# Oil and the G7 business cycle : Friedman's Plucking Markov Switching Approach

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Summary

To analyze whether oil price can account for the business cycle asymmetries in the G7, this paper adopts the 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 Hamilton's 3 year net oil price increases account for 1973-75, 1980, partially 1990-1991 recessions and LNR oil price increases account for 1973-75, 1980, partially 1960, partially 1970, partially 1990-1991 recessions. These results indicate that oil price shocks have not been a principal determinant of common recessions in the G7 except two major OPEC oil price increases in 1973-1974, 1979-1980.

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

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## 1. Introduction

One of the issues of the international business cycle is to identify the business cycle fluctuations in economic activities across G7 countries and to find out main reasons for the G7 business cycle fluctuations.

Changes of oil price are considered as one of the most identifiable exogenous shocks to postwar U.S. business cycle fluctuations. In an important paper, Hamilton (1983) observes that all but one of the U.S recessions since World War II were preceded, typically with a lag of around three-fourths of a year by a dramatic increase in the price of crude petroleum and these exogenous oil shocks were a contributing factor in at least some of the U.S. recessions prior to 1972. Raymond and Rich (1997) have investigated the relationship between oil price and the U.S recessions by the two-state Markov Switching Model of Hamilton (1989) with net oil price compared to previous 1 year of Hamilton (1996) for the period 1952-1995. Raymond and Rich (1997) conclude that while the behavior of oil price was a contributing factor to the mean of low-growth phases of output, movements in oil price generally were not a principal determinant in the historical incidence of these phases. Clements and Krolzig (2002) have also investigated the relationship between oil price and the U.S. recessions by the three-state Markov Switching Model of Hamilton (1989) with oil price of Lee, Ni and Ratti (1995) for the period 1952-1999. Clements and Krolzig (2002) conclude that their findings are broadly in line with those of Raymond and Rich (1997): oil price do not appear to be the sole explanation of regime-switching behavior and the asymmetries detected in the U.S. business cycle do not appear to be explicable by oil price.

These papers about economic activities in the U.S suggest that there may exist a relationship between oil price and common recessions in the G7 business cycles. So, the purpose of this paper is two-fold. First, I will try to investigate the relationship between oil price and common recessions in the G7. Second, I will try to find out whether oil price shocks have been a principal determinant of common recessions in the G7 over the past forty years.

Gregory, Head and Raynauld (1997), Kose, Otrok and Whiteman (2003) identified the common fluctuations in the permanent component of macroeconomic aggregates in G7 countries using the linear dynamic factor model. Monfort, Renne, Ruffer and Vitale (2002) also use the linear dynamic factor model with a common permanent component and suggest that there appears to have been an emergence of at least one cyclically coherent group, the major Euro-zone countries.

In order to find out the relationship between oil price and common recessions in the

G7 business cycles, Yoon (2004) propose the generalization of existing the linear dynamic factor models that allow him to decompose G7 GDPs into common permanent components, common transitory components, and domestic idiosyncratic components. Following the asymmetry Friedman's Plucking Markov Switching Model suggested by Kim and Nelson (1999), Yoon (2004) also included Markov switching asymmetry, infrequent shock in the common transitory components. In this paper, I will add exogenous oil price in the Friedman's Plucking Markov Switching Model.

Friedman's Plucking Markov Switching modeling strategy maintains view that output cannot exceed a ceiling level but occasionally is plucked downward by recessions. Further, if the effects of exogenous oil price increases can account for the majority of the downward plucking movements in common part of G7 GDPs, then the estimation procedure may fail to show the probabilities of downward plucking shift with the oil price. And, the effects of exogenous oil price increases can be identified by comparison between probabilities of common recessions without oil price and probabilities of common recessions with oil price.

For the oil price variable, I use the net oil price compared to previous 3 years of Hamilton (2003)[2] (Hamilton's 3 year net oil price) and the oil price of Lee, K., Ni, S., Ratti, A.(1995) (LNR oil price) covering 1960:1 – 2001:3 following Hamilton (2003) and Clements and Krolzig (2002).

Section 2 presents the use of Friedman's Plucking Markov Switching model with exogenous oil price. Section 3 explains the data used for empirical research. Section 4 summarizes the empirical results. Section 5 concludes this paper.

## 2. Friedman's Markov Switching model with exogenous oil price

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 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

[2] I obtained the oil price data from http://weber.ucsd.edu/~jhamilto

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, Yoon (2004) propose the simple generalization of existing G7 business cycle models that allow him 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), Yoon (2004) also included Markov switching asymmetry, infrequent shock in the common transitory component in this generalization model. In the Friedman's Plucking Markov Switching model, I add exogenous oil price to analyze the relationship between oil price and the common recessions in the G7.

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):

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

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 component respectively, and $\zeta_{it}$ and $\omega_{it}$ 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, $\lambda_i$, 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 [3]. Thus, I take the first difference, then:

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

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

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

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

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

Given $\Delta Y_{it}$, $\delta$, $D_i$ are not separately identified, I concentrate this parameter out of the likelihood function by writing the model in deviations from means:

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

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

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

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

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

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

I add oil price $\sum \beta_i Z_{t-i}$ in the Friedman's Plucking Markov Switching model[4]:

$$\Delta y_{it} = r_i \, \Delta c_t + \lambda_i \, \Delta x_t + z_{it} \qquad (4)$$

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

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

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

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

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

In this framework, when $\lambda_i = 0$, $\pi = 0$, $\sum \beta_i = 0$, 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.

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

[4] A detailed description is provided in the appendix A

## 3. Data

The G7 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.[6]

The choice of the oil price variable is an important issue. There has been a large body of research that the oil price has a clear negative correlation with GDP or GNP in the U.S; for example, Rasche and Tatom(1977, 1981), Hamilton(1983), among others. Nevertheless, there remains controversial when Hooker (1996) concluded that there was a weaker oil price-U.S GDP relationship in data obtained since 1985.

A number of authors have attributed this instability of oil price-U.S GDP relationship to misspecification of the functional form of oil price and suggested the representative oil price variable to analyze the relationship between this representative oil price and U.S GDP; Mork (1989), Lee, K., Ni, S., Ratti, A.(1995), Hamilton(1996), Hamilton (2003).

Raymond and Rich (1997) choose the net oil price compared to previous 1 year of Hamilton (1996) as an alternative to Mork's oil price. Because most of the oil price increases since 1986 have been subsequent to large oil price decreases, Mork's measures that focus solely on positive changes in the price of oil will overstate the significance and magnitude of the price movements. However, the problems with the net oil compared to previous 1 year of Hamilton (1996), are that the oil price surge of 1999 was not followed by a noticeable economic slowing in 2000. Hamilton (2003) explains the reason of this particular situation that the Asian financial crisis was associated with a drop in world oil prices of over 50% during 1997-1998 and the price increases in the first half of 1999 had only recovered what was lost in 1997-1998. So, Hamilton (2003) suggests the net oil price compared to previous 3 years of Hamilton (2003) (Hamilton's 3 year net oil price) as the representative oil price instead of the net oil price compared to previous 1 year of Hamilton (1996). After the statistical analyses of different transformed oil prices, Hamilton (2003) also accept oil price of Lee, K., Ni, S., Ratti, A.(1995) (LNR oil price) as the representative oil price. Clements and Krolzig

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[5] Data sources are summarized in Appendix C.

I obtained the G7 GDP data from http://www.wws.princeton.edu/~mwatson/wp.html

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

(2002) choose LNR oil price by using the best fit in an autoregressive-distributed lag (ADL) model. Following Hamilton (2003) and Clements and Krolzig (2002), I choose Hamilton's 3 year net oil price and LNR oil price covering 1960:1 – 2001:3 as the representative oil price to investigate the relationship between oil price and the common recessions in the G7 in this paper.

## 4. Empirical results

The empirical analysis examines quarterly data on G7 real GDP and the representative oil price covering 1960:1 – 2001:3

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.

In Table 1, the model which used Hamilton's 3 year net oil price has negative coefficient a lag of fourths of a year and the model which used LNR oil price has negative coefficient a lag of three, fourths of a year. These results accord quite well with the results of Hamilton (1983).

In order to find out whether oil price increases are statistically significantly correlated with G7 GDP, I compare the log likelihood values of three models in Table1. The LR test statistics for the hypothesis o1=o2=o3=o4 is 8.62 for the model including Hamilton's 3 year net oil price and 13.22 for the model including LNR oil price, respectively. The test statistics, which is distributed asymptotically as $\chi_{(4)}$ under null hypothesis, rejects the former model at a 10 percent, not 5 percent, significance levels and rejects the latter model at the 2 percent significance level. This finding offers the evidence that oil price increases are negatively and statistically correlated with common transitory components in the G7 GDP.

The degree of the downward plucking movements by oil price increases can be measure with the coefficient $\pi$ . These $\pi$ estimates increase from -2.387 to -2.283 for the model with Hamilton's 3 year net oil price and increase from -2.387 to -1.986 for the model with LNR oil price. This finding offers the implication that the representative two oil price as additional exogenous variables, account well for the occasional downward plucking movements by common recessions in the G7. In addition, an expected duration[7] of plucking shock increases from 2.58 quarters to 2.75 with Hamilton's 3 year net oil price and to 2.87 with LNR oil, respectively.

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

TABLE1: MAXIMUM LIKELIHOOD ESTIMATION OF THE MODEL : G7 GDP(1960.2~2001.3)

| Parameters | Without Oil | Hamilton's 3 year Oil | LNR Oil |
|---|---|---|---|
| $\phi_1$ | 0.701 (0.375) | 0.684 (0.345) | 0.730 (0.401) |
| $\phi_2$ | 0.209 (0.356) | 0.214 (0.332) | 0.184 (0.382) |
| $\psi_1$ | 1.504 (0.179) | 1.375 (0.181) | 1.522 (0.136) |
| $\psi_2$ | -0.562 (0.170) | -0.444 (0.171) | -0.578 (0.129) |
| $r_{us}$ | 0.076 (0.080) | 0.082 (0.049) | 0.070 (0.040) |
| $r_{japan}$ | 0.314 (0.116) | 0.332 (0.113) | 0.303 (0.118) |
| $r_{germany}$ | 0.107 (0.054) | 0.115 (0.056) | 0.102 (0.053) |
| $r_{france}$ | 0.153 (0.061) | 0.166 (0.063) | 0.148 (0.062) |
| $r_{italy}$ | 0.213 (0.085) | 0.232 (0.088) | 0.207 (0.087) |
| $r_{uk}$ | 0.068 (0.050) | 0.077 (0.055) | 0.064 (0.048) |
| $r_{canada}$ | 0.112 (0.052) | 0.124 (0.058) | 0.108 (0.051) |
| $\lambda_{us}$ | 0.403 (0.080) | 0.458 (0.097) | 0.429 (0.075) |
| $\lambda_{japan}$ | 0.044 (0.054) | 0.034 (0.066) | 0.054 (0.055) |
| $\lambda_{germany}$ | 0.013 (0.046) | 0.010 (0.057) | 0.027 (0.047) |
| $\lambda_{france}$ | 0.070 (0.037) | 0.060 (0.045) | 0.071 (0.038) |
| $\lambda_{italy}$ | 0.097 (0.056) | 0.074 (0.067) | 0.092 (0.057) |
| $\lambda_{uk}$ | 0.168 (0.053) | 0.178 (0.058) | 0.177 (0.052) |
| $\lambda_{canada}$ | 0.328 (0.070) | 0.347 (0.068) | 0.335 (0.060) |
| $\tau_{us}$ | -0.194 (0.119) | -0.228 (0.136) | -0.252 (0.122) |
| $\tau_{japan}$ | -0.148 (0.106) | -0.136 (0.108) | -0.145 (0.105) |
| $\tau_{germany}$ | -0.171 (0.078) | -0.171 (0.078) | -0.170 (0.078) |
| $\tau_{france}$ | -0.470 (0.070) | -0.471 (0.071) | -0.468 (0.070) |
| $\tau_{italy}$ | 0.113 (0.083) | 0.115 (0.080) | 0.117 (0.083) |
| $\tau_{uk}$ | -0.110 (0.080) | -0.113 (0.079) | -0.111 (0.079) |
| $\tau_{canada}$ | -0.091 (0.094) | -0.062(0.091) | -0.073 (0.091) |
| $\sigma_{us}$ | 0.644 (0.067) | 0.603 (0.080) | 0.618 (0.069) |
| $\sigma_{japan}$ | 0.718 (0.057) | 0.721 (0.057) | 0.722 (0.055) |
| $\sigma_{germany}$ | 0.954 (0.054) | 0.953 (0.054) | 0.955 (0.053) |
| $\sigma_{france}$ | 0.824 (0.048) | 0.822 (0.048) | 0.825 (0.048) |
| $\sigma_{italy}$ | 0.862 (0.051) | 0.862 (0.051) | 0.865 (0.051) |
| $\sigma_{uk}$ | 0.932 (0.053) | 0.934 (0.053) | 0.932 (0.053) |
| $\sigma_{canada}$ | 0.762 (0.052) | 0.772 (0.052) | 0.771 (0.050) |
| $\pi$ | -2.387 (0.924) | -2.283 (0.953) | -1.986 (0.828) |
| q | 0.941 (0.038) | 0.968 (0.035) | 0.969 (0.030) |
| p | 0.612 (0.194) | 0.636 (0.191) | 0.651 (0.200) |
| o1 | - | -0.025 (0.029) | -0.227 (0.232) |
| o2 | - | -0.036 (0.033) | 0.283 (0.255) |
| o3 | - | -0.025 (0.028) | -0.554 (0.268) |
| o4 | - | -0.051 (0.032) | -0.501 (0.276) |
| Log Likelihood | -442.54 | -438.23 | - 435.93 |

Standard errors of the parameters estimates are reported in the parentheses

Although the factor loadings for the common transitory component, $\lambda_{japan}$, $\lambda_{germany}$ are insignificant, the inferred probabilities of common transitory recessions without oil price, with Hamilton's 3 year net oil price, with LNR oil price in figure 1 through figure 3 show that Hamilton's 3 year net oil price increases account for 1973-75, 1980, partially 1990-1991 recessions and LNR oil price increases account for 1973-75, 1980, partially 1960, partially 1970, partially 1990-1991 recessions.

Figure 1. Probabilities of common transitory recessions without oil price

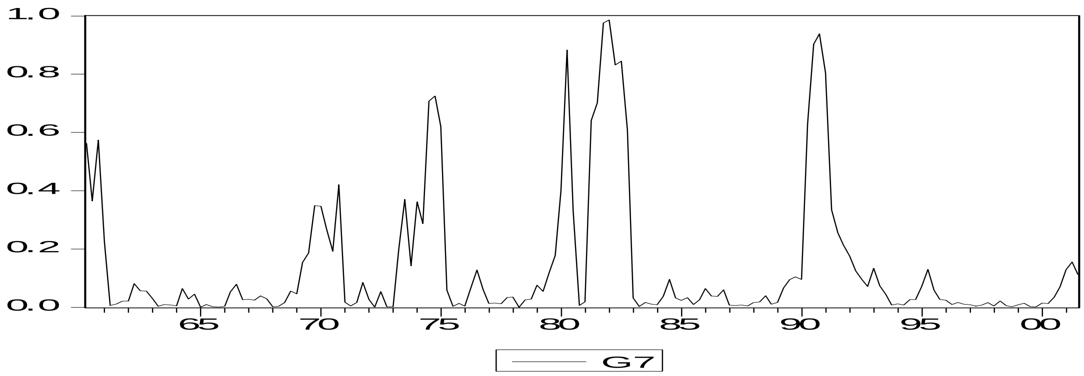



Figure 2. Probabilities of common transitory recessions with Hamilton's 3 year oil price

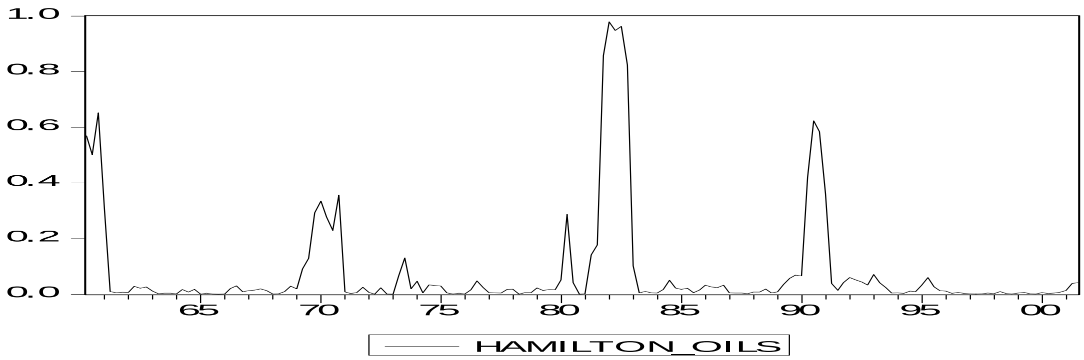



Figure 3. Probabilities of common transitory recessions with LNR oil price

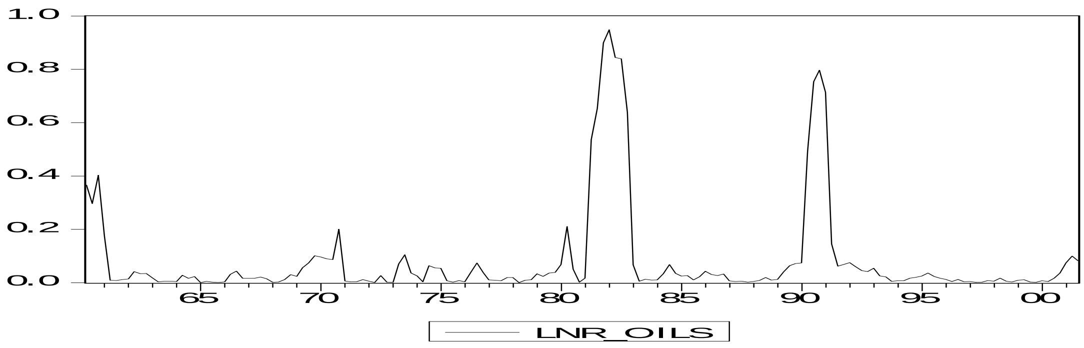
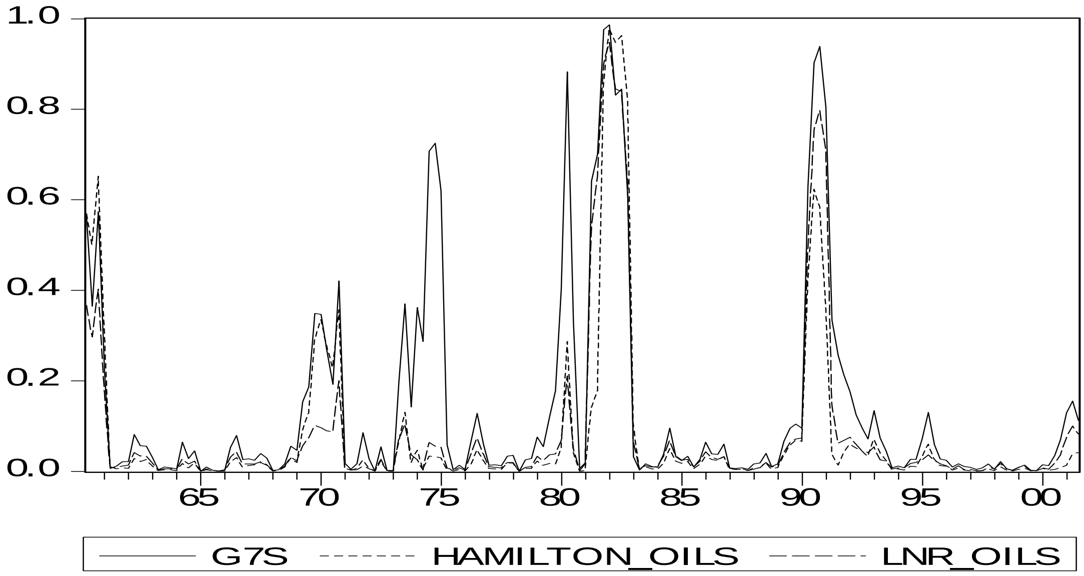


Figure 4. Probabilities of common transitory recessions with Hamilton & LNR oil price




In figure 4, we can clearly compare the oil shocks to the probabilities of common transitory recessions in the G7. From the figure 4, we can infer that oil price shocks have not been a principal determinant of common recessions in the G7 except two major OPEC oil price increases in 1973-1974, 1979-1980. .

## 5. Conclusions

These empirical results suggest a few conclusions. First, the exogenous oil price increases have had impacts on the GDP in the G7. Second, from the probabilities of common transitory recessions with oil price, we can infer that oil price shocks have not been a principal determinant of common recessions in the G7 except two major OPEC oil price increases in 1973-1974, 1979-1980.

An important next step is to find out other reasons for the G7 business cycle fluctuations.

## Acknowledgements

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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 an exogenous variable. The dynamics of Friedman's Plucking Markov Switching model with an exogenous variable can be represented in the following manner:

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

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

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

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

where

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

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

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

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:

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

where $Z_t$ is an exogenous variable. $\xi^{(i,j)}_{t|t-1}$ is an inference on $\xi_t$ 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 $\xi_t$ 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 $\Delta y_t$ 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 $\Omega_t$ 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 $Pr[S_{t-1} = i \mid \Omega_{t-1}]$, we calculate

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

Step 2 :

Consider the joint density of $\Delta y_t$, $S_t$, and $S_{t-1}$ :

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

from which the marginal density of $\Delta y_t$ is obtained by:

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

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

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

Step 3 :

Once $\Delta y_t$ is observed at the end of time t, we update the probability terms:

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

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

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

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

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

Appendix B

1. Summary Unit Root Tests[8] 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[9] 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

[8] 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

4. Sources for GDP Data

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 |

Figure 5. G7 real GDP : 1960:1 ~ 2002:4

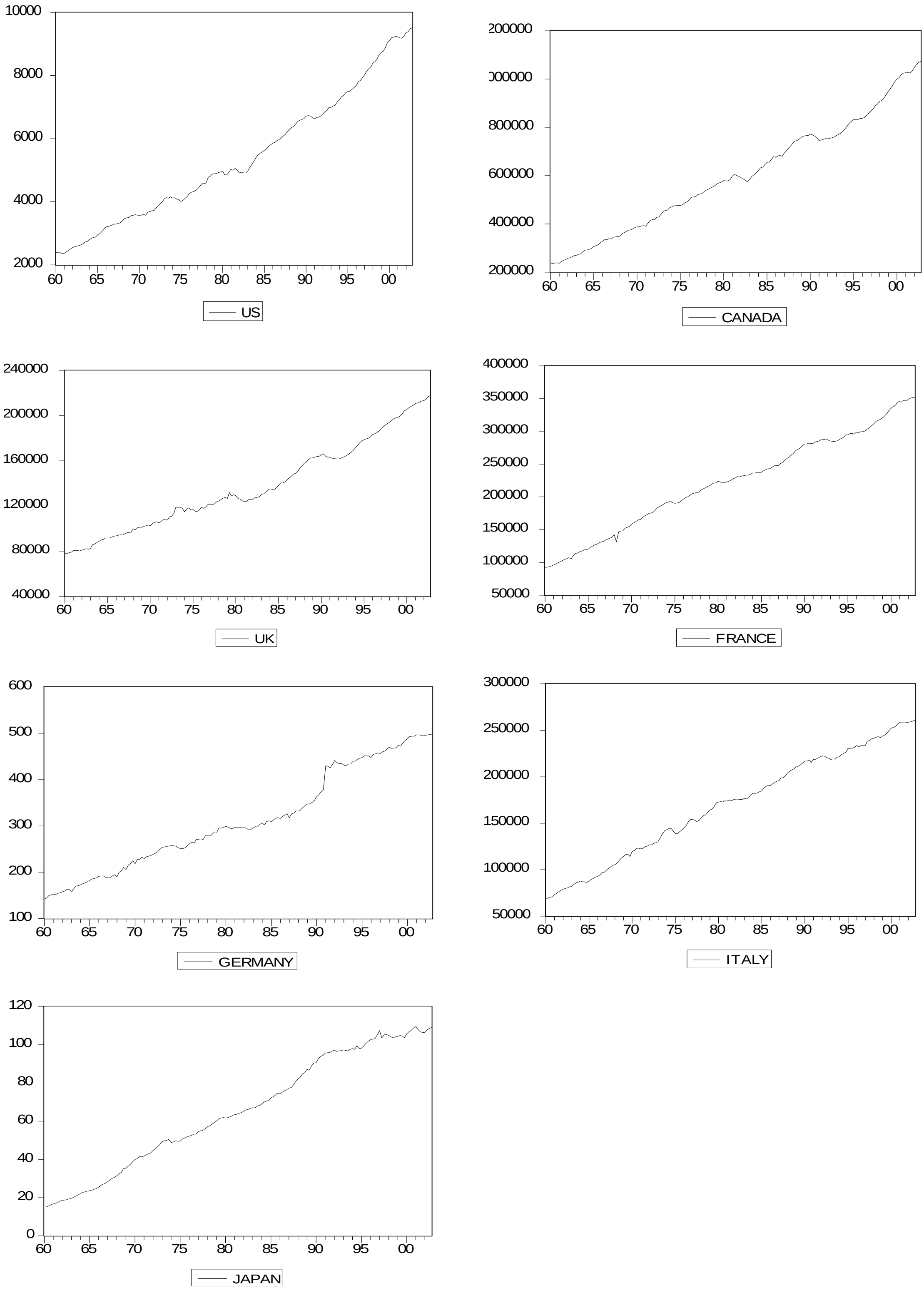
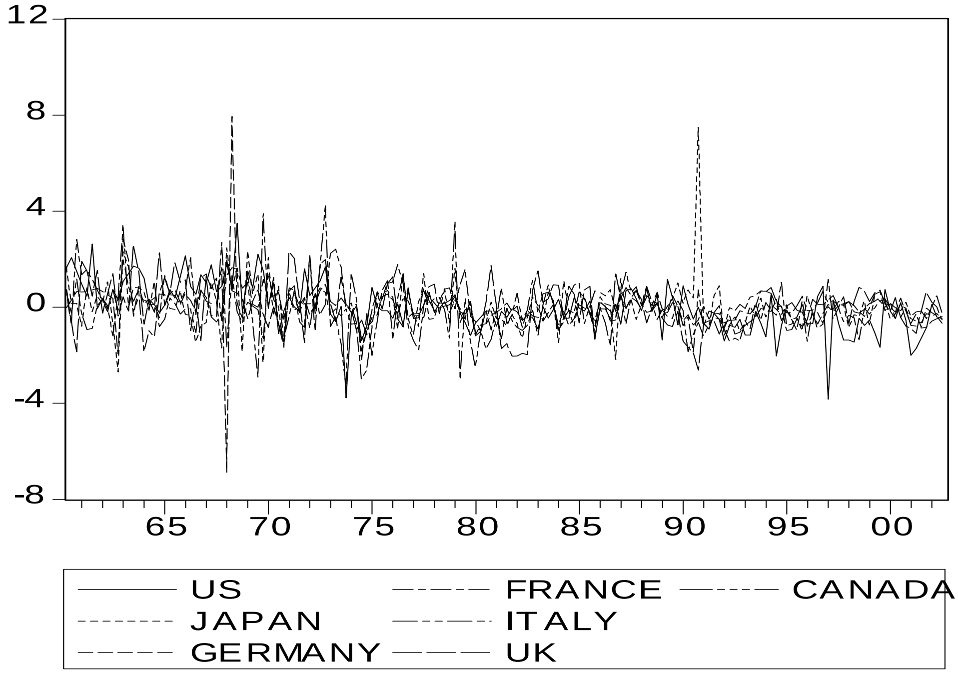


Figure 6. G7 log differenced real GDP from 1960:2 ~ 2002:4



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