size(L_help);
        L=[];
        for j1=1:L_rows
            L_row_product=[];
            for j2=1:L_columns
                L_help1=L_help(j1,j2);
                eval(['L_new=L_help1*Phi' num2str(n) ';']);
                L_row_product=[L_row_product,L_new];
            end;
            L=[L;L_row_product];
        end;
        L_sum=L_sum+L;
     end;
     eval(['L_' num2str(i) '=L_sum;']);
end;
```

```
% Gamma_Y
dinf=raw_data(:,2);                     % inflation rates (FD)
dune=raw_data(:,3);                     % unemployment rates (FD)
dint=raw_data(:,4);                     % short-term interest rates (FD)
p=[1,2,3,4,5,12];                       % lags

% Z
for j=p
    help=zeros(j,1);
    eval(['dinf_' num2str(j) '=[help;dinf(1:end-j)]']);
    eval(['dune_' num2str(j) '=[help;dune(1:end-j)]']);
    eval(['dint_' num2str(j) '=[help;dint(1:end-j)]']);
end;

Z=[];

for j=p
    Z = [Z, eval(['dinf_' num2str(j)])];
    Z = [Z, eval(['dune_' num2str(j)])];
    Z = [Z, eval(['dint_' num2str(j)])];
end;

Z=Z';

Gamma_Y=Z*Z'/T;

Gamma_Y=Gamma_Y^(-1);

% Sigma_alpha
[Gamma_rows, Gamma_columns]=size(Gamma_Y);

Sigma_alpha=[];
for j=1:Gamma_rows
    Gamma_row_product=[];
    for i=1:Gamma_columns
        Gamma_help=Gamma_Y(j,i);
        Gamma_new=Gamma_help*Sigma;
        Gamma_row_product=[Gamma_row_product,Gamma_new];
    end;
    Sigma_alpha=[Sigma_alpha;Gamma_row_product];
end;


% Confidence bands
for j=1:periods
    eval(['CI' num2str(j) '=[]']);
    eval(['CI_help= (L_' num2str(j) '*Sigma_alpha*transpose(L_' num2str(j) '))/
        T']);
    for i=1:9
```

```
            CI_square=CI_help(i,i);
            CI=sqrt(CI_square);
            eval(['CI' num2str(j) '=[CI' num2str(j) ',CI]']);
        end;
        eval(['CI_help2=CI' num2str(j)]);
        eval(['CI' num2str(j) '=zeros(3,3)']);
        for i2=1:3
            eval(['CI' num2str(j) '(:,i2)=CI_help2(i2*3-3+1:i2*3)']);
        end;
end;

CI0=zeros(3,3);

for j=0:periods
    eval(['CIsh_' num2str(j) '=CI' num2str(j) '*sh']);
end;


% Upper and lower bands
for j=0:periods
    eval(['Upper' num2str(j) '=IR' num2str(j) '+ CIsh_' num2str(j)]);
    eval(['Lower' num2str(j) '=IR' num2str(j) '- CIsh_' num2str(j)]);
end;

Upper_all=[];
Lower_all=[];
for i=0:periods
    eval(['Upper_help=Upper' num2str(i)]);
    Upper_all=[Upper_all,Upper_help];
    eval(['Lower_help=Lower' num2str(i)]);
    Lower_all=[Lower_all,Lower_help];
end;

UpperCI1=Upper_all(1,:);
UpperCI2=Upper_all(2,:);
UpperCI3=Upper_all(3,:);

LowerCI1=Lower_all(1,:);
LowerCI2=Lower_all(2,:);
LowerCI3=Lower_all(3,:);


%% Export of impulse responses

Solution=[IRF1',UpperCI1',LowerCI1',IRF2',UpperCI2',LowerCI2',IRF3',UpperCI3',
    LowerCI3'];
dlmwrite(strcat('data_stata/',country,'_',version,'.csv'),Solution,',');
```