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Introduction

This paper examines the readiness for EMU of the EU countries, using techniques of "fuzzy clustering" to ascertain the "degree of belongingness" of each country, either to a core group of EMU-ready countries or to some other grouping. Several studies of the "core" and "periphery" of EMU already exist in the literature: the classic example is perhaps Bayoumi and Eichengreen (1993), but reference may also be made to Canzoneri *et al.* (1996), Bayoumi and Eichengreen (1997a and 1997b), Taylor (1995) and an earlier study by the present authors (Artis and Zhang 1998), among others. In this light and, more especially, given the fact that the initial membership of EMU has already been determined by the decision taken in May 1998 to proceed with EMU on a broad (EU-11) basis from 1st January 1999, the value of a further investigation of this type might seem to need particular justification.

In fact, a motivation is easy to provide. First, the question of the homogeneity of the EMU membership is clearly of significance for the smooth running and sustainability of the declared "Euro-zone". Second, there remains the issue of the "Outs" or "Pre-ins", the position of the UK, Sweden, Denmark and Greece, currently not included in the "Euro-zone". A study such as the present one may help identify the sources of tension inside the EMU and the areas where special adjustment problems may exist, as well as identifying whether an economic rationale exists for the current exclusion of the four countries just mentioned. Third, this study deploys a method for detecting inhomogeneities - fuzzy clustering - which has not to our knowledge previously been employed in this area. Fourth, and finally, we take the occasion here to explore the differences that exist between the Maastricht Treaty criteria broadly defined and the criteria developed in the economics literature following the pioneering study by Mundell (1961) - the so-called "optimal currency area (OCA)" criteria. Whilst the Maastricht Treaty criteria focus on the single criterion of "stability orientation" as reflected in a range of nominal convergence variables (see Winkler (1996) for a discussion), the OCA criteria pertain to real convergence, emphasizing especially as criteria for a monetary union the prevalence of a high degree of intra-trade among the members and the absence of any pronounced asymmetry in the pattern of shocks impacting their economies.

The rest of the paper proceeds as follows. In the next section we discuss first the methodology of fuzzy clustering, clarifying the associated diagnostic statistics and the requirements, in terms of the type of variable involved, of the analysis. Then, in Section 2 we turn to discuss the OCA criteria and the representation we give them in this study. The section concludes with a

discussion of the results obtained by applying fuzzy clustering methods to these data. In Section 3, we discuss the Maastricht Treaty criteria and display the results obtained in applying methods of fuzzy clustering to variables reflecting those criteria. Section 4 compares the results obtained using the Maastricht Treaty criteria with those already obtained for the OCA criteria. Then Section 5 provides some overall conclusions, including some observations on the degree to which the criteria may be "endogenous".

1. Fuzzy clustering analysis

In this paper, fuzzy clustering analysis is proposed to examine the similarities and dissimilarities of economic structure in the data and to uncover homogeneous subgroups. Fuzzy clustering is a type of data partitioning, in which each object in the data set is assigned a "degree of belongingness" to each cluster. The degree of belongingness is quantified by means of membership coefficients. Fuzzy clustering has more power in approximating the situation involving incomplete and uncertain information and produces more detailed information on the structure of the data than does hard clustering.

The algorithm of fuzzy analysis used in this paper is discussed here briefly (see Anderberg (1993) Kaufman and Rousseeuw (1990) for more details). In the terminology of fuzzy analysis there are n objects (countries) and p variables (features) in a data set with each object being denoted by a vector x_i ($x_i=(x_{i1},\ldots,x_{ip})$ for $i=1,\ldots,n$). Each variable is standardised with mean and standard deviation being equal to zero and unity respectively so that they are treated as having equal importance in determining the structure. The dissimilarity coefficient or distance, $\| x_i - x_j \|$, between two objects, x_i and x_j, is defined as the Euclidean distance[1]

$$\|x_i - x_j\| = \sqrt{\sum_{k=1}^{p} (x_{ik}-x_{jk})^2} \tag{1}$$

The particular technique in fuzzy clustering used in this paper is called the fuzzy

[1] With only 13 or 14 observations in our sample, it is difficult to choose a proper mathematical form to express the statistical distribution of this data set. In this paper, we use the Euclidean distance to measure the dissimilarity between objects, which is the most common measure in clustering analysis.

k-means method proposed by Dunn (1974) and Bezdek (1974), which is based on the minimization of the following objective function:

$$\sum_{k}^{m} \frac{\sum_{i}^{n} \sum_{j}^{m} u_{ik}^2 \, u_{jk}^2 \, \|x_i - x_j\|^2}{2\sum_{j}^{n} u_{jk}^2} \tag{2}$$

subject to the following constraints[2]:

$$u_{ij} \geq 0, \qquad \sum_{j} u_{ij} = 1 \qquad for\ i=1,\ 2,\ \cdots,\ n;\ \ j=1,\ 2,\ \cdots,\ m \tag{3}$$

in which u_{ij} stands for the membership coefficient of object x_i belonging to cluster j and m is the number of clusters.

It is useful to introduce two diagnostic statistics employed in fuzzy analysis: Dunn's partition coefficient and the average silhouette width; these are important indicators of the structure found in the data. Dunn's partition coefficient is used to measure the degree of fuzziness, which is defined as the sum of squares of all the membership coefficients divided by the number of objects and may be further normalized as in the following formula:

$$F_m = \frac{m \sum_{i=1}^{n} \sum_{j=1}^{m} \frac{u_{ij}^2}{n} - 1}{m - 1} \tag{4}$$

[2] In fuzzy clustering, the membership coefficients of each object are non-negative, with their sum over all clusters being equal to one. On the contrary, in hard clustering, membership coefficients are effectively forced to take the value of either one or zero. In this respect, fuzzy clustering conveys more information.

The normalized Dunn's coefficient, F_m, varying from 1 to 0 is a useful indicator of the data structure: a value close to 1 indicates no fuzziness in the data whilst a value close to 0 indicates complete fuzziness.

Average silhouette width can be used to measure how well an object or a cluster or the whole data set is classified. For a data partition $\Omega_q=[\omega_1,...,\omega_q]$ with q clusters in it, each cluster being denoted by ω_k (k=1,...,q), the average dissimilarity of object x_i to all other objects in cluster ω_k is defined as

$$d(x_i, \omega_k) = \frac{1}{|\omega_k|} \sum_{x_j \in \omega_k} \|x_i - x_j\| \tag{5}$$

where $|\omega_k|$ denotes the number of objects in the cluster. If $x_i \in \omega_k$, $d(x_i,\omega_k)$ indicates the average dissimilarity of object x_i to all objects in its own cluster (intra-dissimilarity); if $x_i \notin \omega_k$, $d(x_i,\omega_k)$ indicates the average dissimilarity of object x_i to all objects in other clusters (inter-dissimilarity). The silhouette width, s(i), of object x_i may be obtained as:

$$s(i) = \frac{b(i)-a(i)}{\max[a(i),\ b(i)]} \qquad -1 \le s(i) \le 1 \tag{6}$$

where a(i) denotes the intra-dissimilarity and b(i) denotes the smallest inter-dissimilarity. When s(i) is close to 1, it is implied that the intra-dissimilarity is much smaller than the smallest inter-dissimilarity, and it can then be said that object i is well classified into an appropriate cluster. When s(i) approaches 0, then a(i) and b(i) are approximately equal and it is not clear to which cluster the object i should be assigned. When s(i) approaches -1, it is implied that the intra-dissimilarity is much larger than the smallest inter-dissimilarity and hence that object i is misclassified.

Similarly, the average silhouette width of a cluster is calculated as the average of the s(i) for all objects in that cluster, and is thus an indicator of how well a cluster is classified. The average silhouette width for the whole data set is computed as the average of the s(i) for all objects, and can be used as an indicator to search for the "optimal" number of clusters in the data.

2. The OCA criteria

The foundations of the traditional theory of optimal currency areas were laid by Mundell (1961) and McKinnon (1963), with important elaborations by, among others, Kenen (1969) and Krugman (1990). The latter stresses that the criteria can be seen as forming the basis for a cost-benefit calculus. Thus, the benefit of a common currency will be the larger the greater the scope for economizing on exchange costs by adopting it (i.e. the greater the volume of trade), whilst the costs of adopting the common currency are essentially the negative of the benefits of having an independent monetary policy and exchange rate.

An independent monetary policy, with the potential for an adjustment in the real exchange rate, is useful as a means of coping with shocks that are asymmetric between the potential partners in a monetary union. A compensation for the lack of an independent monetary policy can be found in a federal fiscal policy which would effect transfers between countries impacted by asymmetric shocks whilst labour mobility between the partner countries can offset the labour market consequences of such shocks. More recent contributions to this line of literature have added further factors: for example, that internal labour market flexibility may be a good substitute for the external labour mobility stressed in the original literature; that more open economies are likely to be ones where nominal exchange rate change will not readily translate into real exchange rate change (the external content of the consumer basket will be so great that offsetting wage and price adjustments are nearly automatic); that access to a common capital market can do the work that the earlier literature envisaged might be done by a federal fiscal system; and so on.

These elaborations do not affect the spirit of the OCA approach. Two of the most recent additions do. First, whilst the creators of the OCA tradition relied on a fix-price assumption, it has become clear in practical experience that a strong incentive for monetary union is created by an assurance that the union's inflation rate will be low. See Tavlas (1993) for an account. Second, it has recently been asserted that the OCA criteria are "endogenous", in the important sense that a growth in trade promoted by a union would have the effect of inducing greater symmetry in the stochastic experience of the partner economies; in this way the criteria might be better satisfied *ex post* than *ex ante* (Frankel and Rose (1997, 1998)). Alternatively, it might be argued that the common monetary policy itself eliminates a primary source of asymmetric shocks: the ERM experience is consistent, though only in part, with this proposition (Artis and Zhang (1997)). Of these two more recent additions, we set the latter on one side in this paper. Evidence in favour of the "endogenous criteria" approach is still limited to a handful of papers and might fairly be described as more

suggestive than conclusive at this stage. On the other hand, it seems reasonable to incorporate the inflation criterion within the set of criteria suggested by the traditional approach, if only in the spirit of a normalization of the fix-price assumption on which the traditional approach is founded.

2.1 The variables used

In this paper, cluster analysis is first applied to a set of variables, the choice of which is inspired by the OCA criteria, supplemented by an inflation criterion. In what follows, we describe the choice of statistical correlates that are used in the subsequent analysis. In following this description the nature of cluster analysis must be borne in mind; in particular, it needs emphasizing that cluster analysis is a means of pattern recognition, a way of discerning homogenous groups. With this in mind, we proceed by initially designating Germany as the 'centre country'; then the task of the analysis is to group together countries which are similar to each other in respect, basically, of their relationship, or similarity, to Germany. Although our choice of variables to be measured with respect to Germany is inspired by OCA theory, it is the similarity criterion which is dominant, because this is the *fundamentum* of cluster analysis. Thus, following the criteria suggested by optimal currency area theory, we choose six variables by which to describe each of the EU economies. These are: 1) the synchronisation of the business cycle in a country with the German one; 2) the volatility of a country's real exchange rate against the Deutsche mark; 3) the synchronisation in its real interest rate cycle with the German one; 4) its openness to trade with Germany; 5) its inflation differential against Germany and 6) its employment protection legislation ranking. We now turn to consider each of the variables proposed in detail[3].

Synchronisation in business cycle phase
Eschewing the SVAR identification of shocks favoured by Bayoumi and Eichengreen (1993) we employ a more "atheoretical" approach and adopt the method of Baxter and Stockman (1989). Business cycles are identified for each country by applying the Hodrick-Prescott filter to monthly series of industrial production, and cross-correlations of the cyclical components vis-à-vis those

[3] A similar account appears in Artis and Zhang (1998) where "hard" clustering is applied to the same set of variables.

identified for Germany then proxy business cycle symmetry[4]. The same method was used in Artis and Zhang (1997).

Volatility in the real exchange rate
The traditional OCA approach identifies the cost of currency union membership with the loss of an independent monetary policy, more specifically the loss of a separate exchange rate. Of course, it is the *real* exchange rate that is at issue here, even though monetary policy can only directly influence the nominal rate. A "revealed performance" argument thus suggests that a variable measuring variation in the real exchange rate, in the present case against the DM, the currency of the putative "centre" country, would be appropriate: if there has been little cause for variation in the real exchange rate, then little will be revealed and the cost of moving to a single currency can be assumed to be small[5]. We represent volatility in the real DM exchange rate by the standard deviation of the log-difference of real bilateral DM exchange rates, where deflation is accomplished using relative wholesale (producer) prices.

Synchronisation in the real interest rate cycle
A third variable is also indicated by a "revealed preference" argument. If in fact the monetary policy of a candidate country historically has differed little from that in Germany the cost of relinquishing independence is accordingly low. Thus we assume that synchronisation in real interest rates may be interpreted as an indicator of coordination in monetary policy with Germany. Specifically, we measure monetary policy synchronization by reference to the cross-correlation of the cyclical components of the real interest rate cycle of a country with that in Germany. The detrending was accomplished by applying the H-P filter to monthly series of real interest rates, defined as the difference between a short-term nominal rate (assumed to be "set" by the Central Bank) and the rate of consumer price inflation.

[4] The Hodrick-Prescott filter is applied here with a relatively high value for the dampening parameter λ of 50,000. The figure was chosen in light of the fact that our industrial production data are monthly and are relatively noisy; additionally, in earlier work (Artis and Zhang, 1997) we found that setting such a value for the dampening parameter reproduces the series of cyclical components implied by the OECD's PAT (Phase Average Trend) detrending method (see Nilsson (1987) for an explanation of the OECD's methodology).

[5] The implicit assumption - that a freely floating exchange rate would move "in the right way" to offset asymmetric shocks -admittedly receives little support from Canzoneri et al. (1996) who investigate this proposition, but on the other hand, there is encouraging support to be found in Bayoumi and Eichengreen (1998).

Openness to trade
Our measure of this criterion is provided by data on bilateral trade intensity, i.e. for any country i as ($x_{ig}+m_{ig}$)/(x_i+m_i) where x_i and m_i are exports and imports (of goods) and subscript g indicates as destination or source Germany, the centre country in this exercise.

Inflation Convergence
Whilst the traditional OCA literature offers real variables as criteria, we supplement these here with a measure of inflation convergence, specifically the differential in consumer price inflation against Germany.

Labour market flexibility
Traditional OCA theory emphasizes the importance of labour mobility. The data available now suggest that whilst international labour mobility is quite low in the European countries, it is not much lower than interregional labour mobility within member countries, which is also low. Gros and Thygesen (1998) suggest that it is the difference between interregional and international labour mobility that should count. Meanwhile, it is generally agreed that in the face of shocks that cannot be easily buffered internal labour market *flexibility* is desirable; relatively fast adjustment of employment and of wages reduces the persistence in unemployment that will otherwise be induced. This type of argument has dominated much of the discussion of the policy adjustment appropriate for high unemployment in Europe in the 1980s and 1990s. One measure of the rigidity of labour markets that has been used (e.g. OECD (1994)) is a ranking measure of the severity of employment protection legislation; it is such a variable that is used here as an indicator of labour market flexibility[6].

2.2 The sample period

The data corresponding to the measures described above are shown in Table 1, whilst the corresponding sample period for each variable - generally from April 1979 to Autumn 1995 is indicated in Appendix A. The values shown in Table 1 are averages over these sample periods[7].

Table 1. Criteria by optimal currency area theory

[6] Buti *et al.* (1998) provide a recent discussion of the possible significance of this variable in labour market adjustment.

[7] In the clustering analysis the values reported as missing in Table 1 and Table 3 are interpolated from other variables using a regression model.

	Correlation in business cycle	Volatility[1] in exchange rate	Correlation in interest rate cycle	Trade (% of total trade)	Inflation differential (%)	Labour market indicator[3]
France	.683	1.118	.334	16.853	2.365	7
Italy	.459	1.732	.207	18.467	5.744	13
Netherlands	.730	.582	.587	26.181	-.204	3
Belgium	.634	.864	.529	21.353	.835	10
Denmark	.343	1.039	-.015	20.303	2.037	1
Austria	.745	.907	.216	38.525	.432	9
Ireland	.193	1.244	.136	9.650	3.634	5
Spain	.444	1.617	-.141	12.623	5.177	12
Portugal	.474	1.629	.031	14.156	10.398	11
Sweden	.289	1.835	-.031	15.515	3.322	6
Finland	-.075	1.769	.095	13.284	2.279	4
Greece	.235	1.710	n.a.[2]	19.132	13.848	n.a.[2]
UK	.217	2.174	.017	13.137	3.305	2

Notes:
1. Standard deviation ($\times 10^2$) of the log difference in bilateral real exchange rate against deutsche mark.
2. "n.a" denotes that adequate series are not available.
3. Country rankings of employment protection legislation are from the OECD. The rank for Germany is 8.

2.3 The results

Table 2 shows the results of applying fuzzy clustering analysis to these data, where the number of clusters is taken as being equal to 2 and 3 respectively, both of which provide a clear-cut data partition with significantly large membership coefficients for belonging to one group only and significantly positive silhouettes for all objects. On the whole, a classification of three clusters provides a slightly better data partition measured by the silhouettes and the normalized Dunn's coefficient. Thus we concentrate on the results obtained from three clusters in the following discussion. The values of the silhouettes for each of the three clusters (0.56, 0.53, 0.60 respectively) and for the whole data set (0.57) are reasonably high, suggesting that a reasonable structure exists in the data. Silhouettes per object are all positive indicating that each country is well-clustered into a proper group.

Thus one of the most interesting features of Table 2 is that a classification of three groups is identified with little fuzziness in their membership coefficients and those groups may be described as consisting of:

1) the core group {France, the Netherlands, Belgium, Austria};
2) the Northern periphery group {Denmark, Sweden, Finland, Ireland, the UK};
3) the Southern periphery group {Italy, Spain, Portugal, Greece}.

The core group

The core group is identified as one containing France, the Netherlands, Belgium and Austria with the membership coefficients being 62.7%, 87.3%, 87.9% and 66.7% respectively. The membership coefficients of all other countries for belonging to this group are quite small,

Table 2. Membership coefficient (%) by OCA criteria

	Two clusters				Three clusters				
	I	II	Cluster vector	Silhouettes: s(i)	I	II	III	Cluster vector	Silhouettes: s(i)
France	**80.2**	19.8	I	.31	**62.7**	19.9	17.4	I	.25
Italy	27.0	**73.0**	II	.42	11.6	18.5	**69.9**	III	.48
Netherlands	**89.0**	11.0	I	.75	**87.3**	7.0	5.7	I	.71
Belgium	**91.9**	8.1	I	.68	**87.9**	6.1	6.0	I	.68
Denmark	42.2	**57.8**	II	.18	22.8	**58.7**	18.5	II	.51
Austria	**78.7**	21.3	I	.59	**66.7**	16.2	17.1	I	.59
Ireland	17.4	**82.6**	II	.61	8.4	**75.8**	15.8	II	.59
Spain	13.0	**87.0**	II	.68	8.1	28.7	**63.2**	III	.30
Portugal	17.4	**82.6**	II	.64	2.1	4.9	**93.0**	III	.70
Sweden	5.6	**94.4**	II	.72	3.2	**86.8**	10.0	II	.54
Finland	18.5	**81.5**	II	.64	6.1	**82.5**	11.4	II	.70
Greece	25.9	**74.1**	II	.56	8.1	15.5	**76.4**	III	.64
UK	15.3	**84.7**	II	.67	5.3	**82.9**	11.8	II	.66
Average silhouette width per cluster	.58	.57			.56	.53	.60		
Average silhouette width of whole data set	.57				.57				
Normalized Dunn's coefficient	.43				.45				

Note: Bold figures indicate the largest membership coefficients.

with the partial exception of Denmark with a membership coefficient of 22.8%. It seems clear that the countries in the core group have some common features which are far from being fully shared by other countries. What these features are is readily apparent from Table 1; they include 1) a high degree of business cycle symmetry with Germany; 2) low volatility in the real DM exchange rate; 3) a high degree of synchronization in monetary policy with Germany; 4) a high percentage of trade with Germany; 5) a convergence of inflation towards the German level and 6) similar rankings of employment protection legislation as Germany. On this evidence, economies in the core group are much more symmetric than the whole group, suggesting that these countries are good candidates to form a monetary union.

The Northern periphery group

The Northern periphery group contains three Scandinavian countries {Denmark, Sweden, Finland} plus Ireland and the UK. The membership coefficients of all countries belonging to this group are significantly higher than for those belonging to either group-I or group-III. For example, the membership coefficients for Sweden, Finland and the UK in belonging to this group are 86.8%, 82.5% and 82.9% respectively. Silhouettes for all countries in the group are significantly positive, suggesting that all countries in the group are well-classified. These statistics suggest that economies measured by the OCA criteria are much more similar within the group than between groups. The Northern peripheral group distances itself from the core in three main respects (cf. Table 1): 1) the business cycle is less synchronised with the German cycle; 2) the exchange rate against the DM is more volatile and 3) there is less protection of the labour market in this group than in the core.

It is of interest to note that the decision made by the UK, Denmark and Sweden in this group not to join the first wave of EMU could be held to be consistent with the economic fundamentals as identified here. For example, in the case of the UK and Sweden, their exchange rates against the DM are among the most volatile and the degree of business cycle and monetary policy symmetry with Germany are among the lowest (even though both countries could substantially satisfy the Maastricht criteria actually applied in May 1998).

By the same argument, Finland and Ireland have chosen to belong to EMU on grounds other than those identified here as economic fundamentals. The marginal position of Denmark identified here is also perhaps particularly apt.

The Southern periphery group

The Southern periphery or Mediterranean group contains four countries {Italy, Spain, Portugal, Greece}. Each country in this group also has a significantly high membership coefficient and a positive silhouette suggesting that the Southern periphery group is an independent group in the sense that it distances itself both from the core and from the Northern periphery group; there is a high degree of symmetry within the group.

The predominant features in the group may be described as 1) a medium volatility in the exchange rate against the DM; 2) low synchronisation in the interest rate cycle; 3) dispersion in the rate of inflation against the German one and 4) high employment protection legislation in their labour markets.

To summarize, the set of OCA-related variables employed here to characterize the EU economies from the point of view of their homogeneity with Germany identifies a tightly knit core, with two peripheral groups. The constituents of the core are similar to those identified in other studies (e.g. Bayoumi and Eichengreen (1993), Taylor (1995)), whilst our study identifies two separate peripheral groups. We now turn to discuss the identifications that the use of Maastricht Treaty variables would lead to.

3. The Maastricht Treaty criteria

The Maastricht Treaty laid down a set of criteria to be fulfilled by countries aspiring to participate in EMU. Although, in the event, the criterion pertaining to the debt/GDP ratio was effectively set aside when the EU-11 countries were nominated, the other criteria were generally fulfilled and countries evidently responded to the incentive created in the Treaty by the setting of a clear deadline (see Winkler (1996) for an analysis of the Treaty as an incentive contract). The Maastricht criteria refer to exchange rate stability, the budget deficit/GDP and debt/GDP ratios, and to convergence in the rate of inflation and long-term interest rates. Whilst the Treaty set precise values to be achieved in respect of all these criteria (for example the 3% and 60% "reference values" set for the budget/GDP and debt/GDP ratios respectively) here we simply use the absolute values of these variables. The Treaty criteria evidently can be regarded as concentrating on the single issue of 'stability orientation' as this may be recognized in current and prospective inflation achievement, the stance of fiscal policy and exchange rate behaviour. Not surprisingly, the criteria have been criticized for ignoring 'the real side' of the economy, and for concentrating attention on the value of the criteria proposed in a short assessment period. (The Treaty refers to the 'year before the examination', in respect of most of the

criteria and with respect to the exchange rate criterion refers to a period of two years). The lack of attention to real side factors is made good by the OCA criteria, whilst here we take account of the assessment period problem by examining the data both for 1997 (the 'year before the examination') and for longer periods. It could be argued that the longer period data provide a more accurate guide to the true 'stability orientation' of a country, in that they avoid dependence on 'creative accounting' and possible short-term unsustainable policy adjustments. On the other hand, they deny the possibility that the Treaty deadlines created a genuine incentive to change stability orientation.

3.1 The variables used

Table 3 displays the variables used to represent the Maastricht Treaty criteria, with three alternative sample periods - 1997, 1995-97 and 1990-97. Exchange rate volatility is measured as the (monthly) average over the relevant period of the standard deviation of $\Delta \log x$, where x is the bilateral DM nominal exchange rate. For Germany x is defined as the DM exchange rate against the other EMS currencies; the deficit/GDP and debt/GDP ratios are measured in the manner specified in the relevant protocols to the Treaty (e.g., 'debt' is gross debt). The inflation rate is the CPI inflation rate, as specified in the Treaty (precise definition and sources are shown in Appendix A).

3.2 The results

The data partitions based on the Maastricht Treaty criteria are reported in Tables 4 and 5. Table 4 shows the results based on the 1997 data actually used to decide on membership of the first wave of EMU. The results for the three overlapping periods are reported in Table 5 in which we examine how membership coefficients vary across periods.

3.3 Membership in 1997

Two sets of results are shown in Table 4, corresponding to whether the number of clusters (m) is chosen as 2 or 3. We may note that the silhouettes for Italy, the UK and cluster-II are -0.56, -0.42 and -0.21 when m=2, indicating that the two countries and cluster-II are

Table 3. Maastricht Treaty Criteria

	Volatility in exchange rate[1]			Debt/DGP ratio (%)			Deficit/GDP ratio (%)			Long-term interest rate (%)			Inflation rate (%)		
	1990-97	1995-97	1997[2]	1990-97	1995-97	1997[2]	1990-97	1995-97	1997[3]	1990-97	1995-97	1997[3]	1990-95	1995-97	1997[3]
Germany	.707	.824	.327	54.05	64.35	61.3	-3.08	-3.52	-2.7	7.17	6.19	5.7	2.99	1.68	1.8
France	.606	.656	.354	53.04	62.68	58.0	-3.89	-4.14	-3.0	7.96	6.68	5.6	2.25	1.69	1.2
Italy	2.204	2.594	.974	118.56	124.67	121.6	-8.69	-5.64	-2.7	11.30	9.27	6.7	4.69	3.80	1.7
Netherlands	.160	.133	.145	78.44	77.51	72.1	-3.40	-2.90	-1.4	7.43	6.55	5.6	2.55	2.05	2.2
Belgium	.524	.212	.214	131.52	130.28	122.2	-5.29	-3.47	-2.1	7.85	6.50	5.8	2.45	1.74	1.6
Denmark	.720	.439	.197	74.57	74.39	65.1	-2.16	-1.16	.7	8.24	7.30	6.2	2.10	2.14	2.2
Austria	.162	.112	.123	64.20	70.13	66.1	-3.49	-4.03	-2.5	6.98	5.55	5.7	2.87	1.86	1.3
Ireland	1.437	1.606	1.510	88.55	77.79	66.3	-1.96	-1.42	.9	8.37	7.52	6.3	2.41	1.92	1.5
Spain	1.377	1.251	.404	63.70	73.14	68.8	-4.87	-4.69	-2.6	10.63	8.52	6.4	4.82	3.49	2.0
Portugal	1.017	.599	.496	66.64	67.43	62.0	-5.04	-3.96	-2.5	9.38	8.97	6.4	6.96	3.19	2.3
Sweden	2.024	1.908	1.406	70.70	79.82	76.6	-5.09	-4.46	-.8	9.67	8.42	6.6	4.11	1.15	.9
Finland	2.011	.911	.871	49.32	61.28	55.8	-3.20	-3.22	-.8	9.02	6.35	6.0	2.44	.88	1.2
Greece	.960	.969	.771	104.31	110.19	108.7	-11.00	-7.25	-4.0	n.a.[4]	n.a.[4]	9.3	13.16	7.73	5.5
UK	2.031	2.074	1.826	52.56	60.70	53.4	-4.67	-4.24	-1.9	8.76	7.77	7.0	4.03	2.96	3.1

Notes:
1. Volatility in exchange rate is measured by the standard deviation ($\times 10^2$) of the log difference in bilateral nominal exchange rate against deutsche mark for all countries except Germany for which the value of the deutsche mark against the EMS participating currencies is used.
2. Exchange rate data for this column are monthly series from January 1996 to December 1997 for all countries.
3. Sources:
4. "n.a." denotes that no adequate series are available.

Table 4. Membership coefficient (%) by Maastricht Treaty criteria (1997)

	Two clusters				Three clusters				
	I	II	Cluster vector	Silhouettes: s(i)	I	II	III	Cluster vector	Silhouettes: s(i)
Germany	**91.5**	8.5	I	.81	**93.1**	6.1	.8	I	.63
France	**87.0**	13.0	I	.80	**82.9**	15.1	2.0	I	.58
Italy	39.4	**60.6**	II	-.56	**44.7**	43.8	11.5	I	.30
Netherlands	**89.2**	10.8	I	.82	**81.9**	16.2	1.9	I	.52
Belgium	**64.2**	35.8	I	.60	**58.6**	33.6	7.8	I	.53
Denmark	**71.3**	28.7	I	.73	43.0	**51.9**	5.1	II	.01
Austria	**90.7**	9.3	I	.83	**89.4**	9.4	1.2	I	.65
Ireland	**56.8**	43.2	I	.62	14.0	**83.3**	2.7	II	.59
Spain	**87.2**	12.8	I	.76	**88.5**	10.2	1.3	I	.58
Portugal	**81.1**	18.9	I	.73	**80.6**	17.2	2.2	I	.44
Sweden	**58.3**	41.7	I	.66	11.8	**86.5**	1.7	II	.35
Finland	**83.3**	16.7	I	.83	29.4	**69.0**	1.6	II	.14
Greece	32.0	**68.0**	II	.40	.1	.1	**99.8**	III	.00
UK	28.3	**71.7**	II	-.42	31.8	**54.8**	13.4	II	.26
Average silhouette width per cluster	.74	-.21			.53	.27	.00		
Average silhouette width of whole data set	.54				.40				
Normalized Dunn's coefficient	.33				.50				

Note: Bold figures indicate the largest membership coefficients.

misclassified. However, the silhouettes all become non-negative when m=3, suggesting that each country and each cluster is better-classified in three clusters than in only two. It may also be of interest to note that the normalized Dunn's coefficient for two clusters is significantly smaller than in the three clusters classification, suggesting that the pattern is less fuzzy when m=3. Since the results seem to suggest that the classification of three clusters describes the data structure better than that of two clusters we concentrate on the results achieved when using three clusters in the following discussion.

A classification of three groups is identified as group-I containing the core group of countries[8], {Germany, France, the Netherlands, Belgium, Austria}, *plus* three Mediterranean countries, {Italy, Spain, Portugal}; group-II containing {Denmark, Sweden, Finland, Ireland, the UK}, which is identical to what we called the Northern periphery group identified by OCA criteria in the previous section and group-III containing Greece only.

One of most interesting features of group-I is that it contains a group of core countries plus three Mediterranean countries {Italy, Spain, Portugal}, which perform significantly well in meeting the Maastricht Treaty criteria in the run up to the final assessment for EMU's membership. While Germany has the highest membership coefficient (93.1%) belonging to this group, those for Belgium (58.6%) and Italy (44.7%) are relatively low partly because of their high debt/GDP ratio. Italy is the most fuzzy country in the group with membership coefficients of 44.7% and 43.8% for belonging to group-1 and group-II respectively. Silhouettes per country are all positive for the group, suggesting that most countries in the group are well-clustered, in particular, Germany and Austria are the best clustered countries in group-I with the highest silhouettes, at 0.63 and 0.65 respectively.

Group-II contains five countries with three Scandinavian countries, Denmark, Sweden and Finland plus Ireland and the UK. The silhouettes are also positive for this group, suggesting that the intra-group economic structure is much more symmetric than the inter-group structure. The group distances itself from the core, reflecting the phenomena in this group that 1) on the negative side, exchange rates against the DM are more volatile than those in the core and 2) on the positive side, the deficit/GDP ratio is lower than that in the core and

[8] For convenience, the core group identified by OCA criteria in the previous section in this paper will be used throughout. The precise definition of the core group varies from study to study, but it is generally agreed that Germany, France, the Netherlands, Belgium and Austria should be in the core (see, for example, Taylor (1995), Bayoumi and Eichengreen (1997a, 1997b), Artis and Zhang (1998)).

3) the average debt/GDP ratio is lower than that in the core. Denmark, Sweden and the UK, which decided not to join EMU for the time being are all in this group, although their economic performance might have satisfied the Maastricht Treaty examination[9]. Group III, meanwhile, consists only of Greece[10].

Overall, our results are very close to the actual decision made in May 1998 on the composition of the Euro-zone. The only exceptions are that on our analysis Ireland and Finland do not look like the core group. Denmark is again interestingly marginal - with quite a high core group membership coefficient (43%) but an even higher one for Group-II (51.9%).

3.4 Membership across periods

Table 5 and Figure 1 show the membership coefficients for EMU by Maastricht Treaty criteria across three overlapping periods. The main results may be summarized as follows:

[9] Formally, the principal obstacle would be the Treaty's exchange rate requirement which requires ERM membership.

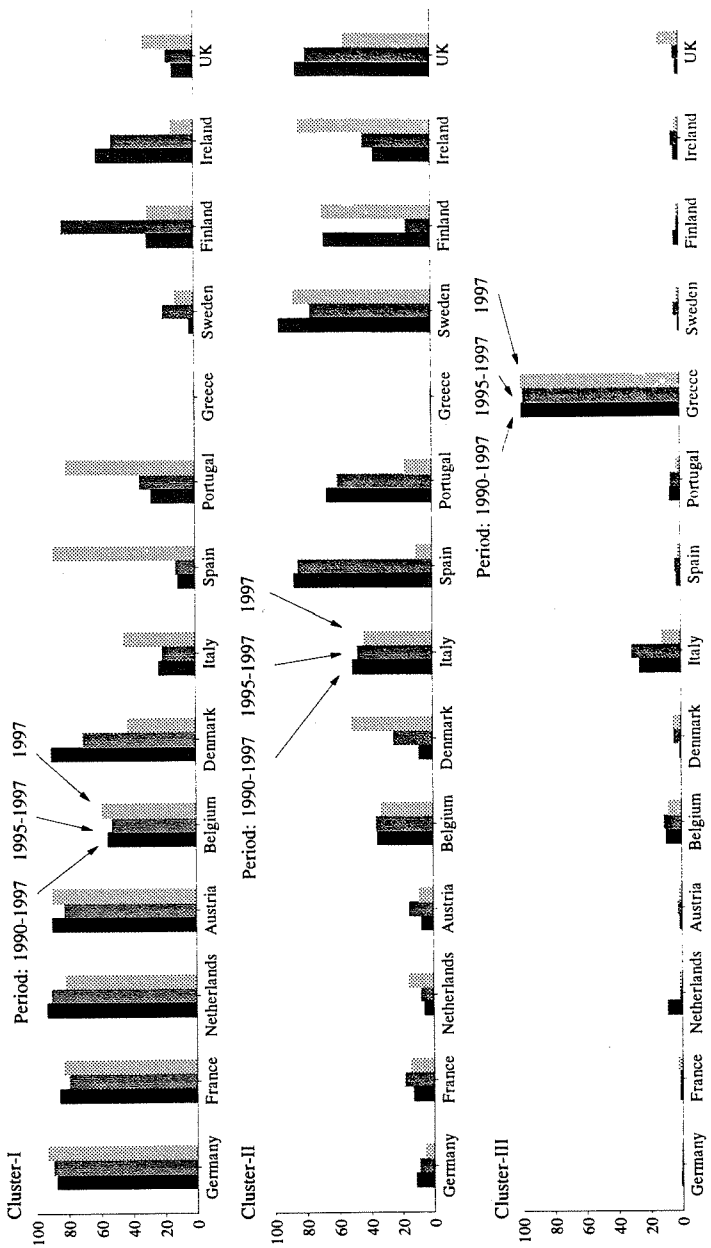
[10] When a cluster contains only a single object, s(i) is set to zero.

Table 5. Membership coefficient (%) by Maastricht Treaty criteria in different periods

	1990-1997				1995-1997				1997			
	I	II	III	Silhouette: s(i)	I	II	III	Silhouette: s(i)	I	II	III	Silhouettes: s(i)
Germany	**87.3**	11.6	1.1	.63	**89.7**	9.5	.8	.61	**93.1**	6.1	.8	.62
France	**85.5**	13.3	1.2	.59	**79.6**	18.8	1.6	.48	**82.9**	15.1	2.0	.58
Italy	23.1	**50.8**	26.1	.41	20.9	**47.8**	31.3	.34	**44.7**	43.8	11.5	.30
Netherlands	**93.0**	6.1	8.9	.77	**90.3**	8.5	1.2	.72	**81.9**	16.2	1.9	.52
Belgium	**55.0**	35.6	9.4	.36	**52.6**	36.5	10.9	.33	**58.6**	33.6	7.8	.53
Denmark	**90.1**	9.1	.8	.71	**70.5**	25.2	4.3	.62	43.1	**51.9**	5.0	.01
Austria	**90.9**	7.9	1.2	.73	**82.2**	15.4	2.4	.63	**89.4**	9.4	1.2	.65
Ireland	**60.7**	36.4	2.9	.41	**51.8**	43.3	4.9	.32	14.0	**83.3**	2.7	.59
Spain	10.8	**86.9**	2.3	.50	12.2	**84.5**	3.3	.46	**88.5**	10.2	1.3	.58
Portugal	27.3	**66.3**	6.4	.24	34.5	**59.7**	5.8	-.09	**80.6**	17.2	2.2	.44
Sweden	3.3	**96.0**	.7	.60	19.7	**76.7**	3.6	.32	11.8	**86.5**	1.7	.35
Finland	29.5	**67.5**	3.0	.11	**82.6**	15.9	1.5	.61	29.4	**69.0**	1.6	.14
Greece	.3	.4	**99.3**	.00	.5	.9	**98.6**	.00	.1	.1	**99.8**	.00
UK	13.3	**84.8**	1.9	.43	17.3	**78.9**	3.7	.40	31.8	**54.8**	13.4	.26
Average silhouette width per cluster	.60	.38	.00		.54	.29	.00		.53	.27	.00	
Average silhouette width of whole data set	.46				.41				.40			
Normalized Dunn's coefficient	.55				.46				.50			

Note: Bold figures indicate the largest membership coefficients.

Figure 1. Membership coefficient by Maastricht Treaty criteria across periods



The countries in the core group {Germany, France, the Netherlands, Belgium, Austria} display a robust performance across periods with significantly large membership coefficients throughout for group-I (core group). Sweden and the UK are viewed as always belonging to group-II, which distances itself from the core in the sense that 1) exchange rates of both currencies vs. the DM are the most volatile almost all the time; 2) their long-term interest rates remain significantly higher than the German one and 3) the rate of inflation in the UK remains higher than that in the core.

The membership coefficients of Italy, Spain and Portugal for belonging to the core group increase significantly over time. For example, the membership coefficients of Spain and Portugal for belonging to the core increase from 10.8% and 27.3% in 1990-97 to 12.2% and 34.5% in 1995-97 and reach 88.5% and 80.6% in 1997 respectively. All three countries, if in particular, Spain and Portugal, have made rapid progress towards meeting the Maastricht Treaty criteria, as reflected in the facts that 1) volatility in their exchange rates against the DM has been reduced significantly; 2) their long-term interest rates and inflation rates have converged gradually on the German level.

On the contrary, the membership coefficient of Denmark and Ireland in respect of their belonging to the core group decreases gradually across periods. For example, both countries are classified as belonging to the core with significantly large membership coefficients in 1990-1997, but are classified as joining the Northern periphery group in 1997. Both countries meet the Maastricht Treaty criteria with even smaller deficit/GDP ratios than the average of the core. However, in the case of Ireland, its exchange rate against the DM is quite volatile and its long-term interest rate remains slightly higher than the core; for Denmark, the long-term interest rate and the rate of inflation remain slightly higher than the core. It is these features together with a much lower deficit/GDP ratio (a distinguishing feature in the Northern periphery group) that classify both countries into the Northern periphery group in 1997.

To summarise, when we compare economic performance measured by Maastricht Treaty criteria across three overlapping periods, some interesting regularities emerge. These results may be described as 1) there is a group containing {Germany, France, the Netherlands, Austria, Belgium} which can be identified as having a robust performance against the criteria across all periods, with significantly large membership coefficients; 2) Sweden and the UK are also identified as those countries which always distance themselves from the core and 3) while the membership coefficients of Italy, Spain and Portugal for joining the core group increase significantly over the time, those for Ireland and Denmark decrease across periods.

4. OCA and Maastricht Treaty criteria compared

How do our identifications of groups based on the OCA criteria compare with those recognised by using the Maastricht Treaty criteria? Table 6 provides a comparison in a classification of three groups based on the two sets of criteria: OCA criteria vs. Maastricht Treaty criteria. It can immediately be seen that, on the one hand, the two sets of criteria provide strikingly similar results despite the fact that those criteria are quite different and in particular, the data periods used to measure OCA criteria are much longer than those used in respect of the Maastricht Treaty criteria. On the other hand, some interestingly dissimilar results also emerge because of the differences between the criteria.

The similarities identified by two sets of criteria shown in Table 6 may be summarized as follows: 1) both sets of criteria identify the same core group {Germany, France, the Netherlands, Belgium, Austria} so this is a robust identification across criteria; 2) both

Table 6 Membership coefficient (%): Maastricht Treaty criteria vs. OCA criteria

	Maastricht Treaty criteria (1997)					OCA criteria					
	I	II	III	Cluster vector	Silhouette: s(i)	I	II	III	Cluster vector	Neighbour	Silhouette: s(i)
Germany	**93.1**	6.1	.8	I	.63	--	--	--	--	--	--
France	**82.9**	15.1	2.0	I	.58	**62.7**	19.9	17.4	I	II	.25
Italy	**44.7**	43.8	11.5	I	.30	11.6	18.5	**69.9**	III	II	.48
Netherlands	**81.9**	16.2	1.9	I	.52	**87.3**	7.0	5.7	I	II	.71
Belgium	**58.6**	33.6	7.8	I	.53	**87.9**	6.1	6.0	I	II	.68
Denmark	43.0	**51.9**	5.1	II	.01	22.8	**58.7**	18.5	II	I	.51
Austria	**89.4**	9.4	1.2	I	.65	**66.7**	16.2	17.1	I	III	.59
Ireland	14.0	**83.3**	2.7	II	.59	8.4	**75.8**	15.8	II	III	.59
Spain	**88.5**	10.2	1.3	I	.58	8.1	28.7	**63.2**	III	II	.30
Portugal	**80.6**	17.2	2.2	I	.44	2.1	4.9	**93.0**	III	II	.70
Sweden	11.8	**86.5**	1.7	II	.35	3.2	**86.8**	10.0	II	III	.54
Finland	29.4	**69.0**	1.6	II	.14	6.1	**82.5**	11.4	II	III	.70
Greece	.1	.1	**99.8**	III	.00	8.1	15.5	**76.4**	III	II	.64
UK	31.8	**54.8**	13.4	II	.26	5.3	**82.9**	11.8	II	III	.66
Average silhouette width per cluster	.53	.27	.00			.56	.53	.60			
Average silhouette width of whole data set	.40					.57					
Normalized Dunn' coefficient	.50					.45					

Note: Bold figures indicate the largest membership coefficients.

criteria sets recognise identically the Northern periphery group {Denmark, Sweden, Finland, Ireland, the UK}, which distances itself from the core and 3) Greece is identified as quite a different country by both criteria sets.

The dissimilarity mainly reflects the fact that Italy, Spain and Portugal are identified as belonging to the Southern periphery group by the OCA criteria but join the core group by the Maastricht Treaty criteria, with significantly large membership coefficients for Spain and Portugal and the lowest membership coefficient for Italy.

What are the implications of these comparisons? The results might help rationalize the position of various countries vis-a-vis EMU. That member states in the core group {Germany, France, the Netherlands, Belgium, Austria} are good candidates for EMU is recognized by both sets of criteria. These findings are also confirmed by Bayoumi and Eichengreen (1993) who find a core group contains {Germany, France, the Netherlands, Belgium, Denmark} in their analysis of demand and supply shocks among eight regions in the US and 11 countries in Europe. They include Denmark in the core which we do not - but outside the core countries, we find that Denmark has the largest membership coefficient for belonging to the core, whichever criterion set is used.

The EMU membership of Italy, Spain and Portugal has been debated by politicians and economists. The arguments on membership for those countries are also reflected in our results in that they are identified as countries joining in the core by Maastricht Treaty criteria based on the 1997 economic performance, but classified as those belonging to a periphery group by OCA criteria, which distance themselves from the core. In judging these results, one has to keep in mind that in this comparison membership of EMU by the Maastricht Treaty criteria is assessed on the 1997 economic performance only (exchange rate stability is based on the period from 1996 to 1997), while the OCA criteria used in this paper are based on a period from 1979 to 1997, which may reflect longer-term economic fundamentals. Although membership of EMU for Italy, Spain and Portugal was granted, OCA criteria indicate that an asymmetry between these new comers and the core remains. This implies that it is particularly important for these countries to achieve a sustainable convergence in fundamentals. Finally, because of their asymmetric nature, some countries may face relatively large potential shocks. The "one-size-fits-all" monetary policy will be inappropriate to certain member countries given the asymmetries within the system.

It has been mentioned above that both sets of criteria identically recognise the Northern periphery group {Denmark, Sweden, Finland, Ireland, the UK},

suggesting the structure within the group is indeed different from that in the core. Three countries, Denmark, Sweden and the UK, which decided not to join the first wave of EMU are all within this group, indicating the intra-similarity within the group and inter-dissimilarity between this group and the core. Enthusiasm for joining EMU in Finland and Ireland, on the other hand, is not explained by our findings, which place the two countries in a peripheral position by both sets of criteria.

5. Conclusions

This paper has used fuzzy cluster analysis to recognize homogenous groups within the set of EU countries eligible to participate in European Monetary Union. From the viewpoint of the coherence and sustainability of EMU, the analysis provides assurance that there is a substantial core of economies that are similar by the criteria we have used. Moreover, a number of the countries whose economies are indicated not to belong to this core are, for the moment at least, outside the Euro-zone. If the criteria are useful diagnostics then perhaps the largest problems are indicated for those countries which seem furthest from the core: both OCA and Maastricht criteria indicate these to be Ireland and Finland. Of the two sets of criteria, it is the OCA criteria that indicate a real problem, related in particular to the asymmetry in business cycle experience enjoyed by these two countries. To overcome the disadvantages that this asymmetry brings, policy-makers in these countries may be called upon to exhibit ingenuity and flexibility in their command of policy instruments that remain under national control. The distinctive behaviour that sets Spain, Portugal and Italy aside is less related to asymmetric business cycle experience and has more to do with the lack of stability orientation exhibited by these countries in the past and to their labour market characteristics. The fact that these countries have taken the steps necessary to qualify may be a sign that the incentive effects built into the Treaty deadlines have worked to produce a sustainable change in stability orientation and in this case past behaviour is of little relevance to the future. It may be more generally true that past experience is little guide to the future: this is what the claim that the OCA criteria are endogenous would imply. If this view is correct, then initial asymmetry will produce transitory costs but not long-lasting strain. But whether this optimistic view is correct, remains to be seen.

Appendix A: Data[1] definitions and Source[2]

Table A Data definitions and periods

Country	IIP[3]	Exchange rate[4]	Interest rate	Period	PPI/WPI[5]	CPI[6]	Trade[7]
Germany	1979:4-95:10	79:4-95:9	Call money rate	79:4-95:8	WPI: 79:4-95:8	79:1-96:10	--
France	1979:4-95:10	79:4-95:9	Call money rate	79:4-95:8	PPI: 80:1-95:8	79:1-96:10	79-95
Italy	1979:4-95:10	79:4-95:9	Interbank deposit rate (3-month)	79:4-95:8	PPI: 81:1-95:6	79:1-96:10	79-95
Netherlands	1979:4-95:10	79:4-95:9	Call money rate	79:4-95:8	PPI: 79:4-95:7	79:1-96:10	79-95
Belgium	1979:4-95:4	79:4-95:9	3-month treasury certificates	79:4-95:8	PPI: 80:1-95:7	79:1-96:10	79-94
Denmark	1979:4-95:10	79:4-95:9	3-month interbank rate	79:4-95:8	PPI: 74:1-95:6	79:1-95:10	79-95
Austria	1979:4-95:10	79:4-95:9	3-month VIBOR	79:4-95:8	WPI: 79:4-95:10	79:1-95:10	79-95
Ireland	1979:4-95:9	79:4-95:9	Call money rate	79:4-95:8	WPI: 79:4-94:11	79:1-95:10	79-94
Spain	1979:4-95:9	79:4-95:9	Call money rate	79:4-95:8	PPI: 79:4-95:6	79:1-95:10	79-95
Portugal	1979:4-95:9	79:4-95:9	Treasury bill rate (91-day)	85:8-95:8	CPI: 79:4-95:8	79:1-95:10	79-95
Switzerland	1979:4-95:10	79:4-95:9	3-month Euro-deposit	79:4-95:8	WPI: 79:4-95:8	79:1-95:10	80-95
Sweden	1979:4-95:10	79:4-95:9	3-month treasury discount notes	79:4-95:8	PPI: 82:1-95:8	79:1-95:10	80-95
Norway	1979:4-95:10	79:4-95:9	Call money rate	79:4-95:8	WPI: 79:4-95:8	79:1-95:10	79-95
Finland	1979:4-95:10	79:4-95:9	Call money rate	79:4-95:8	PPI: 79:4-95:8	79:1-95:10	79-95
Greece	1979:4-95:8	79:4-95:9	n.a.[10]	n.a.[10]	CPI: 79:4-95:8	79:1-95:10	79-94
UK	1979:4-95:10	79:4-95:9	Call money rate	79:4-95:8	PPI: 79:4-95:8	79:1-95:10	79-95
US	1979:4-95:10	79:4-95:9	Federal fund rate	79:4-95:8	PPI: 79:4-95:8	79:1-96:10	79-95
Canada	1979:4-95:10	79:4-95:9	90-day deposit receipts	79:4-95:8	PPI: 79:4-95:8	79:1-95:10	79-95
Japan	1979:4-95:10	79:4-95:9	Certificates of deposit	79:5-95:8	WPI: 79:4-95:8	79:1-95:10	79-95

Notes:
1. All series are monthly except stated otherwise.
2. All series are from the OECD database except for trade data which are abstracted from the IMF-DOTS database.
3. IIP for industrial production index, seasonally adjusted.
4. Exchange rate series are rates against the US dollar, exchange rates against the deutsche mark are derived assuming triangular arbitrage.
5. PPI for producer prices index; WPI for wholesale prices index.
6. CPI for consumer prices index. 7. Trade data are annual.
8. The OECD standardized unemployment rate. 9. Quarterly data. 10. Adequate series are not available.

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