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## A cointegration analysis of a money demand system in Europe

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## **A Cointegration Analysis of a Money Demand System in Europe**

by

Jan Gottschalk



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## Contents

<b>I. Introduction .....</b>	<b>1</b>
<b>II. What Can Be Learned from Past Experience for EMU?.....</b>	<b>4</b>
<b>III. The Data Used.....</b>	<b>5</b>
<b>IV. Cointegration Analysis.....</b>	<b>9</b>
IV.1 Testing for Reduced Rank.....	9
IV.2 Identifying the Cointegration Vectors.....	12
<b>V. Stability Tests .....</b>	<b>16</b>
<b>VI. Conclusions .....</b>	<b>20</b>
<b>Appendix.....</b>	<b>21</b>
A The Data Used.....	21
B The Johansen Procedure .....	22
<b>References.....</b>	<b>24</b>

## **Abstract**

This paper presents a multivariate analysis of a money demand system in Europe. The system comprises real broad money, real GDP, the inflation rate, a long-term and a short-term interest rate. Two stable cointegration vectors can be identified: a money demand function and a long-run Fisher equation. Inflation does not play a role in the specification of the European money demand function. Stability of money demand is generally seen as a precondition for monetary targeting. No suggestive evidence for structural instability is found for long-run money demand. This is of particular relevance for the monetary strategy of the ECB.

JEL Classification: E41, E52

Keywords: Money Demand in Europe, European Monetary Union

## **I. Introduction<sup>1</sup>**

The empirical analysis of so-called 'area-wide' money demand functions for the European Union (EU) as a whole or for different EU country groupings has received considerable attention in recent years.<sup>2</sup> The stability of a European money demand function has been one of the key issues in the debate regarding the choice of the monetary policy strategy of the European Central Bank (ECB). There is a general view that a stable money demand function is a precondition for monetary targeting to be successful. Vice versa, a lack of stability is taken as a strong argument in favour of direct inflation targeting as the monetary strategy.<sup>3</sup> The broad message from the empirical studies seems to be that the EU-wide equations is stable and compare rather favourably with the best equations for individual countries.<sup>4</sup> The ECB eventually decided to give money a prominent role in its monetary policy strategy by choosing to announce a reference value for the growth of a broad monetary aggregate.

Given the importance of money for policy purposes in the common currency area, the empirical analysis of money demand in Europe will continue to be a matter of interest. This paper attempts to extend the literature in several directions:

To start with, a different specification for modelling money demand is proposed.

Most studies consider money demand only as a function of an income variable and an interest rate vector. Here, the inflation rate is included as an additional measure of

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<sup>1</sup> I would like to thank Jörg Döpke, Kai Carstensen, Axel Schimmelpfennig, Carsten Meier and Joachim Scheide for many helpful comments. I am responsible for all remaining shortcomings.

<sup>2</sup> The seminal paper in this area is the one by Kremers and Lane (1990). Since then there have been numerous empirical investigations regarding the stability of money demand in single European countries or country-groupings. For a general overview see Monticelli and Papi (1996) and Browne et al. (1997). For a discussion of methodological and econometric issues see Ericsson (1998).

<sup>3</sup> For a dissenting view regarding this argument see Scheide (1998), p. 8 f.

<sup>4</sup> See Browne, Fagan and Henry (1997), p. 18.

the opportunity cost of holding money, as recently suggested by Ericsson (1998).<sup>5</sup> The inflation variable also allows for the money stock to adjust in nominal and real terms towards equilibrium and so imposes less strict assumptions on the money demand function, as shown in Wolters and Lütkepohl (1996). For Germany, several authors find a significant impact of inflation on money demand.<sup>6</sup> The survey by Browne, Fagan and Henry (1997) shows that this specification is also used in a number of studies regarding other EU countries.<sup>7</sup> As far as an European area-wide aggregate is concerned, only two studies consider the role of inflation. One is the seminal paper in this field by Kremers and Lane (1990) and the other is by Barr (1992), who tested the robustness of Kremers and Lane's results. Both papers find a negative impact of inflation on money demand. The motivation for the inclusion of inflation in the present study is twofold. First, in view of the empirical evidence the money demand function may be misspecified, if inflation is not allowed for. Second, another purpose of this research is to model a money demand system for Europe. So the inflation variable is needed to make the system complete.

Next, a multivariate analysis of an European money demand system will be presented. This approach allows to investigate whether there are also other long-run relationships between the variables considered here - besides money demand - that are relevant for monetary policy in Stage Three of the European Monetary Union (EMU).

Finally, it is tested, whether the identified long-run relationships are stable over time.

The empirical analysis makes use of Johansen's multivariate approach of cointegration analysis. This procedure allows to test for the number of stationary

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<sup>5</sup> See Ericsson (1998) p. 304 for an overview regarding the modelling of opportunity costs.

<sup>6</sup> The results of Wolters and Lütkepohl (1996) are confirmed by Hubrich (1996), who uses the same data set but a different methodology. Also, Hansen and Kim (1994) and Breyer (1994) include the inflation rate in their specification of German money demand.

<sup>7</sup> See Browne et al. (1997), p. 6 f.

relationships; furthermore it facilitates testing of restrictions on the cointegration vectors, stability tests and tests for weak exogeneity. The ultimate goal of the analysis is to obtain stable and identified cointegration vectors. In addition to money demand, this paper considers a long-run relationship between short- and long-term interest rates and tests, whether the long-run Fisher equation holds in Europe.

Due to the uncertainties surrounding the initial membership in Stage Three of EMU, this study is one of the first to use a country-grouping which represents the initial EMU membership. At this time, there are only two other studies which use the same range of countries.<sup>8</sup> The difference to their work is the purpose of the research undertaken; while they focus on the money demand relationship, this study investigates other possible long-run relationships between the variables as well.<sup>9</sup>

The paper is organised as follows. The second section discusses the limitations of European money demand estimates for deriving conclusions regarding the monetary conditions in Stage Three of EMU. The third section describes the variables employed in the empirical analysis. In the fourth section, the vector autoregressive model is estimated and the cointegration rank determined. Suitable restrictions for the identification of the long-run relationships are discussed and tested. Then tests for weak exogeneity of the variables are presented. Section five investigates the stability properties of the two identified long-run relationships. The final section concludes.

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<sup>8</sup> See Hayo (1998) and Clausen and Kim (1998).

<sup>9</sup> In addition there are differences regarding the sample period, the choice of time series, the method of aggregation and econometric methodology. Hayo (1998) also uses a different specification: he omits the short-term interest rate as an explanatory variable, which is employed here and in the paper by Clausen and Kim to model the own rate of broad money. Even though a number of technical issues are treated differently, the paper by Clausen and Kim is broadly comparable with this study and their results will be presented in section 4 to establish the robustness of money demand estimation.

## II. What Can Be Learned from Past Experience for EMU?

There is a broad body of empirical evidence that the stability of money demand in Europe is often superior to those of single country estimates. In order for this finding to be useful for policy conclusions, it is necessary to assume that past experience is also relevant for the future. There are basically two reasons why the statistical stability found so far may not be carried forward into the new regime. First, if the stability of the area-wide aggregate is mainly due to the averaging-out of national shocks, it is essentially a statistical phenomenon. Stability will persist only to the extent that the national shocks do not become more synchronised when the economies in the joint currency area face a common monetary policy.<sup>10</sup> A recent study by Fagan and Henry (1998) took a closer look at this argument. They simulated a perfect correlation of country-specific shocks and found that European money demand was still roughly as stable as money demand in Germany. A second argument why stability of European money demand may not persist is that the introduction of the common currency itself represents a regime shift, which may lead to instability in the behaviour of monetary aggregates. But then again it is likely that there will be behavioural inertia in adapting to EMU, so that a process of gradual change is more likely than a sudden structural break in the relationships governing money demand.<sup>11</sup> Also, monetary conditions in recent years were not unlike those to be expected in Stage Three of EMU. Exchange rates were stable and the arrival of the Euro was widely expected. Therefore the recent past should be able to provide a glimpse on what is to be expected in coming years. For these reasons it appears reasonable to suppose that the investigation of European money demand based on past experience is not a fruitless exercise. But since the 'Lucas critique' is still relevant for this type

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<sup>10</sup> For an exposition of this argument see Arnold (1996) and Browne et al. (1997), p.16 ff.

<sup>11</sup> See also Hayo (1998), p.4.

of empirical analysis - as for any studies related to regime shifts -, some caution regarding policy conclusions is called for.

### III. The Data Used

The empirical work is based on quarterly seasonally adjusted data covering the sample period from 1983(1) to 1997(2). According to a recent study regarding the dating of the European business cycle in the common currency area, this period seems to cover three complete business cycles (from trough to trough these are: 1982(4)-1987(1); 1987(1)-1993(3); 1993(3)-1997(1) ).<sup>12</sup> It is advisable to consider complete cycles, because in this case any effects, which are typical for certain phases of the cycle, cancel each other out and cannot distort the estimation.<sup>13</sup> The countries included in the study are the initial members of the monetary union beginning in 1999. This group includes Austria, Belgium, Finland, France, Germany, Ireland, Italy, Luxembourg, the Netherlands, Portugal, and Spain.

For the conversion of the national series to European series, EMS central parities as of February 1998 were chosen. Even though there has been a minor realignment since then, these rates mirror closely the conversion rates of the national currencies to the Euro. The exchange rates are used for the aggregation of the national series for nominal money stocks and real income to the European series. For the aggregation of national interest rates and consumer price indices, national shares in European income are used.<sup>14</sup>

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<sup>12</sup> See Döpke (1998), p.5.

<sup>13</sup> It would have been preferable to include an earlier business cycle as well, so that the sample period begins with the start of the EMS. Unfortunately, data for the Finnish broad money stock were not available before 1983(1).

<sup>14</sup> For further details on the data see appendix.

A related issue to the construction of a European data base is that of aggregation bias. There are essentially two ways how the aggregation of data affects the estimation. First, aggregation bias can arise when countries have different money demand functions; in this case it is difficult to give a meaningful economic interpretation to the estimate of European money demand. It may not describe money demand in any one country or of an appropriately weighted average. This issue is taken up by Wesche (1998). She tests whether the money demand coefficients are equal across European countries and finds that there is evidence for aggregation bias, but that this bias is probably not very large. Second, single country estimations could be misspecified if relevant aggregate variables are omitted from the equations; an example here is that currency substitution between the members of the coming monetary union plays a role, which is hard to model for single countries. In this case aggregation might help to reduce specification bias, so that aggregate estimates actually perform better than single-country ones.<sup>15</sup>

The central goal of the empirical analysis is to model a money demand system. The choice of variables and the specification of the money demand equation will now be described in detail. The other long-run relationships of interest will be discussed in section four, when the restrictions necessary to identify them are presented. Regarding the choice of variables, this paper focuses on a broad money stock as a proxy for money demand, because the ECB formulated the reference value for M3. The restriction of long-run price homogeneity will be imposed here; that implies that real money demand is going to be investigated. Theory suggests that money demand reflects both transaction purposes and portfolio choices. The former influence is to be captured by real GDP as an income variable, while the later is to be modeled with the help of a short-term and a long-term interest rate. The short-term rate represents

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<sup>15</sup> See Grundfeld and Grillich (1960) for a disussion.

the own rate of the broad money stock and is therefore expected to enter the function just as the income variable with a positive sign. The long-term rate reflects the opportunity cost of holding money and is supposed to have a negative influence on money demand. The inflation rate as measured by the consumer price index is considered as an additional variable to either capture some opportunity costs as well - if the households hold some real assets the inflation rate can be thought of as a measure on the rate of return of those assets - or as a variable to represent adjustment costs towards the optimal money stock.<sup>16</sup> In the former case the expected sign is negative, in the later it is indetermined.

The choice of variables thus implies the following long-run specification for the money demand function:<sup>17</sup>

$$(1) \quad m3r = \beta_0 + \beta_1 gdp + \beta_2 \Delta cpi + \beta_3 St + \beta_4 Lt + \varepsilon$$

with  $\beta_1, \beta_3 \geq 0$ ,  $\beta_4 \leq 0$  and  $\beta_2$  indetermined.

The variables are:

$m3r$ : log of real broad money

$gdp$ : log of real GDP

$St$ : short-term interest rate

$Lt$ : long-term interest rate

$\Delta cpi$ : quarterly inflation rate (quarterly change of the log of the price level)

$\varepsilon$ : white noise error

$\beta_1$ : income elasticity

$\beta_2$ : inflation rate semi-elasticity

$\beta_3$ : short-term interest rate semi-elasticity

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<sup>16</sup> See Wolters and Lütkepohl (1996), p. 8 f. for the adjustment cost argument.

<sup>17</sup> Note that the money stock, gdp and inflation enter in logarithms (small letters), while the interest rates and inflation are in levels (large letters).

$\beta_1$ : long-term interest rate semi-elasticity

To evaluate the time series properties, Augmented Dickey-Fuller (ADF) tests are applied. These test the null hypothesis of non-stationarity. Table 1 shows the results of the unit root tests.<sup>18</sup> The ADF tests suggest that all variables are at least I(1). In addition, a non-parametric Phillips-Perron test is computed, which also tests the null of non-stationarity. The results of the ADF tests are confirmed (table 1). Finally,

Table 1 - Results of Augmented Dickey-Fuller tests

Variable	ADF t-statistic	Phillips- Perron test statistic	Variable	ADF t-statistic	Phillips- Perron test statistic
<i>m3r</i>	-2.16 (c,t;5)	-0.28 (c,t)	$\Delta m3r$	-3.49* (c;0)	-3.43* (c)
<i>gdpr</i>	-2.67 (c,t;0)	-2.70 (c,t)	$\Delta gdpr$	-7.48** (c;0)	-7.51** (c)
$\Delta cpi$	-2.57 (c;5)	-2.27 (c)	$\Delta^2 cpi$	-8.90** (1)	-12.94**
<i>St</i>	-1.73 (c;5)	-0.68 (c)	$\Delta St$	-4.16** (4)	-5.04**
<i>Lt</i>	-1.04 (c;5)	-0.50 (c)	$\Delta Lt$	-2.89** (5)	-4.28**

Note:  $\Delta$  is the first difference operator. The asterisks indicate a rejection of the null hypothesis at the 5% (\*) or the 1% (\*\*) level. The critical values for the test statistics are taken from MacKinnon (1991). The brackets indicate the inclusion of a trend (t) and/or a constant (c) and the lag length.

<sup>18</sup> A maximum of five lags has been the starting point for the specification. The final lag length was chosen according to the Akaike information criterion. Regarding the inclusion of a trend variable and/or a constant, these were included after visual inspection of the time series and after assessing their significance in the regression. Harris (1995) shows that it is necessary to have as many deterministic regressors as there are deterministic components in the data generating process. For example, a constant and a trend are needed in the ADF regression when the null hypothesis of a stochastic trend is to be tested against the alternative hypothesis of trend-stationarity. So when visual inspection showed there is a trend in the data, a constant and a trend were included in the ADF test.

non-stationarity of the time series is also found by unit root tests within the Johansen framework, which test the null hypothesis of stationarity. The null was rejected at conventional significance levels for all variables.<sup>19</sup>

## **IV. Cointegration Analysis**

The unit root tests indicate that the variables are integrated of order one. The further analysis therefore should proceed within the framework of cointegration analysis. The estimation and testing of the cointegration vectors is done with the help of the Johansen procedure (1988).<sup>20</sup> This allows for a multivariate approach. A single-equation estimation does not seem to be appropriate for the purpose at hand, because it does not allow to test for the number of cointegration vectors or to model multiple cointegration vectors.

### ***IV.1 Testing for Reduced Rank***

In a first step the initial VAR needs to be estimated.<sup>21</sup> The VAR includes the variables  $m3r$ ,  $gdpr$ ,  $\Delta cpi$ ,  $St$ ,  $Lt$  and a constant. The constant enters the system unrestricted and thus plays a role in the short-run and long-run part of the system; in the short-run section it accounts for the trend in the data and in the cointegration vectors it represents a scale variable. No dummy or trend variables are included.<sup>22</sup> The Schwarz and the Hannan-Quinn criterion suggest a lag order of two for the VAR, but then the residuals exhibit first-order autocorrelation. So a lag order of

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<sup>19</sup> The test-statistics for all variables are too voluminous to quote. They are available from the author on request.

<sup>20</sup> For a useful guide see Harris (1995) and Hansen and Juselius (1995); see also appendix B.

<sup>21</sup> All estimations in this section are done with the program CATS.

<sup>22</sup> This model specification is also supported by the rank-procedure in CATS. In addition a test for long-run exclusion is performed; the hypothesis that any variable used here can be excluded from the cointegration space must be rejected at the 5 percent significance level. For details, see Hansen and Juselius (1995), p. 64 ff.

Table 2 - Misspecification tests for the system: multivariate statistics

Test	Test statistic	p-value
Test for autocorrelation:		
LM(1)	24.61	0.48
LM(4)	28.86	0.27
Test for normality	7.69	0.66

Table 3 - Misspecification tests for single equations: univariate statistics

	Normality test	ARCH (3) test
<i>m3r</i>	2.21	1.69
<i>gdpr</i>	4.79	1.39
$\Delta cpi$	0.38	2.47
<i>S<sub>t</sub></i>	0.74	2.14
<i>L<sub>t</sub></i>	0.26	8.34*

Notes: The asterisks denote significance level at the 5% level; the test statistic for normality has a  $\chi^2(2)$  distribution (the critical value at the 5% level is 5.99); the test statistic for ARCH (3) is  $\chi^2(3)$  distributed (the critical value at the 5% level is 7.81)

three is chosen. Given this specification, system and single equation misspecification tests do not indicate major problems (see table 2 and 3).<sup>23</sup> Only the equation for the long-term interest rate may be characterised by an ARCH-process, but this is not crucial for further testing.

Next the number of the cointegration vectors needs to be determined. The results of the trace test and the maximum eigenvalue test for reduced rank are given in table 4.

<sup>23</sup> For details on the tests applied here see Hansen and Juselius (1995).

Table 4 - Johansen test for the cointegration rank

$H_0: \text{rank} \leq r$	Trace statistic	90%	L-max statistic	90%
$r=0$	81.83***	64.84	35.63**	30.90
$r \leq 1$	46.19*	43.95	21.14	24.73
$r \leq 2$	25.05	26.79	18.37	18.60
$r \leq 3$	6.68	13.33	6.42	12.07
$r \leq 4$	0.26	2.69	0.26	2.69

Notes: The asterisks denote significance at the 10% (\*), the 5% (\*\*) or the 1% (\*\*\*) level. L-max is the maximum eigenvalue test. Critical values are taken from Osterwald-Lenum (1992)

The maximum eigenvalue test suggests the existence of only one cointegration vector, while the trace test indicates two vectors. But this result is sensitive to the lag order of the VAR. With a lag order of two, as originally suggested by the information criteria, both tests support a choice of two cointegration vectors. In addition, a visual inspection of the plotted cointegration vectors also indicates the existence of a second stationary relationship; so does a calculation of the eigenvalues of the companion matrix.<sup>24</sup> Therefore the system is reestimated under the assumption of two cointegration vectors.<sup>25</sup>

<sup>24</sup> Both available from author on request.

<sup>25</sup> If the system is instead estimated under the assumption of one cointegration vector, the estimation yields a stable money demand function, where inflation enters significantly with a negative sign. The absolute size of the inflation coefficient is broadly similar to the one found by Kremers and Lane (1990). But the evidence indicates the presence of a second vector, which will lead to a different result.

## **IV.2 Identifying the Cointegration Vectors**

Up to now only the cointegration space has been identified. The two cointegration vectors are still unknown. The estimation of the system at this stage simply yields two linear combinations of the cointegration vectors. To obtain two unique cointegration vectors, identifying restrictions need to be introduced.<sup>26</sup> These restrictions are based on economic theory about the long-run relationships between the variables considered here. An obvious candidate to start with is the interest rate spread, which is often thought of as being stationary. This is inferred from the expectations theory of the term structure. This theory states that the yield on a  $n$ -period bond is equal to the average of expected yields on future one-period bonds up to  $(n-1)$  periods in the future plus a term premium, which is assumed to be constant over time. Stationarity of the interest rate spread is tested<sup>27</sup>, but even though the null hypothesis of stationarity is not rejected at the 5% level, it gets very close ( $p$ -value = 0.08). Visual inspection of the spread (figure 1) suggests non-stationarity, so the above result needs to be taken with care. Stationarity is not assumed in the following.

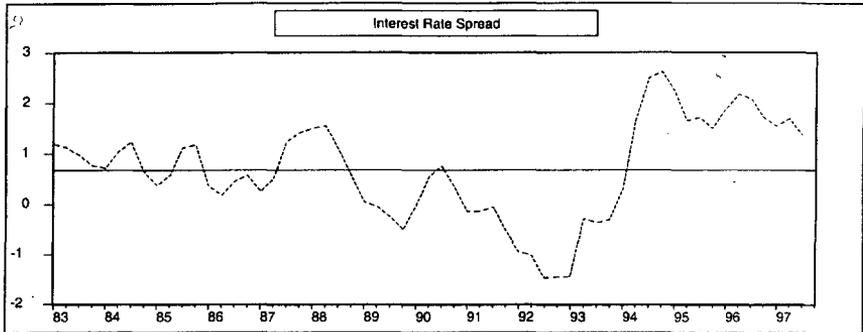
Another candidate for a stationary relationship between the variables is given by the Fisher equation, which states that the nominal interest rate  $i$  is equal to the sum of the real interest rate  $i_r$  and the expected inflation rate. Assuming static expectations,

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<sup>26</sup> For an application to German money demand of this principle see Hubrich (1996), p.12 ff.

<sup>27</sup> Testing is done as follows: The restrictions are imposed on one cointegration vector while the other remains unrestricted. The restrictions imposed here are linear restrictions on the cointegration space in general. In this way one may test whether the cointegration space contains a cointegrating relationship that satisfies the restrictions. This procedure can be thought of as a form of pretesting within the Johansen framework. One has to keep in mind that one cannot estimate individual coefficients without identifying the whole system. For this reason only the test-statistics will be presented, but not the estimated vectors. Later on, when acceptable restrictions have been found, these are simultaneously imposed on both vectors and identification is tested. If identification is accepted, the estimation yields two unique cointegration vectors. Overidentifying restrictions for each vector are then testable. At this stage, a meaningful interpretation can be given to the cointegration vectors and the estimation results are presented. For a further discussion see also Johansen (1995), p. 72 ff.

Figure 1 - Interest rate spread



the inflation expectations are equal to the actual inflation rate  $\pi$ . Allowing for a white noise error term  $\varepsilon$ , the Fisher equation then can be reformulated as follows:

$$(2) \quad i_t = i - \pi + \varepsilon$$

If the real interest rate is stationary, the vector including the nominal interest rate and the inflation is stationary as well. Testing this proposition requires a transformation of the coefficient for  $\Delta cpi$ , because the inflation time series used here is a quarterly inflation rate while the interest rate is a yearly rate. Following approximation is used:  $\pi = 4 \cdot \Delta cpi$ . Now stationarity of the vector  $(i - 4 \cdot \Delta cpi)$  will be tested. The null hypothesis of stationarity cannot be rejected ( $p$ -value = 0.38). So this turns out to be a valid restriction within the cointegration space.

While one of the cointegration vectors may represent the Fisher equation, it remains to be seen whether the second can be interpreted as a money demand function. The reference here is that the coefficients should be of plausible size and have the expected sign. Furthermore, at least one restriction needs to be imposed to obtain an identified cointegration vector. Fortunately, the unrestricted estimation of one vector with the Fisher equation restrictions imposed on the other suggests even two such

restrictions. First, the inflation rate does not seem to play a role in the second vector, which otherwise looks very much like a money demand function. This finding would support the specification of many other money demand functions in the literature, where inflation is not included as a variable. Second, the income coefficient is with 1.14 just slightly greater than unity. Hayo (1998a) finds that a restriction of income-homogeneity holds for half of all EU countries.<sup>28</sup> This restriction implies that a strong version of the quantity theory is valid:

$$(3) \quad m = y + p + v(i),$$

where  $m$  represents money,  $y$  stands for real output,  $p$  for the price level and  $v$  for the velocity of money, which is a function of the interest rate.<sup>29</sup> Both restrictions are tested and not rejected by the data (p-value=0.12).

The restrictions for the Fisher equation and the money demand function are now simultaneously imposed. Two tests follow.<sup>30</sup> First, it is tested whether these restrictions identify the system. Second, for identification only one restriction on each cointegration vector is needed. But there are two restrictions for the money demand relationship and four for the Fisher equation. This means there are overidentifying restrictions, which are testable with respect to the identified cointegration vectors. Testing shows that the estimation yields two identified cointegration vectors and the overidentifying restrictions are not rejected (p-value=0.13).

The first cointegration vector can be interpreted as a long-run money demand relationship:

$$(4) \quad EC_1 = m3r - gdpr - 3.16St + 4.83Lt$$

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<sup>28</sup> It is indeed a very common restriction, as can be seen in the survey by Browne et al. (1997).

<sup>29</sup> All variables in logarithms.

<sup>30</sup> See also footnote 27.

The coefficients have the expected signs and the elasticities are approximately of similar size as those found by Clausen and Kim (1998).<sup>31</sup> Given that there are numerous differences in the estimation procedure, the findings for the money demand function seem to be rather robust.

The second cointegration vector represents the Fisher equation:

$$(5) \quad EC_2 = Lt - 4 \cdot \Delta cpi.$$

This result implies that the real interest rate in Europe is stationary and that the nominal long-run interest rate reflects to a large extent expectations regarding future inflation.

Now the investigation turns to the question of weak exogeneity of the variables. Table 6 gives the loading coefficients and presents the results of the tests for weak exogeneity. At the ten percent significance level none of the variables can be thought of as weakly exogenous; at the five percent level weak exogeneity can be accepted for the short-term interest rate, but just barely so. The money demand relationship appears to have a significant influence on this variable. On balance it seems more reasonable to reject weak exogeneity here as well. An economic interpretation of the loading coefficients at this stage is not very useful, because these parameters are part of the short-run structure of the model, which is a reduced form model. In other words, it is not identified and no inference regarding the structural parameters can be made.

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<sup>31</sup> They find following long-run money demand function:  $m3r = 0.98gdp_r + 2.08St - 4.15Lt$ .

Table 6 - The loading coefficients

			t-values for $\alpha$		Test for weak exogeneity (p-value)
	$\alpha_1$	$\alpha_2$	$\alpha_1$	$\alpha_2$	
<i>m3r</i>	-0.07	0.03	-2.86	-0.48	0.03
<i>gdpr</i>	0.12	-0.18	3.37	-1.88	0.01
$\Delta cpi$	0.05	0.03	2.94	0.81	0.05
<i>St</i>	0.06	-0.13	1.90	-1.66	0.06
<i>Lt</i>	0.01	-0.24	0.55	-4.08	0.00

## V. Stability Tests

The existence of a cointegration vector implies that there is an equilibrium relationship between the variables. This is also referred to as dynamic stability and seems to hold for money demand and the Fisher equation.<sup>32</sup> Next, it needs to be established, whether the two long-run relationships are also stable in the sense of structural stability, i.e. that the coefficients are stable over time. To test this, recursive estimation is used. This estimation technique is applied to the system beginning in 1992. Even though this is a relatively short time span<sup>33</sup>, it covers an interesting period. First, it includes the turbulences in the EMS beginning in the summer of 1992. Second, the last few years prior to the beginning of EMU should contain relevant information for the coming currency union, because, as argued before, the introduction of the euro has for some time now been widely expected and

<sup>32</sup> For an overview regarding concepts of stability see Clausen (1998).

<sup>33</sup> The available sample period is rather short given the relatively large system to be estimated here. Before recursive estimation can begin, a reasonable first estimation is needed and this requires a considerable part of the sample period.

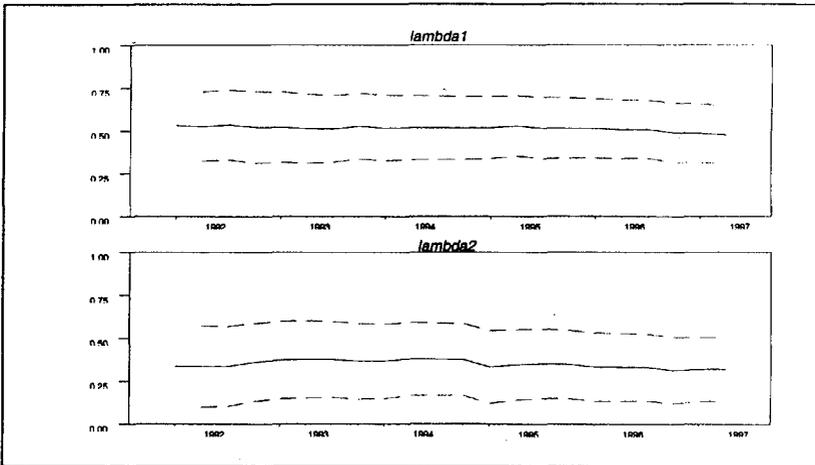
stable exchange rates over the last four years of the sample period mean that this period can be considered as something like a de facto currency union.

Structural stability is now tested by various measures.<sup>34</sup>

To begin with, non-constancy in the cointegration vectors and the loading coefficients should show up in the non-zero eigenvalues. These are plotted in figure 2 and show no sign of non-constancy.

Next, the stability of the maximised likelihood function is considered; the time path of the log-likelihood function is plotted in figure 3.<sup>35</sup> The dotted lines mark the 95% confidence bounds. The path of the log-likelihood value remains well inside the bounds, so there are no signs of non-constancy here either.

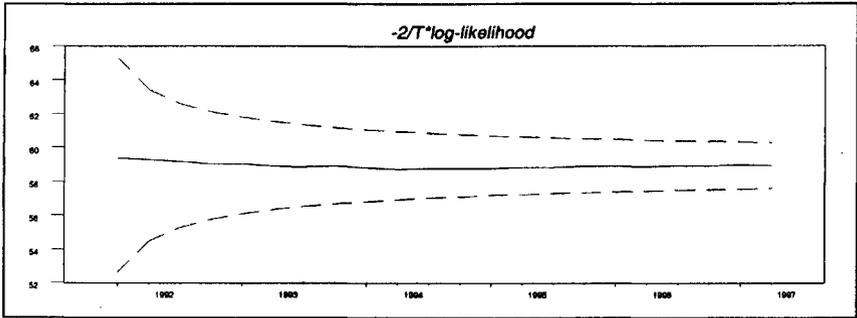
Figure 2 - The eigenvalues



<sup>34</sup> For details on the tests see Hansen and Juselius (1995), p. 55 ff.

<sup>35</sup> The log-likelihood function consists of two components:  $\ln \left| \frac{\Lambda}{\Sigma} \right| = \ln |S_{00}| + \sum_{i=1}^r \ln (1 - \hat{\lambda}_i)$ . These are central for the maximum likelihood estimation. For a more detailed discussion see appendix B.

Figure 3 - The log-likelihood value



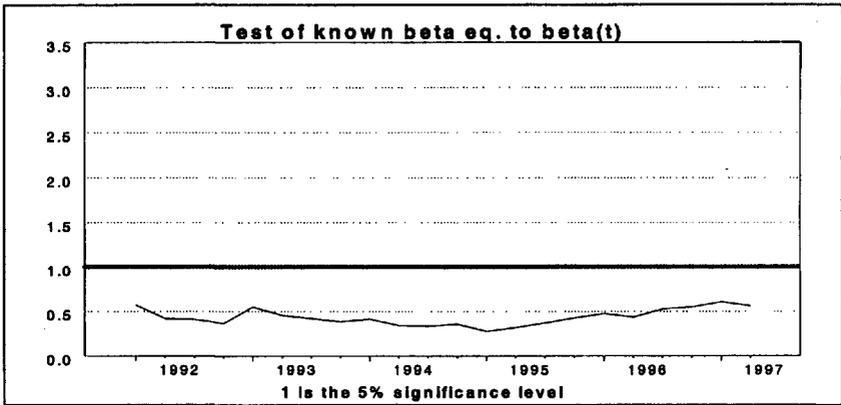
The third test for structural stability is a formal test for constancy of the cointegration space. Figure 4 shows tests of the hypothesis that the full sample estimate of  $\hat{\beta}$  with the overidentifying restrictions imposed is in the space spanned by  $\beta$  each sub-sample. The test-statistic is scaled so that unity corresponds to a test with five percent significance level. These tests essentially confirm the above results, but only when short-term noise has been removed from the data.<sup>36</sup> This indicates that there are problems with the short-run parameters. The goal of this empirical analysis is to find stable long-run relationships so the issue of short-run instability is not further pursued here. But it needs to be noted that also short-run instability poses a problem for a central bank.

Finally, figure 5 shows the results of one-step ahead prediction tests for the system.<sup>37</sup> The test statistics are scaled so that a value above one indicates an outlier, meaning

<sup>36</sup> When the stability test is conducted using the residuals  $R_{0t}$  and  $R_{1t}$  from equation (3A) and (4A) in appendix B for the estimation, there are no signs of instability. These time series have been generated to remove short-term noise from the data in order to facilitate the long-run analysis. They are relevant for the purpose of research undertaken here. When the original time series are used for estimation, the parameters become unstable. This reflects non-constancy in the adjustment to disequilibrium. see also Hansen and Juselius (1995), p. 56 for this point.

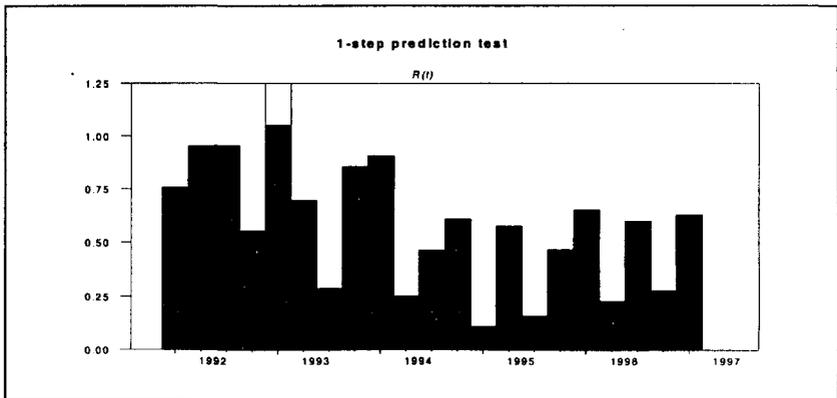
<sup>37</sup> Results for Chow tests for each variable are available from author on request. They confirm the results of the system test.

Figure 4 - Test of constancy of  $\hat{\beta}$



an observation which lies outside the 95% confidence interval for the forecast. There is just one outlier around the EMS crises. But this does not present strong evidence against the hypothesis of constancy; again the result of constancy holds only when short-term noise is not allowed into the data. So the non-constancy of short-run parameters is confirmed here.

Figure 5 - One-step prediction tests



## **VI. Conclusions**

In this paper several long-run relationships influencing the European monetary transmission process have been considered. Two stable cointegration vectors could be identified; one contains a money demand function and the other a Fisher equation. The results regarding the stationarity of the term structure turned out to be ambiguous. As far as the role of inflation in the the money demand function is concerned, it became apparent that inflation does not seem to play a role here. This supports the choice of specification of most other studies regarding European money demand. The result of Kremers and Lane, who find a significant negative impact of inflation on money demand for Europe, could reflect the presence of more than one cointegration relationship in their set of variables. Another goal of this study was to study the stability of the long-run relationships. As far as the long-run is concerned, there is no evidence for non-constancy. But the short-run parameters seem to be instable, which also poses a problem for a central bank. For policy purposes the stability of European money demand is of particular relevance. Before policy conclusions are derived, one needs to keep in mind that some caution is needed, because the 'Lucas critique' may be relevant for this type of analysis. If the results are taken at face-value, they seem to support the choice of a monetary targeting regime by the ECB, because monetary targeting is a long-run concept. Regarding the short-run instability, an explicit modeling of the adjustment path may shed some light on it.

## **Appendix**

### ***A The Data Used***

The calculations for aggregate quarterly data take the OECD data base published in the OECD Main Economic Indicators as a starting point. If necessary, the data for the individual countries are rebased to constant prices as of 1990 and seasonally adjusted with Census-X-11(m). The next step is to convert the series into a common currency according to the EMS central parity as of February 1998. GDP and broad money stock series are then aggregated.<sup>38</sup>

For the money stock national series for M3 are chosen where available. M2 is taken for Italy and Portugal, M4 for Belgium. For real GDP from 1991(1) on the NIA data provided by Eurostat (1998) is used. The consumer price indices are rebased to the base year 1990 and weighted according to the countries' share of GDP in total. Those weights are also used for the aggregation of national interest rates. The short- and long-term interest rates are taken from the OECD Main Economic Indicators.

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<sup>38</sup> The German series are adjusted, if necessary, to account for the effect of unification.

## B The Johansen Procedure

The Johansen procedure is based on an unrestricted vector autoregression (VAR) model involving up to  $k$ -lags of  $z_t$ .<sup>39</sup>

$$(1A) \quad z_t = A_1 z_{t-1} + \dots + A_k z_{t-k} + u_t,$$

where  $u_t$  is iid(0,  $\Sigma$ ). The vector  $z_t$  contains the  $n$  variables of the system and each of the  $A_i$  is an  $(n \times n)$  matrix of parameters. It is assumed that the variables are at most integrated of order one. A reparameterization of the VAR (2) yields a vector error-correction model (VECM):

$$(2A) \quad \Delta z_t = \Gamma_1 \Delta z_{t-1} + \dots + \Gamma_{k-1} \Delta z_{t-k+1} + \Pi z_{t-k} + u_t$$

The matrix  $\Pi$  is a  $(n \times n)$  coefficient matrix, which can be factorized so that  $\Pi = \alpha\beta'$ ;  $\Pi$  has rank  $r$ , where  $r$  represents the number of cointegration vectors. The matrix  $\alpha$  is of dimension  $(n \times r)$  and gives the speed of adjustment to disequilibrium;  $\beta'$  is a  $(r \times n)$  matrix, which contains the long-run coefficients. The term  $\beta' z_{t-k}$  in (2A) represents up to  $(n-1)$  cointegration relationships in the multivariate model.

The Johansen procedure performs a maximum likelihood estimation of the parameters of the above model. The likelihood function is first concentrated with respect to the parameters  $\Gamma_1, \dots, \Gamma_{k-1}$  by regression of  $\Delta z_t$  and  $z_{t-k}$  on  $\Delta z_{t-1}, \dots, \Delta z_{t-k+1}$ :

$$(3A) \quad \Delta z_t = P_1 \Delta z_{t-1} + \dots + P_{k-1} \Delta z_{t-k+1} + R_{0t}$$

$$(4A) \quad z_{t-k} = T_1 \Delta z_{t-1} + \dots + T_{k-1} \Delta z_{t-k+1} + R_{kt}$$

This defines the residuals  $R_{0t}$  and  $R_{kt}$  and the residual cross moment matrices

$$(5A) \quad S_{i,j} = T^{-1} \sum_{t=1}^T R_{it} R_{jt}' \quad i, j = 0, k.$$

The maximum likelihood estimate of  $\beta$  is obtained as the eigenvectors corresponding to the  $r$  largest eigenvalues from solving the eigenvalue problem

<sup>39</sup> See Harris (1995), p.77.

$$(6A) \quad |\lambda S_{kk} - S_{k0} S^{-1} S_{0k}| = 0.$$

This problem yields  $n$  eigenvalues,  $1 > \hat{\lambda}_1 > \dots > \hat{\lambda}_p > 0$  and the corresponding eigenvectors  $\hat{V} = \begin{pmatrix} \hat{v}_1 \\ \dots \\ \hat{v}_n \end{pmatrix}$ . So the  $r$  cointegration vectors can be denoted  $\hat{\beta} = \begin{pmatrix} \hat{v}_1 \\ \dots \\ \hat{v}_r \end{pmatrix}$ .

The maximised likelihood function has the form

$$(7A) \quad L_{\max}^{-2/T} = |S_{00}| \prod_{i=1}^r (1 - \hat{\lambda}_i).$$

The number of eigenvalues which are significantly different from zero is equivalent to the number of cointegration vectors  $r$ . As mentioned above,  $r$  can be determined by considering the rank of  $\Pi$ . A likelihood ratio test can be used to test the null hypothesis  $H_0: \text{rank}(\Pi) = r$  against  $H_1: \text{rank}(\Pi) \geq r+1$  for the trace test or  $H_0: \text{rank}(\Pi) = r$  against  $H_1: \text{rank}(\Pi) = r+1$  for the maximum eigenvalue test. The Trace statistic is

$$-T \sum_{i=r+1}^p \ln(1 - \hat{\lambda}_i) \text{ and the maximum eigenvalue statistic has the form } -T \ln(1 - \hat{\lambda}_{r+1}).$$

The testing is done sequentially for  $r = 1, 2, \dots$  and continues until the null hypothesis is not rejected anymore.<sup>40</sup>

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<sup>40</sup> For this part see also Harris (1995), p.77 ff., Hubrich (1996), p.6 f. and Hansen and Juselius (1995), p. 6 ff.

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