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The Transmission of Shocks between Europe, Japan and the United States

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ABSTRACT
This paper identifies the types of shocks that affect the economies of Europe, the USA and Japan, and the transmission paths of those shocks between these countries. The identification of shocks is based on the Cointegrated VAR methodology. The categorization and interpretation of shocks are based on synthesis of theoretical studies on international business cycles and international policy coordination. We show that the Cointegrated VAR model is a valid choice and that it demonstrates good fit with the data-generating processes of the time series examined. We find that country-specific US permanent shocks transmit to Europe and Japan and, when positive, have a locomotive effect. The USA is not affected by the country-specific permanent shocks of Europe or Japan. The permanent shocks originating in Europe or Japan do not have a significant effect on the opposite country's growth rates. The model identifies one common symmetric transitory shock affecting all three countries.

KEY WORDS transmission of shocks; international policy coordination; international business cycles; locomotive effect; cointegrated VAR; G3

INTRODUCTION

The high degree of openness of modern economies has undoubtedly left the developed nations vulnerable to economic shocks originating outside of their own economy. While the transmission of business cycles from one country to another is an established fact, the question remains as to which varieties of shocks contribute to the common economic fluctuations between countries. The parallel literature on international policy coordination also highlights that the effectiveness of coordinating and implementing macroeconomic policies depends on the correct identification of the type of shocks that economies experience (Meyer *et al.*, 2004).

This paper contributes to the existing studies on international business cycles in three ways. First, we merge the theoretical studies on international policy coordination and business cycles by categorizing shocks based on those two streams of economic literature. Categorization of both external and internal shocks affecting the national economies is a diverse issue and depends on which strand of

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economics literature one chooses to consider. The ability to comprehensively identify a whole variety of these shocks can be crucial for the effectiveness of domestic economic policies and international policy coordination.

Second, the identification of shocks is based on the data-generating process of the underlying time series. Thus the choice of methodology is such that it is free of the regular limitation of many empirical studies of international comovement, where detrending of nonstationary output is necessary. Those studies either measure the level of synchronization between countries' outputs and do not identify the types of shocks affecting the countries, or are unable to provide insight concerning the importance of permanent shocks in international economic fluctuations (Gregory *et al.*, 1997; Kose *et al.*, 2003, 2008; Lumsdaine and Prasad, 2003; Stock and Watson, 2005). Decomposition of time series into trend and cycle components enables us to identify the effect of both transitory and permanent shocks.

Third, we bring Juselius (1998) methodology to an international level of utilization, showing that the methodology makes possible the synthesis of different categories of underlined shocks within a single econometric model while identifying the types of shocks and the transmission path of those shocks. Juselius (1998) relies on three sources of information—economic theory, the institutions of the political economy, and the time series properties of the data—which makes this methodology ideal for accomplishment of the first two objectives discussed above.

This paper takes an empirical approach showing that identification of the origin and nature of the shocks and the transmission of those shocks between countries will enable us to better understand both the dynamics of international business cycles and the effectiveness of international policy coordination. We show that the cointegrated vector autoregressive (CVAR) model is a valid choice that demonstrates good fit with the data-generating process of the time series examined. The dual nature of CVAR models makes it possible to identify both permanent and transitory shocks that affect countries' outputs. Imposing structure on a CVAR model with a set of identifying restrictions on long-run steady-state relation(s) and the common trend(s) of the model will reveal the origins of those shocks and the transmission of the shocks from one country to another. Following the representative group of literature on international policy coordination, this study focuses on the G3 countries: Europe, Japan and the USA.

The next section describes the identification and categorization of shocks. The third section presents general background on the CVAR model and the duality between cointegration relations and common trends within it. The fourth section presents data, results on determination of cointegration rank, and identification of long-run structure. The fifth section discusses the validity of model choice and the sensitivity of estimates. The sixth section discusses the significance of empirical results and the seventh section concludes.

CATEGORIZATION OF THE SHOCKS

International business cycles

Doyle and Faust (2002) state that international transmission of G7 business cycles is attributed to two kinds of shocks: global shocks that are common to all nations and country-specific shocks that transmit from one country to another. An important fact emphasized in international business cycle models is that country-specific and global shocks should be differentiated according to their effect on the economy (Ahmed *et al.*, 1993; Backus *et al.*, 1992; Glick and Rogoff, 1995).

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Within the theoretical framework of business cycles, two types of shocks are commonly accepted: monetary shocks and technology shocks. Monetary shocks, which are assumed to be neutral in neoclassical theory, can indeed have lasting effects on the economies. This point is proven by the slow speed of adjustment of real exchange rates to purchasing power parity. Moreover, Basu and Taylor (1999) insist that a 'good business cycle model should be able to deliver both short-run monetary non-neutrality and long-run reversion to neutrality'. Technology/productivity shocks studied within real business cycle models stress that the long-run behavior of output is determined by supply-side exogenous shocks to technology with permanent effect on the countries' growth paths.

International policy coordination

The literature on international policy coordination accomplishes two ambitious tasks. First, it addresses the effect of monetary and fiscal policy coordination on the countries' current account balances, exchange rate fluctuations, inflation, and growth rates. Second, it estimates the effectiveness of coordinated policy making. Particular interest is devoted to the G3 group, which represents the most influential players in macroeconomic policy coordination (Christodoulakis *et al.*, 1994, 1996; Clarida *et al.*, 1998, 1999; Caporale *et al.*, 2003).

Theoretical analyses of policy coordination and stabilization conflicts differentiate between three types of shocks (Meyer *et al.*, 2004): symmetric shocks, asymmetric shocks and country-specific shocks. Symmetric shocks affect countries in exactly the same way, while asymmetric shocks have an opposite effect on countries. Country-specific shocks are defined as purely idiosyncratic shocks that affect only one country and do not transmit to other countries. In the case of the transmission of a country-specific shock to other countries, it is categorized as symmetric or asymmetric depending on the effect it has on the other countries.

Synthesis

Figure 1 summarizes the econometric methodology of the paper. The duality between cointegration and common trends in the CVAR model enables the identification of permanent and transitory shocks in the system. The economic interpretation of these shocks is given based on textbook theories on business cycles, where supply-side technology/productivity shocks have permanent effect and monetary shocks have transitory effect on the output fluctuations. Further, the paper categorizes shocks as either global or country-specific depending on where the shock originates and its effect on the other countries' outputs. From the literature on policy coordination it can be seen that shocks can have a symmetric or asymmetric effect on the countries, depending on how countries react to the external shocks. In this regard, positive country-specific shocks that have an approximately symmetric effect on the other countries can have a 'locomotive effect' on the rest of the system.[1]

MODEL SPECIFICATION

The general form of the kth-order vector autoregressive model, VAR(k) is

$$x_{it} = \Pi_1 x_{it-1} + \ldots + \Pi_k x_{it-k} + \Phi D_t + \varepsilon_{it}, \quad t = 1, \ldots, T \tag{1}$$

[1]The locomotive effect refers to the instance when a positive country-specific shock is transmitted to another country. Thus increased economic activity in one country stimulates positive economic activity in another country.

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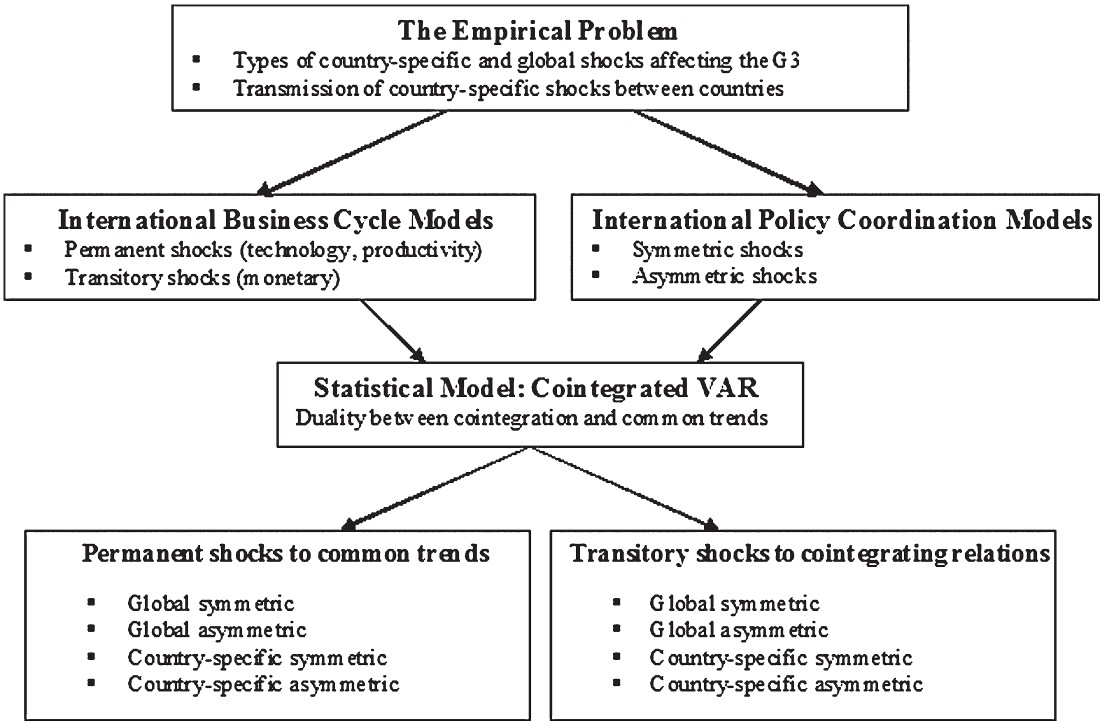

Figure 1. The econometric methodology

where $x_{it} = x_{1t}, x_{2t}, \ldots, x_{pt}$ are the variables of interest, D_t is the deterministic term, which contains permanent impulse dummies and the constant of the model. $\Pi_1, \ldots, \Pi_k$, Φ are parameters of the model, $\varepsilon_{it} \sim$ i.i.d.$N(0, \Omega)$ and k is the lag length. The corresponding vector error correction model (VECM) is

$$\Delta x_{it} = \Gamma_1^{(m)}\Delta x_{pt-1} + \Gamma_2^{(m)}\Delta x_{pt-2} + \ldots + \Gamma_{k-1}^{(m)}\Delta x_{pt-k+1} + \Pi x_{t-m} + \Phi D_t + \varepsilon_{it} \tag{2}$$

where $\Pi = -I + \Sigma_{j=1}^{k} \Pi_j$ and m is an integer between 1 and k. The Π matrix summarizes the long-run effects in the system and stays unchanged regardless of the chosen lag m. $\Gamma_i^{(m)}$ for $i = 1, \ldots, k - 1$ contains the short-run effects of the model and depends on the chosen lag m within the model.

$\Pi = \alpha\beta'$ decomposition allows us to identify the adjustment mechanism in the system examined. Assuming that r is the cointegration rank and p is the number of variables, β' is described by an $r \times p$ matrix, where $\beta' x_{it}$ is the deviation of each variable i from the steady state of the system, and α is a $p \times r$ matrix that shows the speed of adjustment to the steady state for each of the variables in the system. β' represents the common long-run relations in the system with corresponding α factor loadings.

According to the Granger representation theorem stated in Engle and Granger (1987) and Johansen (1991) under the assumption that the variables are integrated of first order, $x_{it} \sim I(1)$, and Δx_{it}, $\beta' x_{it}$ have stationary and invertible vector autoregressive moving average (MA) representation. The VECM $\Delta x_{it} = \alpha\beta' x_{it-1} + \Sigma_j^{k-1}\Gamma_j \Delta x_{it-j} + \Phi D_t + \varepsilon_{it}$ can be presented in its MA form as follows:

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$$x_{it} = C\sum_{s=1}^{t} \varepsilon_{is} + C(L)\varepsilon_{it} + \tau(t) + A \tag{3}$$

where $C = \beta_\perp (\alpha'_\perp \Gamma \beta_\perp)^{-1} \alpha'_\perp$, $\Gamma = I_p - \Sigma_{j=1}^{k-1}\Gamma_j$, $\tau(t) = C\Phi\Sigma_{s=1}^{t} D_s + C(L)\Phi D_t$, the coefficients of $C(L)$ are given by $\Delta C_i = \Pi C_{i-1} + \Sigma_{j=1}^{k-1}\Gamma_j \Delta C_{i-j}$ for $i = 1, 2, \ldots$, and A depends on the initial values of x_{it}. The Granger representation theorem presents a trend-cycle decomposition of a cointegrated VAR. $\alpha'_\perp \Sigma_{s=1}^{t} \varepsilon_{is}$ are common stochastic trends of the model corresponding to $\tilde{\beta}_\perp = \beta_\perp(\alpha'_\perp \Gamma \beta_\perp)^{-1}$ factor loadings and $C(L)\varepsilon_{it}$ is the stationary process, or cycle. The number of common trends is equal to $p - r$.

The common trends, $\alpha'_\perp \Sigma_{s=1}^{t} \varepsilon_{is}$, derived from the MA representation of the model, are the driving forces of the system that push the process along the attractor set. At the same time, the process is pulled towards the attractor set by the adjustment coefficients of the autoregressive representation of the model.

EMPIRICAL RESULTS

Data

The data examined in this paper consist of quarterly real GDP for the USA, Japan and Europe, which is the aggregate of G7 euro area countries France, Germany, and Italy. The period covered is 1970:1–2007:4. Nominal GDP series for France, Italy, and Japan are obtained from the OECD Quarterly National Accounts and Main Economic Indicators database. Nominal GDP series for Germany are obtained from Statistiche Bundesamt Weisbaden. GDP Implicit Price Deflators for France, Italy, and Germany are obtained from the IMF International Financial Statistics database and Eurostat. The US nominal GDP and Implicit Price Deflator are from the US Department of Commerce, Bureau of Economic Analysis. The series are seasonally adjusted, in logarithms, and have a base year of 2000.

We use an aggregate of the G7 euro area countries Germany, France, and Italy as a proxy for Europe. Pre-Euro studies of the G3 either include the UK as well (Elliott and Fatas, 1996) or refer only to Germany, the USA, and Japan. However, after the introduction of the euro the GDP time series of euro area countries are available in euros, while the currency exchange series for the UK would be necessary for aggregation purposes but are not available for the complete period that we examine.

The real GDP series are assumed to follow a random walk with drift process. We estimated a VAR(2) model allowing for a linear trend in the data but not for one in the cointegrated VAR system. The number of lags is selected according to Schwartz, Akaike and Hannan–Quinn information criteria (Table I).

Determination of cointegration rank

The cointegration rank is determined according to the Johansen LR trace test (Johansen, 1988, 1991, 1994). The trace test has size and power distortions, in particular for short time series and for near unit root processes. To correct for the size of the test, small-sample Barlett correction developed by Johansen (2002) is applied. Ho and Sørensen (1996) illustrate that the Johansen (1991) LR test should be used with considerable care for small-sample size, high-dimension systems with $p \geq 4$. The number of variables in this study is 3.

The trace test statistics fail to reject the hypotheses of $p - r = 2$ common trends and $r = 1$ cointegration relation with a very high p-value of 0.76 (Table II). This result is also supported by inspection

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Table I. Tests for lag selection

Model	Observations	Log likelihood	AIC	SIC	HQ
VAR(1)	148	–29.3221	–29.2005	–28.9169	–29.0612
VAR(2)	148	–29.4156	–29.1724	–28.7065	–28.9590
VAR(3)	148	–29.4741	–29.1092	–28.4611	–28.8218
VAR(4)	148	–29.5966	–29.1101	–28.2797	–28.7487

Note: AIC, SIC, and HQ are Akaike, Schwarz, and Hannan–Quinn information criteria, respectively.

Table II. Trace test statistics and roots of the companion matrix

r	$p - r$	Eigenvalue	Trace[a]	95% critical value	p-value[a]
0	3	0.2652	51.5227	29.8044	0.0000
1	2	0.0348	5.4385	15.4082	0.7610
2	1	0.0008	0.1206	3.8415	0.7283

Modulus of three largest roots

Rank = 3	Rank = 2	Rank = 1
0.9978	1	1
0.9851	0.9831	1
0.9094	0.9124	0.9319

Note: r is the number of cointegrating relations and $p - r$ is the number of common stochastic trends in the system.
[a] Barlett correction.

Table III. Restrictions on known β and zero row restrictions on α matrix

USA	Europe	Japan	$\chi^2(\upsilon)$	p-value
β_1	β_2	0	8.5735 (1)	0.0034
0	β_2	β_3	19.6399 (1)	0.0000
β_1	0	β_3	21.6566 (1)	0.0000
0	α_2	α_3	1.5332 (1)	0.2156
α_1	0	α_3	25.1133 (1)	0.0000
α_1	α_2	0	23.7328 (1)	0.0000

Note: '0' signifies a variable whose coefficient in the β vector is restricted to zero. '0' signifies a variable with α row restricted to zero. For the purpose of simplicity, the coefficients of the restricted vectors are suppressed.

of the roots of the companion matrix, which reveals that indeed the lowest root corresponds to $r = 1$ and equals 0.93, and indicates a stationary yet slow equilibrium-adjusting process.

Identification of long-run structure

The information on the long-run steady-state relation of the model is contained in the β cointegrating vector and the long-run identification problem translates into the identification of a β vector. This is achieved by imposing over-identifying restrictions and comparing the significance of the tests. Long-run restrictions on β are tested with the Johansen and Juselius (1992) LR test.

The long-run relations between any pair of countries within the system are rejected finding only one long-run relation (Table III). The cointegration relation is between the entire system: Europe, the USA and Japan and results in one transitory shock that simultaneously affects all three countries and thus is considered to be symmetric.

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Equally important is the identification of a structure that best characterizes the α matrix. There are two important properties of α that should be tested for: a known unit vector and weak exogeneity. The LR test of a known unit vector in α is described in Johansen (1996) and indicates that one of the variables has no permanent effect on the remaining variables in the system. This test is rejected for all three countries with a p-value of zero; thus the results are suppressed.

The weak exogeneity condition is tested for by the LR test described in Johansen and Juselius (1990). This is the hypothesis of whether the cumulative residuals of the variable corresponding to the zero row are a common driving trend in the system. If accepted, that variable affects the long-run stochastic path of the other variables while at the same time is not affected by them. We fail to reject the hypothesis for the USA as a weakly exogenous variable with a p-value of 0.22 (Table III). Consequently, the cumulative residuals of the USA are a common driving trend for the three countries. The shocks to the USA have a permanent influence on the other countries, while the USA itself is not influenced by shocks from those countries. Thus, we categorize US-originated permanent shocks as symmetric permanent shocks that are country-specific and transmit to the remaining countries in the system.

Table IV presents the Π matrix, the α, β vectors and $\alpha_{\perp}$, $\tilde{\beta}_{\perp}$, C matrices according to the restriction that the USA is a weakly exogenous variable in the system. The equilibrium adjustment mechanism is purely between the remaining two countries, Europe and Japan, while, for example, the equilibrium level of Europe's output is

$$\text{Real GDP}^{*}_{\text{Europe}} = 0.5\text{Real GDP}_{\text{U.S.}} + 0.2\text{Real GDP}_{\text{Japan}}$$

According to $\alpha_{\perp}$ the second trend is driven by the cumulative residuals of Europe and Japan. Thus, Europe and Japan transmit permanent shocks between each other and are influenced by permanent shocks from the USA. Figure 2 illustrates that the US common trend plays the dominant role of the driving force in the system, growing 106% over 37 years examined. The Europe–Japan trend is relatively flat and grew only 17%.

To measure the response of the countries' outputs to permanent and transitory shocks, the error terms of the MA representation ε_t are transformed to structural shocks u_t, where orthogonality of structural shocks is achieved by Choleski decomposition (Juselius, 2006). The outcome does not change as a result of varying the order of the countries.

The first row of Figure 3 presents the responses of the outputs of the USA, Europe and Japan to the common transitory shock. The effect of the transitory shock is below 1% for all three countries. It has an immediate effect on Europe and Japan and up to a year lagged effect on the USA. The transitory shock is very persistent, with a half-life of 3 years.

The second row of Figure 3 presents the responses of the outputs of the USA, Europe and Japan to a permanent shock in the USA. A 1% positive permanent shock in the USA will permanently increase the output of Japan by 1.2% and the output of Europe by 0.8%. The US permanent shock will immediately affect Japan but it will take a year to have a permanent effect of the same size on Europe. According to the impulse response functions, the spread of the US permanent shock will be faster in Japan than in Europe.

The third row of Figure 3 presents the responses of the output of the USA, Europe and Japan to a 1% shock to the second common trend. A 1% shock to the second trend will have an insignificant (0.1%) negative transitory effect on US output. However, in the long run it will permanently increase the output of Japan by 1.6% and the output of Europe by only 0.4%.

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Table IV. Long-run and MA representation matrices

$\Pi = \alpha\beta'$ matrix			
	USA	Europe	Japan
USA	0.0000	0.0000	0.0000
	(0.0136)	(0.0266)	(0.0062)
Europe	0.0596	–0.1171	0.0272
	(0.0110)	(0.0217)	(0.0050)
Japan	0.0732	–0.1438	0.0334
	(0.0143)	(0.0280)	(0.0065)
β' matrix			
	USA	Europe	Japan
β_1	1.0000	–1.9658	0.4572
	(NA)	(0.1551)	(0.1261)
α' matrix			
	USA	Europe	Japan
α_1	0.0000	0.0596	0.0732
	(0.0136)	(0.0110)	(0.0143)
C			
	$\Sigma\varepsilon_{1t}$	$\Sigma\varepsilon_{2t}$	$\Sigma\varepsilon_{3t}$
USA	1.0000	–0.0000	0.0000
	(0.1620)	(0.3186)	(0.0741)
Europe	0.7121	–0.4000	0.3256
	(0.1407)	(0.2767)	(0.0643)
Japan	0.8747	–1.7195	1.4000
	(0.3515)	(0.6910)	(0.1607)
$\tilde{\beta}'$			
	USA	Europe	Japan
$\tilde{\beta}_{\perp 1}$	1.0000	0.7121	0.8747
	(0.1620)	(0.1407)	(0.3515)
$\tilde{\beta}_{\perp 2}$	0.0000	–0.4000	–1.7195
	(0.3186)	(0.2767)	(0.6910)
$\alpha'_{\perp}$			
$\alpha_{\perp 1}$	1.0000	0.0000	0.0000
$\alpha_{\perp 2}$	0.0000	1.0000	–0.8142
			(0.2070)

Note: t-values are in parentheses.

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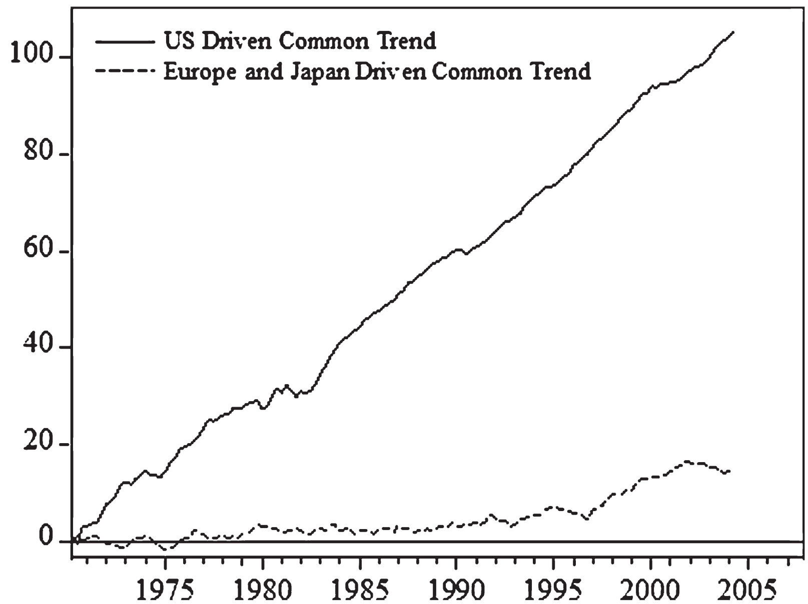

Figure 2. Common trends of the system

VALIDITY OF MODEL CHOICE AND SENSITIVITY OF ESTIMATES

Structural breaks and thresholds

Economic literature documents the following possible existence of structural breaks for the G3: the 1973:2 oil shock (Perron, 1989) and the slowdown in growth rates due to the oil shock in Europe in 1974 (Banerjee *et al.*, 1992). The economic knowledge of reforms and interventions also adds the following possible dates to the list: the 1990:1 Japanese burst of the 'bubble economy' and the 1991:1 German reunification.

Bai and Perron's (1998, 2003) $SupF_T(l+1/l)$tests for multiple structural breaks and at the 5% significance level finds no breaks in the real GDP series of the USA and Europe, and one break in the real GDP of Japan. The break is estimated in 1990:4 and could correspond to the 1990 economic events in Japan. At the same time Bai's (1999) test does not estimate breaks for any of the G3 outputs. Prodan (2008) documents size and power distortions in the Bai and Perron (1998, 2003) tests while arguing that the Bai (1999) test has better size performance. Prodan's (2008) *modified Bai procedure*, which improves the power of the test, is used to calculate the bootstrap critical values for Bai's (1999) test.

We employ Hansen and Seo's (2002) test for the presence of threshold where, under the null hypothesis, the model reduces to a liner VECM. The $SupLM^0$ test for known β with bootstrap critical values (Hansen and Seo, 2002) rejects the presence of threshold at the 5% level.[2] Hansen and Seo (2002) report that the linear Johansen estimator of β performs reasonably well even in the presence of the threshold effect. Table V illustrates results for the Bai and Perron (1998, 2003), Bai (1999), and Hansen and Seo (2002) tests.

[2] Hansen and Seo (2002) simulations show that the size for the $SupLM^0$ test is very similar to the *SupLM* test that estimates β coefficients, and the power is even slightly higher.

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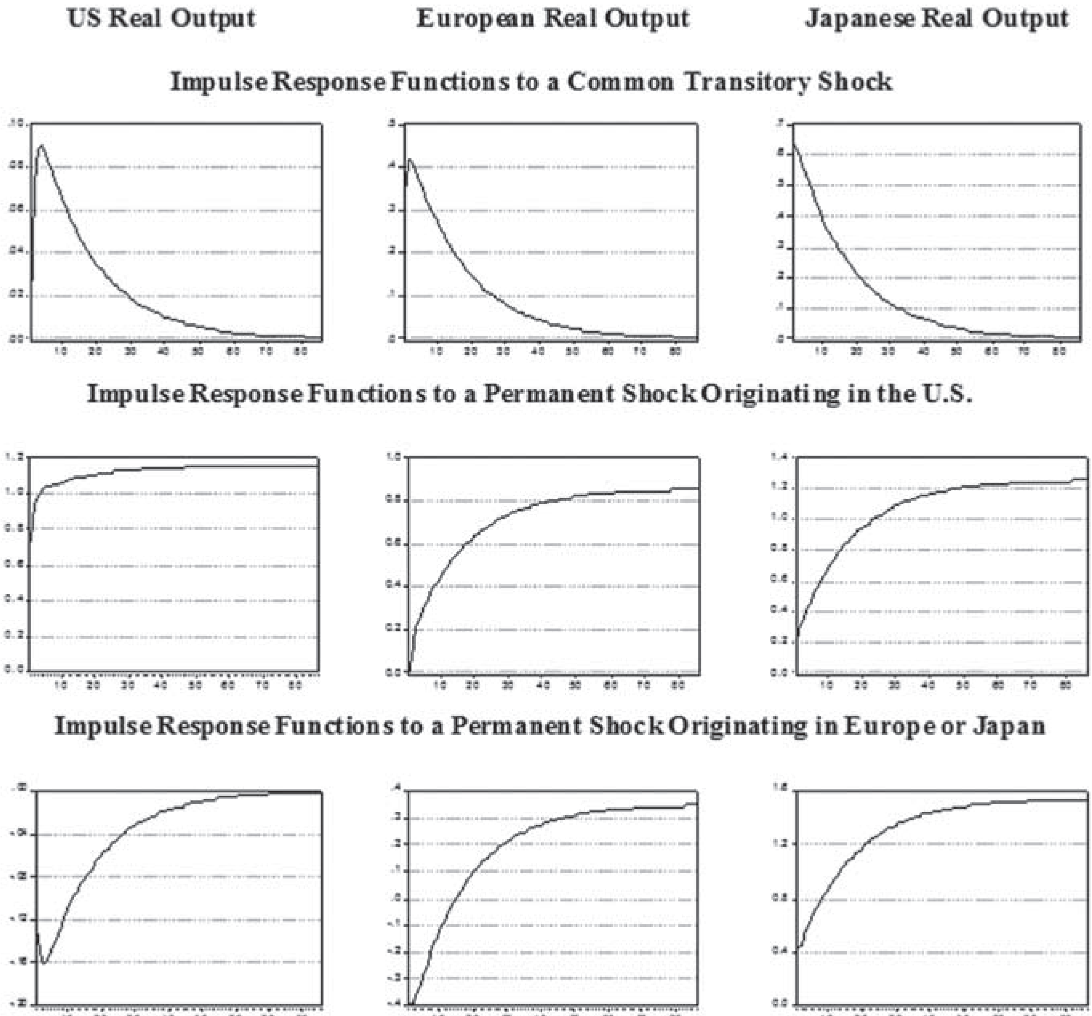

Figure 3. Impulse response functions

Parameter consistency and in-sample forecast

Following Hansen and Johansen (1999), we conduct a recursive analysis to test for parameter consistency in the estimated CVAR model, where the outcome is presented graphically and used as a diagnostic tool. Figure 4 shows the plot of the fluctuation test, where for more symmetric representation the Eigenvalue is transformed as $\zeta_i = \log(\lambda_i) - \log(1 - \lambda_i)$, $i = 1$. Figure 5 illustrates the LM test of β constancy. The details of both test methodologies are discussed in Hansen and Johansen (1999). We chose 1970:2–1990:4 as the base and reference periods for evaluation in order to check whether the parameters are consistent for the remaining period. This choice of reference period should unhide the evidence of non-consistency between the two periods, considering the possible

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Table V. Tests for structural breaks and threshold effect

Bai and Perron (1998, 2003)					
	$SupF_T(1/0)$	*UD*max	*WD*max(5%)	LWZ	BIC
USA	2.9015	4.2254	9.0841	0	0
EU	6.7931	6.7931	8.1676	0	0
Japan	25.6128	25.6128	25.6128	1	1
5% c.v.	*8.58*	*8.88*	*9.91*		

Bai (1999)			Hansen and Seo (2002)	
	$F_T(1/0)$	$F_T(2/0)$	$SupLM_0$	
USA	3.1198	19.0728	LM test statistics	17.1829
5% c.v.	70.*0531*	*70.012*	*Bootstrap 5% c.v.*	*19.5139*
EU	11.3342	19.7231	*Bootstrap p-value*	*0.1408*
5% c.v.	*48.0381*	*49.4170*		
Japan	11.8515	22.4124		
5% c.v.	*23.9146*	*28.6385*		

Note: Both $SupF_T$ and F_T test H_0 of l break against $l + 1$, labeled as $SupF_T(l + 1/l)$ and $F_T(l + 1/l)$). *UD*max and *WD*max test for the presence of at least one break. LWZ and BIC choose number of breaks present. In the case of indication of at least one break, Bai and Perron (2003) recommend implemented sequential procedure. The results of the sequential procedure match the results reported in the table.

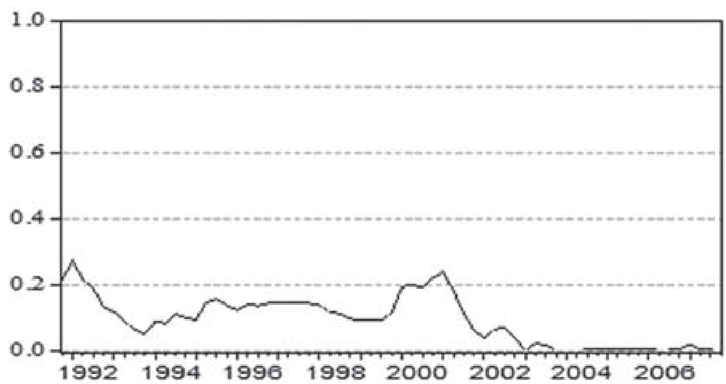

Figure 4. Fluctuation test

break of 1990:4 for Japan's GDP. The test statistics for these tests are divided by the 95% quantile of the distribution. Thus the rejection line is 1.0, indicating that both tests fail to reject consistency of parameters.

A 2-year-ahead in-sample forecast is conducted around the possible break point of 1990:4 for years 1990 and 1991. Figure 6 demonstrates a good fit of model estimates with RMSE approaching zero. Likewise, end-of-sample 1-, 4-, and 10-year-ahead in-sample forecasts indicate a very good fit with the highest RMSE for 10-year-ahead forecasts (Figure 7) of 0.01 (USA), 0.02 (EU) and 0.09 (Japan).

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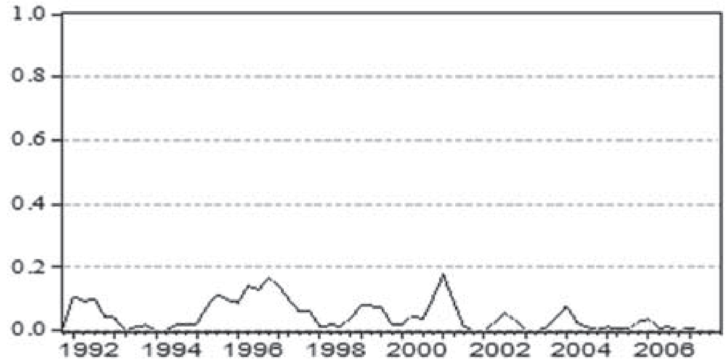

Figure 5. LM test of constancy

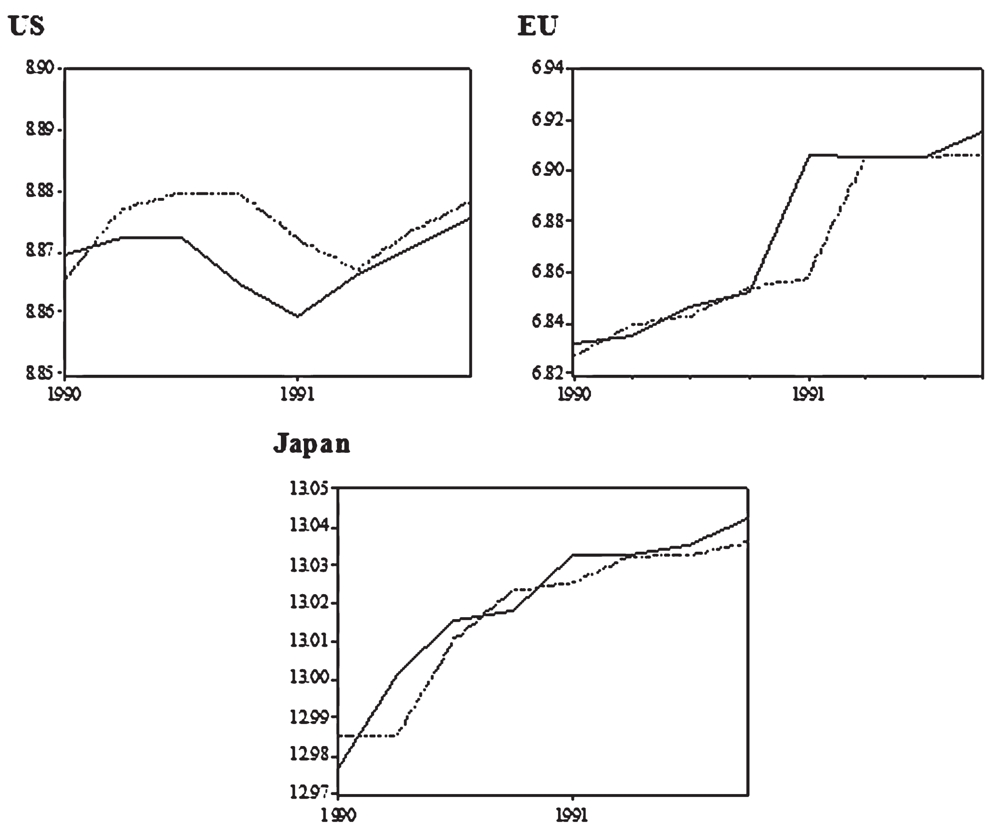

Figure 6. Two-year ahead in-sample forecast starting in 1990:1

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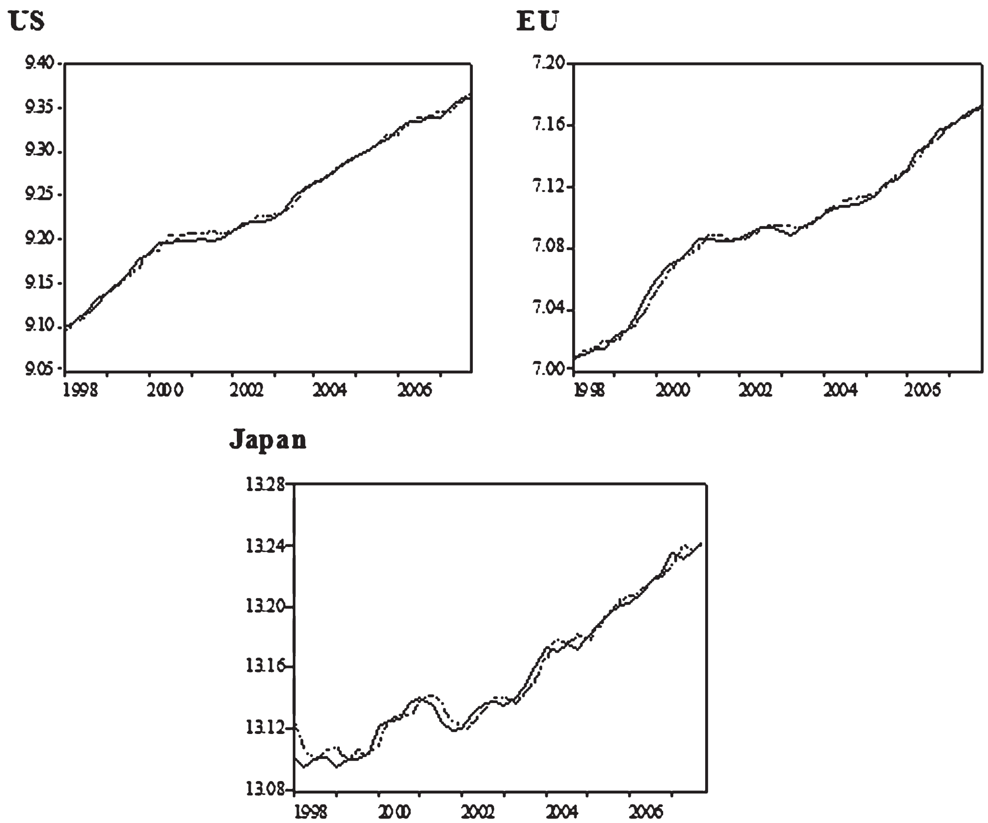

Figure 7. Ten-year ahead in-sample forecast

SIGNIFICANCE OF EMPIRICAL RESULTS

The significance of quantitative measures in understanding the transmission mechanism of shocks, and in particular the possible contribution of those results to the G7 policy coordination efforts, becomes apparent from a look back at the failure of the 1978 Bonn summit. In the summit, leaders of France, Germany, and Japan committed to expansionary fiscal policy packages in order to stimulate their economies and to have a locomotive effect on the other G7 countries' growth rates, while the USA promised to deregulate domestic oil prices. These economic policy commitments contributed to a spurt of global inflation, and thus the Bonn summit is viewed as an example of a failure in international policy coordination. Therefore, the policies promoted by the Bonn summit are in opposition to the conclusions reached by this study and by other empirical investigations on the propagation of productivity shocks among G7 countries (Ahmed *et al.*, 1993; Elliott and Fatas, 1996). The results of this paper show that a change in the growth rate of Europe or Japan will not have a significant effect on the other countries, and that, when experiencing a positive productivity shock, the USA has a locomotive effect on the rest of the countries.

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Result 1: global symmetric transitory shock

The existence of a symmetric transitory shock in the system with one long-run relation that pulls countries to the steady state is supported by Meyer *et al.* (2004), who point out that even though the current monetary authorities are more reluctant to commit to concrete, pre-announced actions of monetary policy coordination, there is an informal consensus on the direction of policy and on the appropriate responses to shocks. Meyer *et al.* (2004) suggest that in the case of monetary policy continuous information exchange between government officials can lead to an implicit form of policy coordination. The finding of a symmetric transitory shock supports the policy cooperation efforts of summits, since the models on policy coordination show that a common monetary response is optimal in the case of symmetric shocks. On the other hand, the persistence of the transitory shock with a half-life of 3 years is evidence of money non-neutrality and of existing rigidities in the economies.

Result 2: country-specific permanent symmetric shock

The permanent shocks originating in the USA have permanent effect on the rest of G3 finding is consistent with Elliott and Fatas (1996), who find that positive cross-country comovements are due to the transmission of productivity shocks originating in the USA. It is also supported by the Ahmed *et al.* (1993) study of international real business cycles that finds that supply shocks originating in the USA are important in generating international business cycles in the remaining G7 economies.

Result 3: country-specific permanent asymmetric shock

The productivity shocks to Europe or Japan transmit but do not have a significant effect on the opposite country's growth rate, and have no effect on US growth rate. The existence of a second common trend between Europe and Japan that has a weak growth rate can be a possible explanation for why the business cycle of the G3 is diverged and for why the growth rates of Europe and Japan are weaker than that of the USA.

Discussion on the synchronization of international business cycles

How does this study contribute to the discussion on the existence of synchronization of business cycles among G7 nations? The conclusions reached in the economics literature on G7 business cycle synchronization and convergence are mixed. Some find a significant world factor and a convergence between developed nations' business cycles (Gregory *et al.*, 1997; Kose *et al.*, 2003, 2008; Lumsdaine and Prasad, 2003; Canova *et al.*, 2004), and others emphasize stronger emergence of group cycles among the G7 (Stock and Watson, 2005; Schirwitz and Wälde, 2004).

In relation to the current study, Stock and Watson (2005) find a divergence among the G3, showing that Japan's cyclical movements are different from those of the rest of the countries, while the rest of the G7 countries are grouped into a Euro zone group and an English-speaking group. Schirwitz and Wälde (2004) conclude that European countries' cycles are more synchronized with themselves than with the rest of the G7. At the same time, while finding significant evidence of a world factor, Canova *et al.* (2004) find no evidence of either a recent increase in synchronization of G7 cycles nor of emergence of an EU cycle.

The findings of this paper do not contradict any of those studies, but rather contribute to them by adding insight as to what can possibly explain the mixed evidence on synchronization among the G3. The finding that the G3 countries are affected by one global symmetric transitory shock can be one possible explanation of existing comovement among those economies. The transmission of the US permanent shocks to Europe and Japan can yield estimations of a strong common factor among

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G3 growth rates, but can be misleading in terms of indicating whether the origin of the shock is global or country-specific. On the contrary, Canova *et al.* (2004) find that US technology shocks are not behind the movements of the world indicator. The existence of a second common trend among the G3 can be a cause for the finding of divergence between G3 business cycles.

CONCLUSION

The objective of this paper was to identify the types of shocks that affect the G3 group and the transmission mechanism of those shocks from one country to another. The categorization and interpretation of shocks is based on theoretical studies on international business cycles and international policy coordination. The objective is achieved through the application of CVAR methodology. We show that the CVAR model is a valid choice that demonstrates good fit with the data-generating process of the time series examined. It is important to note that while the structure of the CVAR model is not imposed based on a theoretical model, there is only one statistically significant structure identified in the system examined. Further extension studies incorporating country-specific variables to trace further the origins of the shocks within each country could be useful.

We identify one symmetric global transitory shock that affects all three countries and that is very persistent with a half-life of 3 years. The country-specific US permanent shocks have an approximately symmetric effect on Europe and Japan. The permanent shocks originating in Europe or Japan do not have a significant effect on the opposite country's growth rate, and have no effect at all on US output.

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