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Tara Sinclair
George Washington University

Sinchan Mitra
Discover Financial Services

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Institute for International Economic Policy
1957 E St. NW, Suite 501
Voice: (202) 994-5320
Fax: (202) 994-5477
Email: iiep@gwu.edu
Web: www.gwu.edu/~iiep

Output Fluctuations in the G-7: An Unobserved Components Approach

Sinchan Mitra
Discover Financial Services
2500 Lake Cook Road
Riverwoods, IL 60015

Tara M. Sinclair[†]
Department of Economics
The George Washington University
Washington, DC 20005

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Abstract

This paper contributes to the debate about the relative importance of permanent versus transitory disturbances as sources of variation in output across the G-7 countries. We employ a multivariate unobserved components model to simultaneously decompose the real GDP for each of the G-7 countries into their respective permanent and transitory components. In contrast to much of the related literature, our model allows for explicit interaction between the components both within and across series. This approach thus allows us to distinguish cross-country correlations driven by the relationships between permanent innovations from those between transitory movements. We find that fluctuations in output are primarily due to *permanent* movements for all of the G-7 countries. We also find that the correlation between the permanent and transitory innovations within each series is significantly negative. With regards to cross-country relationships, we find important idiosyncratic variation in the correlation across different country pairs.

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1 Introduction

The debate about the causes of economic fluctuations has long been at the center of macroeconomic research. One critical issue is whether the business cycle is wholly transitory, or whether it might be "real" in the sense that it is characterized primarily by permanent rather than transitory movements.[1] Research addressing this issue has generally focused on the U.S., but there has been increasing interest in cross-country comparisons as well (e.g. Cogley, 1990; Backus, Kydland and Kehoe, 1992; Canova and de Nicolo, 2003). Another subject that has received attention recently is the *linkage* of economic activity across countries. Research on international business cycles has documented international co-movements in a wide array of macroeconomic variables (e.g. Backus, Kydland, and Kehoe, 1992; Gregory, Head, and Raynauld, 1997; and Kose, Otrok and Whiteman, 2003).

The main objective of this paper is to examine the role of permanent versus transitory disturbances as sources of variation in real GDP across the G-7 countries from 1960 through 2003. We employ a multivariate model to *simultaneously* decompose the real GDP for each of the G-7 countries into their unobserved permanent and transitory components. Cross-country evidence should be helpful to ascertain business cycle characteristics as there are commonalities in the behavior of real quantities across countries (Diebold and Rudebusch, 1996). We thus use the variation across countries to identify the parameters for each individual series in order to improve the efficiency of the estimates. Furthermore, we build on the model of Morley, Nelson, and Zivot (2003), and allow for explicit interaction between permanent and transitory innovations. Our multivariate approach enables us to distinguish cross-country correlations driven by permanent innovations from those driven by transitory movements. We are thus able

[1] For a discussion of this debate, see Kim, Piger, and Startz (forthcoming). Throughout this paper we use the term "business cycle" to refer generally to economic fluctuations. This is in line with the definition that the NBER and the CEPR business cycle dating committees use, according to Harding and Pagan (2005).

to jointly address three major macroeconomic questions: 1) Are fluctuations in output primarily due to permanent or transitory movements? 2) Is the relative importance of permanent versus transitory movements in output similar across countries? 3) What is the pattern of correlation between the permanent and transitory movements in output across the G-7 countries?

This paper employs a multivariate correlated unobserved components model in order to consider these questions. Prior research has explored the role of permanent and transitory innovations in a single real GDP series using a univariate correlated unobserved components model (e.g. Basistha, 2007, for Canada; Morley, Nelson, and Zivot, 2003, for the US). Multiple series relationships for the same country have been explored as well in an unobserved components framework (e.g. Basistha, 2007, for Canadian output and inflation; Morley, 2007, for US consumption and income; Sinclair, forthcoming, for US output and the unemployment rate). There has also been a significant amount of research examining cross-country relationships using various empirical models (e.g. Kose, Otrok and Whiteman, 2003, and references therein). The novelty of this paper is to estimate a multivariate correlated unobserved components model using data from several countries and explore the interactions among their permanent and transitory innovations.

The majority of previous studies that have considered international output co-movements have used detrended or first-differenced data. One benefit of our approach is that it does not require a prior transformation of the GDP series. Common detrending methods, such as the Hodrick Prescott filter and bandpass filters, are known to produce spurious cycles for nonstationary data, such that the results are sensitive to the detrending method that is chosen (Cogley and Nason, 1995; Murray 2003; Doorn 2006). First-differencing can avoid the problem of the spurious cycle for difference-stationary data, but then the permanent and transitory

movements cannot be examined separately. Our approach, however, allows us to estimate the permanent and transitory components jointly as well as the relationships between them.

Our model also places fewer restrictions on the relationships across countries than in several other studies. Dynamic factor models, for example, often assume there is a single common world factor, which may lead to attributing all cross-country relationships to the "world shock" (see discussion in Stock and Watson, 2005). Our empirical framework avoids imposing a common dynamic factor structure on all countries prior to estimation. It is also not necessary to assume common trends or common cycles for identification (see Centoni, Cubadda, and Hecq, 2007; Vahid and Engle, 1993, 1997), though our framework still accommodates potential commonalities (Everaert, 2007; Schleicher, 2003). Finally, we are able to directly use the estimated correlation matrix to examine the cross-country relationships, instead of estimating the correlations in a second stage using the estimated components.

To preview our results, we find that all the G-7 countries have highly variable stochastic permanent components, even after allowing for a structural break to capture the productivity slowdown in 1973. These results further suggest that the structure of the business cycle is similar across the G-7 countries to the extent that permanent shocks play a predominant role and that permanent and transitory innovations within each series are negatively correlated. One interpretation of our results is that each economy is frequently buffeted by permanent shocks. Observed output, however, takes time to adjust to the changing steady state, resulting in the contemporaneous negative correlation between permanent and transitory innovations within each series.

With regards to the cross-country relationships, we find important idiosyncratic variation in the correlation across different country pairs. Innovations to both the permanent and

transitory components are generally positively correlated across countries. The correlations are often stronger among countries within a particular geographic region (North America, Europe) than among countries across these regions. Japan is found to be more closely correlated with the European countries of the G-7 than with the U.S. The correlations between the Eurozone countries and the U.S. are found to be quite low.

The rest of the paper proceeds as follows. In Section 2 we present the model and discuss the data used for estimation. In Section 3 we discuss the results and compare them with other related papers, and in Section 4 we conclude.

2. The Model

The output for each country can be represented as the sum of a stochastic "trend" component and a "cycle" component. The "trend" (τ), also called the permanent component, is the steady-state level after removing all temporary movements from the series. The "cycle" (c), also called the transitory component, embodies all temporary movements and is assumed to be the stationary remainder after removing the random walk component:

$$y_{it} = \tau_{it} + c_{it}, \; i = 1 \text{ to } 7 \text{ for each country} \tag{1}$$

A random walk for each of the trend components allows for permanent movements in the series. We also allow for a drift (μ) in the trend:

$$\tau_{it} = \mu_i + \tau_{it-1} + \eta_{it} \tag{2}$$

We model each transitory component as a second order autoregressive process, AR(2):[2]

$$c_{it} = \phi_{1i} c_{it-1} + \phi_{2i} c_{it-2} + \varepsilon_{it} \tag{3}$$

[2]Univariate specification tests were performed which suggested that an AR(2) model for each individual country would be appropriate. Including additional lags did not qualitatively change the results. Note that an AR(2) transitory component implies that the first difference of each series is an ARMA(2,2). See the discussion of this issue in Morley, Nelson, and Zivot (2003).

We assume the innovations (η_{it}, and ε_{it}) are normally distributed (i.i.d.), mean zero, random variables with a general covariance matrix (allowing possible correlation between any of the contemporaneous innovations to the unobserved components). The two key identifying assumptions of this model are that the permanent component is a random walk with drift and that the remaining stationary part has only autoregressive dynamics (but the reduced form growth rates also have MA dynamics). In general, AR(2) dynamics are sufficient for identification (Morley, Nelson, and Zivot, 2003; Sinclair, forthcoming).[3]

According to Perron and Wada (2006), including a structural break in the trend may be important for proper estimates of the variability of the permanent component. They suggest that a break occurred in 1973:1 for the U.S. Moreover, an extensive literature indicates that there was a productivity slowdown in all the G-7 countries at about that time (Ben-David and Papell, 1998; Bai, Lumsdaine, and Stock, 1998). We, therefore, allow for a structural break in the drift such that we have:

$$\tau_{it} = \mu_{1i} + \tau_{it-1} + \eta_{it} \text{ for t = 1960Q1 to 1972Q4.} \quad (2a)$$

$$\tau_{it} = \mu_{2i} + \tau_{it-1} + \eta_{it} \text{ for t =1973Q1 to 2003Q4.} \quad (2b)$$

We also consider additional structural breaks for individual countries. Based on the results of likelihood ratio tests, the final model also includes an additional structural break in the drift term for Japan in 1990:1.[4] We will discuss this further below in section 3.2.

The key difference between our model and a traditional unobserved components model is in the variance-covariance matrix for the permanent and transitory innovations:

[3]A discussion of identification of this model is available from the authors upon request.

[4] In order to compare our work directly with Perron and Wada (2006), we focus on the large breaks suggested by historical evidence and considered by previous authors. We could alternatively use a structural break test that does not assume known break dates such as Zivot and Andrews (1992) or Bai and Perron (1998). Univariate break tests find structural breaks in approximately 1973Q1 for all seven countries and an additional break for Japan in 1990Q1. Another alternative would be to use the mixture of normals approach as discussed in Wada and Perron (2006).

$$E\left(\begin{bmatrix}\eta_t \\ \varepsilon_t\end{bmatrix}\begin{bmatrix}\eta_t & \varepsilon_t\end{bmatrix}\right)=\begin{bmatrix}\Sigma_\eta & \Sigma_{\eta\varepsilon} \\ \Sigma_{\varepsilon\eta} & \Sigma_\varepsilon\end{bmatrix}, \tag{4}$$

where Σ_η is the 7 x 7 variance-covariance matrix for the innovations to the permanent components, Σ_ε is the 7 x 7 variance-covariance matrix for the innovations to the transitory components, and $\Sigma_{\eta\varepsilon}=\Sigma_{\varepsilon\eta}'$ represents the cross-covariance terms between the permanent and transitory innovations. Traditionally, unobserved components models have imposed restrictions on the variance-covariance matrix. Generally they have assumed that the off-diagonal elements were equal to zero. Our model, however, imposes no restrictions on the variance-covariance matrix and thus we have estimates for all potential contemporaneous within-series and across-series correlations.

We cast the model into state-space form (available from the authors upon request) and apply the Kalman filter for maximum likelihood estimation (MLE) of the parameters using prediction error decomposition and to estimate the permanent and transitory components.[5]

2.2 The Data

We apply the model of Section 2.1 to output data for the G-7 countries; namely Japan, Italy, Germany, France, Canada, the U.K., and the U.S. The data are quarterly observations on real GDP from 1960:1 to 2003:4 from OECD Quarterly National Accounts and International Financial Statistics (IFS) from the International Monetary Fund (IMF). These data correspond to the real GDP data for the G-7 used by Kose, Otrok, and Whiteman (2003).[6] Table 1 presents the

[5]See chapter 3 of Kim and Nelson (1999a) or chapter 4 of Harvey (1993) for a discussion of the implementation of the Kalman filter. All estimation was done in GAUSS version 6.0. To ensure that the estimates represent the global maximum, estimates of all models were repeated using different starting values approximating a coarse grid search. The appropriateness of MLE in the case of random walk components has been examined in Chang, Miller, and Park (forthcoming).

[6] We thank Christopher Otrok for providing us with the data.

correlations between the growth rates of these series. The growth rates of the series are all correlated, providing support for our choice of a multivariate model.

3 The Results

Tables 2 and 3 report the maximum likelihood estimates of our multivariate correlated unobserved components model.[7] Model 1 allows for the general covariance matrix and includes a structural break in the drift term in the first quarter of 1973 for all countries, and an additional structural break for Japan in the first quarter of 1990. The remaining two columns of Table 2 report intermediate models. Model 2 presents results assuming that the permanent and transitory innovations across the series are uncorrelated. It also does not include any structural breaks. Model 3 allows for the general covariance matrix, but does not include structural breaks. Models 2 and 3 are both easily rejected in favor of Model 1 based on likelihood ratio tests.[8] Table 3 then reports the estimates for the correlations based on Model 1. For each country, Figure 1 presents the estimated components based on Model 1 along with the corresponding real GDP series.

3.1 The Estimated Components

Based on the seven panels of Figure 1, the estimated permanent components are clearly variable, often looking very similar to the real GDP series itself. This variability is confirmed by the estimates of the large standard deviations of the innovations to the permanent components presented in the first column of Table 2c and discussed further in section 3.4. The remaining transitory components do not resemble the traditional "cycle." Rather, we interpret them in

[7] The model fit is an improvement over a VAR model of the data in first differences with a similar number of parameters. The Akaike information criterion (AIC) for our model is 17.56. For a VAR(2), we have AIC of 17.981 and for a VAR(3), we have an AIC of 17.953.

[8] It is particularly striking that based on restricted Model 2, which does not allow for $\eta\varepsilon$ correlation or structural breaks, both of the estimated AR parameters for Japan are negative. This suggests that Model 2 is imposing restrictions not appropriate for the Japanese data.

further discussion in section 3.5 as being predominantly transitory adjustments to the permanent innovations.

3.2 The Drift Terms

Table 2a presents the drift terms for our estimated models. Based on the estimates from Model 1, the post-1973 drift term is found to be smaller than that of the pre-1973 sample for all seven countries, further supporting the productivity slowdown hypothesis for the G-7 countries. Using a likelihood ratio test, we can reject the no-break restriction for the first quarter of 1973.[9]

We also considered whether there were structural breaks associated with other important developments that occurred during our sample period. In particular, we considered the Japanese banking crisis and the reunification of Germany. For Japan, the bursting of the asset bubble in the first few months of 1990 appears to be a turning point in the Japanese economy which might be thought of as a one-time outsized structural shock. The first quarter of 1990 thus appears to be a reasonable choice for a break date to consider for Japan. In fact, this break for Japan was found to be statistically significant.[10]

For Germany, we need to consider the German reunification in 1990 (Hoppner, 2001; Brüggemann, and Lutkepohl, 2006). After 1990, many German series refer to the unified Germany whereas data prior to the reunification often refer to West Germany only because reliable data for East Germany are not available. The OECD reports data for a reunified Germany beginning with the first quarter of 1991. Although our data were level-corrected, we introduce a structural break in the drift term in the first quarter of 1991 to account for a possible structural break. For Germany, however, the likelihood ratio test statistic, after including Japan's

[9] The likelihood ratio test statistic is 62.90. With 7 degrees of freedom, the p-value is less than 0.001. The results are robust to which quarter in 1973.

[10] The likelihood ratio test statistic is 9.66 with only one additional parameter, leading to a p-value of 0.002 The results are robust to which quarter in 1990.

additional break, was only 0.029, and was found to be insignificant. Furthermore, the results were not affected by including a structural break for Germany.

3.3 The Autoregressive Parameters

Table 2b presents the AR parameters for our estimated models. The autoregressive coefficients reflect the dynamics of the transitory components. It is important to emphasize that the transitory components are simply the stationary part of the data, as identified from the model presented in Section 2.1. Our estimates suggest that most of the fluctuations in real GDP occur in the permanent components, so movements in the transitory components do not necessarily match the traditional notion of the "cycle." For example, for some of the countries in our sample the autoregressive process in the transitory component does not have complex roots, suggesting that these components do not have the periodic characteristic of a "cycle."

The sum of the autoregressive coefficients provides a measure of persistence of the transitory components. Focusing on our preferred model, Model 1, Italy appears to have the least persistent transitory component with the sum of its autoregressive coefficients being just 0.26. France appears to have the most persistent transitory component, with a sum of 0.84. The remaining countries have persistence ranging from 0.68 for the U.S. to 0.80 for Germany. None of these results appear to be outside the range of previous estimates. Most importantly, these are not approaching the boundary where the transitory component might appear nonstationary.

3.4 The Permanent and Transitory Standard Deviations

The estimates based on Model 1 suggest a large role for permanent movements. In fact, the standard deviation for the innovation to the permanent component exceeds the standard deviation for the innovation to the transitory component for five of the seven countries (Japan, Italy, France, Canada, and the U.S.).

It is interesting here to compare the results of the intermediate models with Model 1. With the exception of the U.S. transitory component, the pattern across the three columns in Table 2c is clear: A traditional unobserved components model without correlation between permanent and transitory innovations or structural breaks has the lowest estimates of standard deviations for both permanent and transitory movements (compare Model 2 with Models 1 and 3). Allowing for correlation in Model 3, without structural breaks, results in the largest estimates. Including the drift breaks, however, reduces the standard deviations of both the permanent and transitory innovations for all countries as seen comparing Model 1 with Model 3. Although smaller than the estimated standard deviations of the permanent innovations from the model without the structural breaks, the estimates based on Model 1 still suggest a large role for permanent movements.

3.5 The Within-Series Relationships

The correlations between the permanent and transitory innovations within each series are found to be significantly negative for all seven countries as can be seen in the first column of Table 2d. These estimates, which are the same as the diagonal entries in Table 3c, range from -0.62 for the U.K. to -0.92 for France. We performed a likelihood-ratio test with the null hypothesis that all cross correlations are zero, but allowing for structural breaks. The drift breaks reduce the size, in absolute value, of the correlation between the innovations to the permanent and transitory innovations within each country series as can be seen in Table 2d, comparing Model 1 with Model 3. However, we still reject the restriction of zero correlation with a p-value of less than 0.001.

It has become common to interpret negative correlation between the permanent and transitory innovations as arising from shocks which shift permanent GDP today, but with slow

adjustment of actual GDP to the steady-state level (see, for example, Stock and Watson, 1988; Morley, Nelson, and Zivot, 2003; Morley, 2007; and Sinclair, forthcoming). Slow adjustment of the series to permanent shocks would result in negative contemporaneous correlation since the difference between the series and the permanent component is negative in the case of a positive permanent shock. This interpretation requires frequent permanent shocks and is thus supported by the variable stochastic permanent component estimated for each of the countries.

Although there is general agreement that the negative correlation arises from slow adjustment of the series to permanent shocks, there remains debate as to the cause of the slow adjustment. Two potential sources have been previously emphasized in the literature. Blanchard and Quah (1989) suggest that the pattern arises from supply shocks combined with nominal rigidities, such as imperfectly flexible prices. Real business cycle theories, such as those of Prescott (1987) and Kydland and Prescott (1982), instead emphasize "time-to-build." They suggest that it may take more than one period for the construction of new productive capital in response to real shocks. Our results are consistent with either of these interpretations.

3.6 The Cross-Country Relationships

The correlations of the growth rates of output for the G-7 countries are provided in Table 1.[11] The estimates of the correlations between the permanent and transitory innovations, presented in Table 3, suggest, however, that merely examining the relationships between the growth rates is not sufficient for understanding the cross-country relationships.[12]

[11] For a discussion of the co-movements among the growth rates of the G-7 countries, see Doyle and Faust (2002, 2005).

[12] We focus on the permanent-permanent and transitory-transitory correlations across countries since these are more directly interpretable. For the permanent-transitory cross-correlations, most are negative, but there are many small (but significant) positive correlations, with the three largest ones again being Japan with Canada, Italy with U.K., and Germany with Canada.

The observed growth rates are functions of the permanent innovations (η_{it}), the transitory innovations (ε_{it}), and the autoregressive parameters (ϕ_{1i} and ϕ_{2i}) for the two series. The growth rate for series i, denoted Δy_{it}, (where y_{it} is the log of output) is:

$$\Delta y_{it} = \mu_i + \eta_{it} + (1-L)(1-\phi_{1i}L - \phi_{2i}L^2)^{-1}\varepsilon_{it}, \qquad (4)$$

where L is the lag operator. The growth rates thus mix permanent innovations and transitory innovations.

Using the multivariate unobserved components model we are able to *separately* identify and estimate the cross-country correlations between the permanent innovations ($\sigma_{\eta i \eta j}$), the transitory innovations ($\sigma_{\varepsilon i \varepsilon j}$), and the permanent and transitory innovations ($\sigma_{\eta i \varepsilon j}$ and $\sigma_{\varepsilon i \eta j}$). We simultaneously estimate the correlation between the innovations when estimating the components. This is an improvement over the conventional method of estimating the components and then estimating their correlation in a second stage. Studying the estimate of the correlation rather than the correlation of the estimates allows us to avoid potential measurement error and spurious results arising from detrending methods. Based on the estimated correlations between the permanent and transitory innovations across countries listed in Table 3, we find that both the permanent correlations and the transitory correlations are important in driving international co-movements.

We focus here on several key results. First, we find important regional relationships among the English-speaking countries and among the continental European countries. We find a much weaker relationship across these regions. As for Japan, it appears to be more closely related to the continental European region than to the English-speaking region. There are also a few country pairs that have negative correlations, either between permanent or transitory innovations.

High positive correlation between both the permanent innovations and the transitory innovations exists between Canada and the U.S. and the U.K. and the U.S. The core European countries, notably France and Germany, and France and Italy are also strongly positively correlated. However, the correlations between the Eurozone countries and the U.S. or Canada (with the exception of Italy with Canada) are quite small in magnitude.[13] On the whole, our results appear to support the hypothesis of two relatively coherent economic clubs: one consisting of the core European countries and another group consisting of English-speaking countries: the U.S., the U.K., and Canada. Similar results have been found by Artis and Zhang (1997), Helbling and Bayoumi (2003), Luginbuhl and Koopman (2004), and Stock and Watson (2005).

The small magnitude of the correlation between the Eurozone countries and the U.S. (between -0.03 and 0.19) might seem surprising as these economies share strong bilateral trading and financial linkages. However, other studies have found similar results (McAdam, 2003; Canova and de Nicolo, 2003). Even when countries are hit by similar shocks, the effects may vary considerably across countries.

The U.K. permanent and transitory innovations are found to be closely related only to the U.S., and to a much lesser degree, Germany. Thus, our results seem to suggest a "U.K. 'idiosyncrasy'" (Artis, 2006, page 43) in the sense that the U.K.'s economic experience of shocks is different from the continental European experience and seems more closely related to that of the U.S. Stock and Watson (2005) also find a decline in the correlation between the growth rate of GDP in the U.K. and that of France and Germany through the 1980s and 1990s and a closer association of the U.K. with North American economies, particularly the United

[13] This pattern is confirmed by the analysis of subgroups of countries in our sample. Results for the subgroups are available on request.

States. Consistent with our findings, their analysis also provides evidence of the emergence of two regional groups, an English-speaking group and the Eurozone economies.

We also find that Japan is closely related to the European group. The correlation between permanent innovations is particularly strong between Japan, Germany, and Italy, and to a lesser degree France.

The main exceptions to the general result that innovations are positively correlated across countries are Japan with Canada, Italy with the U.K., and Germany with Canada. These three pairings appear to have statistically significant and negative correlations between both their permanent and their transitory innovations. The negative signs of these correlations look puzzling at first glance. One possible interpretation of the results is to consider a preference shock in one country, which shifts demand to non-tradable goods, thereby reducing the exports of its trading partners. We can also think of a favorable terms of trade shock in one country with respect to its trading partner which could explain the negative correlation.

3.7 Correlation, Structural Breaks, and Multivariate Information

Prior research has examined the results of estimating a correlated unobserved components model only for the U.S. (Morley, Nelson, and Zivot, 2003) and Canada (Basistha, 2007). Both models found that the correlation between the permanent and transitory innovations for real GDP is negative and significant and the permanent component is highly variable.

Perron and Wada (2006, PW), however, find very different results when they modify the univariate MNZ model allowing for a structural break in 1973. PW find that the correlation between the trend and the cycle becomes zero for U.S. real GDP because the series becomes trend-stationary after accounting for the break. Basistha estimates a model similar to PW for Canada and also finds that the trend becomes almost non-stochastic.

Basistha found, however, that the PW result did not hold in a bivariate model of inflation and output for Canada. Similarly, Sinclair (forthcoming) found that the PW result did not hold in a bivariate model of U.S. real GDP and the unemployment rate. Thus, the information provided from multiple macroeconomic data series *for the same country* suggests that for both the U.S. and Canada, the correlation between the permanent and transitory innovations for real GDP is negative and significant and the permanent component is highly variable.

Our estimates present further evidence that incorporating structural breaks does not change the main results when we take advantage of information provided by using data series from *multiple countries*. Although the time periods of the data vary across the different papers, we observe a pattern. The less restrictive models, particularly the multivariate ones, find negative correlation between the permanent and transitory innovations, and also find a variable permanent component. Overall, our results suggest that the variable permanent component and negative correlation between the permanent and transitory innovations are robust to multivariate modeling, and they are similar across the G-7 countries.

3.8 Allowing for a Break in Variances

A considerable amount of research has explored what appears to be a significant decrease in volatility in U.S. output growth in or around 1984. This "Great Moderation," as it has come to be known, was documented initially by Kim and Nelson (1999b) and McConnell and Perez Quiros (2000) and has since been confirmed by many others. It has also been observed in other countries, including the countries of the G-7 (e.g. Mills and Wang, 2003; van Dijk, Osborn, and Sensier, 2002). The exact break date is less clear for the other countries, with some suggesting as early as 1974 and as late as 1993 for some of the countries in the G-7. A simple exploration of the impact of the volatility reduction is to consider a one-time break in the variances by

adding seven additional parameters to the state-space model, assuming that the correlations stay the same and that the proportional size of the break is the same for the permanent and transitory components. The variance-covariance matrix then becomes:

$$E\left(\begin{bmatrix}\eta_t \\ \varepsilon_t\end{bmatrix}\begin{bmatrix}\eta_t & \varepsilon_t\end{bmatrix}\right)=\begin{bmatrix}\Sigma_\eta & \Sigma_{\eta\varepsilon} \\ \Sigma_{\varepsilon\eta} & \Sigma_\varepsilon\end{bmatrix}$$ for t = 1 to $d-1$ (where d is the break date for the variance), and

$$E\left(\begin{bmatrix}\eta_t \\ \varepsilon_t\end{bmatrix}\begin{bmatrix}\eta_t & \varepsilon_t\end{bmatrix}\right)=\begin{bmatrix}\alpha & 0 \\ 0 & \alpha\end{bmatrix}\begin{bmatrix}\Sigma_\eta & \Sigma_{\eta\varepsilon} \\ \Sigma_{\varepsilon\eta} & \Sigma_\varepsilon\end{bmatrix}$$, for t = d to T, where $\boldsymbol{\alpha}$ is a vector with 7 rows to capture a proportional change in variance in each of the seven series.

Clearly this abstracts from changes in co-movements that have also been documented in the literature (e.g. Kose, Otrok, and Whiteman, forthcoming), but due to the number of parameters in this matrix we focus here on the variance break. Support for our choice of a proportional change in the matrix comes from Doyle and Faust (2005) who cannot reject the hypothesis that correlation has remained the same across the G7 countries. Ahmed, Levin, and Wilson (2004) provide additional support for our choice of modeling, at least for the U.S. They find that they cannot reject the hypothesis that the reduction in volatility in U.S. real GDP growth is proportional across all frequencies. They interpret this result to suggest that the volatility reduction is primarily due to a reduction in innovation variance.

The results presented in Table 4 show the estimates of the alpha parameters. The U.K. has the largest reduction in standard deviation. The permanent and transitory standard deviations for the U.K. after 1984 are estimated to be only 44% of what they were before 1984. The smallest reduction is found for Japan, where the standard deviations after 1984 are 87% the size of what they were before 1984. Japan has often been found in the literature to have little or no break in variance around this time. None of the countries are estimated to have higher standard

deviations after 1984, although the estimates allowed for this possibility. Most importantly, the other results discussed in the previous sections are robust to allowing for this structural break.

4 Conclusions

In this paper we estimated a multivariate correlated unobserved components model for the G-7 countries from 1960 through 2003. Using this new methodology we are able to jointly address three major macroeconomic questions: 1) Are fluctuations in output primarily due to permanent or transitory movements? 2) Is the relative importance of permanent versus transitory movements in output similar across countries? 3) What is the pattern of correlation between the permanent and transitory movements in output across the G-7 countries?

Our findings for the first and second questions suggest that fluctuations in output are primarily due to *permanent* movements for *all* of the G-7 countries. Once we allow for correlation between the countries, we find that the permanent component appears to account for a significant part of GDP fluctuations. We also find that the correlation between the permanent and transitory innovations *within* each country's GDP is significantly negative. These results are remarkably consistent across the G-7 countries. The results hold even after allowing for a structural break in the first quarter of 1973 and an additional structural break in 1990 for Japan.

Finally, the model allows us to examine the correlations between permanent innovations and transitory innovations across countries for this period. We find that innovations to the permanent and transitory components are generally positively correlated across countries, but the degree of correlation varies. Additionally, correlations between permanent innovations across countries are found to be at least as important as correlated transitory innovations in driving international co-movements.

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Table 1. Sample Correlations for the GDP Growth Rates[14]

	Japan	Italy	Germany	France	Canada	U.K.	U.S.
Japan	1						
Italy	0.33	1					
Germany	0.27	0.17	1				
France	0.47	0.52	0.42	1			
Canada	0.24	0.21	0.19	0.24	1		
U.K.	0.21	0.06	0.28	0.33	0.20	1	
U.S.	0.16	0.12	0.11	0.18	0.48	0.23	1

Table 2: Drift Terms, AR Parameters, and Standard Deviations

Table 2a: Log Likelihood Values and Drift Terms

	Model 1 correlation, drift breaks			Model 2 no ηε correlation, no breaks	Model 3 correlation, no breaks
Log Likelihood Value	-1375.85			-1508.21	-1407.30
Drift(s) (μ_i) Estimate (SE)					
Japan	2.22 (0.17)	0.80 (0.12)	1.13 (0.08)	1.13 (0.08)	1.04 (0.19)
Italy	1.26 (0.17)		0.57 (0.11)	0.75 (0.06)	0.76 (0.09)
Germany	1.01 (0.18)		0.50 (0.11)	0.65 (0.05)	0.62 (0.11)
France	1.31 (0.17)		0.53 (0.08)	0.55 (0.06)	0.69 (0.13)
Canada	1.36 (0.16)		0.74 (0.11)	0.80 (0.07)	0.92 (0.09)
U.K.	0.75 (0.14)		0.57 (0.09)	0.60 (0.07)	0.63 (0.07)
U.S.	1.08 (0.14)		0.76 (0.09)	0.80 (0.03)	0.85 (0.07)

[14] The growth rate is defined as the first difference of the log of real GDP for each country. These are the simple growth rate correlations over the entire sample period, not accounting for any structural breaks.

Table 2b: Autoregressive Parameters

	Model 1 correlation, drift breaks	Model 2 no ηε correlation, no breaks	Model 3 correlation, no breaks
1st AR parameter (ϕ_{1i}) Estimate (SE)			
Japan	0.88 (0.08)	-0.17 (0.13)	0.95 (0.02)
Italy	0.40 (0.08)	1.49 (0.07)	0.50 (0.07)
Germany	0.59 (0.06)	0.62 (0.09)	0.67 (0.06)
France	0.27 (0.06)	1.47 (0.12)	0.73 (0.08)
Canada	1.27 (0.03)	1.43 (0.07)	1.27 (0.04)
U.K.	0.75 (0.10)	1.75 (0.06)	0.76 (0.06)
U.S.	1.30 (0.02)	1.33 (0.09)	1.32 (0.05)
2nd AR parameter (ϕ_{2i}) Estimate (SE)			
Japan	-0.19 (0.07)	-0.64 (0.13)	-0.06 (0.02)
Italy	-0.14 (0.04)	-0.70 (0.09)	-0.09 (0.05)
Germany	0.21 (0.05)	0.16 (0.08)	0.20 (0.05)
France	0.57 (0.07)	-0.48 (0.11)	0.19 (0.07)
Canada	-0.54 (0.04)	-0.46 (0.07)	-0.46 (0.06)
U.K.	0.03 (0.11)	-0.79 (0.06)	0.03 (0.05)
U.S.	-0.62 (0.02)	-0.39 (0.09)	-0.59 (0.06)

Table 2c: Permanent and Transitory Standard Deviations

	Model 1 correlation, drift breaks	Model 2 no ηε correlation, no breaks	Model 3 correlation, no breaks
Standard Deviation of the Permanent Innovations ($\sigma_{\eta i}$) Estimate (SE)			
Japan	1.22 (0.11)	1.19 (0.06)	2.86 (0.32)
Italy	1.19 (0.05)	0.83 (0.06)	1.30 (0.11)
Germany	1.15 (0.11)	0.67 (0.10)	1.57 (0.31)
France	0.83 (0.06)	0.51 (0.04)	1.85 (0.51)
Canada	1.19 (0.09)	0.54 (0.08)	1.36 (0.15)
U.K.	0.98 (0.15)	0.92 (0.05)	1.05 (0.17)
U.S.	1.00 (0.07)	0.40 (0.09)	1.08 (0.12)
Standard Deviation of the Transitory Innovations ($\sigma_{\varepsilon i}$) Estimate (SE)			
Japan	1.04 (0.10)	0.11 (0.04)	2.50 (0.32)
Italy	0.90 (0.08)	0.35 (0.10)	1.01 (0.13)
Germany	1.62 (0.09)	1.02 (0.08)	1.99 (0.30)
France	0.36 (0.06)	0.27 (0.06)	1.62 (0.56)
Canada	0.86 (0.10)	0.59 (0.07)	1.07 (0.18)
U.K.	1.11 (0.10)	0.20 (0.05)	1.33 (0.16)
U.S.	0.55 (0.05)	0.67 (0.07)	0.66 (0.14)

Table 2d: Correlations between Within-Series Permanent and Transitory Innovations

	Model 1 correlation, drift breaks	Model 2 no ηε correlation, no breaks	Model 3 correlation, no breaks
Correlation between the Permanent Innovation and Transitory Innovation for the Same Series ($\sigma_{\eta i \varepsilon i}$) Estimate (SE)			
Japan	-0.73 (0.06)	0 (by assumption)	-0.95 (0.01)
Italy	-0.81 (0.03)	0 (by assumption)	-0.82 (0.04)
Germany	-0.75 (0.04)	0 (by assumption)	-0.83 (0.06)
France	-0.92 (0.02)	0 (by assumption)	-0.98 (0.02)
Canada	-0.83 (0.05)	0 (by assumption)	-0.88 (0.04)
U.K.	-0.62 (0.09)	0 (by assumption)	-0.77 (0.07)
U.S.	-0.79 (0.05)	0 (by assumption)	-0.84 (0.06)

Table 3. Maximum Likelihood Estimates for the Correlations Based on Model 1

Table 3a: Correlation Parameters, Permanent Innovations (Σ_η)

	Correlations Across Countries (SE)						
	Japan	**Italy**	**Germany**	**France**	**Canada**	**U.K.**	**U.S.**
Japan	1						
Italy	0.53 (0.06)	1					
Germany	0.79 (0.07)	0.13 (0.11)	1				
France	0.43 (0.10)	0.43 (0.05)	0.70 (0.09)	1			
Canada	-0.27 (0.06)	0.55 (0.08)	-0.45 (0.10)	0.14 (0.07)	1		
U.K.	-0.05 (0.02)	-0.43 (0.11)	0.27 (0.12)	0.13 (0.07)	0.07 (0.13)	1	
U.S.	0.20 (0.07)	-0.03 (0.07)	0.18 (0.05)	0.11 (0.07)	0.25 (0.08)	0.79 (0.04)	1

Table 3b: Correlation Parameters, Transitory Innovations (Σ_{ε})

	Correlations Across Countries (SE)						
	Japan	**Italy**	**Germany**	**France**	**Canada**	**U.K.**	**U.S.**
Japan	1						
Italy	-0.14 (0.11)	1					
Germany	0.70 (0.06)	-0.12 (0.08)	1				
France	0.35 (0.09)	0.57 (0.06)	0.25 (0.08)	1			
Canada	-0.38 (0.11)	0.49 (0.12)	-0.34 (0.06)	0.23 (0.09)	1		
U.K.	0.24 (0.09)	-0.28 (0.14)	0.26 (0.11)	-0.14 (0.08)	0.19 (0.15)	1	
U.S.	0.08 (0.11)	0.19 (0.07)	0.11 (0.10)	0.12 (0.11)	0.63 (0.07)	0.76 (0.09)	1

Table 3c: Permanent and Transitory Innovations Cross-Correlations ($\Sigma_{\eta\varepsilon}$)

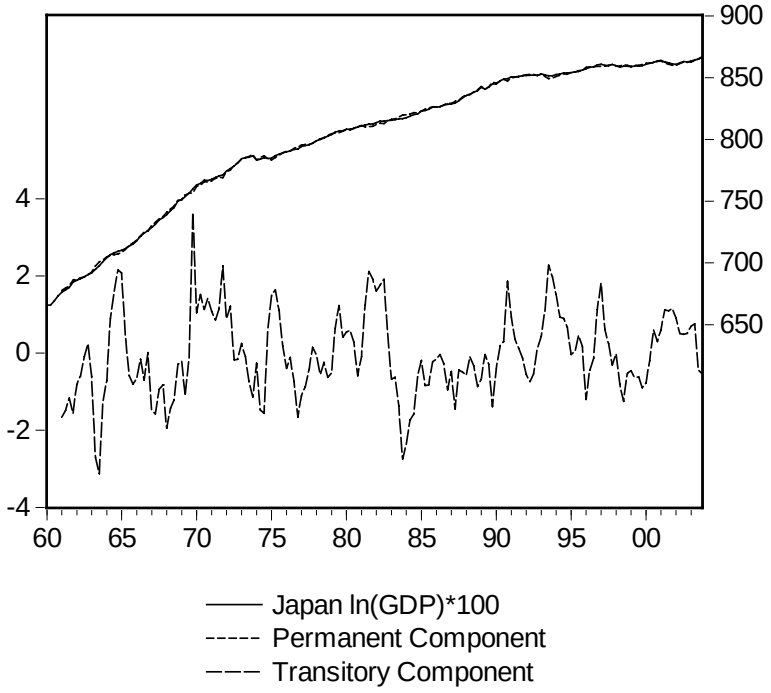
		PERMANENT (η)						
		Japan	**Italy**	**Germany**	**France**	**Canada**	**U.K.**	**U.S.**
TRANSITORY (ε)	**Japan**	**-0.73 (0.06)**	-0.28 (0.10)	-0.67 (0.05)	-0.35 (0.10)	0.14 (0.08)	-0.30 (0.08)	-0.34 (0.08)
	Italy	-0.13 (0.07)	**-0.81 (0.03)**	0.15 (0.09)	-0.34 (0.05)	-0.81 (0.07)	0.18 (0.15)	-0.14 (0.10)
	Germany	-0.65 (0.07)	-0.04 (0.08)	**-0.75 (0.04)**	-0.32 (0.08)	0.31 (0.06)	-0.41 (0.07)	-0.23 (0.06)
	France	-0.38 (0.09)	-0.56 (0.04)	-0.53 (0.11)	**-0.92 (0.02)**	-0.47 (0.06)	-0.28 (0.06)	-0.37 (0.08)
	Canada	0.68 (0.07)	-0.04 (0.12)	0.59 (0.08)	0.02 (0.11)	**-0.83 (0.05)**	-0.27 (0.13)	-0.18 (0.10)
	U.K.	0.15 (0.07)	0.43 (0.11)	0.08 (0.13)	0.26 (0.08)	0.04 (0.12)	**-0.62 (0.09)**	-0.64 (0.09)
	U.S.	0.28 (0.07)	0.17 (0.03)	0.28 (0.07)	0.20 (0.09)	-0.50 (0.07)	-0.75 (0.11)	**-0.79 (0.05)**

Table 4: Estimates of Alpha Parameters
(Relative Size of Standard Deviations pre- and post- 1984)

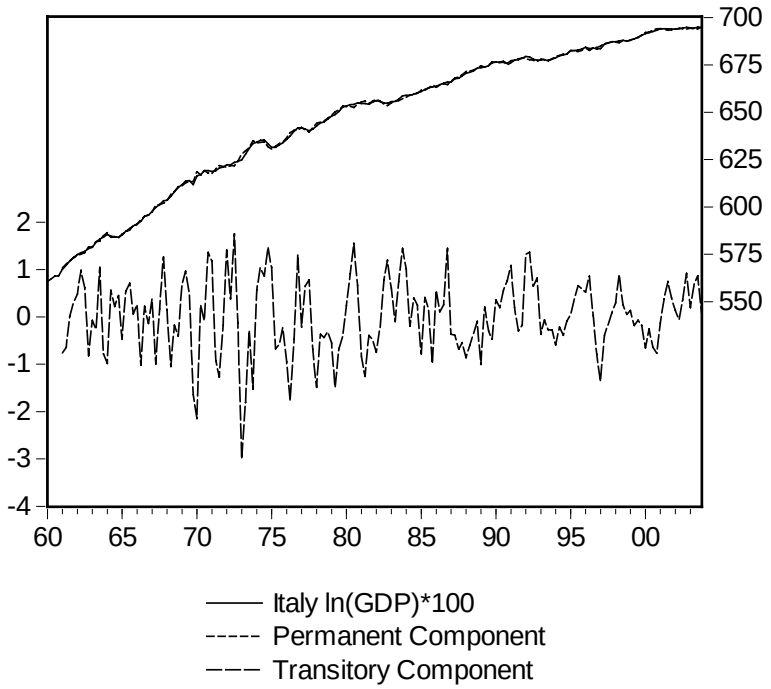
Country	Alpha Estimate (SE)
Japan	0.87 (0.02)
Italy	0.54 (0.01)
Germany	0.61 (0.02)
France	0.76 (0.02)
Canada	0.62 (0.02)
U.K.	0.44 (0.01)
U.S.	0.47 (0.01)

Figure 1: **Real GDP and the Estimated Components**

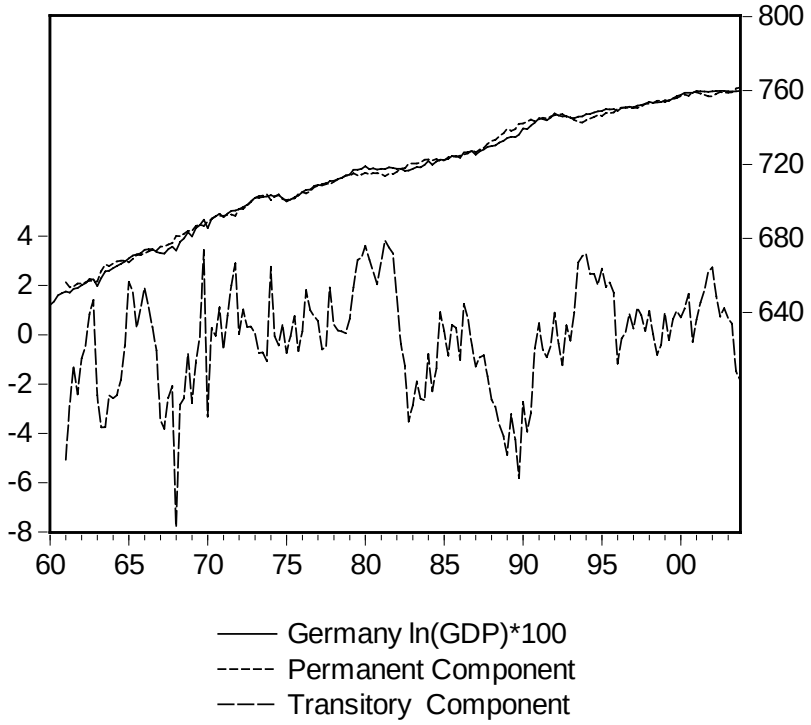
Panel 1: Japan



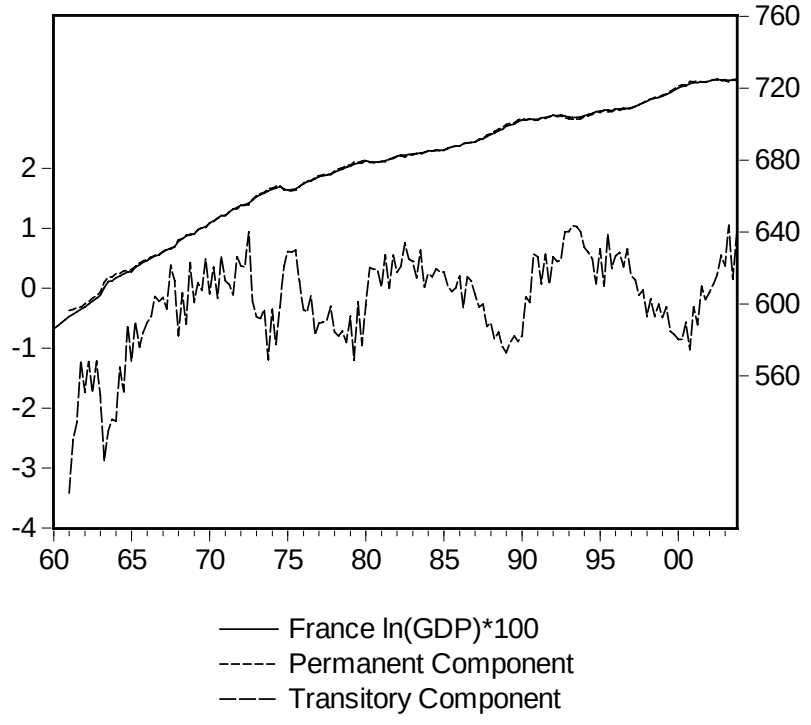
Panel 2: Italy



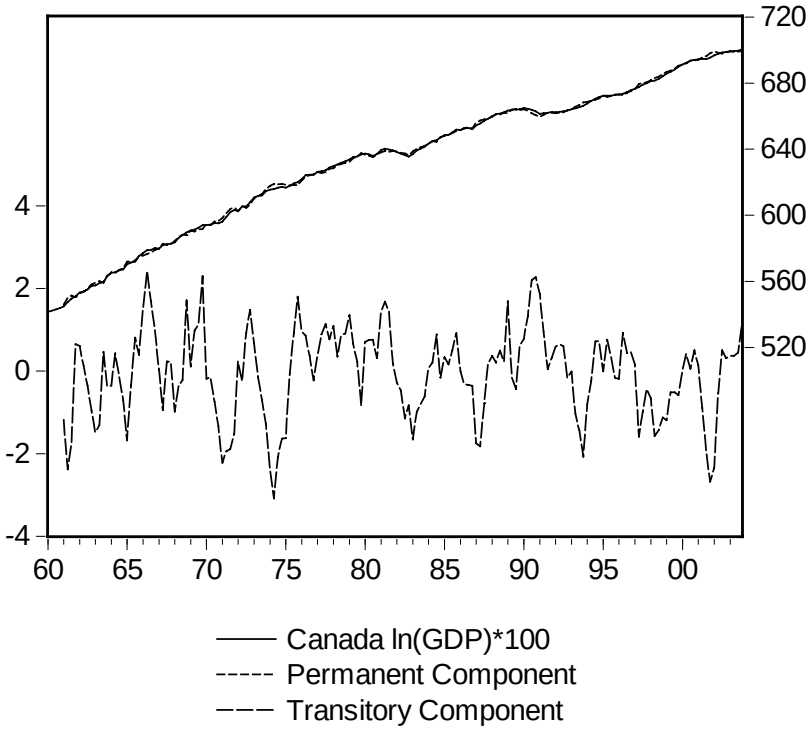
Panel 3: Germany



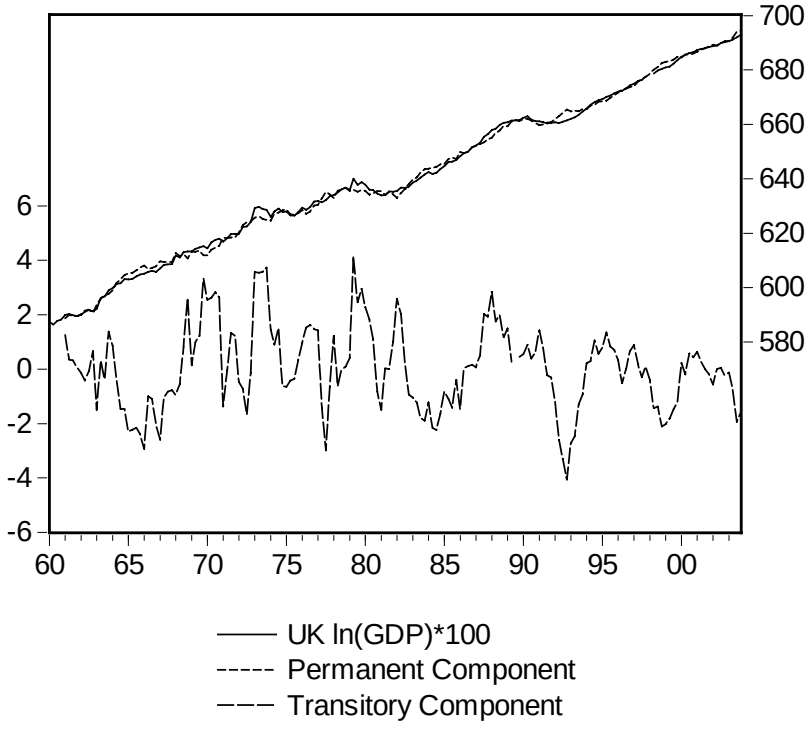
Panel 4: France



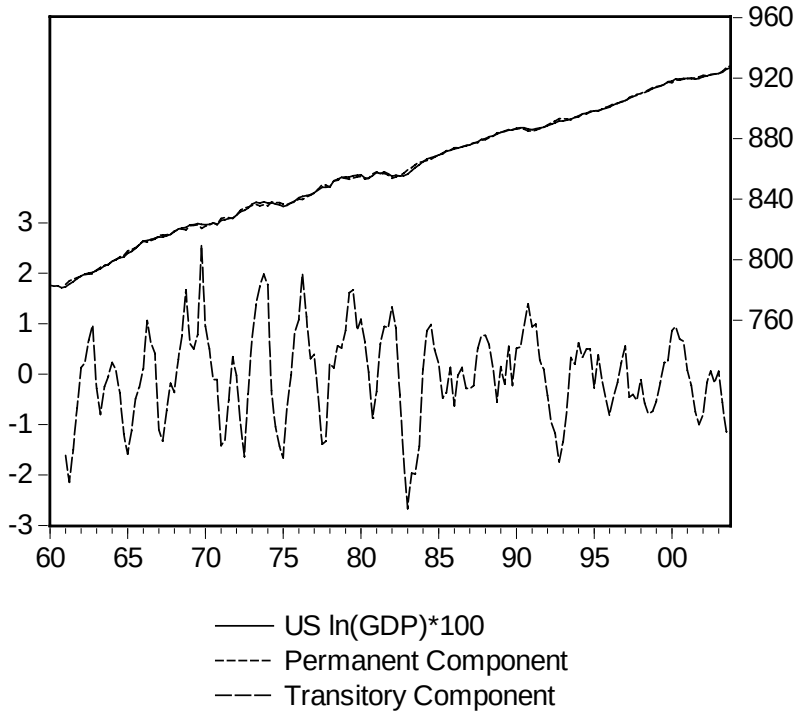
Panel 5: Canada



Panel 6: U.K.



Panel 7: US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95
00
US ln(GDP)*100
Permanent Component
Transitory Component