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ABSTRACT

This paper empirically models the relationship between quarterly business cycle movements in the US and the other G7 countries, including an analysis of the US with a European (E15) aggregate. By using a nonlinear smooth transition vector autoregressive framework, the possibility of asymmetric business cycle linkages is explored. Different types of possible business cycle linkages are represented through three nonlinear VAR models for each country with the US, where these represent common business cycle regimes, US-led (but not common) regimes and country-specific (or idiosyncratic) regimes. In general, high annual US growth is found to lead to a distinct business cycle regime in other G7 countries compared with average or low US growth. Tests indicate that quarterly US growth patterns are important for other countries primarily in the lower regime, with domestic autoregressive lags then sometimes insignificant.

1 Introduction

International business cycle fluctuations constitute a fascinating, and important, topic of macroeconomic research. While early contributions examined the extent of business cycle correlations across major industralised countries (see, for example, Artis and Zhang, 1997; Backus, Kehoe and Kydland, 1995), a number of recent studies have sought to document the existence of a world and/or European business cycle (including Artis, Krolzig and Toro, 2004; Lumsdaine and Prasad, 2003; Kose, Otrak and Whiteman, 2003) or to model international interactions (for example, Pesaran, Schuermann and Weiner, 2003). However, there is also evidence that these international business cycle relationships may not be constant over time, possibly due to increased economic integration in Europe (Artis and Zhang, 1997, 1999; Inklaar and Haan, 2001). Nevertheless, the hypothesis that the business cycle linkages of important European countries with the US have lessened due to European integration has been called into question, due to the apparently closer correlations between the US and European countries at the beginning of the twenty-first century than during the 1990s (Doyle and Faust, 2002; IMF, 2001; OECD, 2002; Perez, Osborn and Sensier, 2003). It seems, therefore, that European integration provides at best only a partial answer to the changing linkages between the US and other important world economies.

This paper focuses on business cycle asymmetries in international business cycle linkages through the use of a nonlinear system of equations for the bivariate relationship between quarterly growth in the US and that of other G7 countries. In the light of European economic integration, we also examine the relationship between the US and an aggregate series for the European Union. In contrast to the many studies that consider international business cycle movements in a linear framework, our nonlinear model permits the cross-country links to be asymmetric, in the sense they can alter as a function of the regime, which is defined in terms of annual growth.

As the dominant country in the world economy, our analysis focuses on the role of the US, and we investigate whether regimes in US growth affects each of the other G7 countries. More specifically, in the context of regimes detected in a smooth transition vector autoregressive (STVAR) system, we examine three possibilities for regimes in growth, namely: that the country (or the E15) has common regimes with the US, that the regimes differ but are nevertheless led by the US, and that the regimes are country-specific. The only study of which we are aware that examines similar issues in a nonlinear framework is Phillips (1991). However, that analysis is based on a Markov switching nonlinear model and is more restrictive in assuming that the dynamics are constant over regimes. Our preference for the STVAR approach is based on the flexibility with which the underlying regimes can be defined, including the possibility of intermediate (or multiple) regimes that arise from the use of a continuous regime indicator.

Although smooth transition models are widely applied in their univariate form, nonlinear STVAR systems are relatively rare. Perhaps closest to our application is Anderson and Vahid (2001), who estimate bivariate STVAR systems for output growth and the term structure of interest rates in each of the G7 countries. Other applications of these models include Huh and Lee (2002), Weise (1999) and Rothman, van Dijk and Franses (2001). With the exception of Anderson and Vahid (2001), these studies assume that the same transition function drives the regimes in all equations of the STVAR. However, one of the key questions in our analysis is the relationship between the regimes in US growth and that of the other G7 countries, so that the nature of the transition function(s) is given a particular focus below.

The next section details our model specification and the estimation procedure, including the interpretation of the three transition functions employed in our analysis. Section 3 details our results, presenting evidence of nonlinearity in the bivariate relationships, as well as discussing the implications of the estimated models. Finally, Section 4 offers some conclusions.

2. STVAR Models

We model the quarterly growth in (seasonally adjusted) real GDP from 1970:I to 2002:I, as shown in Figure 1; details of the series are given in the Data Appendix. As noted above, our bivariate models examine the relationships between the US and the European Union (represented by the aggregate series E15)[1], and between the US and each of the G7 countries.

Our first step is to estimate a two country linear VAR for the growth rate of the US and each of the other countries (or the E15). We examined the Akaike, Schwarz (Bayesian) and Hannan-Quinn lag length selection criteria, to a maximum lag of 6. On the basis of these results[2], we adopted a VAR(2) specification for the subsequent modelling.

[1] The E15 series is an aggregate for the 15 countries that were members of the European Union prior to the enlargement of May 2004.

[2] The Akaike is the least parsiminous of these criteria and, using a common sample for all estimations, this indicated one or two lags, except for Italy and Japan where three lags were indicated. However, both Schwarz and Hannan-Quinn indicated one or two lags for the Italy/US and Japan/US models. To ease comparison across models, we adopted two lags in all cases.

The remainder of section first discusses the nature of the STVAR models examined, before turning to the practical issues of nonlinearity testing and STVAR model estimation. Finally, we discuss the interpretation of hypothesis tests we conduct on the coefficients of the estimated models.

2.1 The ST-VAR Model for Business Cycle Linkages

Based on the two lags of the linear specification, the STVAR model we employ has the form:

$$\begin{aligned}
\Delta US_t &= \alpha_1 + \sum_{i=1}^{2} \beta_{1i} \Delta US_{t-i} + \sum_{i=1}^{2} \delta_{1i} \Delta X_{t-i} \\
&\quad + F_1(z_{1t}) \left(\alpha_2 + \sum_{i=1}^{2} \beta_{2i} \Delta US_{t-i} + \sum_{i=1}^{2} \delta_{2i} \Delta X_{t-i} \right) + \varepsilon_{1t} \\
\Delta X_t &= \alpha_3 + \sum_{i=1}^{2} \beta_{3i} \Delta US_{t-i} + \sum_{i=1}^{2} \delta_{3i} \Delta X_{t-i} \\
&\quad + F_2(z_{2t}) \left(\alpha_4 + \sum_{i=1}^{2} \beta_{4i} \Delta US_{t-i} + \sum_{i=1}^{2} \delta_{4i} \Delta X_{t-i} \right) + \varepsilon_{2t}
\end{aligned} \qquad (1)$$

where ΔUS_t represents the quarterly US growth rate and ΔX_t is the growth rate in the other country. The disturbances $\varepsilon_t = (\varepsilon_{1t}, \varepsilon_{2t})'$ are assumed to be white noise with $E(\varepsilon_t \varepsilon_t') = \Omega$.

In this model, regimes are captured through the logistic transition functions

$$\begin{aligned}
F_1(z_{1t}) &= [1 + \exp\{-\gamma_1 (z_{1t} - c_1)/\hat{\sigma}_1\}]^{-1} \\
F_2(z_{2t}) &= [1 + \exp\{-\gamma_2 (z_{2t} - c_2)/\hat{\sigma}_2\}]^{-1}
\end{aligned} \qquad (2)$$

which satisfy $0 \leq F_i(z_{it}) \leq 1$. As is clear from (2), these regimes are defined by the values of the transition variables z_{1t}, z_{2t}, and the logistic form ensures that they are continuous and monotonically increasing functions of the transition variables. For interpretation purposes, it is convenient to distinguish the regimes that apply at the extremes, where $F_i(z_{it}) = 0$ and $F_i(z_{it}) = 1$. We later refer to these as the lower and upper regimes, respectively. Since the intercept and all coefficients of an equation in (1) can change as a function of the transition variable, this model allows the possibility that the dynamics of growth varies over regimes.

Nevertheless, an advantage of this smooth transition framework over one with binary regimes (such as the Markov switching model, used by Phillips, 1991) is that it is sufficiently flexible to allow a mixture of regimes, where $0 < F_i(z_{it}) < 1$. For example, $F_i(z_{it}) = 0.5$ when $z_{it} = c_i$, so that this value delivers a model with coefficients given by an equal weighting of the distinct coefficients sets that apply in the two extreme regimes. The slope parameter γ_i in (2) dictates the slope of the transition function, with $F_i(z_{it})$ approaching a binary indicator variable, with threshold value c_i, as $\gamma_i \to \infty$. Conventionally for these models, and to aid comparison across models, the exponential term in (2) is standardised by the sample standard deviation of the corresponding transition variable, $\hat{\sigma}_i$ (i = 1, 2).

In order to examine the role of the US in the international propagation of business cycle movements, we consider three possibilities for z_{1t} and z_{2t} as follows:

1. Common regimes. Common regimes are captured by restricting the equations of (1) so that the same transition function is used for each equation, namely $F_1(z_{1t}) = F_2(z_{2t})$. As the largest economy in the world, we regard it as *a priori* more plausible that these regimes originate from the US than the other country, so that the transition variable in this case depends on the US business cycle, but the parameters c and γ are obtained through a joint estimation of the two equations.
2. US-led regimes. Although this case specifies $z_{1t} = z_{2t}$ to depend on US growth, the values of γ_1, γ_2 and c_1, c_2 are not restricted to be identical in the two transition functions of (2). Thus, we allow the US business cycle to determine the regimes of the other country, but these regimes are not identical across countries.
3. Country-specific regimes. We allow each country to have its own idiosyncratic business cycle regimes. Since the first equation of (1) refers to the US and the second equation to another G7 country or the E15, z_{1t} depends on US growth, while z_{2t} depends on the country's own growth rate.

Since we model GDP growth, the business cycle measures we employ for the transition variable(s) are based on this variable. However, it is unclear whether quarterly, six-monthly or annual growth rates provide the appropriate measure of business cycle movements[3]. We initially considered each of these, but for all countries the annual growth rate gave the strongest evidence of nonlinearity. Further, since annual growth is a relatively smooth series, the regimes may be expected to capture general movements in economic growth. Therefore, we use annual GDP growth as the transition variable in all models considered here.

2.2 Nonlinearity Tests, Model Specification and Estimation

Prior to undertaking nonlinear modelling, we employ tests of the null hypothesis of linearity, using with the linear VAR as the baseline. As spelt out in, for example, Weise (1999) or Rothman *et al*. (2001), this can be considered as a test of the null hypothesis H_0: $\gamma_1 = \gamma_2 = 0$ in (2). However, some parameters of (1) are unidentified under this null hypothesis, and this

[3] As usual, these growth rates were measured as the difference over one, two or four quarters (as appropriate) of the logarithm of real GDP.

problem can be avoided by taking a Taylor series approximation to the transition function. We use a linear approximation to conserve degrees of freedom in this VAR context, so that the approximating model is

$$\begin{aligned}
\Delta US_t &= \alpha_1 + \sum_{i=1}^{2} \beta_{1i}\Delta US_{t-i} + \sum_{i=1}^{2} \delta_{1i}\Delta X_{t-i} \\
&\quad + \theta_{10} z_{1t} + \sum_{i=1}^{2} \theta_{1i} z_{1t}\Delta US_{t-i} + \sum_{i=1}^{2} \theta_{1,i+2} z_{1t}\Delta X_{t-i} + \varepsilon_{1t} \\
\Delta X_t &= \alpha_3 + \sum_{i=1}^{2} \beta_{3i}\Delta US_{t-i} + \sum_{i=1}^{2} \delta_{3i}\Delta X_{t-i} \\
&\quad + \theta_{20} z_{2t} + \sum_{i=1}^{2} \theta_{2i} z_{2t}\Delta US_{t-i} + \sum_{i=1}^{2} \theta_{2,i+2} z_{2t}\Delta X_{t-i} + \varepsilon_{2t}
\end{aligned} \tag{3}$$

and the test for nonlinearity is a test of the significance of the terms involving z_{1t}, z_{2t} in (3).

We conduct a test for nonlinearity in the system, which considers the joint null hypothesis H_0: $\theta_{ji} = 0$ ($j = 0, \ldots, 4$; $i = 1, 2$) in (3). Let $\hat{\Omega}_0 = \sum e_t e_t{}'/T$ and $\hat{\Omega}_1 = \sum e_t^U e_t^U{}'/T$ be the estimated variance-covariance matrices of residuals from the restricted and unrestricted systems, respectively. Then, under the null hypothesis of linearity, the likelihood ratio statistic $LR = T\{\log|\hat{\Omega}_0| - \log|\hat{\Omega}_1|\}$ is asymptotically distributed as χ^2 with 10 degrees of freedom. We follow the proposal of Sims (1980) and replace T by $T - c$, where c is the number of parameters estimated per equation in the unrestricted system[4]. Although based on a first-order Taylor series approximation, this test is a natural extension to the vector case of the nonlinearity test recommended by Teräsvirta (1994) for univariate smooth transition models.

Each STVAR model is estimated by nonlinear least squares. In order to obtain reliable starting values, particularly for the γ and c parameters in (2), we initially undertake a grid search over a range of possible starting values. To be more precise, we estimate each equation of (3) by ordinary least squares over a grid of values of γ_i = 1, 2, …, 1000, 1010, …, 10,000. For the location parameter c_i, we trim the extreme 15% of observations from either end of the observed distribution of values for z_{it} and then take 100 equally spaced points.

For the common regimes model, the grid search just outlined is undertaken over the parameters of the single transition function in the context of the system of two equations. Each set of parameters delivers an implied transition function and, conditional on this function, ordinary least squares (separately for each equation) is used to obtain corresponding

[4] In practice, we estimate the unrestricted model using two observations less then the restricted model, since each z_{it} is a lagged annual difference, resulting in two additional starting observations being required compared with the restricted model. The sample size T used in computing the test statistic is that for the unrestricted model.

estimates of all other coefficients in (1). The set of values that minimises $\log|\hat{\Omega}|$ provides the initial values for a nonlinear estimation undertaken over all parameters, including those of the transition function(s).

For the US-led regimes and country-specific regimes models, distinct transition functions are used in each equation and hence the preliminary grid search over the parameters of the relevant transition function is performed separately for each equation. The initial values used for the (system) nonlinear estimation are those that minimise the residual sum of squares of the equation.

2.3 Hypothesis Tests in the STVAR Models

The models using US transition functions in both equations, namely the first two cases discussed in Section 2.1, are nested. Consequently, (conditional on the presence of nonlinearity in the equations) a conventional likelihood ratio statistic for the validity of the restrictions is valid. We conduct such a test for common regimes below[5].

To focus on the different regimes implied by $F_i(z_{it}) = 0$ and $F_i(z_{it}) = 1$, (1) can be equivalently reparameterized as

$$\begin{aligned}
\Delta US_t &= [1 - F_1(z_{1t})]\left(\alpha_{10} + \sum_{i=1}^{2}\phi_{1i}^{0}\Delta US_{t-i} + \sum_{i=3}^{4}\phi_{1i}^{0}\Delta X_{t-i+2}\right) \\
&\quad + F_1(z_{1t})\left(\alpha_{11} + \sum_{i=1}^{2}\phi_{1i}^{1}\Delta US_{t-i} + \sum_{i=3}^{4}\phi_{1i}^{1}\Delta X_{t-i+2}\right) + \varepsilon_{1t} \\
\Delta X_t &= [1 - F_2(z_{2t})]\left(\alpha_{20} + \sum_{i=1}^{2}\phi_{2i}^{0}\Delta US_{t-i} + \sum_{i=3}^{4}\phi_{2i}^{0}\Delta X_{t-i+2}\right) \\
&\quad + F_2(z_{2t})\left(\alpha_{21} + \sum_{i=1}^{2}\phi_{2i}^{1}\Delta US_{t-i} + \sum_{i=3}^{4}\phi_{2i}^{1}\Delta X_{t-i+2}\right) + \varepsilon_{2t}.
\end{aligned} \tag{4}$$

In order to consider the role of US in leading growth in other G7 countries, our principal interest focuses on the second equation of (4). For a given transition function $F_2(z_{2t})$, causality tests can be conducted for the role of quarterly US growth in the separate regimes through tests of

$$\phi_{21}^{r} = \phi_{22}^{r} = 0, \tag{5}$$

[5] Anderson and Vahid (1998) present a test for common nonlinearity based on a Taylor-series approximation to the transition function. However, since we have used only a first-order approximation, we prefer to base the test on estimated nonlinear models. We do not use the test of Vahid and Engle (1997) for codependent cycles, since this is based on a linear specification.

which is computed separately for $r = 0, 1$. In a similar way, the importance of autoregressive terms in the separate regimes can be examined as a test of

$$\phi_{23}^{r} = \phi_{24}^{r} = 0, \qquad (6)$$

which is again considered for the separate regimes $r = 0, 1$.

The hypotheses of (5) and (6) examine the possibly distinctive roles played by quarterly US and domestic growth rates over regimes. In order to investigate whether such differences may apply, we also examine regime invariance for quarterly US growth through the joint test

$$\phi_{21}^{0} = \phi_{21}^{1}, \quad \phi_{22}^{0} = \phi_{22}^{1}. \qquad (7)$$

Similarly, constancy of the autoregressive lags is examined through

$$\phi_{23}^{0} = \phi_{23}^{1}, \quad \phi_{24}^{0} = \phi_{24}^{1} \qquad (8)$$

while the corresponding test for invariance of the intercepts over regimes considers

$$\alpha_{20} = \alpha_{21}. \qquad (9)$$

Since these tests of (7)-(9) examine only sub-sets of coefficients, they do not constitute overall tests for the presence of nonlinearity[6], and hence they can be conducted using the conventional (asymptotic) χ^2 distribution.

We also perform analogous causality and invariance tests to those of (5) to (9) for the US equation in each system. Although parameterised here in terms of the representation of (4), equivalent linear restrictions exist in terms of (1). All these test are conducted as Wald tests[7].

3. Results

Before we turn to the estimated models, Table 1 reports substantial evidence of nonlinearity in the bivariate VAR models, with the test statistics significant at 10 percent in all cases. For France and E15, the use of lagged annual US growth as the transition variable in both

[6] Note that we cannot perform a test that all coefficients in (4) vary over regimes, since this constitutes a test for the presence of nonlinearity and hence (since they are regime-dependent) the coefficients are not identified under the null hypothesis. Each of these tests on sub-sets of coefficients is valid, conditional on the presence of nonlinearity relating to other coefficients.

[7] As a check, we estimate both (1) and (4), with the tests performed using the appropriate restrictions on the parameters of each.

equations leads to more significant rejection of nonlinearity than the use of own growth as the transition. On the other hand, for Japan the opposite is true. In the cases of Canada, Germany the UK and, to a lesser extent, Italy, the similar significance of the two sets of results in Table 1 makes it difficult to identify the appropriate transition variables.

Based on these results, we estimate STVAR models for the three cases of common business cycle regimes, US-led regimes and country-specific regimes, as discussed in Section 2.1. The focus in the final two subsections is the nature of the impact of the US output growth on the other G7 countries and Europe (section 3.2) and whether the US economy can be considered closed with respect to other countries (section 3.3).

3.1 Overview of Estimated STVAR Models

Prior to considering the implications of the estimated STVAR models, Table 2 summarises their system goodness-of-fit according to the log determinant of the estimated disturbance covariance matrix and presents the results of the test for common regimes. Note that since the same number of parameters are estimated in the models with US-led regimes and country-specific regimes, the log determinant values can be compared for these models. A comparison across the models with different numbers of parameters is provided by minimising AIC/SIC, for which the values are also presented.

Consider, first, the test for common regimes for the two estimated STVAR specifications involving $F_2(\Delta_4 US_{t-1})$. For the European aggregate, together with Italy and Japan, the evidence against common regimes is not very strong. However, (according to the log-determinant and AIC, but not BIC for Italy) country-specific regimes provide a better fit than ones based on US growth for Italy and Japan, a finding in accordance with the results of Table 1. Taken in conjunction with AIC/BIC, the results for E15 in Table 2 point to a common regimes model for the US and the European aggregate.

The models involving Canada, France, Germany and the UK reject common regimes for these countries with the US (at the 5 percent level), against an unrestricted US-led regime. Nevertheless, in each of these cases, $\log\left|\hat{\Omega}\right|$ indicates that, when US-led unsynchronised regimes and country-specific regimes are compared, US growth provides the transition variable for these countries. AIC also points to these US-led models, although BIC prefers the more parsimonious common-regime model for France.

Therefore, while Table 2 points to the regimes in most G7 countries being determined by US growth, the common regimes specification is not supported strongly overall. The estimated transition functions (Table 3) indicate why this is the case. The transition function $F_1(\Delta_4 US_{t-1})$ for the US equation, whether used in a common regimes model or not, typically has a threshold value c_1 around 2.2 percent growth over a year; as seen from Figure 2, this value approximates average annual growth. However, the estimated threshold value for US growth in the equation for other G7 countries, c_2, is generally higher, at around 3-5 percent. Therefore, whereas the business cycle regimes for the US can be interpreted as above and below average annual growth, the US regimes relevant for other countries distinguish high growth, where $F_2(\Delta_4 US_{t-1}) = 1$, from average and low growth.

These comments are reinforced by Figures 3 and 4 which plot the values of the transition functions over time for the common-regimes and US-led models. (Note that, in the latter case, the transition function shown for the US is that from the bivariate model with E15.) Not surprisingly, and with the single exception of the UK model, the transition function values are similar for all common-regimes models in Figure 3. The upper regime occurs less frequently for non-US countries in Figure 4, although there is a substantial proportion of such observations for France and the E15. Although obtained from distinct models, the similarity of the regimes in Figure 4 for Italy, Canada, Japan and (to a lesser extent) Germany and the UK is also noteworthy.

The above comments about the transition function for the non-US country generally carry over to the models with country-specific regimes, where the transition function indicates regimes of high versus average/low growth (see Figures 2 and 5). The notable exception, however, is Japan, where the threshold value of zero is compatible with regimes of business cycle expansion and recession, with a mixture of these applying when $\Delta_4 JP_{t-1}$ is a relatively small (positive or negative) value. The modest values of the estimated slope γ_2 for this model further indicates that mixtures of the two regimes can apply in Japan.

With the single exception of the country-specific regimes case for Japan just mentioned, the estimated transition functions are steep, with large estimated γ. Consequently, the regimes are effectively binary and few observations in Figures 3 to 5 are intermediate between regimes.

3.2 The Impact of US Growth on G7 Countries

Table 4 shows, in summary form, the coefficients of the estimated linear and STVAR models. To conserve space, we show the estimated ϕ_{2i} (i = 1, 2 or 3, 4) of (4) as a sum, together with the p-value for the joint test that the two individual coefficients are zero. Thus, we separately consider the coefficients capturing causality effects from the US and autoregressive ones, while also showing the results of the hypothesis tests of (5) and (6).

In a linear VAR system, lags of US growth have positive effects on other countries, with this causality being significant at 5 percent in all cases except France (marginally) and Japan. The detailed estimation results (not shown) indicate that both the first and second lags of US growth have positive and generally significant (at the 5 percent level) effects on Germany, Italy, UK and E15. Indeed, for all European countries (including France), the first and second US lags are approximately equal in value and significance, indicating that the effects of US growth take some time to be felt in Europe. Perhaps surprisingly, the autoregressive lags are not significant for Canada, Germany, Japan or the UK. The combination of significant US coefficients and insignificant autoregressive lags for Canada, Germany and the UK in these linear VARs points to a crucial role for the US in determining output growth for these countries.

Before considering regime-dependent causality in the STVAR context, it is appropriate to examine which coefficients vary over regimes, through the hypothesis tests of (7) to (9). Irrespective of the model considered, Table 4 provides no evidence of regime-specific effects of quarterly US growth on either Italy or Japan. In all other cases except Germany, the US-led growth model rejects regime-invariance for these US coefficients. However, in the model for Germany, there is strong evidence that the intercept varies with the regime in annual US growth. Further, many models, and especially those for US-led growth, imply that the effects of domestic conditions (captured through the autoregressive lags) varies over the regimes in US growth.

Before turning to further discussion of specific G7 countries, consider the nonlinear interactions of the US and E15, which (according to Tables 1 and 2) are more adequately captured by models based on US regimes than one with country-specific regimes. Both the common regimes and US-led regimes tell a similar story for the nature of the impact of the US on Europe. That is, the E15 autoregressive dynamics are relatively unimportant in the lower regime, but are significant and positive in the upper regime. Therefore, even if the coefficients of quarterly US growth do not change over regimes (and there is little evidence of this in the preferred common regimes model), growth in Europe is more self-sustaining in the upper regime than in the lower one.

In terms of the US-led regimes model and across all countries except Japan, the causality from quarterly US growth indicated by the linear VAR derive primarily from the lower regime in the STVAR specification. Interestingly, the implication from the linear VAR that US growth is not significant (at 5 percent) for France is contradicted in the US-led specification, where the effects are significant and positive in the lower regime. The models for Canada, Germany and the UK also show a similar pattern in the upper regime, with a large increase in the intercept when US growth is high, with all other coefficients then either insignificant of an unexpected negative sign[8]. The interpretation is that high US growth over a year (greater than the respective threshold) has a constant positive impact on quarterly growth in these countries, with the precise value of recent quarterly US or domestic growth being irrelevant.

The causality implications of the US-led regimes model are that quarter-to-quarter patterns in US growth are important only in the lower regime, with recent domestic growth playing a relatively modest role. This does not apply in the upper regime. Thus, other G7 countries and the E15 tend to track patterns in quarterly US growth only when US conditions (as indicated by annual growth) are not very strong. The only exceptions relate to Italy and Japan, which may reflect the nonlinearity test results of Table 1, which imply that regimes in these cases may be country-specific.

Due to the close links between Canada and the US, the model with country-specific regimes delivers similar implications for the effect of US growth on Canada as the US-led regimes model. In the case of Japan, all model specifications in Table 4 merely serve to reinforce the conclusion that this country has not been influenced by the US over the period. For Italy, on the other hand, the main effect of regimes is that the autoregressive coefficients play a more important role in the upper regime, with this effect being strongest when the regimes are defined by domestic growth.

3.3 Is the US Economy Closed?

The final question we examine is whether the US economy is influenced by growth in other G7 countries. To this end, Table 5 shows the estimated US equation for the linear VAR and the US-led regimes model. Since a US transition function is employed in all STVAR models, the US equation is largely unchanged across the STVAR specifications and hence (to conserve space) we present only this case.

The linear VARs largely support the proposition that the US economy is unaffected by world conditions. Indeed, although some European countries (France, Italy and the E15) are found to have a significant effect on US growth, these effects are negative. In the lower

[8] The apparently perverse large and significant negative total (autoregressive or US) effects for Germany and the UK in the upper regime may be a consequence of the relatively small number of observations in this regime.

regime of the STVAR model, the US autoregressive coefficients are highly significant, with the small total coefficient in the table reflecting a relatively large positive coefficient at lag one and a corresponding negative one at lag two. Interestingly, the pattern of quarterly growth having a negative impact on the US noted for the linear VAR now applies for all other countries in the lower regime. These effects are, however, muted in the upper regime. Judged by the lack of significance of both the US and other country coefficients, quarterly (log) US output is quite well described by a random walk with drift when in the regime of above average growth.

Table 5 establishes that the nonlinearity in the US equation derives primarily from the autoregressive dynamics, which alter in a significant way over regimes. The positive autoregressive coefficients in this upper regime tend to reinforce conditions of above average growth. In neither regime does growth elsewhere in the G7 have a significant and positive impact on the US. This is the case for the Europe as a whole (E15), as well as for individual countries.

4. Concluding Remarks

Our analysis considers the nature of nonlinearity in the bivariate relationships between the US and other G7 countries. Although our US model is effectively univariate and the nonlinearity in US output growth has been previously established (see, among others, Hamilton, 1989; Teräsvirta and Anderson, 1992), the investigation of the nonlinear nature of the dependence of other countries on the US is new. Using a Markov switching framework, Phillips (1991) concludes that regimes are common and due to world-wide shocks, but this is not confirmed by our analysis. With the exceptions of the common regimes supported for the US and aggregate for the European Union and the country-specific regimes indicated for Japan, we find that regimes in the US generally determine the regimes in the other G7 countries.

Our results also indicate that the autoregressive dynamics within these countries alters with the regime. Where autoregressive dynamics are important for non-US countries, these dynamics typically apply only in the upper regime of relatively high annual US growth. In contrast, the causality effects of quarterly US growth on other countries often applies only in the lower regime. Therefore, while the US leads the world in terms of regimes, its patterns of quarter to quarter growth rates are particularly important for other countries when US growth is not high. Thus, the primary finding of this study can be summarised as implying that lower growth from the US may be more readily transmitted internationally than higher growth.

Our results may also explain the apparent transmission of the US recession of 2000 to Europe, which has been investigated in a number of studies, including Doyle and Faust (2002), IMF (2001), OECD (2002) and Perez *et al*. (2003). That is, US annual growth was strong through much of the 1990s, but then declined sharply at the end of the decade. Thus correlations in the business cycle patterns between the US and Europe may not have strong during the 1990s, but may have risen with the implied switch to the lower regime at the end of this period.

REFERENCES

Anderson, H.M. and Vahid, F. (1998), "Testing multiple equation systems for common nonlinear components", *Journal of Econometrics*, 84, 1-36.

Anderson, H.M. and Vahid, F. (2001), "Predicting the probability of a recession with nonlinear autoregressive-leading indicator models", *Macroeconomic Dynamics*, 5, 482-505.

Artis, M.J. and W. Zhang (1997), "International business cycles and the ERM: is there a European business cycle?", *International Journal of Finance and Economics*, 2, 1-16.

Artis, M.J. and W. Zhang (1999), "Further evidence on the international business cycle and the ERM: is there a European business cycle?", *Oxford Economic Papers*, 51, 120-132.

Artis, M., Krolzig, H.-M. and J. Toro (2004), "The European business cycle", *Oxford Economic Papers*, 56, 1-44.

Backus, D.K., Kehoe, P.J. and Kydland, F.E. (1995), "International business cycles: Theory and evidence", in T.F. Cooley (ed.) *Frontiers of Business Cycle Research*, Princeton University Press, Princeton NJ, pp.331-357.

Doyle, B.M. and J. Faust (2002), "An investigation of co-movements among growth rates of the G-7 countries", *Federal Reserve Bulletin*, 88, pp.427-437.

Hamilton, J.D. (1989), "A new approach to the economic analysis of nonstationary time series and the business cycle", *Econometrica*, 57, 357-384.

Huh, H-S. and Lee, S-H. (2002), "Asymmetric output cost of lowering inflation: Empirical evidence for Canada", *Canadian Journal of Economics*, 35, 2, pp.218-238.

Inklaar, R. and J. de Haan (2001), “Is There Really a European Business Cycle?: A Comment”, *Oxford Economic Papers*, 53, 215-220.

International Monetary Fund (2001), “International Linkages: Three Perspectives”, *World Economic Outlook*, October, 65-104.

Kose, M.A., C. Otrak and C.H. Whiteman (2003), “International business cycles: World, region and country-specific factors”, *American Economic Review*, 93, 1216-1239.

Lumsdaine, R.L. and Prasad, E.S. (2003), Identifying the common components in international economic fluctuations”, *Economic Journal*, 113, 101-127.

OECD (2002), *OECD Economic Outlook*, June, pp.141-157.

Perez, P.J., D.R. Osborn and M. Artis (2003), “The international business cycle in a changing world: volatility and the propagation of shocks”, Centre for Growth and Business Cycle Research, University of Manchester, Discussion Paper 37.

Perez, P.J., D.R. Osborn and M. Sensier (2003): “Business cycle affiliations in the context of European integration”, Discussion Paper 29, Centre for Growth and Business Cycle Research, University of Manchester.

Pesaran, M.H., T. Schuermann and S.M. Weiner (2003), “Modelling regional interdependencies using a global error-correcting macroeconometric model”, *Journal of Business and Economic Statistics*, 22, 129-181 (with discussion).

Phillips, K.L. (1991), “A two-country model of stochastic output with changes in regime”, *Journal of International Economics*, 31, 121-142.

Rothman, P., van Dijk, D. and Franses, P.H. (2001), “Multivariate STAR analysis of money-output relationship”, *Macroeconomic Dynamics*, 5, 506-532.

Sims, C.A. (1980), “Macroeconomics and reality”, *Econometrica*, 48, 1-48.

Teräsvirta, T. and Anderson, H.M. (1992), “Characterizing nonlinearities in business cycles using smooth transition autoregressive models”, *Journal of Applied Econometrics*, 7, S119-S136.

Vahid, F. and Engle, R.F. (1997), “Codependent cycles”, *Journal of Econometrics*, 80, pp.199-221.

Weise, C.L. (1999), “The asymmetric effects of monetary policy: A nonlinear vector autoregression approach”, *Journal of Money Credit and Banking*, 31, 1, pp. 85-108.

Data Appendix

We model the first difference of seasonally adjusted quarterly real GDP. All data are obtained from the OECD or IMF databases. We attempted to use comparable series for each country, but in some cases, to obtain longer samples, different sources were used.

For all the countries except Italy and Germany, but including the E15 aggregate**,** GDP is from the Main Economic Indicators database of the OECD. Concretely our measure of GDP is: GDP volume index seasonally adjusted (the code typically is country_NAGVVO01_IXOBSA)

For Germany, the series GDP (PAN BD from 1991) CONA, (with Datastream code BDGDP…D) was used. This series comes from the OECD National Accounts and was corrected to take into account the jump in 1991, due to German reunification.

For Italy, a GDP volume index from the IMF is used (13699BVRZF…) the series was corrected in 1970 and 1966 for a jump and an outlier respectively.

The samples periods for our data are:

DEU	1970:1- 2002:1	**USA**	1970:1- 2002:1
FRA	1970:1- 2002:1	**CAN**	1970:1- 2002:1
ITA	1970:1- 2001:4	**JPN**	1970:1- 2002:1
E15	1970:1 -2002:1	**UK**	1970:1- 2002:1

Table 1: System Linearity Tests

VAR for US with	$z_1 = z_2 = \Delta_4 \boldsymbol{US}_{t\text{-}1}$	$z_1 = \Delta_4 \boldsymbol{US}_{t\text{-}1}$ $z_2 = \Delta_4 \boldsymbol{X}_{t\text{-}1}$
Canada	0.0433	0.0568
France	0.0031	0.0313
Germany	0.0020	0.0015
Italy	0.0017	0.0005
Japan	0.0801	0.0013
UK	0.0213	0.0135
E15	0.0025	0.0160

Notes: Results are shown as *p*-values. The test employs the degrees of freedom adjustment suggested by Sims (1980).

Table 2: Goodness-of-Fit Criteria for Nonlinear Models

	Canada	France	Germany	Italy	Japan	UK	E15
$\log\left\|\hat{\Omega}\right\|$							
Common regimes	-19.802	-20.608	-19.318	-19.941	-19.088	-19.233	-20.894
US-led regimes	-19.919	-20.675	-19.404	-19.978	-19.134	-19.333	-20.915
Country-specific regimes	-19.841	-20.599	-19.371	-20.009	-19.215	-19.206	-20.866
Test for common regimes	0.0013	0.0220	0.0074	0.1214	0.0727	0.0033	0.3021
AIC							
Common regimes	-19.447	-20.253	-18.964	-19.584	-18.734	-18.879	-20.539*
US-led Regimes	-19.532*	-20.288*	-19.017*	-19.588	-18.763	-18.945*	-20.528
Country-specific regimes	-19.453	-20.212	-18.984	-19.619*	-18.828*	-18.873	-20.479
BIC							
Common regimes	-18.947	-19.753*	-18.463	-19.081*	-18.233	-18.378	-20.038*
US-led regimes	-18.986*	-19.742	-18.471*	-19.039	-18.240	-18.400*	-19.982
Country-specific regimes	-18.908	-19.666	-18.438	-19.070	-18.282*	-18.327	-19.933

Notes: The test for common regimes compares the models with common regimes and with US-led regimes, and is computed as a likelihood ratio test that the parameters of the transition functions in the two equations of (1) are identical. The result of this test is presented as a *p*-value. * indicates the preferred nonlinear specification by AIC/BIC.

Table 3: Estimated Transition Functions

	Canada	France	Germany	Italy	Japan	UK	E15
			Common Regimes Model				
c	0.02290	0.0253	0.02199	0.02282	0.02280	0.04900	0.02291
γ	322.1	3012	30.68	229.6	2365	2949	7000
			US-Led Regimes Model				
US-Equation Transition							
c	0.01847	0.02232	0.02240	0.02284	0.02288	0.022700	0.02095
γ	664.5	49.93	25.21	249.4	495.0	126.5	26.51
Other-Equation Transition							
c	0.04458	0.03067	0.04900	0.04276	0.04340	0.04900	0.03058
γ	642.0	9500	288307	650.0	3724	2473	7650
			Country-Specific Regimes Model				
US-Equation Transition							
c	0.02099	0.02205	0.02247	0.02283	0.02287	0.02129	0.02034
γ	361.8	55.67	27.16	246.1	370.4	749.5	43.50
Other-Equation Transition							
c	0.05290	0.03394	0.02670	0.03007	-0.0001	0.04986	0.03656
γ	23890	3090	4201	283.5	0.9592	8750	3000

Table 4. Estimated Equations for G7 Countries and Europe

Coefficients	Canada	France	Germany	Italy	Japan	UK	E15
Linear Model							
	0.0047	0.0023	0.0023	0.0011	0.0053	0.0024	0.0021
Intercept	(.000)	(.007)	(.082)	(.280)	(.001)	(.065)	(.004)
US	0.403	0.161	0.493	0.329	0.142	0.495	0.229
Growth	(.000)	(.064)	(.001)	(.003)	(.573)	(.002)	(.002)
Own	0.139	0.410	-0.167	0.373	0.151	-0.115	0.358
Growth	(.381)	(.001)	(.086)	(.000)	(.449)	(.682)	(.001)
Common Regimes Model							
Lower Regime							
Intercept	0.0017	0.0027	0.0011	0.0012	0.0052	0.0013	0.0025
	(.233)	(.006)	(.534)	(.356)	(.014)	(.294)	(.005)
US	-0.185	0.234	0.288	0.424	-0.241	0.570	0.223
Growth	(.012)	(.098)	(.549)	(.027)	(.615)	(.001)	(.140)
Own	0.449	-0.149	0.042	0.071	0.056	-0.024	-0.126
Growth	(.024)	(.349)	(.103)	(.455)	(.890)	(.968)	(.110)
Upper Regime							
Intercept	0.0060	0.0038	0.0050	0.0008	0.0035	0.0335	0.0026
	(.003)	(.006)	(.025)	(.647)	(.147)	(.000)	(.023)
US	0.439	-0.055	0.332	0.256	0.296	-1.337	0.111
Growth	(.008)	(.747)	(.207)	(.063)	(.339)	(.020)	(.228)
Own	-0.063	0.571	-0.309	.549	0.202	-0.141	0.487
Growth	(.679)	(.000)	(.013)	(.000)	(.274)	(.556)	(.000)
Regime-Invariance Tests							
Intercept	.080	.553	.161	.867	.601	.000	.911
US Growth	.040	.136	.954	.161	.249	.001	.733
Own Growth	.056	.003	.015	.059	.668	.613	.013
US-Led Regimes Model							
Lower Regime							
Intercept	0.0028	0.0022	0.0020	0.0013	0.0061	0.0013	0.0024
	(.006)	(.008)	(.101)	(.185)	(.000)	(.296)	(.001)
US	0.409	0.263	0.358	0.252	0.071	0.566	0.290
Growth	(.000)	(.008)	(.026)	(.067)	(.760)	(.001)	(.002)
Own	0.195	0.109	-0.049	0.293	-0.004	-0.035	0.132
Growth	(.027)	(.486)	(.884)	(.030)	(.876)	(.966)	(.274)
Upper Regime							
Intercept	0.0201	0.0050	0.0263	0.0028	0.0075	0.0355	0.0027
	(.000)	(.002)	(.000)	(.469)	(.151)	(.000)	(.076)
US	-0.089	-0.179	-0.293	0.329	-0.284	-1.463	0.051
Growth	(.905)	(.105)	(.425)	(.314)	(.592)	(.007)	(.075)
Own	-0.454	0.624	-1.140	0.411	0.694	-0.087	0.563
Growth	(.342)	(.000)	(.000)	(.000)	(.032)	(.762)	(.000)
Regime-Invariance Tests							
Intercept	.000	.124	.001	.708	.798	.000	.848
US Growth	.016	.001	.097	.654	.460	.000	.008
Own Growth	.039	.016	.002	.018	.060	.847	.093

Table 4 (continued)

Coefficients	Canada	France	Germany	Italy	Japan	UK	E15
			Country-Specific Regimes				
Lower Regime							
Intercept	0.0029	0.0024	0.0005	0.0024	-0.0089	0.0030	0.0023
	(.004)	(.003)	(.729)	(.015)	(.743)	(.016)	(.001)
US	0.401	0.101	0.591	0.296	-0.705	0.385	0.161
Growth	(.008)	(.198)	(.001)	(.019)	(.848)	(.013)	(.034)
Own	0.284	0.365	-0.485	.301	-1.357	0.037	0.407
Growth	(.010)	(.036)	(.029)	(.015)	(.700)	(.458)	(.000)
Upper Regime							
Intercept	0.0220	0.0082	0.0109	-0.0076	0.0155	0.0017	0.0028
	(.000)	(.007)	(.001)	(.010)	(.020)	(.849)	(.456)
US	-0.034	0.430	0.294	0.477	0.356	1.496	0.616
Growth	(.105)	(.003)	(.175)	(.014)	(.441)	(.070)	(.012)
Own	-0.703	-0.319	-0.563	0.870	0.169	-0.838	-0.052
Growth	(.019)	(.592)	(.024)	(.000)	(.716)	(.043)	(.981)
Regime-Invariance Tests							
Intercept	.001	.067	.002	.001	.409	.888	.897
US Growth	.232	.016	.268	.553	.759	.110	.087
Own Growth	.011	.139	.828	.003	.787	.021	.287

Notes: The table refers to the non-US equation in a linear VAR or, for the nonlinear models, to the second equation of (4). For the US and own country coefficients, the value presented is the sum of the corresponding coefficients, with the *p*-value given in parentheses for the joint test that both individual coefficients are zero. The estimated intercept is also shown with *p*-value in parentheses. The regime invariance tests consider the null hypothesis that the corresponding coefficients do not vary over regimes. The invariance tests are computed as Wald tests and the results presented as *p*-values.

Table 5. Estimated US Equations

Coefficients	Canada	France	Germany	Italy	Japan	UK	E15
				Linear Model			
Intercept	0.0047	0.0055	0.0049	0.0055	0.0043	0.0048	0.0052
	(.000)	(.000)	(.000)	(.000)	(.001)	(.000)	(.000)
US	0.355	0.378	0.350	0.371	0.330	0.326	0.350
Growth	(.034)	(.004)	(.009)	(.004)	(.015)	(.025)	(.014)
Other Ctry.	0.033	-0.115	0.025	-0.098	0.119	0.079	-0.023
Growth	(.800)	(.019)	(.429)	(.020)	(.508)	(.321)	(.019)
				US-Led Regimes Model			
Lower Regime							
Intercept	0.0018	0.0040	0.0021	0.0027	0.0025	0.0021	0.0039
	(.212)	(.017)	(.127)	(.047)	(.127)	(.148)	(.014)
US	0.027	0.106	-0.079	0.010	0.066	0.143	0.117
Growth	(.073)	(.011)	(.010)	(.017)	(.001)	(.002)	(.049)
Other Ctry.	-0.122	-0.662	-0.406	-0.172	-0.061	-0.117	-0.787
Growth	(.185)	(.141)	(.012)	(.000)	(.522)	(.667)	(.038)
Upper Regime							
Intercept	0.0063	0.0068	0.0057	0.0064	0.0055	0.0065	0.0060
	(.001)	(.001)	(.002)	(.001)	(.004)	(.001)	(.004)
US	0.198	0.297	0.240	0.268	0.227	0.205	0.260
Growth	(.505)	(.160)	(.268)	(.140)	(.289)	(.382)	(.238)
Other Ctry.	0.088	-0.070	0.196	-0.002	0.184	0.082	0.080
Growth	(.781)	(.010)	(.314)	(.356)	(.117)	(.594)	(.145)
Regime Invariance Tests							
Intercept	.047	.290	.121	.125	.225	.074	.401
US Growth	.107	.035	.009	.028	.002	.005	.078
Other Ctry.	.135	.107	.005	.039	.180	.701	.123

Notes: The table refers to the US equation in a linear VAR or, for the US_led regimes model, to the first equation of (4). For the US and other country coefficients, the value presented is the sum of the corresponding coefficients, with the *p*-value given in parentheses for the joint test that both individual coefficients are zero. The estimated intercept is also shown with *p*-value in parentheses. The regime invariance tests consider the null hypothesis that the corresponding coefficients do not vary over regimes. The invariance tests are computed as Wald tests and the results presented as *p*-values.

Figure 1. Quarterly GDP Growth

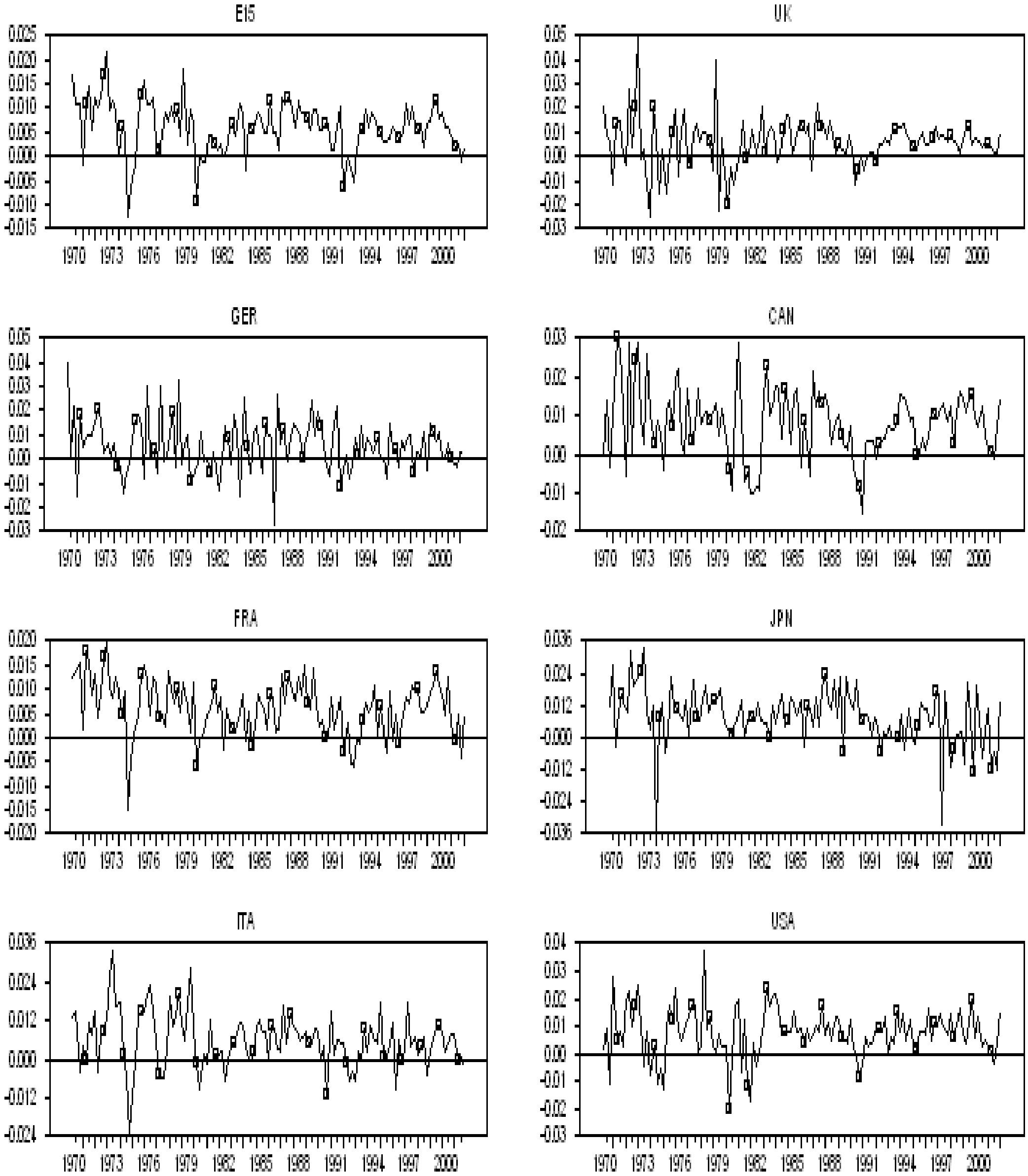


Figure 2. Annual GDP Growth

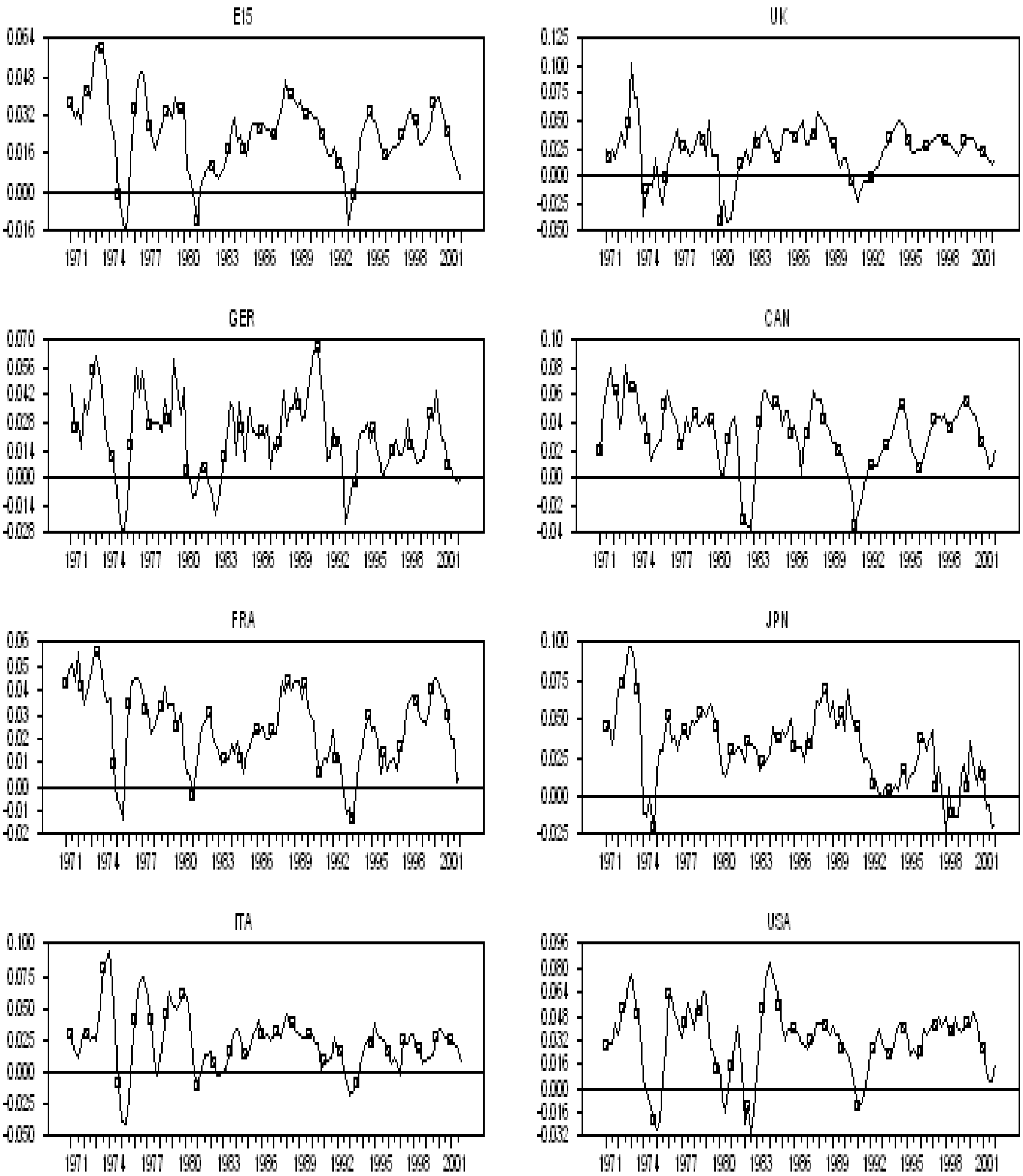


Figure 3. Transition Functions for Common Regimes Models

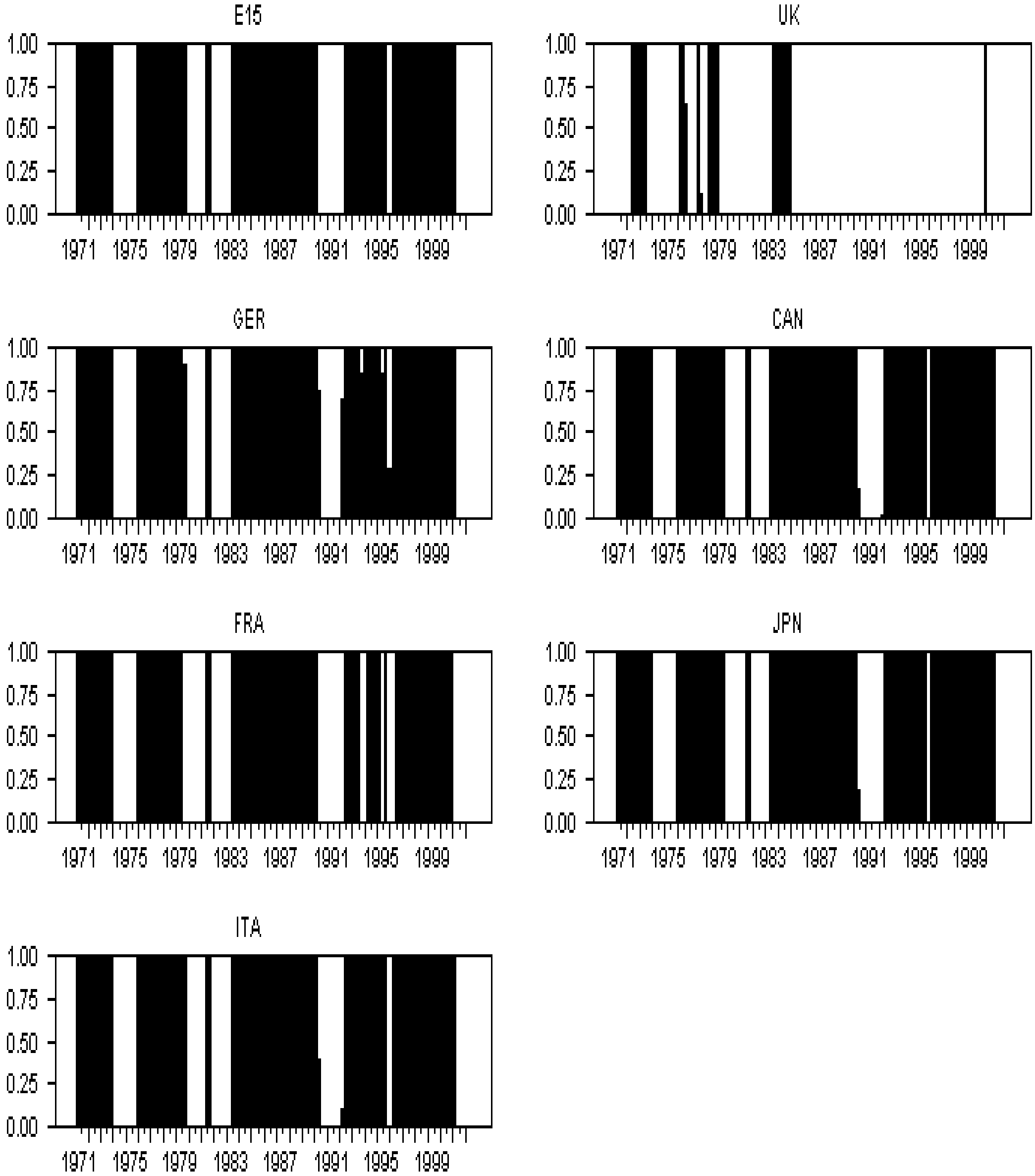
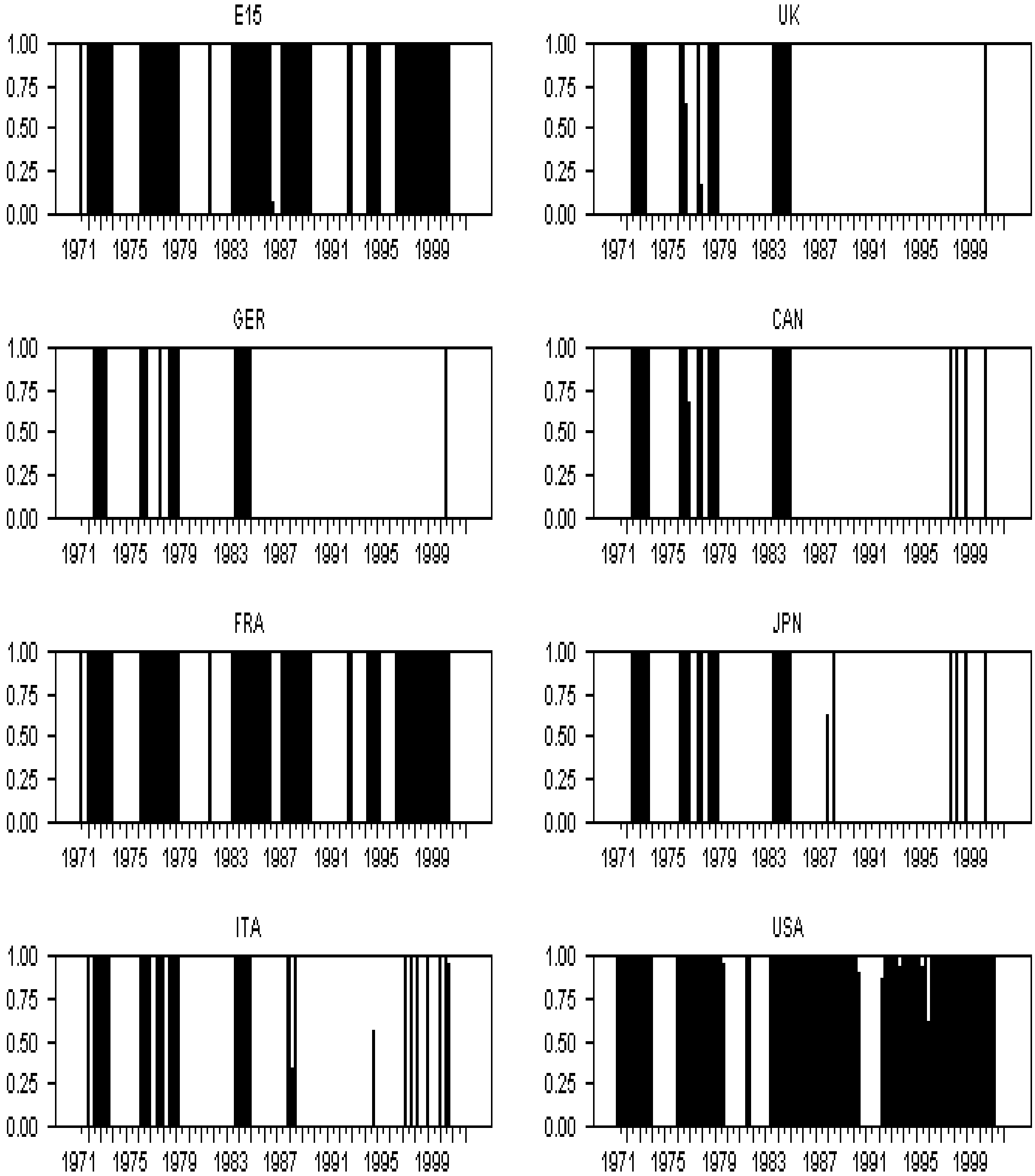
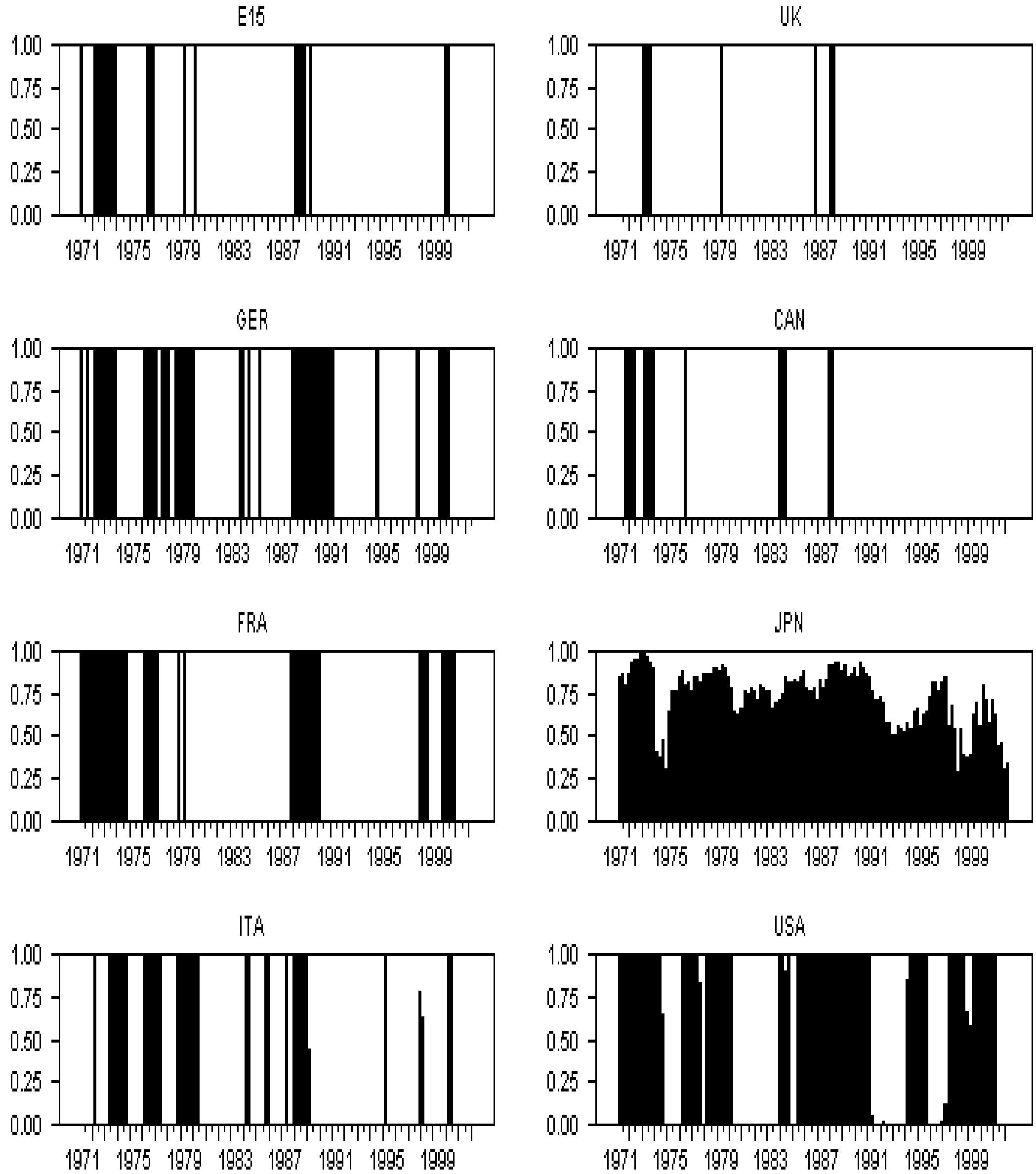


Figure 4. Transition Functions for US-Led Regimes Models



Note: The transition function shown for the US relates to the bivariate model with E15.

Figure 5. Transition Functions for Country-Specific Regimes Models



Note: The transition function shown for the US relates to the bivariate model with E15.