

# Asymmetries of Monetary Policy Transmission between US and Euro Area.<sup>1</sup>

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This Version: April 2004

<sup>1</sup>The estimations of this paper have been carried out by using OX 3.2. We also thank Michael Ehrmann for providing us with the code to estimate state-dependent impulse response functions.

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## **Abstract**

The aim of this paper is to study the asymmetries in the business cycle transmission between US and Euro Area. Using the Markov Switching VAR methodology we analyze the relationships among the US and Euro Area GDP, the interest rates differential between US and Euro Area, and the Euro Dollar exchange rate. By analyzing the state-dependent impulse response functions we find strong evidence in favor of asymmetries in the transmission mechanism of business cycle. Moreover we show that the interest rates differential and the Euro Dollar exchange rate play a crucial role in explaining those asymmetries.

Keywords: Markov Switching VAR Models, State-Dependent Impulse Response Functions, Business Cycles, Asymmetries, International Business Cycle Transmission.

JEL Classification Codes: C51, E32, F42

# 1 Introduction

The aim of this paper is to analyze the asymmetries in the transmission mechanism of monetary policy and how Euro area GDP reacts to a US GDP shock dependently on the state of the economy (low and high growth).

The US business cycle predominance in the international transmission of shocks has been widely proved by empirical studies in the economic literature<sup>1</sup>. Agresti and Mojon (2001) argue that US and Euro Area business cycles are highly comparable. This synchronicity is also found for the main components of GDP as well as for the short term interest rate. Furthermore, interest rates lead business cycles. Other important aspects concerning the business cycle analysis are the recent changes in the deepness and duration of cycles. There is some empirical evidence (IMF, 2001, 2002) that in general recessions have become less deep and less frequent over time, while booms have a longer duration. Krolzig (1996) specified a MS-VECM to analyze the business cycle for six countries. He found that the coefficient of US GNP in the cointegration relationships was the highest respect to the other countries included in the sample confirming the dominance of US economy for the global economy system.

An interesting question concerns the asymmetries of US business cycles shocks on Euro Area conditionally to the economy regime (boom or recession) and what role plays the interest rates differential and the exchange rate in explaining such asymmetries (Cacciotti et al. 2003). For this purpose we use Markov Switching models which permit to identify regimes and to obtain the correspondent dating.

By following the empirical modelling procedure by Artis et al. (2003) and Krolzig (2003) we conduct two preliminary steps in our analysis before constructing the final MS-VAR model:

- The co-switching analysis of the variables included in the final multivariate model, by using univariate Markov Switching models;
- The cointegration analysis of variables by using linear VAR models.

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<sup>1</sup>A deep description of linkages among major advanced economies business cycles is provided by IMF (2001)

The paper proceeds as follows. First, in section 2 we discuss the Markov switching VAR models, the estimation algorithm and the state-dependent impulse response functions. In section 3 we conduct an univariate analysis for each variable included in the final MS-VAR by following the Artis et Al. (2003) and Krolzig (2003) approach as mentioned before. The MS-VAR model is estimated in section 4 where impulse response functions are computed to analyze how Euro Area GDP reacts to a unit shock on the US GDP. In section 5 we employ the regime-dependent impulse response functions to study the asymmetries in this transmission mechanism. Section 6 concludes.

## 2 Markov Switching VAR model

### 2.1 The model

MS-VAR (Markov Switching Vector Autoregression) models provide a generalized framework of VAR models which take into accounts changes in regimes  $s_t$ .

The mean adjusted MS-VAR process of order  $p$  and  $M$  regimes may be written in the general form as:

$$\mathbf{y}_t - \boldsymbol{\mu}(s_t) = \mathbf{A}_1(s_t)(\mathbf{y}_{t-1} - \boldsymbol{\mu}(s_{t-1})) + \dots + \mathbf{A}_p(s_t)(\mathbf{y}_{t-p} - \boldsymbol{\mu}(s_{t-p})) + \mathbf{u}_t \quad (1)$$

where  $\mathbf{u}_t \sim NID(\mathbf{0}, \boldsymbol{\Sigma}(s_t))$  and  $\boldsymbol{\mu}(s_t), \mathbf{A}_1(s_t), \dots, \mathbf{A}_p(s_t), \boldsymbol{\Sigma}(s_t)$  are the regime-dependent parameters.

A different representation (intercept form) of MS-VAR, is the following:

$$\mathbf{y}_t = \boldsymbol{\nu}(s_t) + \mathbf{A}_1(s_t)\mathbf{y}_{t-1} + \dots + \mathbf{A}_p(s_t)\mathbf{y}_{t-p} + \mathbf{u}_t \quad (2)$$

where  $\boldsymbol{\nu}(s_t) = \boldsymbol{\mu}(s_t)(\mathbf{I} - \sum_{j=1}^p \mathbf{A}_j(s_t))$ .

The mean-adjusted form (1) and the intercept form (2) of MS-VAR models are not equivalent because they imply different dynamic reactions of dependent variables to a regime shift<sup>2</sup>. More precisely, while in the model (1) a regime change in the mean  $\boldsymbol{\mu}(s_t)$  determines an immediate adjustment of dependent variables to new levels, in the model (2) a regime shift causes a smooth and dynamic change of the

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<sup>2</sup>Differently from VAR(p) model where both representations are equivalent

intercept. The last model seems to be more preferable because it is more plausible that means approach smoothly new levels after a regime shift.

In the general MS-VAR specifications all parameters are regime-dependent. However, in the empirical applications it is preferable to consider only some parameters dependent on the state  $s_t$ . The fact that parameter may be (or not) regime-dependent determines a lot of MS-VAR specifications.

By following the Krolzig (1997) notation, we could add to the MS (Markov-Switching) notation, the following letters, to specify the regime-dependent parameters:  $M$  for Markov-Switching Mean,  $I$  for Markov-Switching Intercept,  $A$  for Markov-Switching autoregressive parameters,  $H$  for Markov-Switching heteroskedasticity (e.g MSMH-VAR is a Markov-Switching Mean specification with  $\Sigma$  varying).

In all MS-VAR specifications, the unobservable regime  $s_t$  is governed by a first order Markov process, which is defined by the transition probabilities:

$$p_{ij} = Pr(s_{t+1} = j | s_t = i) \quad \sum_{j=1}^M p_{ij} = 1 \quad i, j = 1 \dots M \quad (3)$$

where  $p_{ij}$  is the probability that event  $i$  is followed by event  $j$  and an element of the transition matrix:

$$\mathbf{P} = \begin{bmatrix} p_{11} & p_{21} & \cdot & \cdot & \cdot & p_{N1} \\ p_{12} & p_{22} & \cdot & \cdot & \cdot & p_{N2} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ p_{1N} & p_{2N} & \cdot & \cdot & \cdot & p_{NN} \end{bmatrix}$$

## 2.2 Estimation

The estimation technique implemented for MS-VAR models, the EM (Expectation-Maximization) algorithm, is discussed in Krolzig (1997) (and in Hamilton (1990) for the univariate case). The EM algorithm has been originally described by Dempster et al. (1977).

The parameters must be estimated by maximizing a log-likelihood function. The problem is that the FOCs are non linear and consequently have not a closed solution; it is not possible to solve them analytically . To solve the equations, it can be implemented two steps. Firstly, arbitrary initial values of parameters are defined.

The first step (The Expectation Step) is based on the computation of transition probabilities which depend on the initial values above mentioned.

The second step (The Maximization Step) makes use of the previous probabilities to compute the maximum likelihood estimates of parameters. These two steps are repeated until parameters estimates converge.

### 2.3 Regime-dependent impulse response functions

Important tools in the context of VAR models are impulse response functions which permit to simulate the responses of endogenous variables, included in the model, to exogenous shocks.

For the MS-VAR models, Ehrmann et al. (2003) have introduced the same tool, the regime-dependent impulse response functions.

Differently from VAR models, in which it has been assumed that there are not relevant regime shifts, regime-dependent impulse response functions are conditional on the prevailing regime at the time  $t$  when the shock occurs and on the entire horizon length.

The horizon length must reasonably depend on the predicted persistence of the regime prevailing at time  $t$ . Therefore, the horizon length have not to be longer than predicted regime duration.

As for VAR models, we need to consider the problem of identification in the MS-VAR models. Rewrite the (2) in the following form:

$$\mathbf{y}_t = \mathbf{A}_{1i}\mathbf{y}_{t-1} + \dots + \mathbf{A}_{pi}\mathbf{y}_{t-p} + \mathbf{B}_i\boldsymbol{\epsilon}_t \quad i = 1, \dots, M \quad (4)$$

where  $M$  is the number of regimes,  $\boldsymbol{\epsilon}_t \sim N(\mathbf{0}, \mathbf{I})$  and where

$$\boldsymbol{\Sigma}_i = E(\mathbf{B}_i\mathbf{u}_t\mathbf{u}_t'\mathbf{B}_i') = \mathbf{B}_iE(\mathbf{u}_t\mathbf{u}_t')\mathbf{B}_i' = \mathbf{B}_i\mathbf{I}\mathbf{B}_i' = \mathbf{B}_i\mathbf{B}_i'$$

To compute impulse response functions we need to estimate the matrices  $\mathbf{B}_i$ ; but the EM algorithm gives only estimates of variance and covariance matrices  $\boldsymbol{\Sigma}_1, \dots, \boldsymbol{\Sigma}_M$  and not the matrices  $\mathbf{B}_1, \dots, \mathbf{B}_M$ . To identify these matrices we have to impose restrictions on the unrestricted model. The identity  $\mathbf{B}_i\mathbf{B}_i' = \boldsymbol{\Sigma}_i$  imposes  $K(K + 1)/2$  restrictions on  $\mathbf{B}_i$  because the matrix of variance and covariance is

symmetric. For example, we can impose that the matrix  $\mathbf{B}_i$  is lower triangular (the Cholesky Decomposition of the matrix  $\mathbf{\Sigma}_i$ ). Obviously, the order of variables in the system assumes now a particular importance; in fact it causes that each variable determines only contemporaneous effects on itself and on variables ordered below it.

In our model there are  $MK^2$  impulse response functions corresponding to the reaction of  $K$  variables to  $K$  shocks in  $M$  regimes.

Equation (5) defines the reaction (for an horizon length equal to  $h$ ) of endogenous variables to a one standard deviation shock to the  $k$ -th disturbance at time  $t$ .

$$\frac{\partial E_t \mathbf{y}_{t+h}}{\partial \mathbf{u}_{k,t}} \Big|_{s_t=\dots=s_{t+h}=i} = \boldsymbol{\theta}_{ki,h} \quad (5)$$

Erhmann et al. (2003) demonstrates that impulse response functions are the following:

$$\hat{\boldsymbol{\theta}}_{ki,0} = \hat{\mathbf{B}}_i \boldsymbol{\epsilon}_0 \quad (6)$$

$$\hat{\boldsymbol{\theta}}_{ki,h} = \sum_{j=1}^{\min(h,p)} \hat{\mathbf{A}}_{ji}^{h-j+1} \hat{\mathbf{B}}_i \boldsymbol{\epsilon}_0 \quad h > 0 \quad (7)$$

The equation (6) represents the the first impulse response function (at time  $h=0$ ) and (7) the following ones.

### 3 Univariate analysis by using MS models

#### 3.1 Euro business cycle

We consider two aggregate GDP datasets for Euro Area. The first is the AWM (Area Wide Model) database reconstructed by European Central Bank for the period 1970:1-2002:4 quarterly data<sup>3</sup> the second supplied by OECD National Statistics. Our aim is to identify Euro Area business cycle turning points and compare them with those found by the CEPR (Centre for Economic Policy Research) Committee (Paolillo, Petragallo 2004). The idea is to replicate Hamilton's (1989) and Chauvet and Piger (2003) experiment, that identify US business cycle turning points with

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<sup>3</sup>This dataset has been reconstructed by Fagan et al. ([www.ecb.int/pub/wp/ecbwp042.zip](http://www.ecb.int/pub/wp/ecbwp042.zip)) for the period 1970:1-1998:4. We thank Alistair Dieppe at ECB for providing us with an updated version of the data.

Table 1: Euro Zone GDP Estimation Results using MSI(2)-AR(0) specification.

	AWM Database	OECD
Regime Dependent Intercept		
$v_1$	0.14	-0.02
$v_2$	0.89	0.80
Transition Probabilities		
$p_{11}$	0.81	0.83
$p_{22}$	0.88	0.95
Standard Error		
$\sigma$	0.48	0.41
Persistence of Regime 1		
Erg. Prob.	0.37	0.24
Duration	5.21	5.88
Log Lik.	-110.88	-85.54
LR Test	15.49	29.42

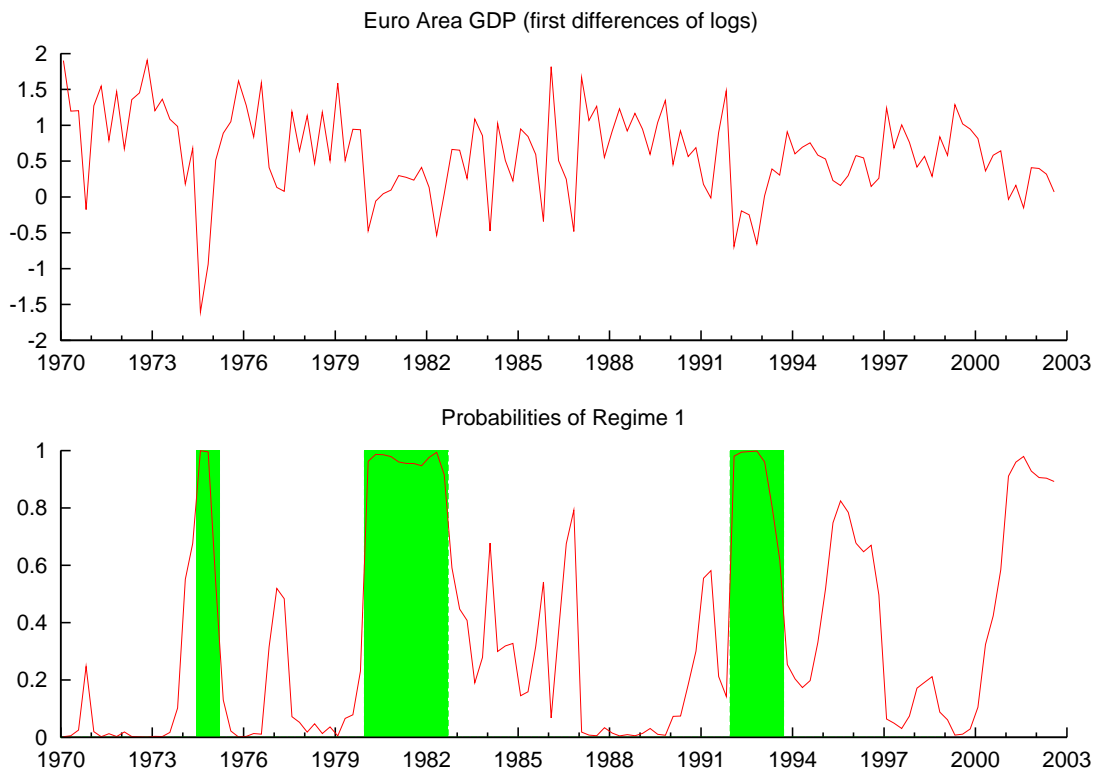
Markov Switching models comparing the estimated results with those announced by NBER, using the above said dataset. We should expect a certain degree of synchrony between the business cycles dating calculated by using the Markov Switching model and the methodology employed by CEPR (as Hamilton, Chauvet and Piger did in their studies with their respective dataset).

Euro zone dataset is different from the US one. The Euro GDP is calculated by grouping a set of different countries with different institutions and policies at least up to 1999 that make difficult the aggregation. Long time series are not available for all constituent countries and data definitions differ across them. We have differentiated the series in logs to obtain stationary series.

The estimated results using AWM database are listed in the middle column of table 1. The transition probability of being in state 1 (recession) is 0.81 with an estimated average duration of over 5 quarters. This means that the recession regime is quite persistent. The relatively low ergotic probability ( $p=0.37$ ) is confirmed by a graphical point of view. In fact the bottom graph of figure 1 shows that the periods in which smoothed probabilities of being in recession regime ( $p > 0.5$ ) are not so relevant compared to the whole sample period considered.

The results are quite interesting as can be seen in figure 1 where the smoothed probabilities of a recession are plotted against time together with the dating computed by CEPR (shaded area). It can be easily seen that the episodes of recessions

Figure 1: Euro Area MSI(2)-AR(0), 1970:2-2002:4 using AWM dataset.



calculated by the model nearly matches those of CEPR. From 1998 on, CEPR has not announced any period of recession yet, while our estimates show clearly that from 2001:2 the Euro Zone economy can be considered in recession. Our estimated model detects another period of recession (1995:2-1996:4). The estimated probabilities associated with this period is not very high (0.69). Therefore, classifying this period as recession or not depends on the decision rule one applies.

A more detailed comparison between the Euro Area cycles dating by CEPR and our estimates are reported in table 2. By just looking at the right pane of the table it can be seen that the first estimated recession regime classifications lead by two periods and lag by one those published by CEPR. The second estimated recession leads and lags by one period. Those mismatches are justified by the different methodology applied. CEPR identifies recession periods as the time span between a peak and a trough, while Markov Switching models classify a recession when the  $p$  probability is less than 0.50. Also the 1992-1993 recession is nearly coincident confirming the

Table 2: Chronology of euro area business cycles. Markov Switching Estimation using AWM Database.

High Growth Periods		Recession Period	
CEPR	Switching Model	CEPR	Switching Model
1970:2-1974:3	1970:2-1974:1	1974:4-1975:1	1974:2-1975:2
1975:2-1980:1	1975:3-1980:1	1980:3-1982:3	1980:2-1983:1
1982:4-1992:1	1983:2-1992:1	1992:2-1993:3	1992:2-1993:4
-	1994:1-1995:1	-	1995:2-1996:4
1993:4-2000:4	1997:1-2001:1	to be announced	2001:2-2002:4

Table 3: Chronology of euro area business cycles. Markov Switching Estimation using OECD database.

High Growth Periods		Recession Period	
CEPR	Switching Model	CEPR	Switching Model
1970:2-1974:3	1970:2-1974:2	1974:4-1975:1	1974:3-1975:2
1975:2-1980:1	1975:3-1980:1	1980:3-1982:3	1980:2-1983:1
1982:4-1992:1	1983:2-1992:1	1992:2-1993:3	1992:2-1993:2
1993:4-2000:4	1993:3-2001:1	to be announced	2001:2-2002:1

validity of MS models as a useful substitute device to date business cycles<sup>4</sup>.

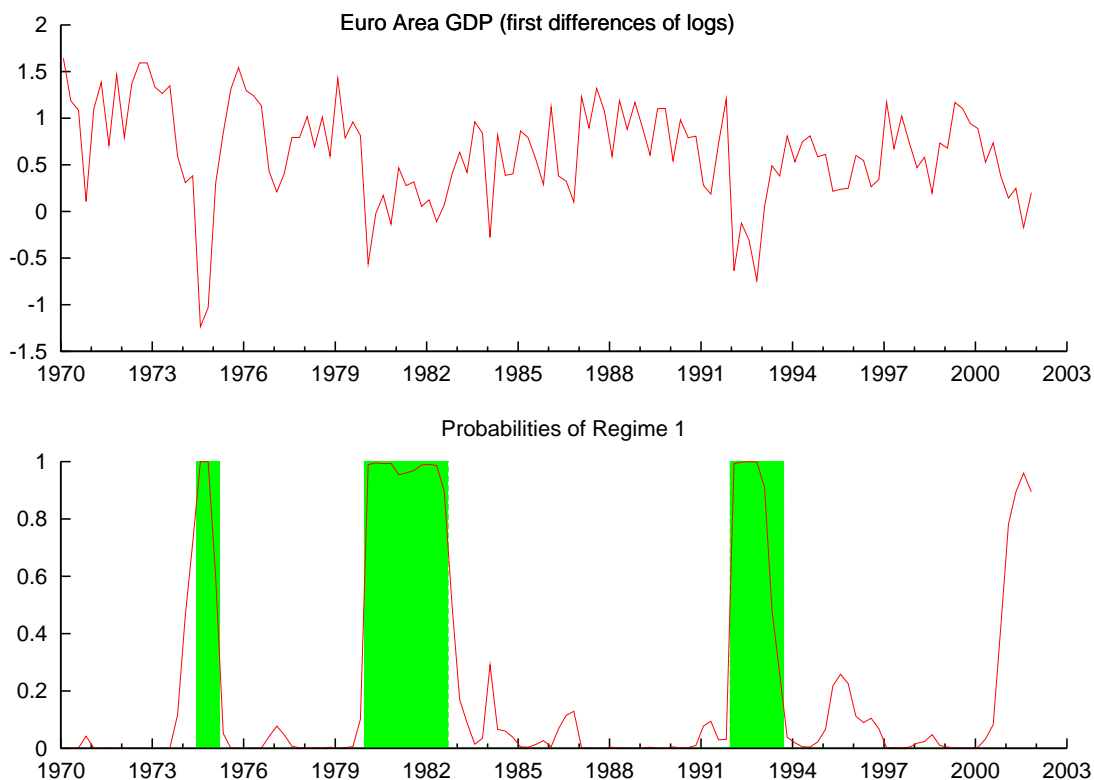
The other dataset we have considered is the OECD GDP series that goes from 1970:1 to 2002:1. We have proceeded in the estimation as above. The estimation results are listed in the last column of table 1. Bearing in mind in the OECD dataset the latest three observations are missing, it can be seen that the results are quite similar. The main difference is that the ergotic probability of being in state 1 is lower. This fact together with the a negative value for  $v_1$  should imply less recession episodes. This is confirmed by looking at figure 2.

From figure 2 it is also evident that there is a great degree of synchronization between the dating of cycle by CEPR (shaded area) and that obtained by using the MS model. This is confirmed by table 3. In both models the latest smoothed probabilities tend to decrease. This can let us infer a possible sudden regime change in the near future which means a recovery from a recession for the whole Euro Area.

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<sup>4</sup>The results are more interesting when considering the original AWM database constructed by Fagan et al. (2002). The original dataset from 1970:1 to 1998:4. We have estimated the model as usual and obtained a nearly exact synchronization between the CEPR dating and those estimated. Our updated dataset differs from the original one for the inclusion of Greece, a different base year (1995=100) and a different interpolation methodology.

Figure 2: Euro Area MSI(2)-AR(0), 1970:2-2002:4 using OCSE dataset.



### 3.2 US business cycle

In this section we analyze the US Business cycles from 1970:1 to 2002:4. Data are obtained from OECD database. We identify the regime of recessions by employing the Markov Switching model and compare the obtained results with those of NBER in a similar fashion as Hamilton (1989) and Chauvet and Piger (2003). Assuming that NBER dates the cycles correctly we start by applying the most parsimonious MS model MSI(2)-AR(0) and verify if both methodologies lead to the same results.

The estimation results are reported in table 4. The transition probability of being in recession ( $p_{11}$ ) is 0.74 confirming that the recession regime is quite persistent. On the other hand the transition probability of remaining in state 2 (high growth) is higher than  $p_{11}$  (0.94). This has an interesting economic interpretation, that is once the US economy reaches the recovery phase it is more likely that remains in this state for a longer period. The ergotic probabilities of being in recession is 0.20 with an expected estimated duration of 4 quarters. This is confirmed by a graphical inspection at the bottom of figure 3 where it is evident that the recessions are not

Table 4: US GDP Estimation Results by using MSI(2)-AR(0) specification.

US GDP Estimation Results	
Regime dependent intercept	
$v_1$	-0.26
$v_2$	1.01
Transition Probabilities	
$p_{11}$	0.74
$p_{22}$	0.94
Standard Error	
$\sigma$	0.70
Persistence of Regime 2	
Erg. Prob.	0.20
Duration	4.00
Log Lik.	-159.90
LR Test	16.24

Table 5: US business cycles Dates. NBER and Markov Switching Model Estimations.

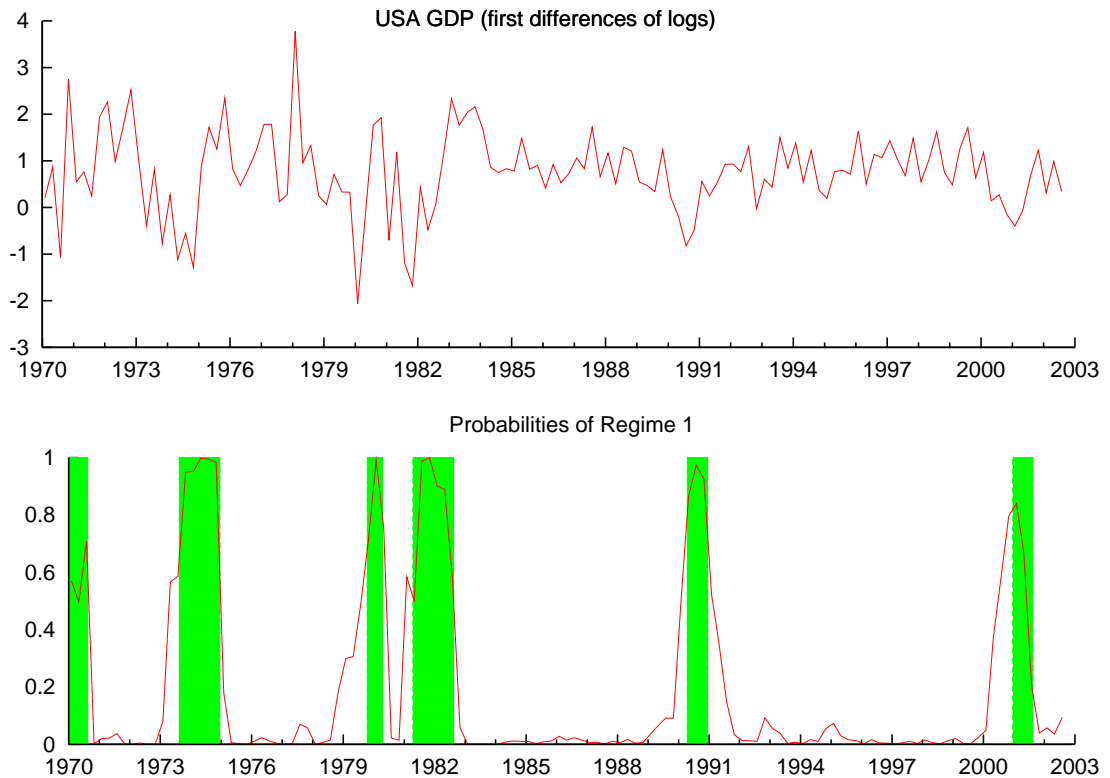
Recession Period		High Growth Periods	
NBER	Switching Model	NBER	Switching Model
1970:1 - 1970:4	1970:1 - 1970:4	1971:1 - 1973:4	1971:1 - 1973:2
1974:1 - 1975:1	1973:3 - 1975:1	1975:2 - 1980:1	1975:2 - 1979:4
1980:2 - 1980:3	1980:1 - 1980:3	1980:4 - 1981:3	1980:4 - 1981:1
1981:4 - 1982:4	1981:2 - 1982:4	1983:1 - 1990:3	1983:1 - 1990:1
1990:4 - 1991:1	1990:2 - 1991:2	1991:2 - 2001:1	1991:3 - 2000:3
2001:2 - 2001:4	2000:4 - 2001:3	not yet announced	2001:4 - 2002:4

so frequent in the full sample.

Turning the attention to the shaded area (NBER US business cycles dating) in figure 3 we can derive that the smoothed probabilities captures quite well the recession episodes for the US economy announced by NBER. More details can be analyzed in table 5 where all the NBER and MS cycles dates are listed. Without loss of generality we can say that the Markov switching model anticipates by one or two quarters the recessions. This is in line with the results by Chauvet and Piger (2003).

Above we have proved the validity of Markov Switching model as good device to date US and Euro Area business cycles. It would be interesting, at this stage, to investigate empirical regularities (if any) in the synchronization of business cycles between these two macro areas.

Figure 3: Usa MSI(2)-AR(0), 1970:2-2002:4

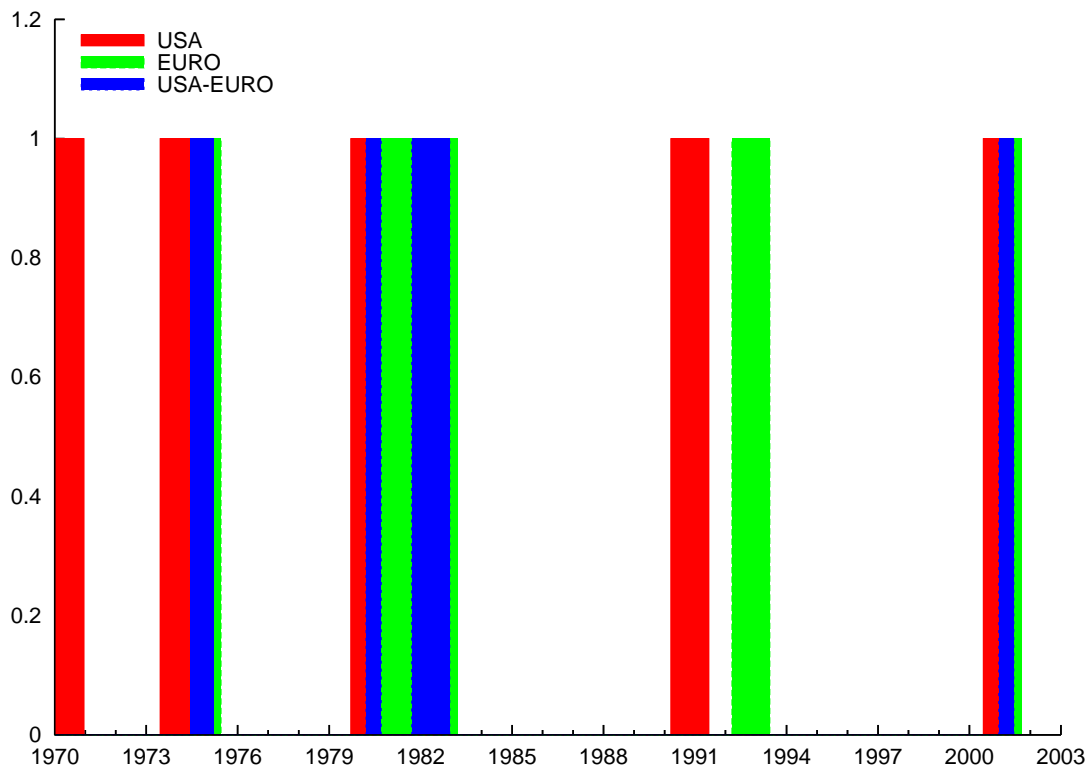


In figure 4 we have plotted three colored areas identifying the US, Euro Area, and overlapped recession periods. The US recessions are those calculated in the this section while Euro Area ones are those identified using the OECD database.

The main important regularity we can observe is that the US always anticipate Euro Area recessions. It is also the case that US leads the Euro Area recovery. Nevertheless there is not a clear pattern if we consider by what degree US leads Euro Area recessions. The US recession of 1970s is longer than the Euro Area one. Besides it anticipates the Euro recession by three quarters. In the 1980s there are two recessions for the US economy that anticipate by two quarters and overlap a longer Euro Area recession. The recessions in the 1990s have the same duration but are not synchronized even tough US completely leads the Euro Area. Analyzing the latest years it is clear that US enters the recession state two quarters earlier than the Euro Area. According to our sample (up to 2002:4), US economy has already recovered from the recession while Euro Area is still in recession.

These results support that US economy led the business cycles of European countries before and after the EU.

Figure 4: US-Euro Area Business Cycles.



### 3.3 Dollar-Euro exchange rate

Dollar-Euro exchange rate variable is the spot rate available from Bank of England interactive database that reconstructs the quarterly exchange rate of US dollar into Euro for the period before 1999. According to the Bank of England, prior to 1999, the Euro/Dollar exchange rate has been calculated by geometrically weighting the bilateral exchange rates of the eleven euro area countries using the “internal weights” reported in the table 6 based on the country shares of extra euro-area trade. With this dataset we have a large sample from 1975:1 to 2003:3.

Obviously, we have followed the same approach to specify the model. We started by allowing for zero lags in the determination of the MS-AR model mimicking the bottom-up procedure to capture the most parsimonious specification. Following this specification rule we found that the most suitable model for the data at hand was MSI(2)-AR(2).

The estimation results are listed in table 7. The transition probabilities of remaining in each regime show high values, by confirming the presence of long swings

Table 6: Internal Weights used to calculate the Euro/Dollar exchange rate (Bank of England)

Countries	Weights (%)
Germany	33.2
France	19.7
Italy	14.8
Belgium	9.2
Netherlands	8.2
Spain	6.7
Austria	4.4
Finland	1.5
Portugal	1.3
Ireland	1.1
<b>Total</b>	<b>100</b>

Figure 5: MSI(2)-AR(2) 1975:1 - 2003:3

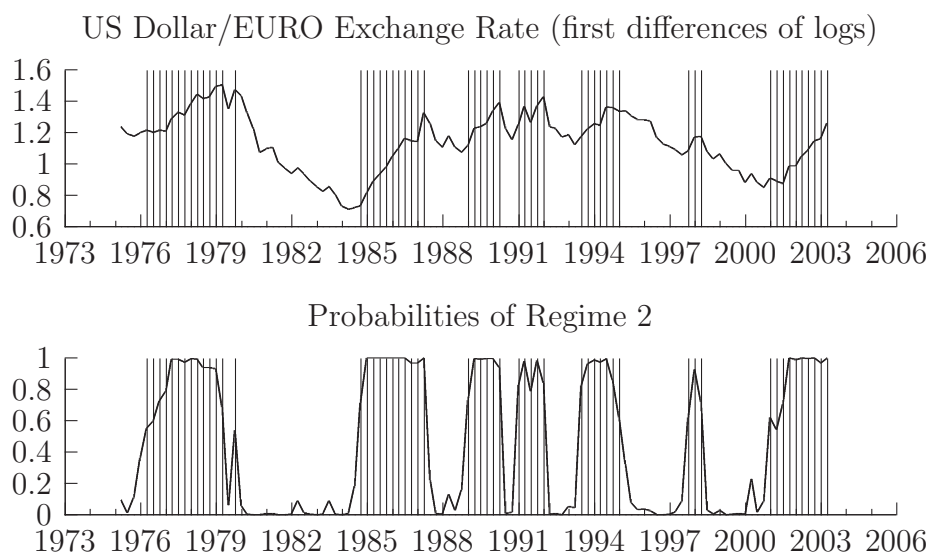


Table 7: Exchange Rates Estimation Results using MSI(2)-AR(2) specification.

US Dollar/Euro Estimation Results	
Regime dependent intercept	
$v_1$	-4.14
$v_2$	4.77
Estimated coefficients	
$\phi_1$	-0.21
$\phi_2$	-0.28
Transition Probabilities	
$p_{11}$	0.86
$p_{22}$	0.84
Standard Error	
$\sigma$	4.15
Persistence of Regime 2	
Erg. Prob.	0.48
Duration	6.37
Log Lik.	-349.77
LR Test	12.72

also in the aggregate exchange rate. This is reasonable since the variable considered should be an aggregate measure of the Euro area exchange rates. It is interesting to note how the Markov switching model captures the latest appreciation of the Euro. This swing seems to start from the last quarter of 2000 until 2003:4.

### 3.4 Interest rates differential

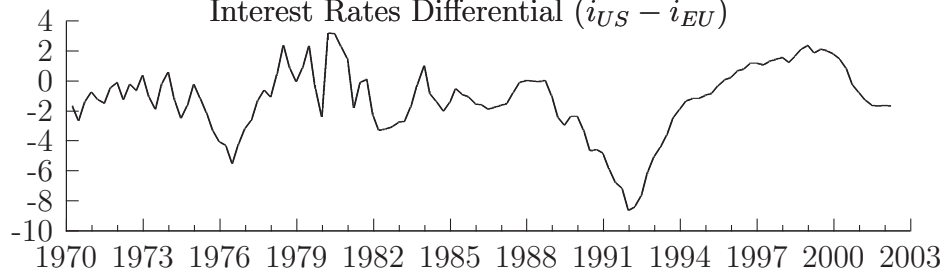
Another variable we are considering in our analysis is the interest rate differential between US and Euro area. To construct this variable we have chosen the US money market rate from IFS database and a reconstructed short term rate for the Euro Area provided by AWM by Fagan. Our goal is to identify two separate and persistent regimes in order to justify the inclusion of this variable in the final multivariate setting.

The best specification we have found turned out to be the MS(2)-AR(3).

We have identified two regimes with negative and positive interest rate differentials. This is evident in table 8 where the estimated intercepts are opposite in signs and significant. The transition probabilities are quite high ( $p_{11} = 0.77$  and  $p_{22} = 0.90$ ) and the expected duration of regime 1 is beyond 4 quarters.

From figure 6 it can be inferred that the periods of negative interest rate differ-

Figure 6: MSI(2)-AR(2) 1970:1 - 2002:4  
Interest Rates Differential ( $i_{US} - i_{EU}$ )



Probabilities of Regime 1

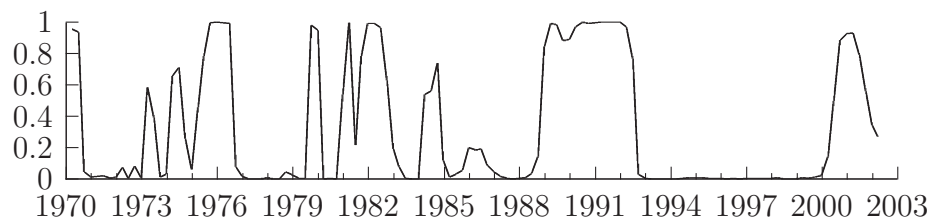


Figure 7: Interest Rates and Interest Rate Differential.

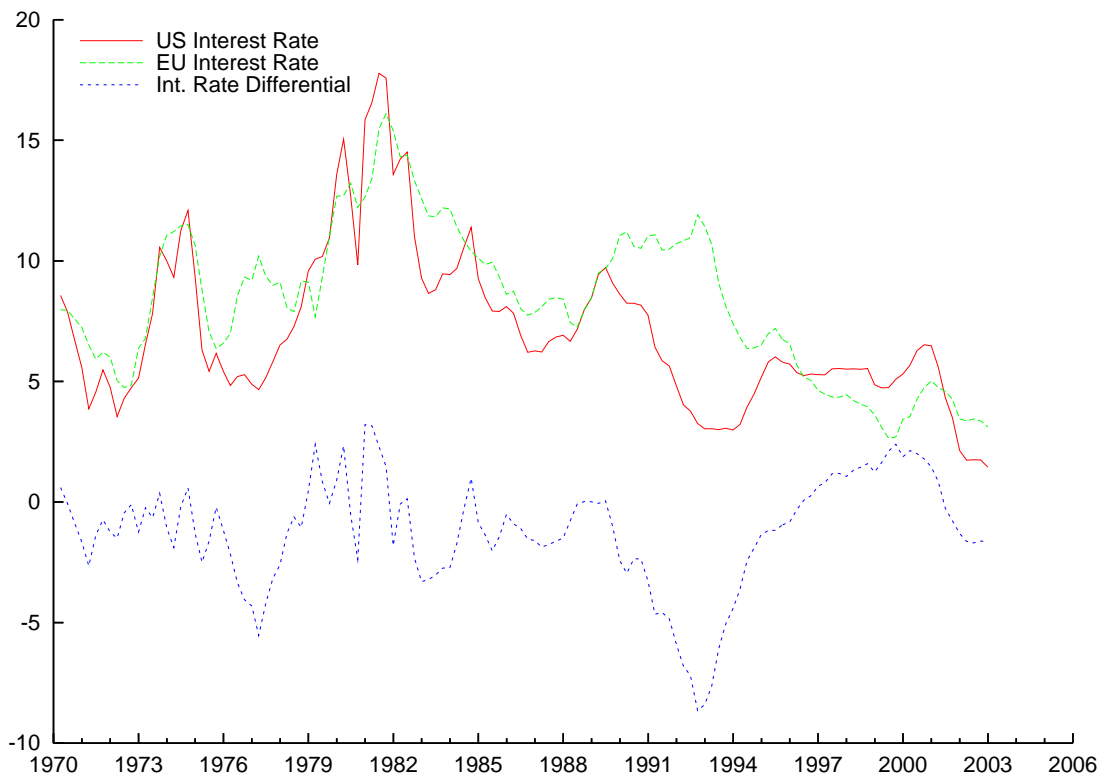


Table 8: Interest Rate Differential using MSI(2)-AR(3) specification.

Interest Rate Differential Estimation Results	
Regime dependent intercet	
$v_1$	-1.26
$v_2$	0.31
Estimated coefficients	
$\phi_1$	0.79
$\phi_2$	-0.30
$\phi_3$	0.36
Transition Probabilities	
$p_{11}$	0.77
$p_{22}$	0.90
Standard Error	
$\sigma$	0.74
Persistence of Regime 1	
Erg. Prob.	0.31
Duration	4.31
Log Lik.	-174.92
LR Test	13.63

entials correspond somewhat with those of recession captured by the model in our previous univariate analysis for each currency area. This is important to our multivariate analysis since we can expect a certain degree of co-switching (co-movements) between the variables.

Obviously the interpretation of the time series pattern of interest rate differentials is not so immediate because it could be determined by the different behavior of the single interest rates. In figure 7 US and Euro interest rates and the differential are reported separately. We could notice for example that the periods of negative interest rate differential from 1989:3 to 1993:1 correspond to periods of decreasing US interest rates and almost constant Euro interest rates. This period covers the US recession of 1990:2-1991:2 and that of Euro area of 1992:2-1993:2.

## 4 Analysis of monetary policy transmission: the symmetric case

In this section we specify a MS-VAR model for a system of four variables, the first differences of logs of Euro GDP (DYEURO) , US GDP (DYUSA), Euro-Dollar exchange rate (DEXCH) and the US-Euro short term interest rates differential (DIFF)

Table 9: Unit Root test (Augmented Dickey Fuller Test).

<i>Variables</i>	<i>P</i>	<i>ADF</i>
YUSA	1	1.27*
YEURO	4	0.59*
DIFF	5	-3.25
EXCH	4	-1.72*

\* Significant at 5%.

from 1975:1 to 2002:4. Dollar-Euro exchange rate is taken from the interactive database of the Bank of England, Euro short term interest rate are taken from the AWM (Area Wide Model) database reconstructed by European Central Bank, US short term interest rate from the IFS database, US GDP (USA1119C1) and Euro Area GDP(EUZ710851) from OECD database. All variables are quarterly.

By following the empirical modelling procedure by Artis et al. (2003) and Krolzig (2003), as mentioned in the introduction we have to conduct two preliminary steps in our analysis. The co-switching analysis of the variables included in the final multivariate model that has already been conducted in the previous section. The second step is the cointegration analysis of variables by using linear VAR models. To check if the cointegration relationships among variables in levels exist, we have to test the presence of unit roots in the variables in level. In table 9 we report the Augmented Dickey Fuller test statistics for each variable. Trends have been excluded in each test because not significant. The null hypothesis of the test statistic in equation 8 is  $\pi = 0$  :

$$\Delta Z_t = \alpha_0 + \pi Z_{t-1} + \sum \beta_i \Delta Z_{t-i} + \epsilon_t \quad (8)$$

where the sum is taken over the  $p$  lags. The VAR order ( $p$ ) is selected by using the Akaike Information Criteria.

The null hypothesis (variable has a unit root) cannot be rejected for all variables except for the interest rate differential. Since this variable is stationary we do not carry out the cointegration analysis using the MS-VECM specification.

The next step in our analysis to specify a Markov Switching Vector Autoregressive model where the autoregressive coefficients do not vary among regimes. In this section we are interested in analyzing the effects of shocks to US GDP on Euro Area

GDP and the role that the interest rates differential has by means of Euro/Dollar exchange rate on this transmission mechanism.

For this purpose we employ impulse response functions tool. When using the MS-VAR framework we can obtain two different impulse response functions: the traditional and the state-dependent ones. The traditional IRFs are obtained using a MS-VAR specification with autoregressive coefficients constant across regimes. This specification produces IRFs that are symmetric and therefore are not state-dependent. In fact IRFs depend on autoregressive coefficients and matrix of variance and covariance which do not vary among regimes. A good candidate for producing symmetric IRFs is the MSI-VAR specification. Indeed in this model only the intercept is allowed to vary.

The state-dependent IRFs instead are derived from MSIA-VAR specification where not only the intercept but also the autoregressive coefficients and/or the matrix of variance and covariance can vary across regimes.

In this section we are interested in the analysis of transmission mechanism disregarding the asymmetries due to the state of economy (boom and recession). In the next section we will consider state-dependent IRFs in order to highlight the importance of the state of the economy to explain asymmetries in the business cycle transmission mechanism.

We employ a MSI(2)-VAR(1) which has proved to be the most appropriate specification. We have chosen two regimes to identify high and low growth regimes and by following a bottom-up procedure we select  $p = 1$ . Estimation results are reported in table 10. The non-linear specification is more suitable in this context (AIC and HQ criteria select the non-linear model). More evidence is given by the linearity tests that reject the hypothesis of linearity at 99% level.

In Appendix we report the diagnostic statistics of residuals. In figure A-1 we plot the autocorrelation functions (ACF) and the partial autocorrelation functions (PACF) where it can be seen that residuals are not significantly autocorrelated. In figure A-3 and A-4 we report the graphs of the density and the QQ plot of standard residuals. These figures confirm the good approximation of the standard residual densities to a normal distribution and consequently that the model specification is

appropriate.

The results of the estimation procedure are listed in table 10. The number of parameters to be estimated is 36 which is relatively low since, as stressed before, the only parameter that is allowed to vary across regimes is the intercept. As we will see in the next section this number increases considerably when considering the MSIA setting. The ergotic probability and the associated duration are important measures when analyzing the results obtained by a Markov Switching in the context of business cycles. As a matter of fact in order to justify the state-dependent impulse response functions a regime must be persistent or at least have a duration that is consistent with the number of periods used in the IRF analysis. The MSI(2)-VAR(1) estimates produce a duration of 5.35 periods confirming a certain degree of persistence of a recession phase<sup>5</sup>.

In the upper pane of Figure 8 the four variables under analysis are plotted. In the lower pane we have plotted the filtered and smoothed probabilities of being in state 1 (low growth regime) obtained by estimating the MSI(2)-VAR(1) model. It is interesting to note that the dating we have obtained is quite similar to that of United States in the univariate analysis. The only evident exception is the 1990-1993 recession captured in our specification that is longer than the one we have calculated in the univariate case. At first glance this result might be misleading, but a closer look at figure 8 and 4 should make clear that this specification has considered not only the US recession but also the Euro Area one which started and ended later. Of course also the DIFF and DEXCH variable have their influence in determining these probabilities in the model. Someone might argue that this is a crucial limitation of Markov Switching VAR models to study the inter-relationships among variables since if we do not find a dating that approximately replicates that obtained by the univariate model or that of NBER (in this context) it is not possible to carry out the Impulse Response Function analysis constraining the regime because the regime itself is not correctly specified in the first place. In a later section we will make an in-depth discussion of this limitation. Indeed it is important for a researcher to

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<sup>5</sup>This is in line with what we would expect since the univariate estimates conducted in the previous sections on business cycles showed similar results.

Table 10: Estimation Results using MSI(2)-VAR(1) specification (Standard errors in parenthesis).

<i>Coefficients</i>				
	DYUSA	DYEURO	DIFF	DEXCH
C (Reg.1)	-0.25 (0.20)	0.17 (0.11)	-0.99 (0.25)	-2.35 (1.45)
C (Reg.2)	0.85 (0.16)	0.56 (0.10)	0.45 (0.23)	-0.78 (1.29)
DYUSA(-1)	0.05 (0.10)	-0.01 (0.06)	-0.14 (0.13)	-0.38 (0.80)
DYEURO(-1)	-0.01 (0.15)	0.23 (0.09)	-0.37 (0.21)	1.38 (1.22)
DIFF(-1)	-0.09 (0.03)	0.02 (0.02)	0.85 (0.04)	-0.30 (0.24)
DEXCH(-1)	-0.01 (0.01)	0.01 (0.01)	-0.02 (0.02)	0.04 (0.10)
<i>Transition Probabilities</i>				
$p_{11}$	0.81			
$p_{22}$	0.95			
<i>Standard Errors</i>				
$\sigma$	0.65	0.41	0.91	5.67
n. par	36			
<i>Persistence of Regime 1</i>				
Erg. Prob.	0.21			
Duration	5.35			
Log Lik.	-673.86			
LR Test	18.69			

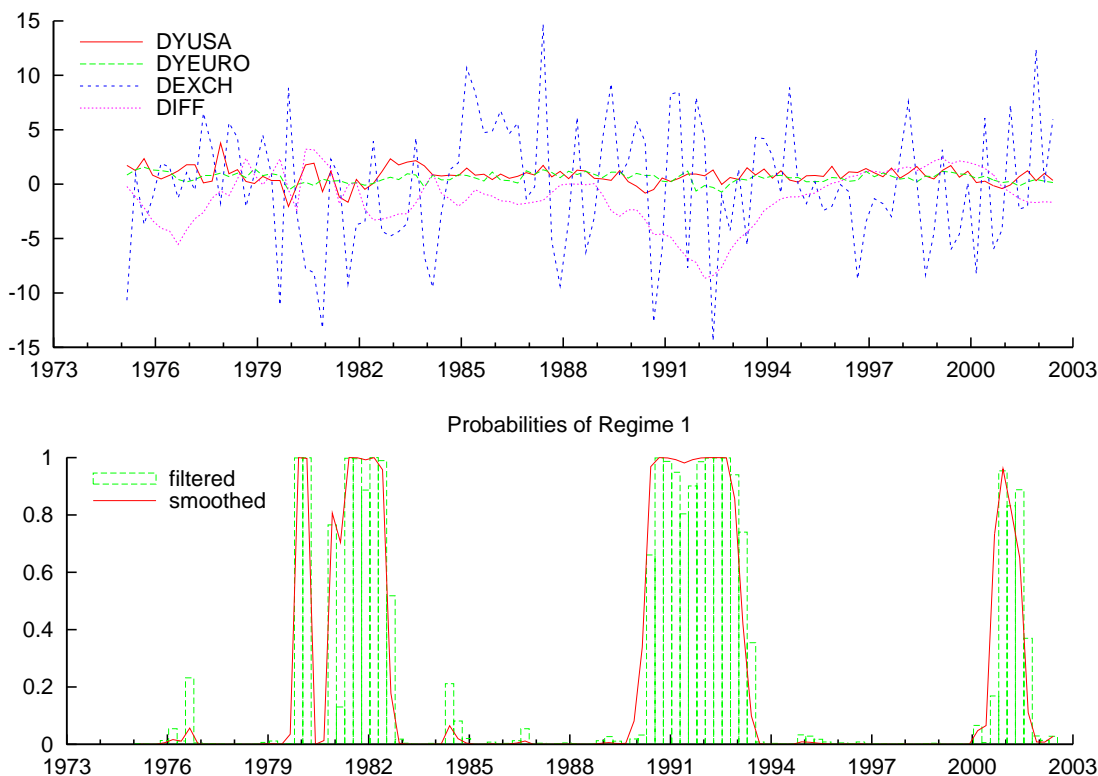
find a dating that is at least in line with those of the univariate case. This will be more evident in the next section when the state-dependent IRFs will be chosen as analytical tool to analyze the business cycle asymmetries. Moreover, it is worth to stress that the MSI(A)-VAR model do not impose any kind of restrictions or weights to variables in order to obtain such results.

In this section we apply the traditional IRF to the MSI(2)-VAR(1) specification. As for the case of linear VAR model, to identify structural shocks we need to transform the matrix of variance and covariance of residuals into an identical one. For this purpose a set of restrictions have to be imposed. In this case we use the Cholesky identification which consists of ordering the variables from the most exogenous to the most endogenous in the system. Here we chose the following order: DYUSA, DYEURO, DIFF, DEXCH. By positioning the DYUSA at top, we make the hypothesis that the US GDP does not react almost at the first time to structural shocks of the other variables. Differently the exchange rate, being at bottom, is the most endogenous and react immediately to the shocks of the other variables.

By putting the US GDP before Euro GDP implicitly make the hypothesis that US drives Euro economy, as discussed above. These IRFs produces symmetric responses to a shock. In the next section we use a quite recent development (state-dependent IRFs) introduced by Ehrmann et al. (2003). Our aim is to make a comparison between the two results and ascertain asymmetries (if any).

The impulse response functions to a unit shock on USA GDP and interest rates differential between US and Euro Area are plotted in figure 9 and 10 respectively. The confidence bands are calculated by using the bootstrapping technique with 1000 replications. In figure 9 it is clear that a unit shock to the variable DYUSA causes an increase of Euro Area GDP (DYEURO) in the first period. From the second period on the sign of the impulse of DYEURO is negative which does not necessarily mean a loss of output but a lower output compared to the previous period. Therefore, we would say that from the second period on the IRF can be interpreted as a return to the equilibrium. Another interesting result is that the unit shock to DYUSA causes, for the first period, a significant increase in the interest rate differential which is accompanied by a US Dollar appreciation. Also in this case the effects can

Figure 8: MSVAR: Regime probabilities. MSI(2)-VAR(1), 1975 (3) - 2002 (4).



be considered quite instantaneous since they level out and not significant after two periods.

Figure 10 shows the effect of a unit shock on the interest rates differential. The most striking result from this analysis is that the the US GDP is significantly decreasing. Moreover this effect dies out after many periods that are well beyond those considered in our analysis. The Euro Area GDP seems to react positively after one period with an intensity which is higher (in absolute terms) than that of US GDP. Interestingly, the DEXCH variable reacts immediately and significantly to a unit shock on DIFF with a sign and amplitude that seems to be in line with the theory Uncovered Interest rate Parity (UIP).

## 5 Analysis of the monetary policy transmission: the asymmetric case

MSI-VAR models (as VAR models) does not permit to analyze the asymmetries of impulse responses conditionally to the state of economy (recession and boom). In

Figure 9: Impulse Response Functions to a unit shock on USA GDP.

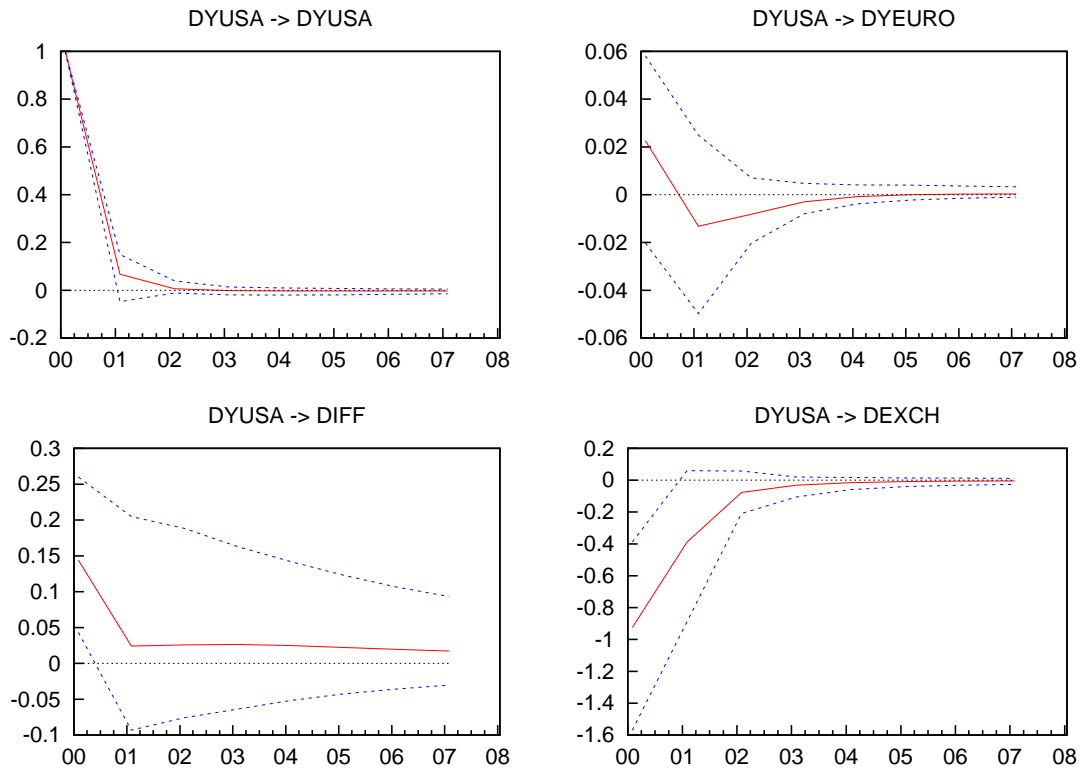
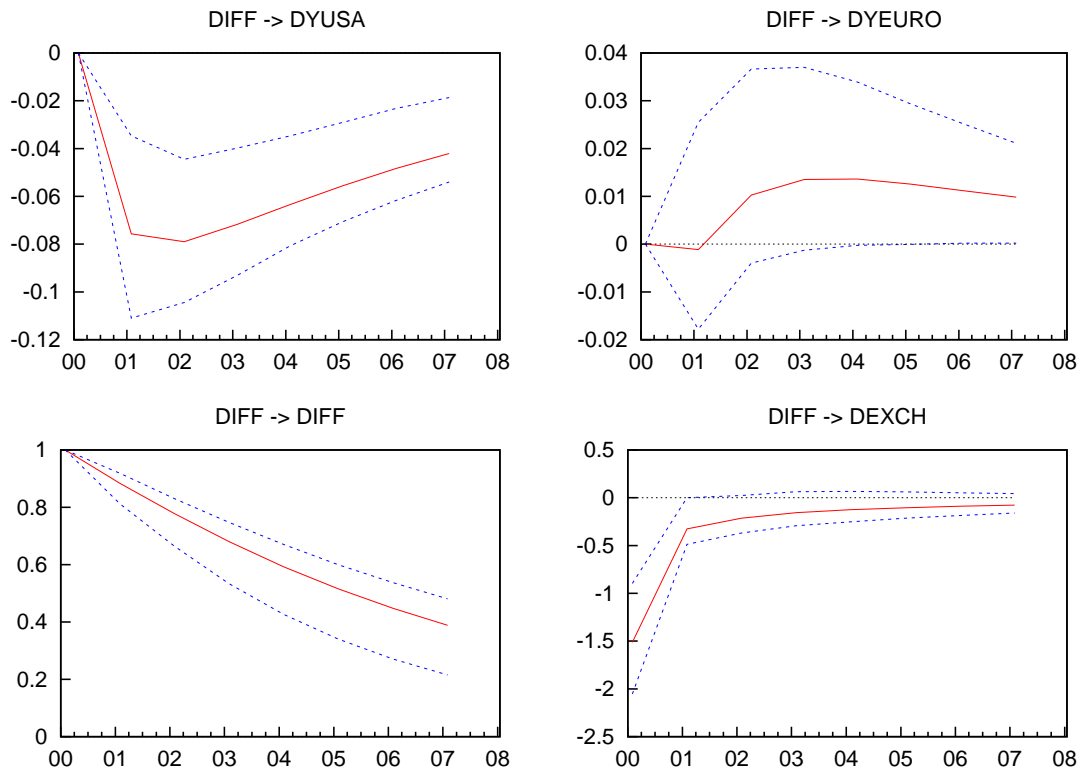


Figure 10: Impulse Response Functions to a unit shock on Interest Rates Differential.



our particular case of study it would be interesting to highlight the differences in the reactions of the variables to a US GDP and a interest rates differential shock among regimes. We will analyze if Euro GDP reacts asymmetrically to a US GDP shock and what are the main causes of these asymmetries.

In order to implement the state-dependent analysis we need to estimate a MS-VAR model with parameters which vary across regimes (MSIA-VAR model).

We have chosen the MSIA(2)- VAR(1) specification. The choice of this specification derives from the fact that by increasing the number of lags the parameters increases noticeably. So we start by the most parsimonious specification and check the statistical properties of residuals. As for the previous model the correct specification is evident by conducting the analysis of residuals. Figure A-5, A-6, A-7, A-8 in Appendix report the ACF and PACF, the spectral density, the density and the QQ plot of residuals. By observing these plots can be easily inferred that residuals are not significantly autocorrelated and their density is very close to the normal distribution. This residual analysis is referred to the regime 1<sup>6</sup>.

The estimation results are listed in table 11

The high values of transition probabilities  $p_{11}$  and  $p_{22}$  confirm the presence of highly persistent regimes. The average duration of regime 1 (5.46) gives support to this fact. The low value of ergotic probability (0.16) indicates that the number of periods which belong to the regime 1 is relatively small if compared to that of regime 2<sup>7</sup>. As for the previous specification, the AIC criteria selects the non-linear model and the linearity tests reject the hypothesis of linearity at 99% level.

In the bottom panel of figure 11 filtered and smoothed probabilities of being in regime 1 (recession regime) are plotted. By comparing this graph with that obtained with the MSI specification (figure 8) it is evident that the dating is not similar for the latest dates. In fact the MSIA specification does not capture the recession from 2002:1 to 2002:4 as for the MSI specification. More precisely, by specifying the model differently, the latest dates corresponding to recession state of US economy

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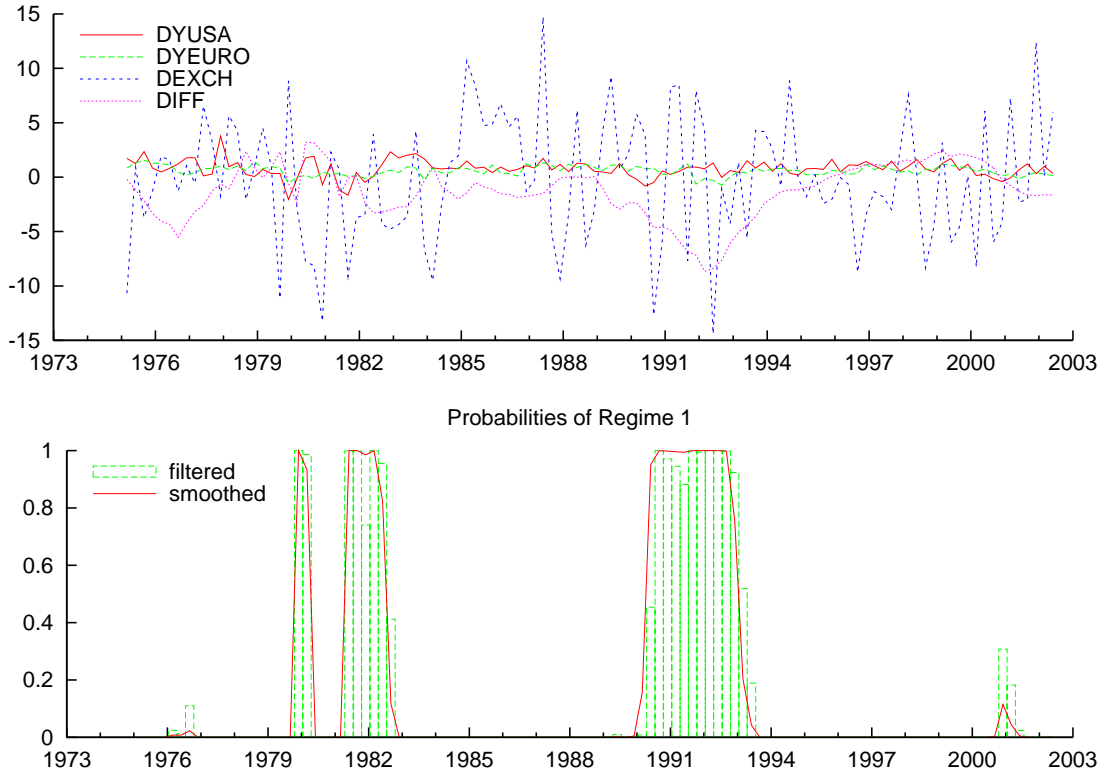
<sup>6</sup>The analysis of regime 2 is redundant because produces similar results to the regime 1.

<sup>7</sup>The low number of observations in regime 1 could determine some difficulties in the interpretations of parameters estimates and consequently of IRFs when conditioning to state 1.

Table 11: Estimation Results using MSIA(2)-VAR(1) specification (Standard errors in parenthesis).

<i>Coefficients</i>				
Regime 1				
	DYUSA	DYEURO	DIFF	DEXCH
C	-0.78 (0.27)	0.04 (0.16)	-1.96 (0.36)	1.47 (2.23)
DYUSA(-1)	-0.13 (0.18)	-0.11 (0.11)	-0.81 (0.25)	3.43 (1.53)
DYEURO(-1)	-0.03 (0.29)	0.46 (0.18)	-0.05 (0.40)	-0.41 (2.45)
DIFF(-1)	-0.22 (0.05)	-0.01 (0.03)	0.66 (0.07)	0.74 (0.44)
DEXCH(-1)	0.01 (0.02)	0.05 (0.01)	-0.06 (0.03)	-0.11 (0.18)
Regime 2				
C	0.67 (0.15)	0.45 (0.09)	0.24 (0.22)	-0.64 (1.26)
DYUSA(-1)	0.11 (0.10)	0.04 (0.06)	0.09 (0.14)	-1.16 (0.86)
DYEURO(-1)	0.15 (0.16)	0.27 (0.09)	-0.44 (0.24)	1.72 (1.44)
DIFF(-1)	-0.07 (0.03)	0.01 (0.02)	0.88 (0.05)	-0.62 (0.31)
DEXCH(-1)	-0.01 (0.01)	-0.01 (0.01)	0.01 (0.02)	0.08 (0.11)
<i>Transition Probabilities</i>				
$p_{11}$	0.82			
$p_{22}$	0.97			
<i>Standard Errors</i>				
$\sigma$	0.64	0.40	0.86	5.39
n. par	52			
<i>Persistence of Regime 1</i>				
Erg. Prob.	0.16			
Duration	5.46			
Log Lik.	-654.70			
LR Test	57.02			

Figure 11: MSVAR: Regime probabilities. MSIA(2)-VAR(1), 1975 (3) - 2002 (4)



are dropped out from the recession dates. Obviously in the state-dependent impulse response functions the dating of states in the system is very important for the interpretation of results.

Firstly, we analyze the state-dependent IRFs of a shock to USA GDP on all the variables in the system and particularly to the Euro Area GDP. Later we will look closer to the state-dependent IRFs of a shock to the interest rates differential. By doing this we want to stress the impact that a shock in the US GDP has on the Euro Area economy conditional to a regime and the role that the interest rates differential (and consequently the US-Euro exchange rate) plays in the transmission mechanism.

The figures 12 and 13 depict the reactions to a one per cent shock on the USA GDP in Regime 1 and 2 respectively. In the low growth regime except for the first period the Euro Area GDP reacts positively. Instantaneously the effect on this variable seems to be symmetric among regimes (about +0.02%). In the second period the magnitude of the reaction seems to be stronger in regime 1. From the second period on in both regimes there is a convergence towards the equilibrium.

Although it seems that the responses (in low growth regime) are not significant and vary about the zero value the signs of the responses are coherent with what we would expect. In regime 2 the impact of a unit shock to US GDP causes a significant increase in the interest rates differential and consequently hits negatively the Euro Dollar exchange rate. This significant Dollar appreciation has a positive impact on the Euro Area GDP.

The most interesting results are obtained hitting the interest rates differential (figures 14 and 15). The effect that the interest rate differential has on the US GDP is negative and stronger in recession than in the high growth regime. The magnitude on average is three times higher in the second regime. Moreover the confidence bands confirm the significance of these effects. This is a striking evidence in favor of asymmetries in the mechanism of monetary policy transmission. These asymmetries are reflected in the other variables in the system. The Euro Area GDP in regime 1 after the first period of negative growth has a positive sign until the converge to equilibrium. In regime 2 the positive effect is already evident in the first period. Also in this case there seems to be asymmetries when constraining the analysis to a regime. It is interesting to note that the exchange rate variable in both regimes reacts instantaneously negatively to a unit shock on the DIFF and the magnitude is in line with the UIP theory as we found in the previous section.

## 6 Conclusion Remarks

The aim of this paper was to analyze the asymmetries in the transmission mechanism of monetary policy depending on the state of the economy (low and high growth). Following Artis et al. (2003) and Krolzig (2003) we conducted firstly a univariate analysis for each of the variables we wanted to consider in the final system. Later, after verifying the co-switching of the variables, we estimated the multivariate model. The first estimated model was the MSI(2)-VAR(1) that is suitable to obtain impulse response functions not regime-dependent. The reason is technical since the only parameter which is allowed to vary across regimes is the intercept. Nonetheless, we used the estimated results obtained as a good benchmark to evaluate how the signs and the magnitude of impulse responses functions behaves in this special case.

Figure 12: Impulse Response Functions to a unit shock on USA GDP (Regime 1).

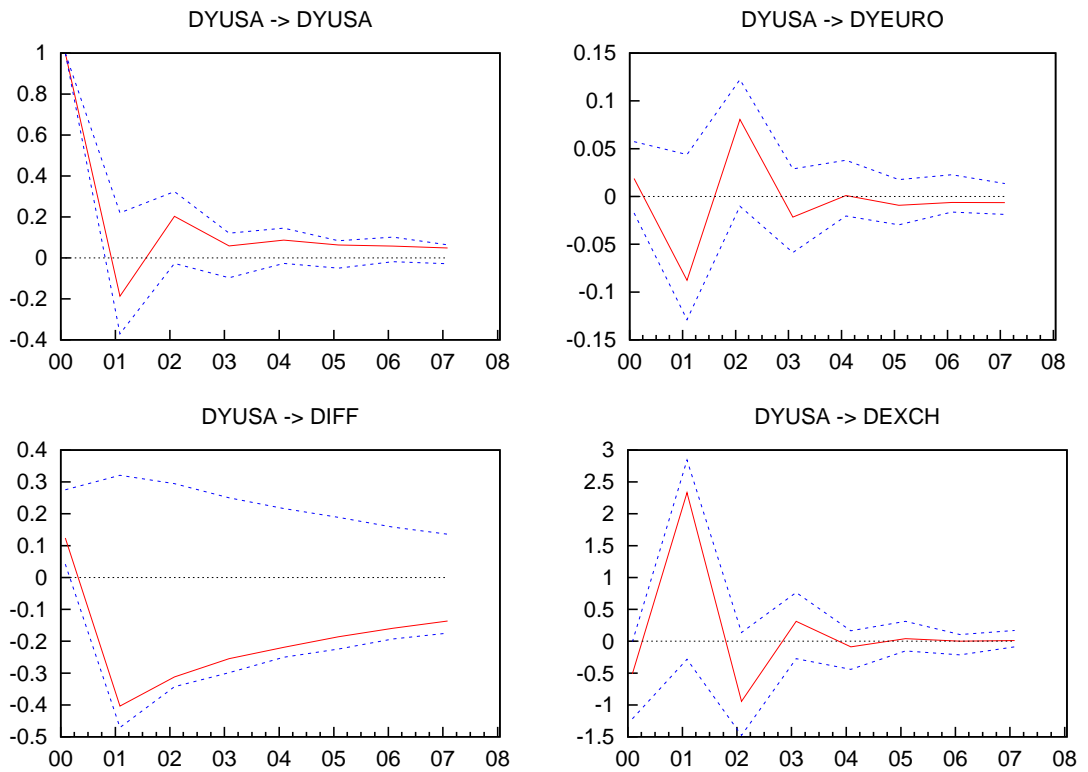


Figure 13: Impulse Response Functions to a unit shock on USA GDP (Regime 2).

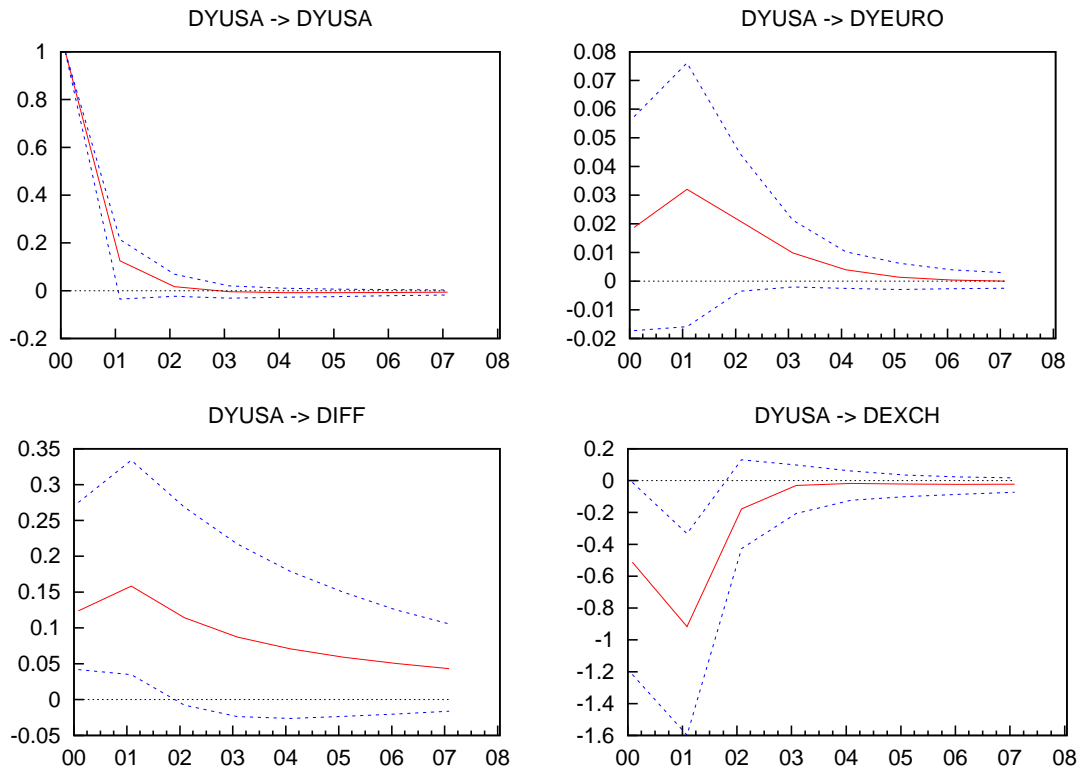


Figure 14: Impulse Response Functions to a unit shock on interest rate differential (Regime 1).

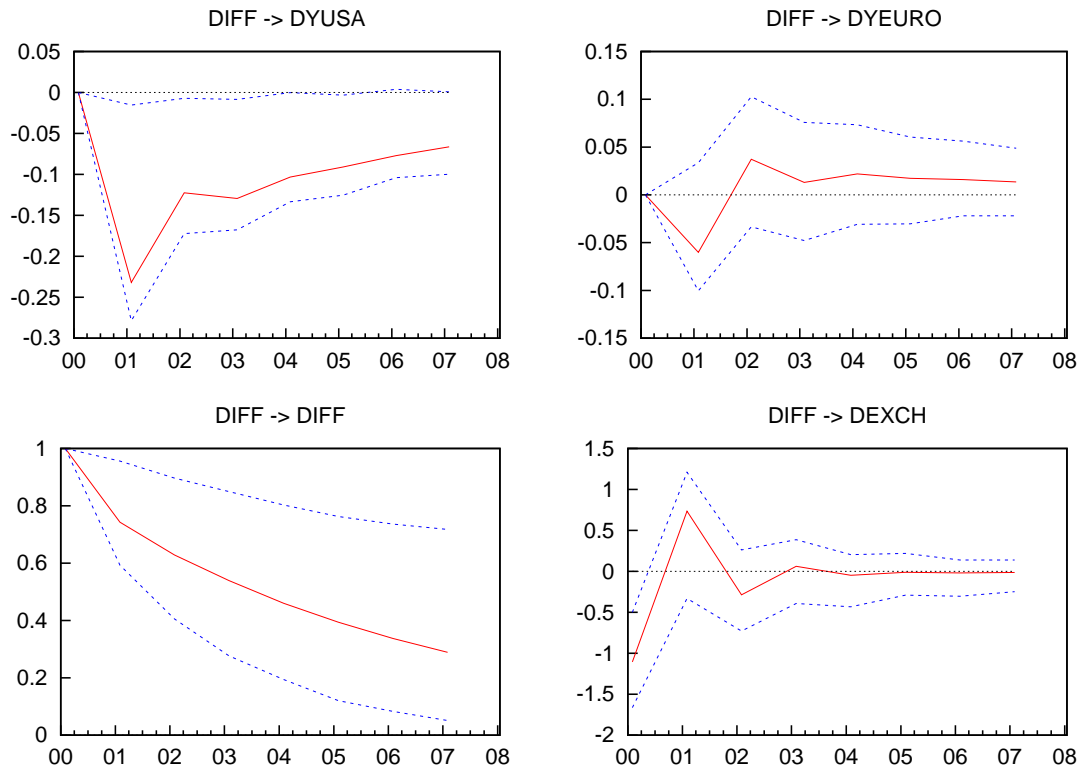
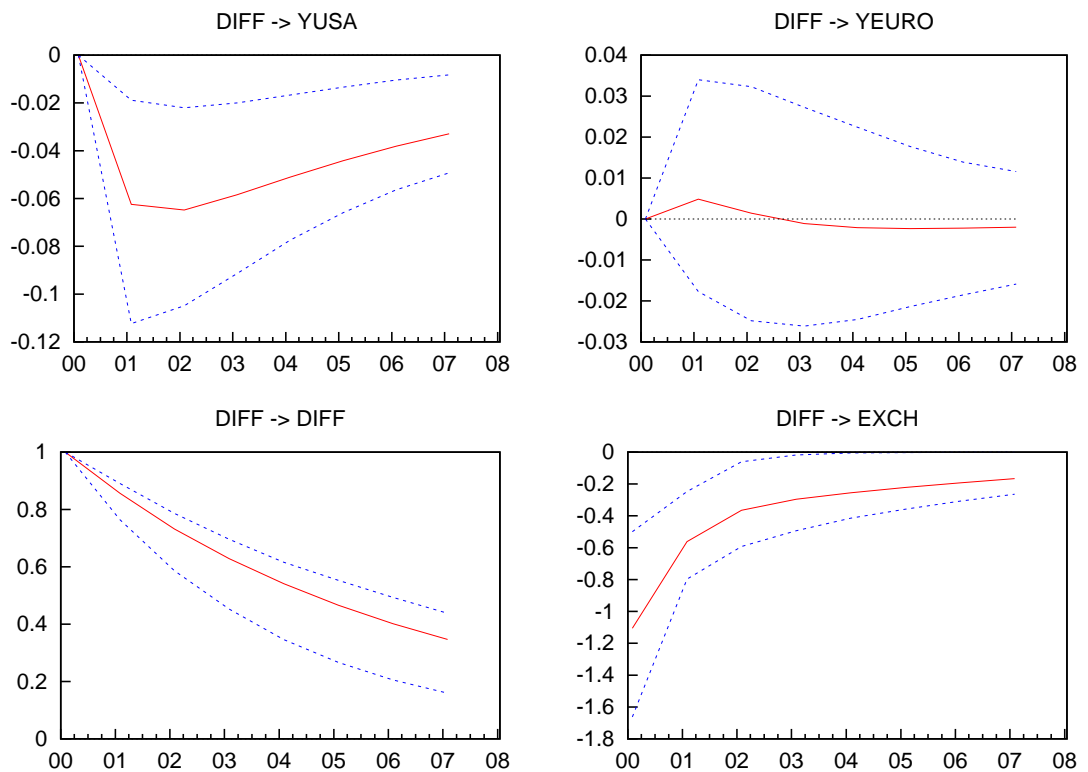


Figure 15: Impulse Response Functions to a unit shock on interest rate differential (Regime 2).



The second model we took under consideration was the MSIA(2)-VAR(1). This model is suitable to calculate state-dependent impulse response functions and verify how a shock to a variable can affect the others in the system. Our results suggest the presence of asymmetries in the transmission mechanism of monetary policy depending on the regime especially in the case of US GDP. As a matter of fact, a shock hitting the interest rates differential between US and Euro Area causes a significant drop in the US output that is more accentuated in the recession state. Similar conclusions can be drawn from inspecting the IRFs for the Euro Area GDP. Interestingly, a decisive role in this transmission mechanism seems to be played by the exchange rate. In fact, in both regimes a shock on the interest rates differential causes an immediate and significant dollar appreciation that can be interpreted as the engine behind such asymmetries.

The main advantage of this approach is the possibility of studying the asymmetries with a non-linear parametric methodology. Markov Switching models are suitable in the business cycle analysis and the extensions by Krolzig (1997) to the multivariate VAR model makes this methodology useful when examining the relationship among variables. Another advantage is the possibility of calculating regime-dependent impulse response functions.

Our main contribution is to shed light in the area of asymmetries in the transmission mechanism of monetary policy when considering the different states of the economy. The most important policy implication of this analysis is that the monetary policy instrument is more effective in the recession than in the high growth state.

## APPENDIX

This appendix reports some diagnostic tests resulting from model estimation in the paper.

Figure A-1: MSVAR Diagnostics. Correlogram of Standard residuals. MSI(2)-VAR(1).

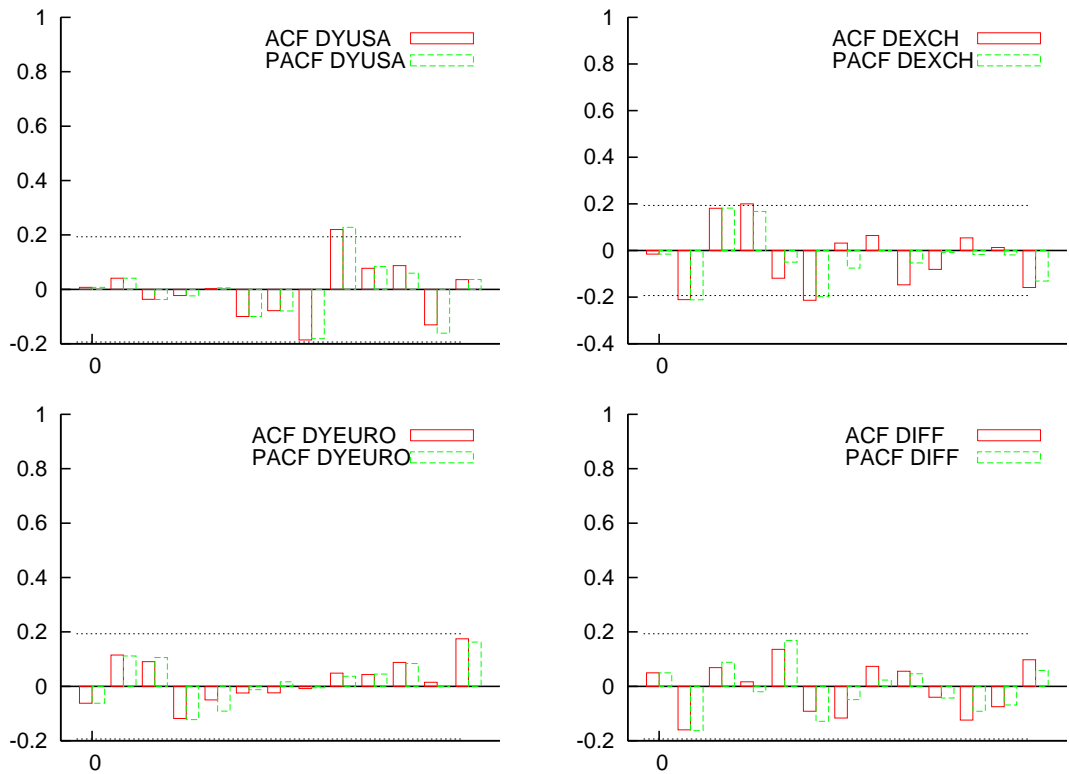


Figure A-2: MSVAR Diagnostics. Spectral density. MSI(2)-VAR(1).

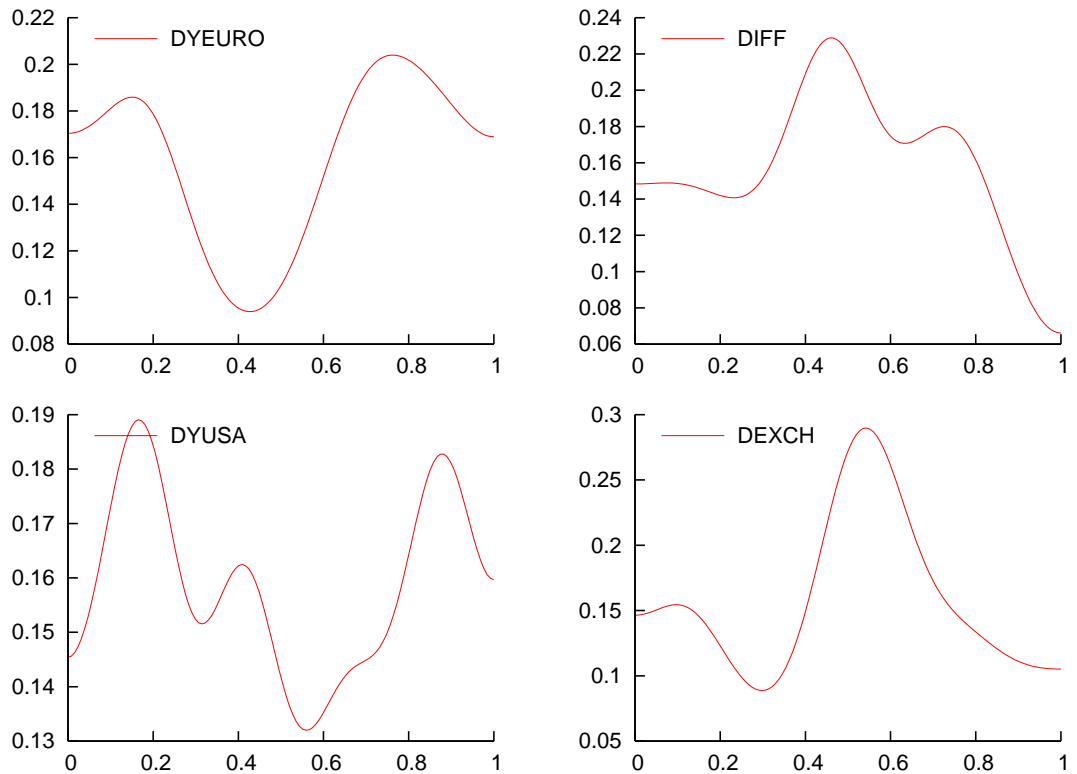


Figure A-3: MSVAR Diagnostics. Density: standard residuals. MSI(2)-VAR(1).

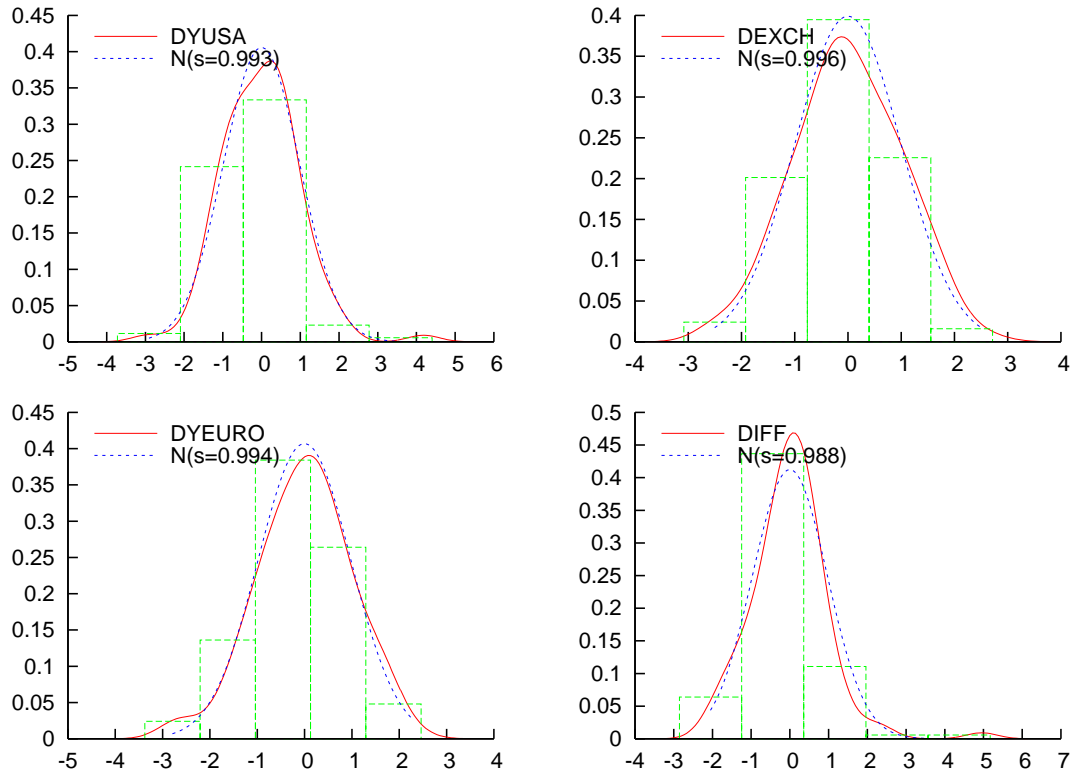


Figure A-4: MSVAR Diagnostics. QQ Plot: standard residuals. MSI(2)-VAR(1).

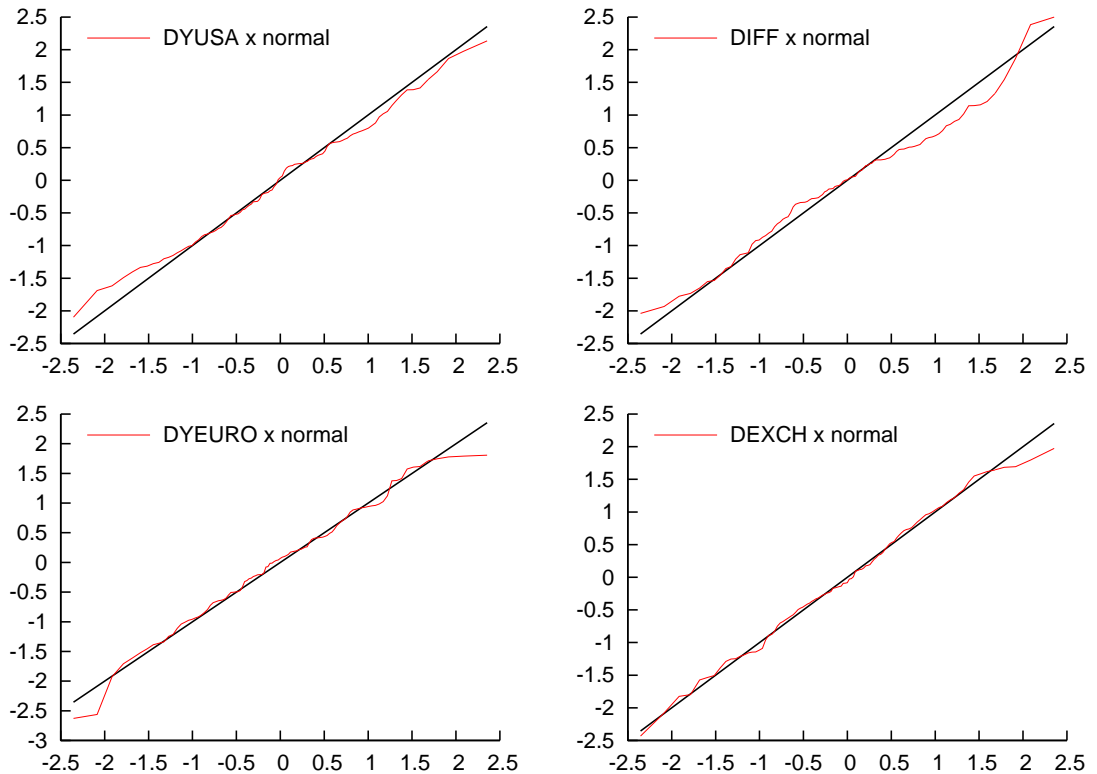


Figure A-5: MSVAR Diagnostics. Correlogram of Standard residuals. MSIA(2)-VAR(1).

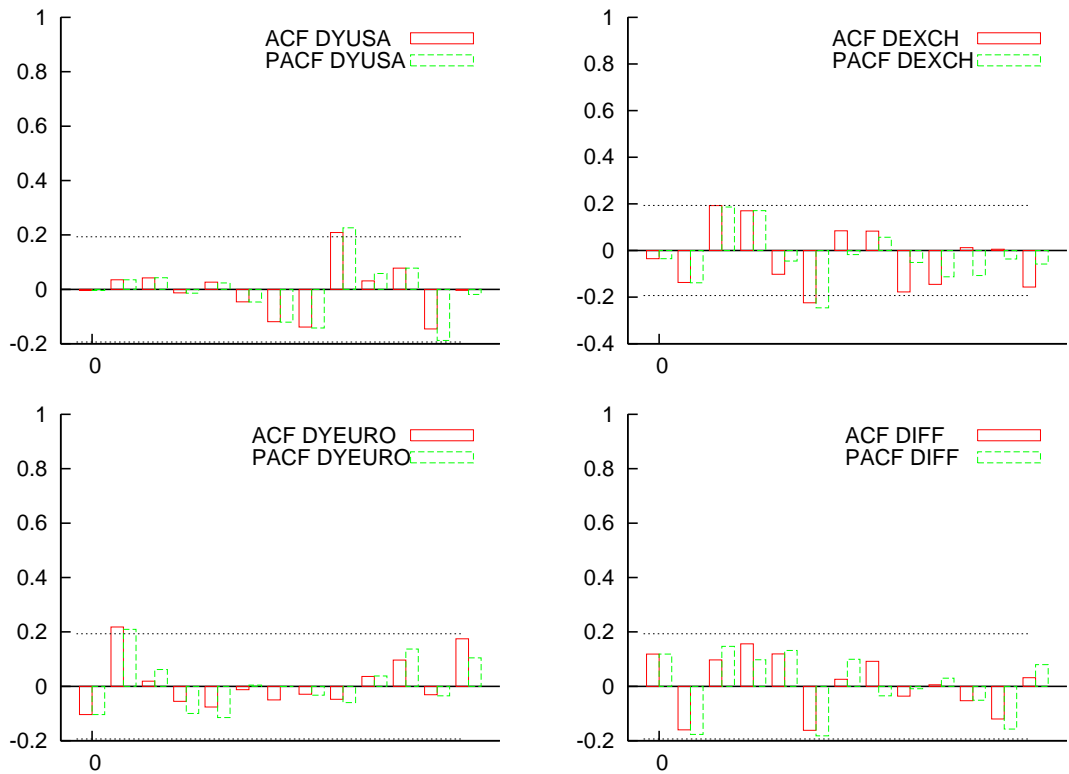


Figure A-6: MSVAR Diagnostics. Spectral density. MSIA(2)-VAR(1)

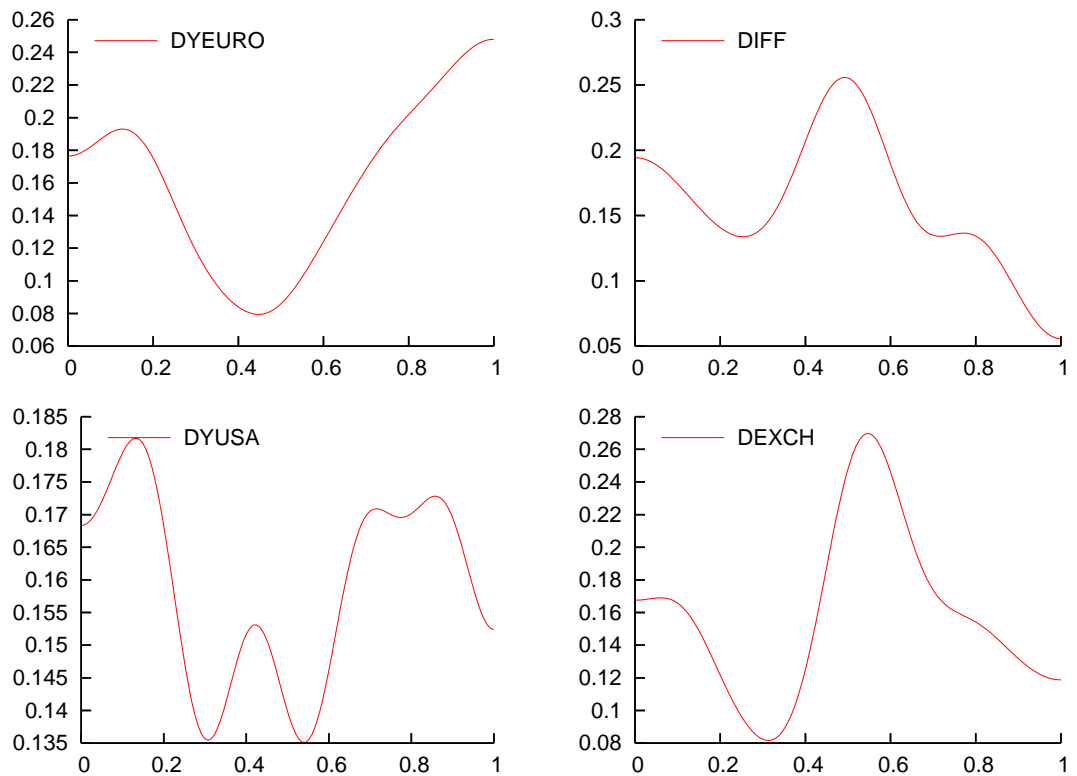


Figure A-7: MSVAR Diagnostics. Density: standard residuals. MSIA(2)-VAR(1)

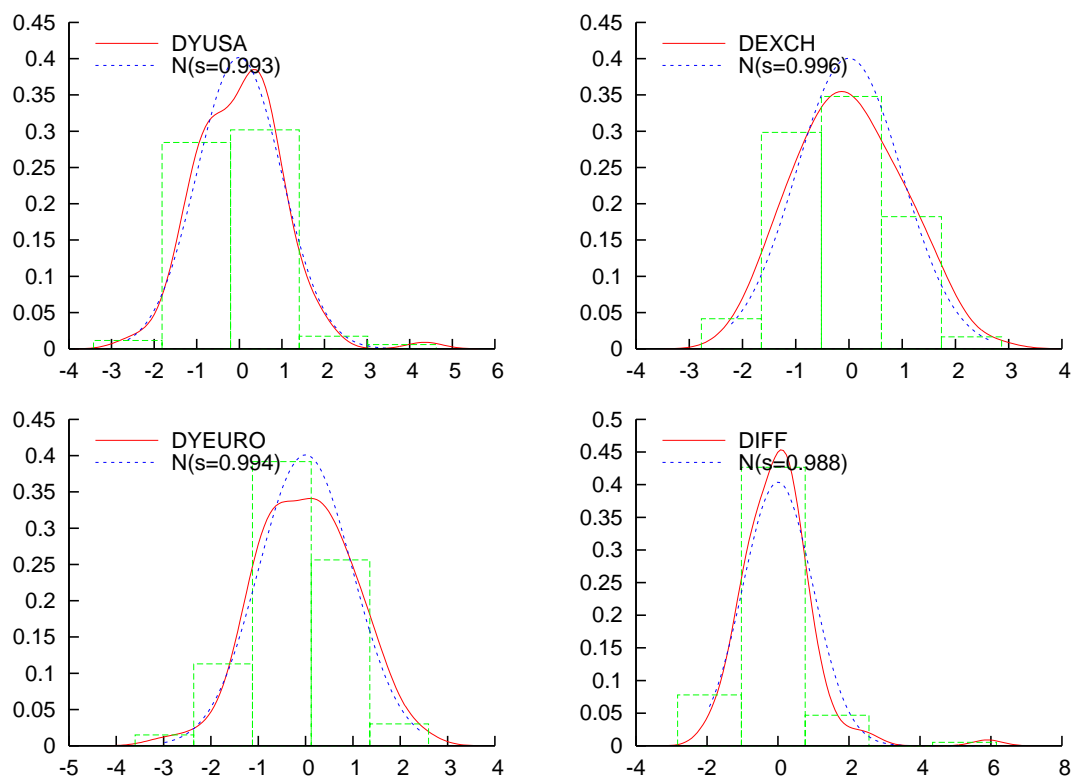


Figure A-8: MSVAR Diagnostics. QQ Plot: standard residuals. MSIA(2)-VAR(1)

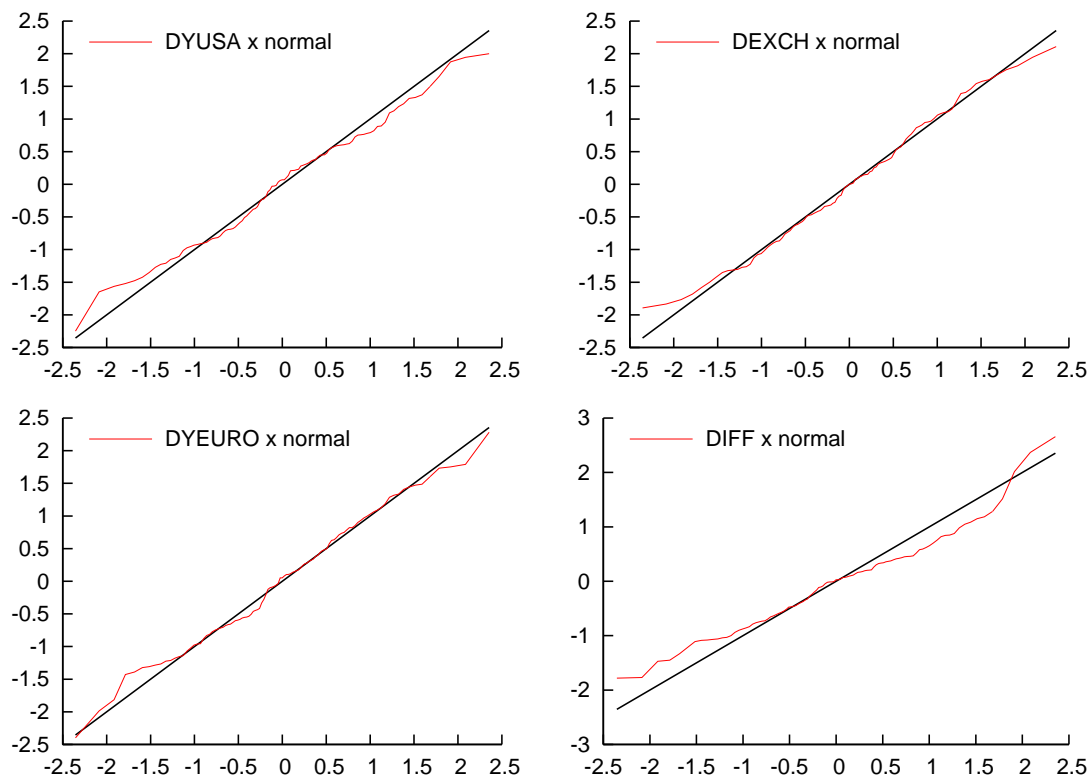
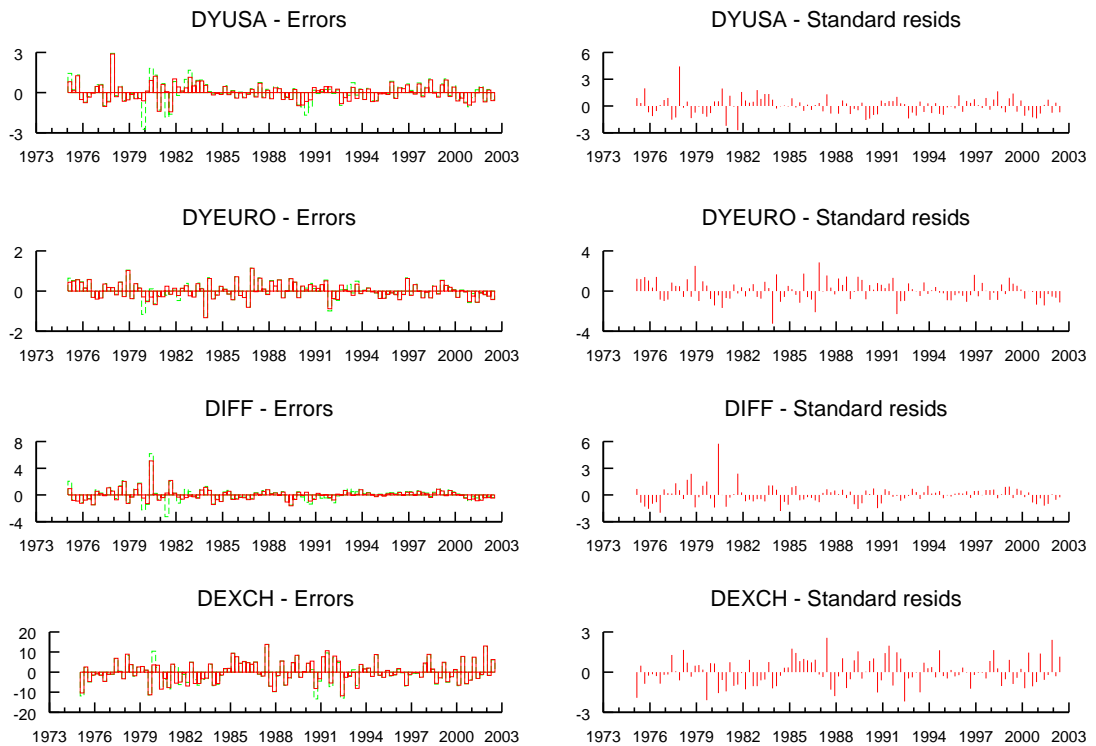


Figure A-9: MSVAR residuals. MSIA(2)-VAR(1)



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