Is Europe converging to optimality?

On dynamic aspects of optimum currency areas

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Abstract *This paper investigates whether Europe is converging towards becoming an optimum currency area. To this end, a structural vector autoregression with exclusively long-run exclusion restrictions is employed on European bilateral real exchange rates, relative CPIs and real output to compare the incidence of the underlying shocks to aggregate supply, aggregate demand and the money market over time. Inferences on historical convergence are drawn for the EU15, the 11 countries originally participating in the European Monetary Union (EMU11) and the original members of the exchange rate mechanism of the EMS (EMS6). The results indicate significant convergence across the EU.*

Introduction

The project of economic and monetary union (EMU) has entered a new dimension with the launch of the euro on 1 January 1999. With the 11 currencies of the founding members linked by permanently fixed exchange rates, the club may soon be expanded to comprise the entire membership of the European Union (EU) as well as a number of aspirants in central and eastern Europe[1]. Whether or not the expanding delimitations of the euro zone make sense from an economic point of view has been the subject of a large and growing body of literature. While there are numerous aspects of the costs and benefits of monetary integration, one of the most prominent aspects of investigation has been and still is the question of whether the euro zone can be considered an optimum currency area (OCA)[2]. Much of this discussion centres on the incidence of shocks within a currency area[3]. As long as goods market shocks are sufficiently symmetrical, equilibrium real exchange rates should remain stable and the nominal exchange rate may as well be fixed across the region. If, on the other hand, shocks are mostly asymmetrical, frequent adjustments in relative price levels are called for and the nominal exchange rate rather than national price levels becomes the preferred instrument to accomplish the necessary adjustments in the real exchange rate.

The one big problem with the concept of the OCA is the lack of an operational criterion to gauge optimality. In order to get around this problem, one strand of the literature has adopted the strategy of starting from an already existing and functioning currency area to compare the incidence of regional shocks within this area with the nature of shocks across the countries of the potential OCA. Eichengreen (1992) compares regions within the USA with EU

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member states and finds that the asymmetry of shocks remains much larger across European countries compared with regions of comparable size and structure within the USA. Regions within Germany constitute an alternative basis of comparison with the size of shocks within a functioning currency area. Using this alternative benchmark, von Hagen and Neumann (1994) as well as Funke (1997) find an even stronger case for failing to classify Europe as an OCA. A different approach is to compare the incidence of shocks across the prospective currency area. Decomposing real GDP data into common and country-specific shocks for 20 European countries, Karras (1996) finds that the latter are both large and asymmetrical so that the common European currency will bring very few stabilization benefits. Examining fluctuations and long-run movements in European outputs, Caporale *et al.* (1999) arrive at the contrasting view that most European countries can already be seen as constituting an optimum currency area.

Whether or not Europe today can be classified as an OCA, the question which naturally arises in this context is whether Europe has at least been converging to optimality in its recent history. These "dynamic aspects of OCAs" have been investigated by Fatás (1997) in terms of cross-regional and cross-country correlations of business cycle fluctuations for regions, respectively nations of the EU. He finds that the cross-regional correlations have decreased, whereas the cross-country correlations increased in the period 1979-1992 compared with the period 1966-1979.

This paper takes a similar approach to evaluating the track record of the EU. Rather than using business-cycle data, however, real exchange rate movements are decomposed into the underlying shocks in goods and money markets and these are then compared across EU nations. Shocks are identified using a structural vector autoregression (SVAR) analysis with exclusively long-run exclusion restrictions in the tradition of Blanchard and Quah (1989), adapted to exchange rates, as in Clarida and Galí (1994)[4]. From the correlations of shocks with aggregate supply, aggregate demand and the money market, inferences of convergence are drawn not only for the EMU11, but also for the EU15 as well as the original members of the exchange rate mechanism of the EMS (EMS6).

Identification of shocks

This section briefly reviews the structural trivariate vector-autoregression (SVAR) set-up used by Clarida and Galí (1994) to recover from structural shocks to aggregate supply, aggregate demand and the money market from first differences of the series on real exchange rates, relative price levels and real output. The following unrestricted trivariate vector-autoregressive format is estimated:

$$X_t = B_1 X_{t-1} + B_2 X_{t-2} + \ldots + B_r X_{t-r} + e_t, \tag{1}$$

where $X_t \equiv [d\ln(y_t/y_t^*), d\ln(q_t), d\ln(P_t/P_t^*)^T$, where T denotes the transposition, d is a difference operator, y_t, q_t and P_t are real output, the real exchange rate and the price level respectively, and asterisks denote foreign variables. The B_i are 3×3 matrices and e_t is the 3×1 vector of residuals. As long as all eigenvalues of $B = (I - B_1 - \ldots - B_r)$ have modulus less than one, the process in Equation (1) possesses a dual vector moving average representation:

$$X_t = \sum_{j=0}^{\infty} C_j e_{t-j}. \tag{2}$$

Let the actual process driving X_t be given by:

$$X_t = \sum_{j=0}^{\infty} A_j \varepsilon_{t-j}, \tag{3}$$

where $\varepsilon = (\varepsilon_s, \varepsilon_d, \varepsilon_m)'$ contains the orthogonal supply, demand and money market shocks and var(ε) = I. Comparing Equations (2) and (3), the vector of innovations e and the vector of underlying disturbances ε are related by $e = A_0\varepsilon$ for $j = 0$ and $A_j = C_jA_j$ for all $j > 0$. Thus knowledge of A_0 allows recovery of ε from e. A_0 can be identified from the covariance matrix Ω:

$$\Omega = \text{var}(e) = E(ee') = A_0E(\varepsilon\varepsilon')A_0' = A_0A_0'. \tag{4}$$

The normalization $\Omega = A_0A_0'$ imposes six non-linear restrictions on the 3×3 matrix A_0. The other three restrictions needed to uniquely identify A_0 from the set of all possible Cholesky factorizations of Ω is given by the assumptions that money market shocks have no lasting effect on the real exchange rate and that neither money market nor demand shocks exert a long-run impact on the level of real output[5].

The three orthogonal shocks identified from the VAR have the following characterization. Supply shocks are those with a potential to affect nominal and real exchange rates as well as real output permanently. In contrast, demand shocks can affect both nominal and real exchange rates permanently, but have at best a transitory effect on real output. Finally, money market shocks may have a transitory effect on real magnitudes like the real exchange rate and real output, but the only permanent effect is on the level of the nominal exchange rate.

Results

Quarterly data have been taken from the IMF International Financial Statistics database for the time period 1973:I to 1997:IV. Bilateral real exchange rate and real output series were constructed by combining nominal exchange rates and seasonally adjusted nominal industrial production data with the respective bilateral national consumer price indices with all series expressed relative to those of Germany. Augmented Dickey-Fuller and Phillips-Perron tests are on (y_t/y_t^*), q_t and (P_t/P_t^*), and indicate that none of the series has a unit root in first differences. The lag length p is chosen such that $B_p \neq 0$ and $B_i = 0$ and for $i > p$, making p the smallest possible order[6]. A lag length four is found to be the maximum required for any of the regressions and r is maintained for all regressions in the interest of preserving symmetry.

Table I presents the variance decompositions of the orthogonal supply, demand and money market shocks of the unweighted averages for the EMS6, the EMU11 and the EU15 at a short forecast horizon (one-quarter), a medium horizon (four-quarters) and for the long run (20 quarters). Money market shocks account for at most a moderate share of overall real exchange rate variability across the sample even in the short run, and the impact of money market disturbances fades quickly, as the forecast horizon is extended. Supply disturbances begin to play a more noticeable role at the long horizon. However, demand shocks turn out to be the dominant source of real exchange rate variability for most countries across the union at both the short and long horizons.

Figure 1 shows the impulse response functions of the real exchange rate for selected countries of the sample. These are The Netherlands and France for the EMS6, Spain for the members of the EMU11 not formerly part of the EMS6, and the UK for the EU15 countries not part of EMU11. The adjustments of the real exchange rates visualized in these graphs are representative for all countries in the sample. From left to right, the graphs display the real exchange rate dynamics at a 40-quarter horizon in the wake of a money demand shock, an aggregate demand disturbance as well as a shock to aggregate supply. All real exchange rates depreciate in response to the money demand shock but revert to their pre-shock positions as time progresses. Moreover, the two-standard error confidence bounds indicate that all real exchange rate responses are temporarily significant. The aggregate demand shock induces the real exchange rates to jump to their new appreciated levels on impact. These real exchange rate reactions are significant throughout. Finally, the real exchange rate depreciates significantly in response to an aggregate supply shock, but here the adjustments are much slower relative to those in response to the demand shock.

All real exchange rate reactions are as predicted by economic theory. The dynamics of the real exchange rates in response to the money demand shock conform with the Dornbusch (1976) overshooting scenario, whereas the appreciations (respectively depreciations) to disturbances in aggregate demand and aggregate supply reflect the requisite changes in international relative price levels necessary to maintain equilibrium in world output markets. These effects are in line with the predictions of equilibrium models of the real

Table I. Variance decompositions of bilateral real exchange rates *vis-à-vis* Germany at various forecast horizons (unweighted averages)

	Shares of supply shocks at forecast horizons of 1, 4 and 20 quarters			Shares of demand shocks at forecast horizons of 1, 4 and 20 quarters			Shares of monetary shocks at forecast horizons of 1, 4 and 20 quarters		
EMS6	9.90	10.80	28.70	71.13	76.65	71.13	18.97	12.55	0.17
EMU11	14.10	11.93	27.83	65.33	76.67	72.04	20.57	11.40	0.13
EU15	9.34	8.73	20.48	75.02	83.69	79.39	15.64	7.58	0.13

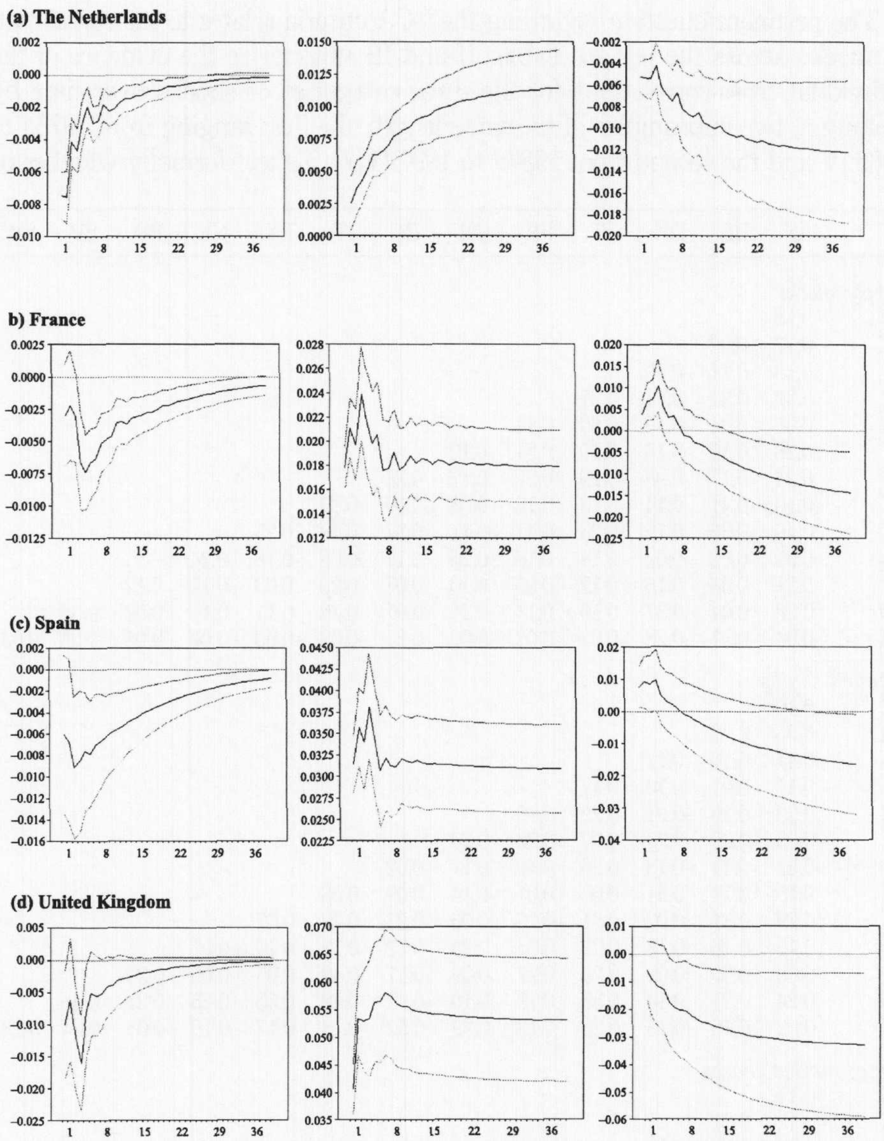

Figure 1. Impulse response functions of the real exchange rate

Note: Graphs from left to right show the reactions of the real exchange rates in response to a money market disturbance, an aggregate demand disturbance and an aggregate supply shock, respectively. Real exchange rates are defined such that an increase reflects an appreciation. The two-standard-error confidence bounds are obtained from a Monte-Carlo simulation with 500 replications

exchange rate, in which real shocks persistently alter the equilibrium position of the real exchange rate (see, for example, Stockman (1987)). The impulse response functions thus suggest that the model is correctly specified and may be utilized to analyze the incidence of the various categories of shocks for the individual member countries of the sample.

The pertinent question regarding the OCA criteria relates to the correlation of shocks across the region. Tables II and III summarize the evidence of the individual cross-correlations for the three categories of shocks over time by looking at two subsamples of the same length, the first ranging from 1976:I to 1986:IV and the second from 1987:I to 1997:IV[7]. To test formally whether or

Table II. Correlations of shocks, 1976:I-1986:IV

	AS	BE	DK	FI	FR	GR	IR	IT	LX	NL	PO	SP	SW
Supply shocks													
BE	0.18												
DK	0.17	0.02											
FI	0.18	0.11	–0.10										
FR	0.39	0.27	0.41	0.27									
GR	0.01	–0.04	–0.13	–0.30	–0.14								
IR	0.28	0.10	0.16	0.10	0.31	0.10							
IT	0.24	0.17	0.38	–0.19	0.32	0.17	0.26						
LX	–0.10	0.41	0.14	0.13	0.13	–0.08	–0.09	0.22					
NL	0.46	0.36	0.15	0.25	0.47	–0.11	0.37	0.49	0.25				
PO	0.01	0.02	–0.02	–0.14	0.16	0.25	0.11	–0.08	–0.18	–0.24			
SP	0.21	0.38	0.15	0.12	–0.05	0.10	0.07	0.20	0.03	0.11	0.12		
SW	0.08	0.04	0.37	0.19	0.14	0.21	–0.07	0.26	0.11	0.11	0.02	0.35	
UK	–0.04	–0.31	0.28	0.22	0.02	0.06	0.30	–0.08	–0.05	–0.07	–0.08	–0.05	0.03
Demand shocks													
BE	0.10												
DK	0.38	0.32											
FI	0.41	0.10	0.17										
FR	0.17	0.01	0.10	0.17									
GR	0.35	–0.19	–0.01	0.22	0.09								
IR	–0.05	–0.09	–0.23	0.00	0.28	0.20							
IT	0.51	0.11	0.13	0.26	0.40	0.17	0.02						
LX	0.15	0.71	0.41	0.00	0.01	–0.14	0.09	0.08					
NL	0.29	0.31	–0.02	0.31	–0.15	0.06	–0.23	0.22	0.07				
PO	0.15	–0.16	0.18	0.22	0.34	0.25	0.12	0.12	0.10	–0.01			
SP	0.08	0.00	0.09	0.24	0.27	0.09	0.17	0.43	0.05	0.00	0.20		
SW	0.24	0.21	0.14	0.55	0.18	0.10	–0.12	0.42	0.06	0.25	0.22	0.46	
UK	–0.02	–0.16	–0.16	0.28	0.13	0.29	0.52	0.13	–0.17	–0.13	–0.03	0.24	0.28
Money market shocks													
BE	0.11												
DK	–0.12	0.31											
FI	0.02	0.00	0.02										
FR	–0.02	0.26	0.22	0.34									
GR	–0.15	–0.06	0.12	0.33	0.49								
IR	–0.04	0.28	0.20	0.22	0.36	0.21							
IT	0.00	0.07	0.10	0.24	0.47	0.28	0.32						
LX	–0.02	0.30	0.15	–0.19	–0.08	–0.09	0.16	0.05					
NL	0.14	0.35	0.14	–0.14	–0.03	–0.05	0.37	0.18	0.10				
PO	–0.05	0.14	–0.13	0.32	0.22	0.02	0.11	0.19	–0.09	0.09			
SP	–0.07	–0.05	0.13	0.33	0.62	0.56	0.43	0.21	–0.04	–0.19	0.02		
SW	–0.03	0.04	0.13	0.61	0.23	0.19	0.12	0.05	–0.15	–0.12	0.04	0.45	
UK	–0.05	0.14	0.08	0.34	0.31	0.13	0.36	0.02	0.19	–0.22	0.15	0.38	0.17

	AS	BE	DK	FI	FR	GR	IR	IT	LX	NL	PO	SP	SW
Supply shocks													
BE	0.50												
DK	0.54	0.49											
FI	0.47	0.39	0.48										
FR	0.33	0.64	0.48	0.61									
GR	0.26	0.26	0.20	0.34	0.41								
IR	0.40	0.56	0.42	0.50	0.52	0.19							
IT	0.23	0.19	0.28	0.32	0.49	0.44	0.14						
LX	0.32	0.51	0.48	0.36	0.50	0.15	0.55	0.28					
NL	0.56	0.50	0.43	0.56	0.63	0.33	0.53	0.39	0.46				
PO	0.07	0.22	0.33	0.39	0.53	0.35	0.36	0.23	0.38	0.25			
SP	0.41	0.40	0.35	0.31	0.41	0.14	0.47	0.36	0.37	0.44	0.27		
SW	0.14	0.16	0.21	0.58	0.41	0.50	0.33	0.30	0.22	0.38	0.38	0.12	
UK	0.25	0.30	0.35	0.55	0.68	0.55	0.35	0.39	0.08	0.57	0.50	0.28	0.33
Demand shocks													
BE	0.21												
DK	0.21	0.42											
FI	0.10	0.23	0.18										
FR	0.43	0.52	0.54	0.11									
GR	0.13	0.10	0.32	−0.17	0.23								
IR	0.01	0.22	0.34	0.11	0.33	0.26							
IT	0.05	0.02	0.26	0.28	0.24	0.26	0.13						
LX	0.21	0.58	0.45	0.03	0.50	0.46	0.31	0.02					
NL	0.45	0.24	0.25	0.01	0.46	0.17	−0.05	0.03	0.28				
PO	−0.02	0.07	0.14	0.16	0.37	0.41	0.45	0.36	0.11	−0.12			
SP	0.21	0.15	0.20	−0.03	0.30	0.38	0.36	0.52	0.19	0.10	0.61		
SW	0.04	0.24	0.48	0.16	0.39	0.10	0.35	0.49	0.24	0.16	0.21	0.43	
UK	0.08	0.03	0.13	0.34	0.26	0.04	0.29	0.48	0.02	0.07	0.31	0.38	0.48
Money market shocks													
BE	0.16												
DK	0.10	0.09											
FI	0.20	0.36	0.19										
FR	0.04	0.12	0.22	0.37									
GR	0.08	0.30	0.27	0.31	0.40								
IR	0.22	0.44	−0.01	0.33	0.08	−0.26							
IT	−0.18	0.24	−0.07	0.54	0.59	0.18	0.42						
LX	0.39	0.24	0.06	0.22	0.26	0.09	0.17	0.11					
NL	0.31	−0.07	0.16	0.27	0.34	0.26	0.13	0.08	0.41				
PO	0.10	0.10	0.04	0.02	−0.01	0.06	0.01	−0.09	0.19	0.16			
SP	−0.19	0.26	0.31	0.16	0.55	0.27	0.21	0.44	0.07	0.10	0.04		
SW	0.19	0.18	0.31	0.45	0.14	−0.01	0.19	0.04	0.26	0.21	0.16	0.19	
UK	0.05	0.39	0.22	0.55	0.70	0.47	0.40	0.59	0.21	0.33	−0.04	0.57	0.24

Table III. Correlations of shocks, 1987:I-1997:IV

not the individual or average correlation coefficient ρ is significantly different in the two subperiods, the statistic of Kendall and Stuart (1967, pp. 292-3) is employed, according to which the value $\{0.5 \ln[(1+\rho/1-\rho)]\}$ is distributed approximately normal with expected value $\{0.5 \ln[(1+\hat{\rho}/1-\hat{\rho})]\}$ and variance $\{1/(n-3)\}$, with n denoting the sample size.

With a total of 91 correlation coefficients for each category of shocks, fewer than half turn out to be individually significant. In particular, all of the 43 significant coefficients for the supply shocks, 15 of the 20 significant coefficients for the demand shocks and 17 of the 21 significant coefficients for the money market shocks show an increase in the correlation from the first to the second subperiod. Significant reductions in the demand coefficients can only be observed for the Finnish correlations relative to Austria, Greece, The Netherlands and Sweden as well as for the Italian-Austrian coefficient. The results for Finland appear particularly plausible in the light of the Finnish recession following the demise of the Soviet Union in the early 1990s. Significant reductions in the money market coefficients occur for the Greek correlations relative to Ireland and Spain as well as for the Belgian-Dutch and the Finnish-Portuguese coefficients.

The correlation coefficients can also be averaged by category (Table IV) and by country (Table V). Table IV reports the test results of the joint significance of the average correlation coefficients of Table II against the corresponding correlation coefficients of Table III for each category of shocks. The evidence points to a significantly higher correlation of aggregate supply, aggregate demand and money market shocks in the second relative to the first subperiod with the exception of the EMS6, for which the incidence of money market shocks is not significantly different in the two subperiods. The latter result can be explained by the fact that these countries had already coordinated their monetary policies throughout parts of the first subperiod by means of the exchange rate mechanism of the EMS.

Table V presents the evidence of the average correlation coefficients for the different categories of shocks across countries. This exercise provides an indication of whether shocks have become more similar or more dissimilar for individual countries within the EU15, the EMU11 and the EMS6. Here the evidence shows that none of the correlation coefficients significantly decreases from the first to the second subperiods with the exception of Finnish supply shocks within the EU15. The evidence thus points to substantial convergence within the EU.

Table IV. Significance of the difference in the correlations between the two subperiods by category

	EU15	EMU11	EMS6
Supply shocks	+	+	+
Demand shocks	+	+	+
Money market shocks	+	+	0

Note: Based on the statistic of Kendall and Stuart (1967, pp. 292-3), the Table reports whether the average correlation coefficient ρ significantly increases (+), decreases (–) or does not change (0) at the 5 per cent significance level from the first to the second subperiods

	EU15			EMU11			EMS6		
	Supply	Demand	Money	Supply	Demand	Money	Supply	Demand	Money
Austria	+	0	+	+	0	+		NA	
Belgium	+	+	0	+	+	0	+	0	0
Denmark	+	+	0		NA			NA	
Finland	+	–	+	+	0	+		NA	
France	+	+	0	+	+	0	+	+	+
Greece	+	+	0		NA			NA	
Ireland	+	+	0	+	+	0		NA	
Italy	+	0	0	+	0	0	0	0	0
Luxembourg	+	+	+	+	+	+	+	0	+
The Netherlands	+	+	+	+	0	0	0	0	0
Portugal	+	+	0	+	+	0		NA	
Spain	+	+	0	+	+	0		NA	
Sweden	+	0	0		NA		NA		
UK	+	+	+		NA		NA		

Notes: Based on the statistic of Kendall and Stuart (1967, pp. 292-3), the Table reports whether the average correlation coefficient ρ significantly increases (+), decreases (–) or does not change (0) at the 5 per cent significance level from the first to the second subperiods

Table V. Significance of the difference in the correlations between the two subperiods by country

Conclusion

Whether or not the euro zone can be considered an OCA has been the subject of numerous studies in the 1990s. While the issue is not yet settled in the literature, a pertinent question to be addressed is whether Europe today is at least converging to becoming an OCA. This paper has analyzed such dynamic aspects of OCAs by employing a three-dimensional structural vector autoregression analysis on European bilateral real exchange rates, relative CPIs and real output to compare the incidence of the underlying shocks to aggregate supply, aggregate demand and the money market for the time periods 1976:I to 1986:IV and 1987:I to 1997:IV. Shocks are identified on the assumptions that money market disturbances exert no lasting effect on the real exchange rate and that neither money market shocks nor demand shocks have a long-run impact on the level of real output. The size and correlations of shocks are then computed separately for all three kinds of disturbances, and inferences of historical convergence are drawn not only for the EMU11, but also for the EU15 as well as the EMS6.

The overall evidence indicates that convergence has been occurring for all three groups of countries in the run-up to monetary union, bringing the European Union closer to being an OCA. While this bodes well for the smooth operation of EMU, the analysis cannot answer the question of whether or not the process of convergence continues after the introduction of the euro. While this is inherently an empirical question, the recent literature on the endogeneity of the OCA criteria suggests an answer. Countries are more likely to fulfil the OCA criteria *ex post*, if monetary union is accompanied by closer economic integration, leading to more tightly correlated business cycles (Frankel and

Rose (1997, 1998)). Accordingly, the process of convergence can be expected to continue even after EMU comes into effect.

Notes

1. This process has already begun with the accession of Greece as the 12th member of EMU on 1 January 2001.
2. For overviews see Masson and Taylor (1993), De Grauwe (1994) and Melitz (1995).
3. For recent contributions see Bayoumi and Eichengreen (1997), Fatás (1997) and Frankel and Rose (1997).
4. It should be noted that the SVAR technique employed here is not the only strategy of using the real exchange rate to uncover the incidence of the underlying shocks. Other approaches are based on real interest differentials or utilize the Beveridge-Nelson technique of decomposing real exchange rates into temporary and permanent components. Clarida and Galí (1994) review these approaches and provide further references.
5. The exact format of the identifying restrictions is given in the Appendix.
6. Choosing an unnecessarily large p reduces the forecast precision of the model under a mean squared error measure (Lütkepohl, 1993, ch. 4).
7. While the break at the end of 1986 is chosen primarily on technical grounds to maximize the size of observations in each of the subsamples, the period beginning in 1987:I also marks the turning-point, after which the EMS strengthened and the EMU project gathered momentum.

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Appendix

The empirical strategy to identify shocks to aggregate supply, aggregate demand and the money market from the residuals of an unrestricted VAR estimation of nominal and real exchange rates as well as real output has been pioneered by Clarida and Galí (1994). Transformation of the residuals into the underlying shocks requires knowledge of the matrix A_0. Assuming orthogonality and unitary variances of the shocks, the estimated covariance matrix of the VAR can be used to identify six of the nine elements of the matrix A_0. This follows from Equation (4) of the text, which is reproduced here as Equation (A1):

$$\Omega = \text{var}(e) = E(ee') = A_0 E(\varepsilon\varepsilon') A_0' = A_0 A_0' \tag{A1}$$

Equation (A1) can alternatively be written as

$$\begin{bmatrix} \omega_{11} & \omega_{21} & \omega_{31} \\ \omega_{12} & \omega_{22} & \omega_{32} \\ \omega_{13} & \omega_{23} & \omega_{33} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{bmatrix} a_{11} & a_{21} & a_{31} \\ a_{12} & a_{22} & a_{32} \\ a_{13} & a_{23} & a_{33} \end{bmatrix} \tag{A2}$$

Equation (A2) imposes six independent non-linear restrictions on the 3×3 matrix A_0:

$$\omega_{11} = a_{11}^2 + a_{12}^2 + a_{13}^2, \tag{A3}$$

$$\omega_{22} = a_{21}^2 + a_{22}^2 + a_{23}^2, \tag{A4}$$

$$\omega_{33} = a_{31}^2 + a_{32}^2 + a_{33}^2, \tag{A5}$$

$$\omega_{12} = \omega_{21} = a_{11}a_{21} + a_{12}a_{22} + a_{13}a_{23}, \tag{A6}$$

$$\omega_{13} = \omega_{31} = a_{11}a_{31} + a_{12}a_{32} + a_{13}a_{33}, \tag{A7}$$

$$\omega_{23} = \omega_{32} = a_{21}a_{31} + a_{22}a_{32} + a_{23}a_{33}. \tag{A8}$$

The remaining three restrictions needed to uniquely identify A_0 from the set of all possible Cholesky factorizations of Ω are given by the assumptions that nominal shocks have no lasting effect on the real exchange rate and that neither nominal nor demand shocks exert a long-run impact on the level of real output. Formally these assumptions have the following format:

$$\sum_{j=0}^{\infty} A_j = \begin{bmatrix} \cdot & 0 & 0 \\ \cdot & \cdot & 0 \\ \cdot & \cdot & \cdot \end{bmatrix}, \tag{A9}$$

implying the restrictions:

$$c_{21}a_{13} + c_{22}a_{23} + c_{23}a_{33} = 0, \tag{A10}$$

$$c_{11}a_{13} + c_{12}a_{23} + c_{13}a_{33} = 0, \tag{A11}$$

$$c_{11}a_{12} + c_{12}a_{22} + c_{13}a_{32} = 0. \tag{A12}$$

The trivariate SVAR therefore correctly identifies the three unobservable structural disturbances.