Has the G7 business cycle become more synchronized ?

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Abstract

This paper adopts Friedman's Plucking Markov Switching Model to decompose G7 real GDPs into common permanent components, common transitory components, infrequent Markov Switching negative shock and domestic idiosyncratic components. The findings show that the common components explain a 53.1% average volatility of G7 GDPs from 1960 to 2002. Despite the moderated volatility of G7 economies, the G7 business cycle (except Japan) has become more synchronized in its fluctuations. In addition, from the dynamic factor model with Markov switching, there appears to have been a common permanent synchronized fluctuation in the Euro-zone countries after 1984. The probability that the common transitory component is contracting, accords quite well with U.S recessionary dates.

Keyword : G7, GDP, business cycle, Friedman's Plucking Markov Switching Model, permanent, transitory,

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1. Introduction

One of the issues of the international business cycle is the co-movement in economic activities across G7 countries. Gregory, Head and Raynauld (1997), Kose, Otrok and Whiteman(2003) identified the common fluctuations across macroeconomic aggregates in G7 countries. Dalsgaard, Elmeskov and Park (2002), Kose, Otrok and Whiteman (2002), and Stock and Watson(2003) provided the evidence of the moderated volatility of G7 GDP growth over the past forty years. Monfort, Renne, Ruffer and Vitale (2002) found the emergence of at least one cyclically coherent group, the major Euro-zone countries.

Moreover, Kose, Otrok and Whiteman(2002) claim that from 1960-1972 the co-movement of G7 outputs is generally low, from 1973-1986 the co-movement is much higher, and from 1986-2001 there is a fall in the co-movement of G7 outputs using the dynamic factor model with common permanent component. However, Stock and Watson (2003) and Dalsgaard, Elmeskov and Park (2002) claim that there appears to have been a diminished international output volatility, The G7 business cycle synchronization did not point to clear trends.

As Stock and Watson (2003) point out, "Over the past four decades, international trade flows have increased substantially, financial markets in developed economies have become increasingly integrated, and continental European countries moved to a single currency. These developments raise the possibility of changes in the severity of international business cycles, but also in their synchronization". This paper will examine whether economic activities in the G7 really have become more synchronized over the past forty years.

In order to examine the degree of G7 business cycle synchronization, I propose the generalization of existing G7 business cycle models that allow me to decompose G7 GDPs into common permanent components, common transitory components, infrequent Markov Switching negative shock and domestic idiosyncratic components.

For the measure of G7 countries' synchronized fluctuations, this paper compares the share of each country's total variance of real GDP growth explained by the common components during the 1960-1983 period to that during the 1984-2002 period.

Section 2 presents the use of Friedman's Plucking Markov Switching model. Section 3 explains the data used for empirical research. Section 4 summarizes the empirical results about the change of synchronized fluctuations from 1960-1983 and 1984-2002 using variance decomposition. Section 5 concludes this paper.

2. Markov Switching model with common permanent and transitory components

There has been a large body of research that the economic activity in the U.S has a permanent component which has the persistence of shocks; for example, Nelson and Plosser (1982), Campbell and Mankiw (1987), Watson (1986) and Cochrane (1988), Stock and Watson (1989, 1991). There also has been a large body of research that the economic activity in the U.S has a transitory component which has a smaller persistence of shocks; for example, Clark (1987), Beaudry and Koop (1993).

From the the Markov-switching model of Hamilton (1989), many papers have demonstrated that economic activity in the U.S has shown an asymmetrical behavior in the permanent component of real output. This means that if there will be a shock, the shock will switch the trend of real output and it will persist; for example, Hamilton (1989), Lam (1990), Chauvet (1998), Kim and Nelson (1998). Many papers have also demonstrated that the economic activity in the U.S has shown an asymmetrical behavior in the transitory component of real output. This means that if there is infrequent shock, the shock will just be temporary and transitory and will have no relation to the trend of real output; for example Kim and Nelson (1999), Kim and Murray (2002), Kim, J. Piger and R. Startz (2002).

These papers about economic activities in the U.S suggest that there may exist unobserved common permanent and transitory components in the G7 business cycles. In order to find out whether the G7 GDPs have common permanent and transitory components like U.S real output, I propose the simple generalization of existing G7 business cycle models that allow me to decompose G7 GDPs into common permanent components, common transitory components, and domestic idiosyncratic components. Following the plucking asymmetry model suggested by Kim and Nelson (1999), I also included Markov switching asymmetry, infrequent shock in the common transitory component in this generalization model.

Consider the following unobserved components of economic fluctuations in the log of real GDP (Y_{it}) are decomposed into a deterministic time trend (DT_{it}), a permanent component with unit root (P_{it}), and a transitory component (T_{it}) suggested by Kim and Nelson (1999), Kim and Murray (2002):

$$Y_{it} = DT_{it} + P_{it} + T_{it} \qquad (1)$$

$$\text{where } DT_{it} = \alpha_i + D_i T$$

$$P_{it} = r_i C_t + \zeta_{it}$$

$$T_{it} = \lambda_i X_t + \omega_{it}$$

where C_t and X_t are the international common permanent and common transitory components respectively, and ζ_{it} and ω_{it} are the domestic idiosyncratic components, respectively. The r_i terms are permanent factor loadings and indicate the extent to which each series is affected by the common permanent component, C_t. Similarly, the transitory factor loadings, λ_i, indicate the extent to which each series is affected by the common transitory component, X_t.

To the empirical results, G7 data is integrated, but not co-integrated [2]. Thus, I take the first difference, then:

$$\Delta Y_{it} = D_i + r_i \Delta C_t + \lambda_i \Delta X_t + z_{it} \qquad (2)$$

$$\text{where } z_{it} = \Delta \zeta_{it} + \Delta \omega_{it}$$

$$\phi(L) \Delta C_t = \delta + v_t, \qquad v_t \sim \text{iid } N(0, 1)$$

$$\psi(L) X_t = \pi S_t + u_t, \quad \pi \neq 0 \qquad u_t \sim \text{iid } N(0, 1)$$

z_{it} can be interpreted as a total domestic idiosyncratic component which is unrelated to the two international common components.

Given ΔY_{it}, δ, D_i are not separately identified, I concentrate this parameter out of the likelihood function by writing the model in deviations from means[3]:

$$\Delta y_{it} = r_i \Delta c_t + \lambda_i \Delta x_t + z_{it} \qquad (3)$$

$$\text{where } \Delta y_{it} = \Delta Y_{it} - \Delta \hat{Y}_i$$

$$\Delta c_t = \phi_1 \Delta c_{t-1} + \phi_2 \Delta c_{t-2} + v_t, \qquad v_t \sim \text{iid } N(0, 1)$$

$$x_t = \psi_1 x_{t-1} + \psi_2 x_{t-2} + \pi S_t + u_t, \quad \pi \neq 0 \qquad u_t \sim \text{iid } N(0, 1)$$

$$z_{it} = \tau_i z_{it-1} + e_{it}, \qquad e_{it} \sim \text{iid } N(0, \sigma^2_i)$$

$$\Pr(S_t = 0 \mid S_{t-1} = 0) = q, \ \Pr(S_t = 1 \mid S_{t-1} = 1) = p$$

In this framework, when $\lambda_i = 0$, $\pi = 0$, this model is the linear dynamic factor model of Kose, Otrok and Whiteman(2002, 2003) and Monfort, Renne, Ruffer and Vitale(2002) without regional or area model.

To measure the G7 countries synchronized fluctuations, this paper compares the share of each country's total variance of real GDP growth explained by the common components suggested by Kose, Otrok and Whiteman(2002), Monfort, Renne, Ruffer

[2] A detailed description of test results is provided in the appendix B
[3] A detailed description is provided in the appendix A

and Vitale(2002). [4]

I decompose the variance of each observable into the fraction that is due to the two common components and the domestic idiosyncratic component. With orthogonal factors the variance of each observable can be written as:

$$Var(\Delta y_{it}) = r_i^2 Var(\Delta c_t) + \lambda_i^2 Var(\Delta x_t) + Var(z_{it}) \quad (4)$$

The fraction of volatility due to the common permanent and transitory component would be the measure of the G7 countries synchronized fluctuations;

$$\frac{r_i^2 Var(\Delta c_t) + \lambda_i^2 Var(\Delta x_t)}{Var(\Delta y_{it})} \quad (5)$$

3. Data

The data represents quarterly real GDPs for the G7 countries (US, Japan, Germany, France, Italy, UK, Canada) covering 1960:1 – 2002:4, the same data used in Stock & Watson(2003)[5]. For the empirical results, G7 data are integrated, but not co-integrated. Using the Augmented Dickey-Fuller Test, I fail to reject the unit root null for any of the series. Using the Johansen's tests for co-integration, I fail to reject the null hypothesis that there are no co-integrating vectors.

4. Empirical results

I estimate the model presented in Section 2, using log differenced data. Furthermore, the differenced data is demeaned by removing the sample mean and the variance is standardized to one. Estimation results are summarized in Table 1. The coefficients in Model 1 and Model 2 have almost the same level and significance[6]. I chose Model 1 to analyze the G7 business cycles because Model 1 is the unrestricted, general model that not only has an asymmetric discrete negative shock πS_t but also a symmetric, continuous shock u_t in the common transitory component compared with Model 2, which has only a symmetric, continuous shock u_t in the common transitory component.

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[4] The calculation of the variance is provided in the appendix C

[5] Data sources are summarized in Appendix D

[6] Model 2 results are summarized in Appendix E. In this paper, Model 2 has almost same implication as Model 1 although Model 2 doesn't have asymmetry, discrete shock in the common transitory component

TABLE 1

MAXIMUM LIKELIHOOD ESTIMATION OF THE MODEL: G7 GDP (1960 ~ 2002)

Parameters	Model 1	Model 2
ϕ_1	0.705 (0.352)	0.692 (0.378)
ϕ_2	0.196 (0.335)	0.219 (0.361)
ψ_1	1.448 (0.154)	1.640 (0.071)
ψ_2	-0.509 (0.146)	-0.672 (0.058)
r_{us}	0.079 (0.043)	0.063 (0.043)
r_{japan}	0.323 (0.110)	0.311 (0.112)
$r_{germany}$	0.116 (0.053)	0.111 (0.053)
r_{france}	0.160 (0.059)	0.150 (0.059)
r_{italy}	0.224 (0.082)	0.213 (0.084)
r_{uk}	0.073 (0.050)	0.061 (0.047)
r_{canada}	0.114 (0.051)	0.097 (0.049)
λ_{us}	0.405 (0.076)	0.520 (0.079)
λ_{japan}	0.037 (0.053)	0.073 (0.067)
$\lambda_{germany}$	0.009 (0.045)	0.023 (0.057)
λ_{france}	0.066 (0.036)	0.102 (0.047)
λ_{italy}	0.091 (0.055)	0.119 (0.072)
λ_{uk}	0.165 (0.051)	0.230 (0.059)
λ_{canada}	0.326 (0.064)	0.443 (0.061)
τ_{us}	-0.200 (0.120)	-0.164 (0.127)
τ_{japan}	-0.141 (0.105)	-0.144 (0.101)
$\tau_{germany}$	-0.171 (0.077)	-0.172 (0.076)
τ_{france}	-0.471 (0.069)	-0.469 (0.069)
τ_{italy}	0.114 (0.082)	0.116 (0.083)
τ_{uk}	-0.108 (0.078)	-0.113 (0.079)
τ_{canada}	-0.081 (0.092)	-0.087(0.094)
σ_{us}	0.638 (0.067)	0.661 (0.073)
σ_{japan}	0.715 (0.055)	0.715 (0.054)
$\sigma_{germany}$	0.951 (0.053)	0.951 (0.053)
σ_{france}	0.820 (0.047)	0.822 (0.047)
σ_{italy}	0.856 (0.050)	0.859 (0.050)
σ_{uk}	0.933 (0.052)	0.929 (0.052)
σ_{canada}	0.765 (0.051)	0.751 (0.053)
π	-2.613 (0.799)	-
q	0.945 (0.030)	-
p	0.636 (0.164)	-
Log Likelihood	-454.29	-456.23

Standard errors of the parameters estimates are reported in the parentheses

Also, with Model 1, I can find the timing and duration of the common transitory component.[7]

I considered both common components as either an AR(1) or an AR(2), and all domestic idiosyncratic components as either an AR(1) or an AR(2). Based on various checks, I selected both common components as an AR(2) and domestic idiosyncratic components as an AR(1).

The factor loadings for the common permanent component, r_i, i = 1,2,3,4,5,6,7 are significant. However, the factor loadings for the common transitory component, λ_{japan}, $\lambda_{germany}$ are insignificant. So the probabilities of negative shock to common transitory component are for the U.S, France, Italy, U.K and Canada but not for Japan and Germany. This means that Japan and Germany only have common permanent components with G7 countries and don't have common transitory components with other G7 countries from 1960 to 2002.

To measure the G7 countries synchronized fluctuations, I decomposed the variance of each observable into the fraction that is due to the two common components and the domestic idiosyncratic component. The share of variance is summarized in Table 2.

TABLE 2

SHARE OF VARIANCE OF MODEL 1 IN THE TABLE 1: G7 GDP (1960 ~ 2002) (%)

Country	Common				Domestic
	Permanent	Transitory	Switching	Sub-Total	Sub-Total
US	0.4	71.1	23.2	94.6	5.4
Japan	44.8	4.5	1.5	50.7	49.3
Germany	6.1	0.3	0.1	6.4	93.6
France	9.9	12.7	4.1	26.7	73.3
Italy	16.8	21.2	6.9	45.0	55.0
UK	1.1	43.4	14.2	58.8	41.2
Canada	1.1	66.5	12.7	89.2	10.8
Average	11.4	31.4	10.2	53.1	46.9

Average share of common components variance is 53.1%, which is bigger than domestic idiosyncratic share of variance. For the share of variance in the two common components, 41.6% share of variance comes from transitory components and 11.4% comes from permanent components. For the transitory component, the stable AR part explains for 31.4% and the discrete, infrequent shock in the transitory component explains for 10.2% of total variance. This implies that G7 countries have been more

[7] I also estimated a more general model in which I allowed regime switching to have both permanent and transitory with same Markov-Switching state variable S_t. But, all the coefficients r_i were insignificant.

influenced by common G7 fluctuation than by each of the domestic idiosyncratic factors. Furthermore, the stable common AR parts explain more synchronized G7 fluctuation than the transitory discrete, infrequent shocks in the transitory component.

Japan's share of permanent component variance is 44.8%. Germany's share of permanent component variance is just 6.1%. This means that Germany does not have more synchronized fluctuations than Japan in the G7 countries. For the U.S, the share of common components variance is the highest of the G7 countries. For the U.S, of 94.6% of the share of variance in the two components, 71.1% comes from the stable transitory component, 23.2% comes from the discrete, infrequent shock in the transitory component, 0.4% comes from the permanent component, and 5.4% from the domestic component. This means that G7's synchronization is heavily influenced by the U.S fluctuations and that the U.S source of synchronization comes from almost stable transitory shock, and not from discrete, infrequent shock or permanent shock.

In Figure 4 through Figure 6, I summarize the common permanent and transitory components and probabilities of negative shock to transitory components of G7 real GDPs. An expected duration of negative shock is 2.75 quarters.[8]

4. The change of synchronized fluctuations from 1960-1983 and 1984-2002

Table 3 and Table 4 summarize the common permanent and transitory components of G7 real GDPs from 1960-1983 and 1984-2002. Over the two periods, probabilities of negative shock to the transitory component are somewhat different. An expected duration of negative shock to the transitory component is decreasing from 2.70 quarters from 1960-1983 to 2.08 quarters from 1984-2002

Over 1960-1983, the factor loadings for the common permanent component, r_i, i = 1,2,3,4,5,6,7 are significant. However, the factor loadings for the common transitory component, λ_{japan} are insignificant. This means that Japan only has a common permanent component with G7 countries and doesn't have a common transitory component with other G7 countries from 1960-1983.

From 1984-2002, the factor loadings for the common permanent component, $r_{germany}$, r_{france}, r_{italy} are significant. But, the factor loadings for the common permanent component, r_{usa}, r_{japan}, r_{uk}, r_{canada} are insignificant. This result suggests that from 1984-2002, there appears to have been a common permanent synchronized fluctuation in the Euro-zone countries. The factor loadings for the common transitory

[8] With constant transition probabilities, the expected duration of a contraction is 1/(1-p)

component, $\lambda_{japan,,}$ $\lambda_{germany}$ are insignificant.

TABLE 3

MAXIMUM LIKELIHOOD ESTIMATION OF THE MODEL: G7 GDP

Parameters	Model 1		
	(1960~2002)	(1960~1983)	(1984~2002)
ϕ_1	0.705 (0.352)	0.517 (0.247)	0.393 (0.225)
ϕ_2	0.196 (0.335)	0.221 (0.221)	0.296 (0.196)
ψ_1	1.448 (0.154)	1.367 (0.206)	1.731 (0.071)
ψ_2	-0.509 (0.146)	-0.453 (0.194)	-0.743 (0.074)
r_{us}	0.079 (0.043)	0.136 (0.082)	0.000 (0.000)
r_{japan}	0.323 (0.110)	0.587 (0.134)	0.150 (0.117)
$r_{germany}$	0.116 (0.053)	0.227 (0.071)	0.370 (0.116)
r_{france}	0.160 (0.059)	0.207 (0.059)	0.627 (0.130)
r_{italy}	0.224 (0.082)	0.230 (0.096)	0.489 (0.154)
r_{uk}	0.073 (0.050)	0.229 (0.080)	0.025 (0.107)
r_{canada}	0.114 (0.051)	0.159 (0.078)	0.000 (0.000)
λ_{us}	0.405 (0.076)	0.326 (0.126)	0.252 (0.071)
λ_{japan}	0.037 (0.053)	0.000 (0.012)	0.018 (0.050)
$\lambda_{germany}$	0.009 (0.045)	0.094 (0.053)	0.000 (0.000)
λ_{france}	0.066 (0.036)	0.048 (0.035)	0.253 (0.070)
λ_{italy}	0.091 (0.055)	0.096 (0.067)	0.203 (0.061)
λ_{uk}	0.165 (0.051)	0.080 (0.054)	0.247 (0.065)
λ_{canada}	0.326 (0.064)	0.265 (0.107)	0.283 (0.076)
τ_{us}	-0.200 (0.120)	-0.136 (0.143)	-0.139 (0.149)
τ_{japan}	-0.141 (0.105)	-0.272 (0.215)	-0.047 (0.123)
$\tau_{germany}$	-0.171 (0.077)	-0.336 (0.100)	-0.173 (0.133)
τ_{france}	-0.471 (0.069)	-0.511 (0.089)	-0.321 (0.253)
τ_{italy}	0.114 (0.082)	0.185 (0.106)	-0.249 (0.154)
τ_{uk}	-0.108 (0.078)	-0.202 (0.104)	0.191 (0.132)
τ_{canada}	-0.081 (0.092)	-0.172 (0.117)	-0.071 (0.148)
σ_{us}	0.638 (0.067)	0.685 (0.079)	0.743 (0.075)
σ_{japan}	0.715 (0.055)	0.556 (0.118)	0.978 (0.081)
$\sigma_{germany}$	0.951 (0.053)	0.867 (0.067)	0.857 (0.082)
σ_{france}	0.820 (0.047)	0.814 (0.061)	0.522 (0.135)
σ_{italy}	0.856 (0.050)	0.895 (0.068)	0.708 (0.087)
σ_{uk}	0.933 (0.052)	0.901 (0.068)	0.739 (0.067)
σ_{canada}	0.765 (0.051)	0.776 (0.070)	0.675 (0.070)
π	-2.613 (0.799)	-3.237 (1.728)	-4.351 (1.456)
q	0.945 (0.030)	0.924 (0.048)	0.984 (0.021)
p	0.636 (0.164)	0.629 (0.170)	0.519 (0.225)
Log Likelihood	-454.29	-248.01	-176.49

Standard errors of the parameters estimates are reported in the parentheses

From 1984-2002, Japan has no common components with other G7 countries. This reveals that from 1960-1983, only the common permanent component showed strong comovement with Japanese output. But from 1984-2002, the downturn of Japan's economy was idiosyncratically Japanese and therefore not related to other G7 countries. This finding is consistent with Stock and Watson (2003) that Asian trade with Japan is increasingly important for the Japanese economy and that Japan has experienced domestic economic difficulties in the 1990s. From 1984-2002, Germany related with other G7 countries with only permanent component. The reunification of the German economy makes it hard to be influenced by the common transitory component of other G7 countries and makes it stand out as a domestic idiosyncratic event.

To measure the G7 countries synchronized fluctuations, I calculated equation (5). Average share of two common components variance has increased from 49.5% to 75.3% from 1960-1983 and 1984-2002. This implies that G7 countries were more synchronized from 1984-2002, despite the fact that there was widespread reduction in volatility in G7 GDPs.

TABLE 4

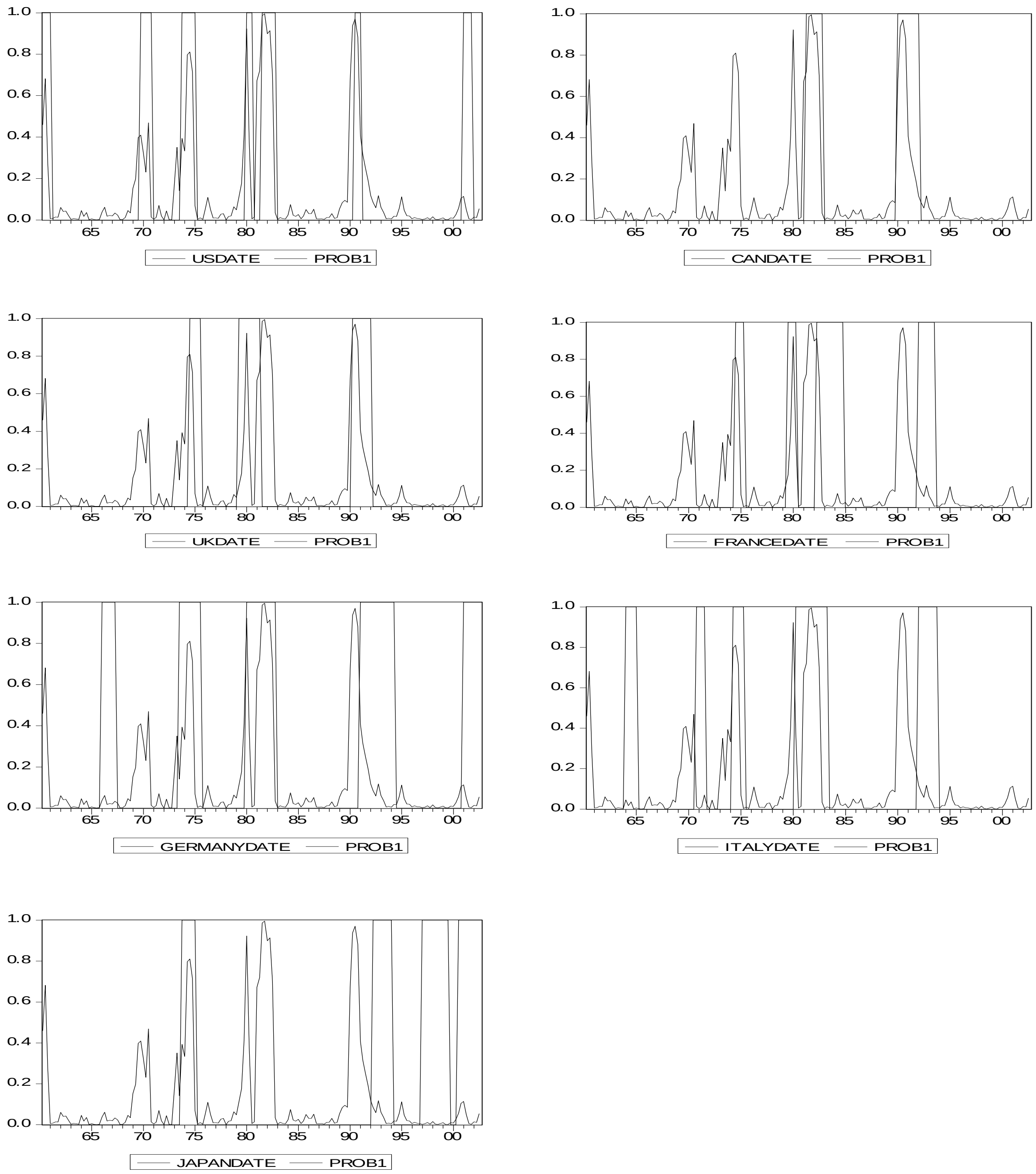
SHARE OF VARIANCE IN THE TABLE 3: G7 GDP (1960~ 1983 vs 1984~2002) (%)

Country	Common								Domestic	
	Permanent		Transitory		Switching		Sub-Total		Sub-Total	
	(60~83)	(84~02)	(60~83)	(84~02)	(60~83)	(84~02)	(60~83)	(84~02)	(60~83)	(84~02)
USA	0.8	0.0	53.0	75.8	35.2	22.1	89.0	97.9	11.0	2.1
Japan	66.0	3.2	0.0	8.9	0.0	2.6	66.0	14.7	34.0	85.3
Germany	7.7	22.3	15.2	0.0	10.1	0.0	32.9	22.3	67.1	77.7
France	7.6	2.3	4.8	74.9	3.2	21.8	15.5	98.9	84.5	1.1
Italy	7.9	2.1	15.8	73.5	10.5	21.4	34.2	97.1	65.8	2.9
UK	8.3	0.0	11.9	75.8	7.9	22.1	28.1	97.8	71.9	2.2
Canada	1.5	0.0	47.6	76.4	31.6	22.3	80.6	98.7	19.4	1.3
Average	14.3	4.3	21.2	55.0	14.1	16.0	49.5	75.3	50.5	24.7

For the common factors, G7 countries are more influenced by the transitory components from 1984-2002. Average share of transitory common component variance increased from 35.3% to 71% from 1984-2002. For the transitory component, average share of the stable AR part in the total variance increased from 21.2% to 55.0%. But, the discrete, infrequent shock just increased from 14.1% to 16.0% of total variance. This implies that the G7 business cycle was more synchronized by the increased share of common stable AR part and not by the increased, discrete shock from 1984-2002. From

1984-2002, the common permanent components were less influenced by the G7 business cycle fluctuations because average share of permanent common component variance decreased from 14.3% to 4.3%. This implies that synchronization by the common permanent components in the 1980s and 1990s was not as they were in the 1960s and 1970s.

Figure 1. Probability of negative shock and G7 Business Cycle Peak & Trough Dates



In Figure 1, we can clearly observe periods of high probabilities of negative Markov

switching shocks that are highly correlated with US recessionary periods.[9]
The probability that the common transitory component is contracting, accords quite well with U.S recessionary dates except 2001:1 - 2001:4.

From this finding, we can infer that U.S recession is one of the influential factors in other G7 country recessions.

5. Summary and Discussion

These empirical results suggest a few conclusions. First, despite the moderated volatility of economic activities in the G7 GDPs over the past forty years, the total G7 business cycle has become more synchronized in its fluctuations with the Friedman's Plucking Markov Switching Model. Also, there have been important changes, in particular the emergence of Euro-zone countries in the 1980s and 1990s with the common permanent synchronized fluctuation.

Second, the Japanese experience is in many ways exceptional. Over 1960-1983 Japan has common permanent components with G7 and doesn't have common transitory components with other G7 countries. But, from 1984-2002 Japan doesn't have common permanent or transitory components with other G7 countries. This reveals that from 1960-1983, only the common permanent component showed strong comovement with Japanese output. But from 1984-2002 the downturn of Japan's economy was idiosyncratically Japanese and therefore not related to other G7 countries.

Finally, the probability that the common transitory component is contracting, accords quite well with U.S recessionary dates.

An important next step is to determine the reasons for these changes of synchronization despite the moderated volatility and their implications.

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[9] The exact peak and trough dates are in Appendix F

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Appendix A

1. Representation

In this section, I discuss representation of the model presented in Section 3. I employ the following state space representation for equations (2)-(4) assuming AR(2) dynamics for the common permanent, common transitory components, and AR(1) dynamics for idiosyncratic component. This model involves unobserved Markov-switching variable S_t in the transitory component and the dynamics can be represented in the following manner:

Measurement Equation : $\Delta y_t = H\ \xi_t$

Transition Equation : $\xi_t = \alpha_{St} + F\ \xi_{t-1} + V_t$

$$E(V_t V_t') = Q$$

$$\Pr(S_t = 0 \mid S_{t-1} = 0) = q\ ,\ \Pr(S_t = 1 \mid S_{t-1} = 1) = p, \quad \pi \neq 0 \text{ for the } \pi S_t$$

where

$$H = \begin{pmatrix} r_1 & 0 & \lambda_1 & -\lambda_1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ r_2 & 0 & \lambda_2 & -\lambda_2 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ r_3 & 0 & \lambda_3 & -\lambda_3 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ r_4 & 0 & \lambda_4 & -\lambda_4 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ r_5 & 0 & \lambda_5 & -\lambda_5 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ r_6 & 0 & \lambda_6 & -\lambda_6 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ r_7 & 0 & \lambda_7 & -\lambda_7 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

$$\xi_t = \begin{pmatrix} \Delta c_t \\ \Delta c_{t-1} \\ x_t \\ x_{t-1} \\ z_{1t} \\ z_{2t} \\ z_{3t} \\ z_{4t} \\ z_{5t} \\ z_{6t} \\ z_{7t} \end{pmatrix} \qquad \alpha_{St} = \begin{pmatrix} 0 \\ 0 \\ \pi S_t \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \qquad V_t = \begin{pmatrix} v_t \\ 0 \\ u_t \\ 0 \\ e_{1t} \\ e_{2t} \\ e_{3t} \\ e_{4t} \\ e_{5t} \\ e_{6t} \\ e_{7t} \end{pmatrix}$$

$$F = \begin{pmatrix} \phi_1 & \phi_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \psi_1 & \psi_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \tau_1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \tau_2 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \tau_3 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \tau_4 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \tau_5 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \tau_6 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \tau_7 \end{pmatrix}$$

and

$$Q = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \sigma^2_1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \sigma^2_2 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \sigma^2_3 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \sigma^2_4 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \sigma^2_5 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \sigma^2_6 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \sigma^2_7 \end{pmatrix}$$

2. Estimation

Defining S_t and its transitional dynamics as in equations (2)~(4), the above state-space model is an example of that considered by Kim(1994). The following describes Kim's Markov Switching approximate maximum likelihood estimation algorithm. For details of the nature of the approximation and the Bayesian alternative to the estimation procedure, readers are referred to Kim and Nelson(1998). The above state-space model's specific feature is that G7 real GDP's common transitory component follows the Friedman's plucking model by Kim and Nelson(1999), Kim and Murray (2002) .

The Kim's Markov Switching approximate maximum likelihood estimation algorithm is computationally efficient, and experience suggests that the degree of approximation is small ; See Kim(1994) and Kim and Nelson(1998).

Conditional on $S_t = j$ and $S_{t-1} = i$, the Kalman filter equations can be written as:

$$\xi^{(i,j)}_{t|t-1} = \alpha_{St} + F\,\xi^{i}_{t-1|t-1}$$
$$P^{(i,j)}_{t|t-1} = F\,P^{i}_{t-1|t-1}\,F' + Q$$
$$n^{(i,j)}_{t|t-1} = \Delta y_t - H\,\xi^{(i,j)}_{t|t-1}$$
$$f^{(i,j)}_{t|t-1} = H\,P^{(i,j)}_{t|t-1}\,H'$$
$$\xi^{(i,j)}_{t|t} = \xi^{(i,j)}_{t|t-1} + P^{(i,j)}_{t|t-1}\,H'[f^{(i,j)}_{t|t-1}]^{-1}\,n^{(i,j)}_{t|t-1}$$
$$P^{(i,j)}_{t|t} = (I - P^{(i,j)}_{t|t-1}\,H'[f^{(i,j)}_{t|t-1}]^{-1})\,H\,P^{(i,j)}_{t|t-1}$$

where $\xi^{(i,j)}_{t|t-1}$ is an inference on ξ_t based on information up to time t-1, conditional on $S_t = j$ and $S_{t-1} = i$; $\xi^{(i,j)}_{t|t}$ is an inference on ξ_t based on information up to time t, conditional on $S_t = j$ and $S_{t-1} = i$; $P^{(i,j)}_{t|t-1}$, $P^{(i,j)}_{t|t}$ are the MSE matrices of $\xi^{(i,j)}_{t|t-1}$ and $\xi^{(i,j)}_{t|t}$ respectively; $n^{(i,j)}_{t|t-1}$ is the conditional forecast error of Δy_t based on information up to time t-1; $f^{(i,j)}_{t|t-1}$ is the conditional variance of $n^{(i,j)}_{t|t-1}$.

As noted by Harrison and Stevens(1976) and Gordon and Smith(1988) each iteration of the Kalman filter produces a 4-fold increase in the number of cases to consider. To render the Kalman filter operational, we need to collapse the 4^2 posteriors ($\xi^{(i,j)}_{t|t}$ and $P^{(i,j)}_{t|t}$) into 4 at each iteration. Collapsing requires the following approximations suggested by Harrison and Stevens (1976) :

$$\xi^{j}_{t|t} = \frac{\sum^{2}_{i=1} \Pr[S_{t-1} = i, S_t = j \mid \Omega_t]\ \xi^{(i,j)}_{t|t}}{\Pr[S_t = j \mid \Omega_t]}$$

and

$$P^{j}_{t|t} = \frac{\sum^{2}_{i=1} \Pr[S_{t-1} = i, S_t = j \mid \Omega_t]\ \{ P^{(i,j)}_{t|t} + (\xi^{j}_{t|t} - \xi^{(i,j)}_{t|t})(\xi^{j}_{t|t} - \xi^{(i,j)}_{t|t})' \}}{\Pr[S_t = j \mid \Omega_t]}$$

where Ω_t refers to information available at time t.

In order to obtain the probability terms necessary for collapsing, we needs the following procedure due to Hamilton(1989) :

Step 1 :

At the beginning of the i^{th} iteration, given $Pr[S_{t-1} = i | \Omega_{t-1}]$, we calculate

$$Pr[S_{t-1} = i, S_t = j | \Omega_{t-1}] = Pr[S_t = j | S_{t-1} = i]\ Pr[S_{t-1} = i | \Omega_{t-1}]$$

Step 2 :

Consider the joint density of Δy_t, S_t, and S_{t-1} :

$$f(\Delta y_t, S_{t-1} = i, S_t = j | \Omega_{t-1}) = f(\Delta y_t | S_{t-1} = i, S_t = j, \Omega_{t-1})\ Pr[S_{t-1} = i, S_t = j | \Omega_{t-1}]$$

from which the marginal density of Δy_t is obtained by:

$$\begin{aligned} f(\Delta y_t | \Omega_{t-1}) &= \Sigma^2_{i=1} \Sigma^2_{j=1} f(\Delta y_t, S_{t-1} = i, S_t = j | \Omega_{t-1}) \\ &= \Sigma^2_{i=1} \Sigma^2_{j=1} f(\Delta y_t | S_{t-1} = i, S_t = j, \Omega_{t-1})\ Pr[S_{t-1} = i, S_t = j | \Omega_{t-1}] \end{aligned}$$

where the conditional density $f(\Delta y_t | S_{t-1} = i, S_t = j, \Omega_{t-1})$ is obtained via the prediction-error decomposition:

$$\begin{aligned} & f(\Delta y_t | S_{t-1} = i, S_t = j, \Omega_{t-1}) \\ &= (2\pi)^{-T/2} | f^{(i,j)}_{t|t-1}|^{-1/2} \exp\{-1/2\ n^{(i,j)'}_{t|t-1} f^{(i,j)}_{t|t-1}{}^{-1} n^{(i,j)}_{t|t-1}\} \end{aligned}$$

Step 3 :

Once Δy_t is observed at the end of time t, we update the probability terms:

$$\begin{aligned} Pr[S_{t-1} = i, S_t = j | \Omega_t] &= Pr[S_{t-1} = i, S_t = j | \Omega_{t-1}, \Delta y_t] \\ &= \frac{f(S_{t-1} = i, S_t = j, \Delta y_t | \Omega_{t-1})}{f(\Delta y_t | \Omega_{t-1})} \\ &= \frac{f(\Delta y_t | S_{t-1} = i, S_t = j, \Omega_{t-1})\ Pr[S_{t-1} = i, S_t = j | \Omega_{t-1}]}{f(\Delta y_t | \Omega_{t-1})} \end{aligned}$$

with $Pr[S_t = j | \Omega_t] = \Sigma^2_{i=1} Pr[S_{t-1} = i, S_t = j | \Omega_t]$

As a byproduct of the above filter in Step 2, we obtain the log likelihood function:

$\ln L = \Sigma \ \ln(f(\Delta y_t | \Omega_{t-1}))$

which can be maximized with respect to the parameters of the model.

Appendix B

1. Summary Unit Root Tests[10] for the quarterly G7 real GDP (1960:1 – 2002:4)

	Augmented Dickey Fuller t-Statistic	Critical Value 10%	5%	1%
$Y_{U.S.A}$	-0.78			
Y_{JAPAN}	-1.56			
$Y_{GERMANY}$	-2.52			
Y_{FRANCE}	-2.45	-3.14	-3.44	-4.02
Y_{ITALY}	-2.31			
$Y_{U.K}$	-1.15			
Y_{CANADA}	-1.16			

* reject 10% critical value, ** reject 5% critical value, *** reject 1% critical value

3. Johansen(1991, 1995) Cointegration Tests[11] for the quarterly G7 real GDP (1960:1 – 2002:4)

Null Hypothesis	Test Statistic	Critical Value 5%	1%
No Cointegration Vectors	125.6*	124.2	133.6
At Most One Cointegration Vectors	78.5	94.2	103.2
At Most Two Cointegration Vectors	47.3	68.5	76.1
At Most Three Cointegration Vectors	30.1	47.2	54.5
At Most Four Cointegration Vectors	15.2	29.7	35.7
At Most Five Cointegration Vectors	6.8	15.4	20.0
At Most Six Cointegration Vectors	0.0	3.8	6.7

* reject 5% critical value ** reject 1% critical value

[10] 4 lag was chosen for real GDP. Tests for real GDP included a time trend and constant in the test regression

[8] The test statistic is the Likelihood Ratio statistic and calculated in Eviews using a lag order 4 and each series has a linear trend but the co-integration equation has only intercepts.

Appendix C

$\Delta c_t = \phi_1 \ \Delta c_{t-1} + \phi_2 \ \Delta c_{t--2} + v_t$, $\quad v_t \sim$ iid N (0, 1)

$Var(\Delta c_t) = \phi_1 Cov(\Delta c_t \Delta c_{t-1}) + \phi_2 Cov(\Delta c_t \Delta c_{t--2}) + Var(v_t)$, where, $Var(v_t) = 1$

Following the the Box and Jenkins(1976 p62 (3.2.28)),

$$Var(\Delta c_t) = Var(v_t)*(1 - \phi_2)/(1 + \phi_2) / \{ (1 - \phi_2)^2 - \phi_1^2 \} \qquad (1)$$

$x_t = \psi_1 x_{t-1} + \psi_2 x_{t--2} + u_t$, $\quad u_t \sim$ iid N (0, 1)

$\Delta x_t = \psi_1 \Delta x_{t-1} + \psi_2 \Delta x_{t--2} + u_t - u_{t-1}$,

$Var(\Delta x_t) = \psi_1 Cov(\Delta x_t \Delta x_{t-1}) + \psi_2 Cov(\Delta x_t \Delta x_{t--2}) + Var(u_t - u_{t-1})$

where, $Var(u_t - u_{t-1}) = Var(u_t) + Var(u_{t-1}) - 2 Cov(u_t, u_{t-1}) = 2$

$$Var(\Delta x_t) = Var(u_t - u_{t-1}) * (1 - \psi_2)/(1 + \psi_2) / \{ (1 - \psi_2)^2 - \psi_1^2 \} \qquad (2)$$

$z_{it} = \tau_i z_{it-1} + e_{it}$, $\quad e_{it} \sim$ iid N $(0,\sigma^2_i)$

$Var(z_{it}) = \tau_i Cov(z_{it}, z_{it-1}) + Var(e_{it})$, $\quad$ where $Var(e_{it}) = \sigma^2_i$

$Var(z_{it}) = Var(e_{it}) / (1- \tau_i^2)$, $\quad$ (the the Box and Jenkins(1976 p58 (3.2.14))

If there is markov switching part in the transitory, then

$x_t = \psi_1 x_{t-1} + \psi_2 x_{t--2} + \pi S_t + u_t$, $\quad \pi \neq 0$, $\quad u_t \sim$ iid N (0, 1)

$\Delta x_t = \psi_1 \Delta x_{t-1} + \psi_2 \Delta x_{t--2} + \pi (S_t - S_{t-1}) + u_t - u_{t-1}$,

$Var(\Delta x_t) = \psi_1 Cov(\Delta x_t \Delta x_{t-1}) + \psi_2 Cov(\Delta x_t \Delta x_{t--2}) + Var(u_t - u_{t-1}) + \pi^2 Var(S_t - S_{t-1})$,

$$Var(\Delta x_t) = \{Var(u_t - u_{t-1}) + \pi^2 Var(S_t - S_{t-1})\} * (1-\psi_2)/(1+\psi_2)/\{(1-\psi_2)^2 - \psi_1^2\} \quad (3)$$

where, $Var(u_t - u_{t-1}) = Var(u_t) + Var(u_{t-1}) - 2 Cov(u_t, u_{t-1}) = 2$

where $Var(S_t - S_{t-1}) = Var(S_t) + Var(S_{t-1}) - 2 Cov(S_t, S_{t-1})$,

$= \pi_1 (1 - \pi_1) + \pi_1 (1 - \pi_1) - 2 \lambda_1 \pi_1 (1 - \pi_1)$

$= 2 (1 - \lambda_1) \pi_1 (1 - \pi_1)$

$= 2 (2 - p - q)(1-q)(1-p)/(2-q-p)^2$

$= 2 (1-q)(1-p)/(2-q-p) = 2 (1-p) \pi_1$

where $\pi_1 = (1-q)/(2- q - p)$, $\lambda_1 = p + q - 1$,

$S_t = (1-q) + (p + q -1) S_{t-1} + v_t$, $E(v_t) = 0$, $Var(v_t) = p (1-p) \pi_1 + q (1-q) (1-\pi_1)$

Appendix D

4. Sources for GDP Data

I obtained the data from http://www.wws.princeton.edu/~mwatson/wp.html.

I thank Dalsgaard, Elmeskov and Park for sending me the internal OECD series from Dalsgaard, Elmeskov and Park(2002). In the Stock and Watson(2003) p27, Real GDP series were used for each of the G7 countries for the same period 1960:1 – 2002:4. The table below gives the data sources and sample periods for each periods for each data series used. Abbreviations used the source column are (DS) DataStream, (DRI) Data Resources and (E) for an internal OECD series from Dalsgaard, Elmeskov, and Park(2002).

Country	Source	Sample period	
Canada	OECD (DS)	1960:1	1960:4
	STATISTICS CANADA (DS)	1961:1	2002:4
France	OECD (DS)	1960:1	1977:4
	I.N.S.E.E. (DS)	1978:1	2002:4
Germany	DEUTSCHE BUNDESBANK (DS)	1960:1	2002:4
Italy	OECD (DS)	1960:1	1969:4
	ISTITUTO NAZIONALE DI STATISTICA (DS)	1970:1	2002:4
Japan	OECD (DS)	1960:1	2002:4
UK	OFFICE FOR NATIONAL STATISTICS (DS)	1960:1	2002:4
US	Dept. of Commerce (DRI)	1960:1	2002:4

Appendix E

TABLE 1

MAXIMUM LIKELIHOOD ESTIMATION OF THE MODEL 2 : G7 GDP (1960 ~ 2002)

Parameters	Model 2 (1960~2002)	(1960~1983)	(1984~2002)
ϕ_1	0.692 (0.378)	0.544 (0.257)	0.330 (0.176)
ϕ_2	0.219 (0.361)	0.222 (0.235)	0.323 (0.175)
ψ_1	1.640 (0.071)	1.546 (0.106)	1.753 (0.072)
ψ_2	-0.672 (0.058)	-0.598 (0.082)	-0.768 (0.063)
r_{usa}	0.063 (0.043)	0.159 (0.076)	0.000 (0.000)
r_{japan}	0.311 (0.112)	0.536 (0.121)	0.138 (0.117)
$r_{germany}$	0.111 (0.053)	0.231 (0.072)	0.359 (0.100)
r_{france}	0.150 (0.059)	0.208 (0.061)	0.653 (0.100)
r_{italy}	0.213 (0.084)	0.257 (0.098)	0.499 (0.024)
r_{uk}	0.061 (0.047)	0.218 (0.080)	0.037 (0.108)
r_{canada}	0.097 (0.049)	0.177 (0.076)	0.000 (0.000)
λ_{usa}	0.520 (0.079)	0.549 (0.100)	0.389 (0.076)
λ_{japan}	0.073 (0.067)	0.000 (0.000)	0.021 (0.072)
$\lambda_{germany}$	0.023 (0.057)	0.130 (0.073)	0.000 (0.000)
λ_{france}	0.102 (0.047)	0.050 (0.060)	0.335 (0.084)
λ_{italy}	0.119 (0.072)	0.067 (0.107)	0.259 (0.074)
λ_{uk}	0.230 (0.059)	0.141 (0.077)	0.314 (0.085)
λ_{canada}	0.443 (0.061)	0.420 (0.084)	0.447 (0.075)
τ_{usa}	-0.164 (0.127)	-0.191 (0.169)	-0.139 (0.149)
τ_{japan}	-0.144 (0.101)	-0.189 (0.213)	-0.047 (0.123)
$\tau_{germany}$	-0.172 (0.076)	-0.336 (0.101)	-0.173 (0.133)
τ_{france}	-0.469 (0.069)	-0.512 (0.089)	-0.321 (0.253)
τ_{italy}	0.116 (0.083)	0.189 (0.106)	-0.249 (0.154)
τ_{uk}	-0.113 (0.079)	-0.207 (0.103)	0.191 (0.132)
τ_{canada}	-0.087 (0.094)	-0.149 (0.120)	-0.071 (0.148)
σ_{usa}	0.661 (0.073)	0.636 (0.104)	0.716 (0.077)
σ_{japan}	0.715 (0.054)	0.613 (0.104)	0.981 (0.081)
$\sigma_{germany}$	0.951 (0.053)	0.867 (0.066)	0.883 (0.081)
σ_{france}	0.822 (0.047)	0.813 (0.062)	0.496 (0.128)
σ_{italy}	0.859 (0.050)	0.896 (0.069)	0.720 (0.074)
σ_{uk}	0.929 (0.052)	0.899 (0.068)	0.778 (0.072)
σ_{canada}	0.751 (0.053)	0.776 (0.072)	0.615 (0.074)
Log Likelihood	-456.23	-249.41	-180.40

Standard errors of the parameters estimates are reported in the parentheses

TABLE 2

SHARE OF VARIANCE IN THE MODEL 2 : G7 GDP (1960 ~ 2002) (%)

Country	Common			Domestic
	Permanent	Transitory	Sub-Total	Sub-Total
USA	0.1	98.2	98.3	1.7
Japan	31.5	33.8	65.3	34.7
Germany	5.8	4.6	10.4	89.6
France	5.6	50.0	55.7	44.3
Italy	9.6	58.1	67.7	32.3
UK	0.3	84.9	85.2	14.8
Canada	0.2	96.8	97.0	3.0
Average	7.6	60.9	68.5	31.5

TABLE 3

SHARE OF VARIANCE IN THE MODLE 2: G7 GDP (1960~ 1983 vs 1984~2002) (%)

Country	Common						Domestic	
	Permanent		Transitory		Sub-Total		Sub-Total	
	(60~83)	(84~02)	(60~83)	(84~02)	(60~83)	(84~02)	(60~83)	(84~02)
USA	0.3	0.0	96.9	98.8	97.3	98.8	2.7	1.2
Japan	60.2	2.5	0.0	11.4	60.2	13.9	39.8	86.1
Germany	6.1	19.3	46.4	0.0	52.6	19.3	47.4	80.7
France	8.0	1.9	11.0	97.2	19.1	99.1	80.9	0.9
Italy	11.5	1.8	18.4	95.4	29.8	97.2	70.2	2.8
UK	5.1	0.0	50.9	97.7	56.0	97.8	44.0	2.2
Canada	0.7	0.0	92.7	99.3	93.4	99.3	6.6	0.7
Average	13.1	3.6	45.2	71.4	58.3	75.1	41.7	24.9

Appendix F

TABLE 1

G7 Business Cycle Peak and Trough Dates

Period		Plucking Model*	US	Canada	Germany	France	Italy	UK	Japan
60~61	P	III/60	II/60						
	T	III/60	I/61						
62~66	P				I/66		I/64		
	T						I/65		
67~68	P								
	T				II/67				
69~73	P		IV/69				IV/70		
	T		IV/70				III/71		
73~75	P	II/74	IV/73		III/73	III/74	II/74	III/74	IV/73
	T	IV/74	I/75		III/75	II75	II/75	III/75	I/75
76~78	P								
	T								
79~80	P	I/80	I/80		I/80	III/79	II/80	II/79	
	T	I/80	III/80			II/80			
81~83	P	I/81	III/81	II/81		II/82			
	T	III/82	IV/82	IV/82	IV/82		II/83	II/81	
84~86	P								
	T					IV/84			
86~89	P								
	T								
90~91	P	I/90	III/90	I/90	I/91			II/90	
	T	IV/90	I/91						
92~94	P					I/92	I/92		II/92
	T			I/92	II/94	III/93	IV/93	I/92	I/94
94~97	P								
	T								
97~99	P								I/97
	T								III/99
00~01	P		I/01		I/01				III/00
	T		IV/01						

Source : Economic Cycle Research Institute (except for the US, NBER)

* $Pr(St = 1|\Omega_t) > 0.5$ for the Friedman's Plucking Model

Figure 2. G7 real GDP : 1960:1 ~ 2002:4

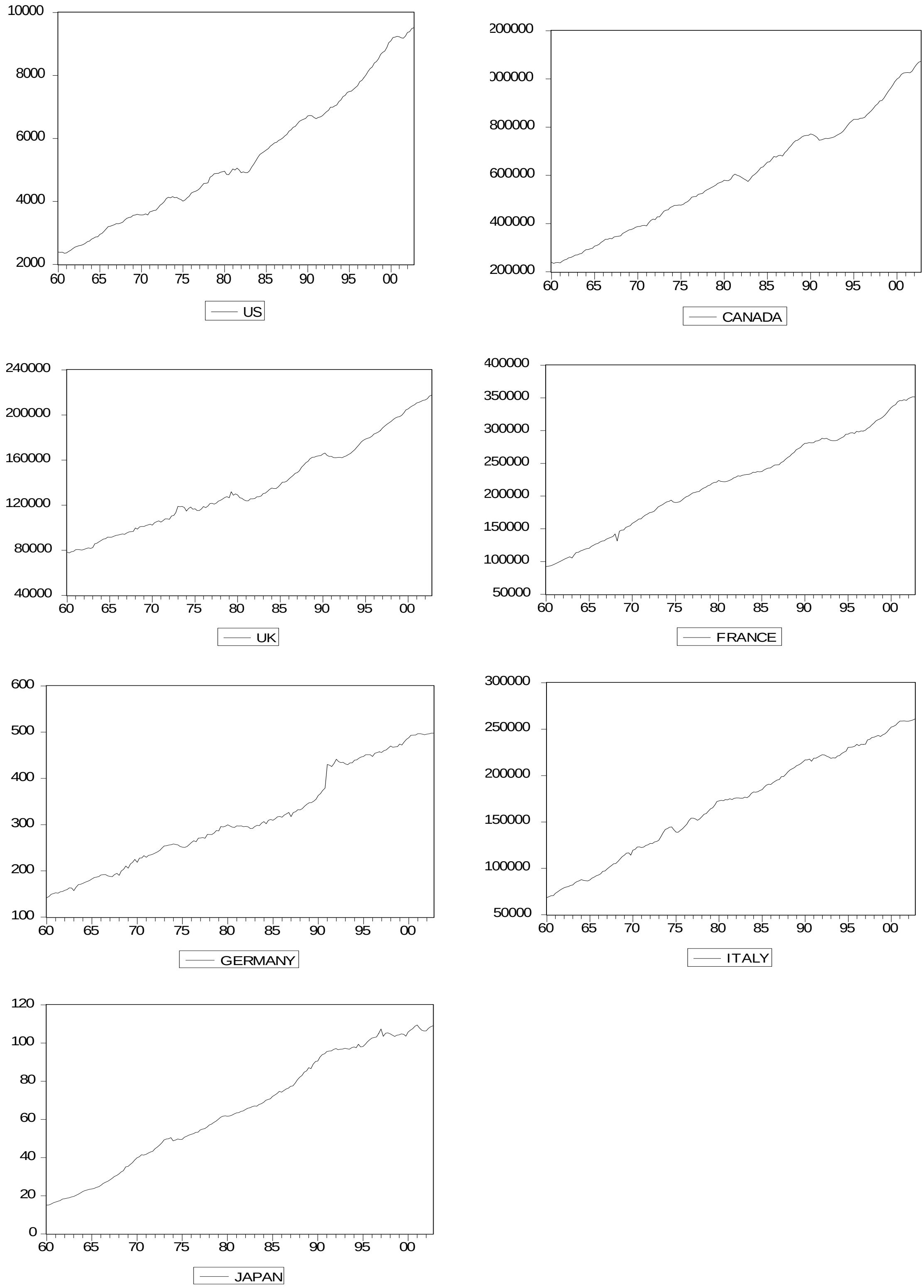

Figure 3. G7 log differenced real GDP from 1960:2 ~ 2002:4

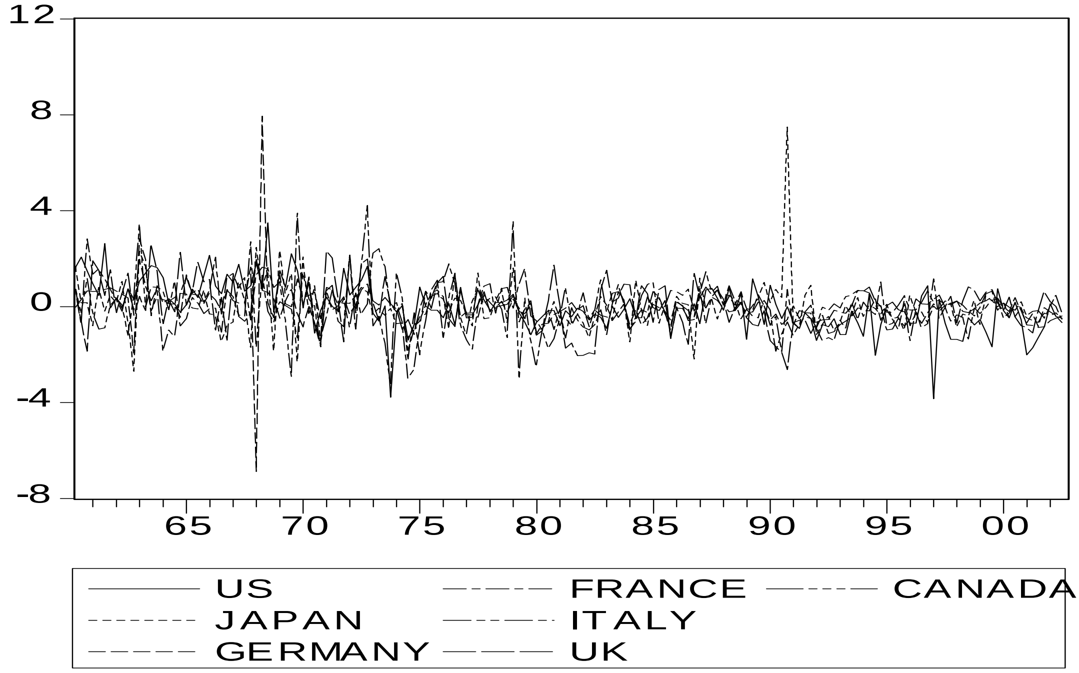

Figure 4. Common permanent component : Δc_t

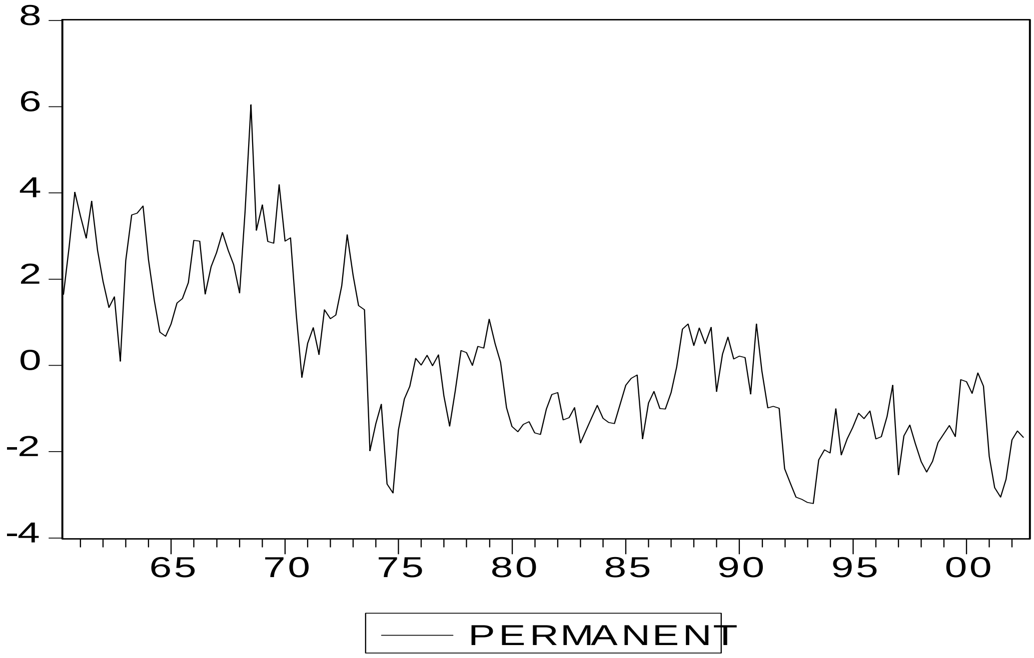

Figure 5. Common transitory component : x_t

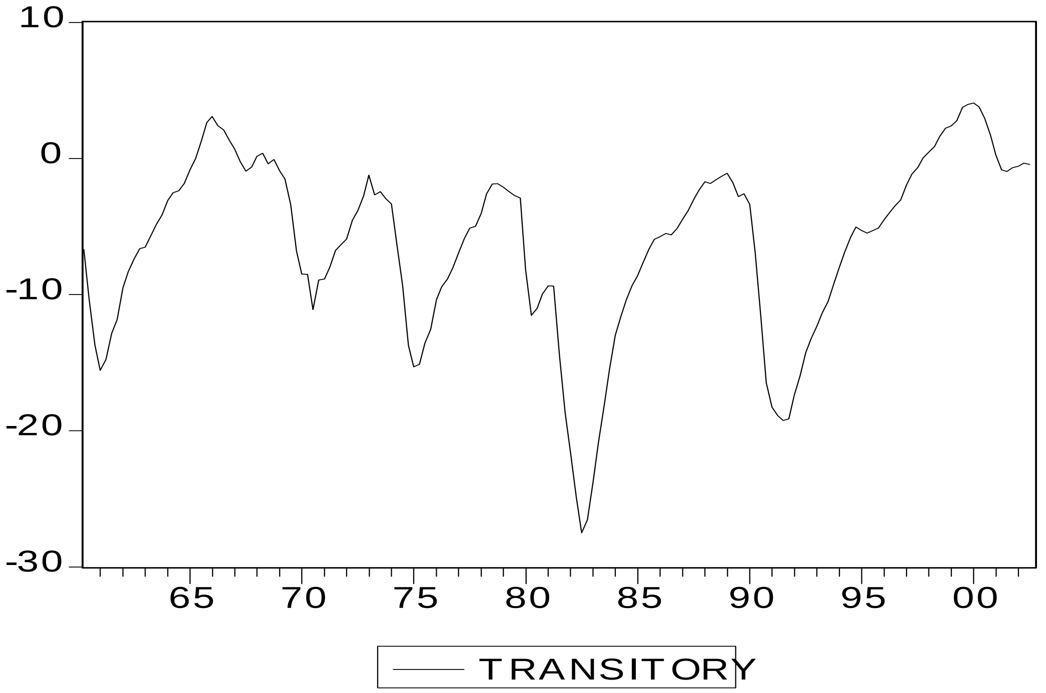

Figure 6. Probabilities of negative shock to common transitory component