FIW – Working Paper

FIW Working Paper N° 58
November 2010

International Spillovers of Output Growth and Output Growth Volatility: Evidence from the G7

Nikolaos Antonakakis[1] Harald Badinger[2]

Abstract

This paper examines the transmission of GDP growth and GDP growth volatility among the G7 countries over the period 1960 q1 - 2009 q3, using a multivariate generalized autoregressive conditional heteroskedasticity (MGARCH) model to identify the source and magnitude of spillovers. Results indicate the presence of positive own-country GDP growth spillovers in each country and of cross-country GDP growth spillovers among most of the G7 countries. In addition, the large number of significant own-country output growth volatility and cross-country output growth volatility spillovers indicates that output growth shocks in most of the G7 countries affect output growth volatility in the remaining others. An additional finding is that U.S. is the dominant source of GDP growth volatility transmission, as its volatility exerts a significant unidirectional spillover to all remaining G7 countries.

Key words: Business cycle transmission, Spillovers, Recession
JEL codes: E32, F41, F44

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International Spillovers of Output Growth and Output Growth Volatility: Evidence from the G7

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1 Introduction

The global economy has recently experienced exceptional levels of volatility. Despite the fact that such volatility was mostly apparent in financial markets, international production was also harshly hit. The decline in global output during the most recent downturn is comparable to that during the Great Depression. Individual countries experienced large scale contractions during the latest recession. For instance, in Germany, real gross domestic product (GDP) per capita, which grew 2% on average since 1960 (with a standard deviation of 2.3%), contracted by 6.7% in 2009.

The volatility of output growth is a potentially important determinant of economic growth, as output volatility raises economic uncertainty, hampering investment due to its irreversibility nature which in turn leads to lower long-term economic growth (Bernanke, 1983).

Despite the fact that studies investigated the relation between output volatility and growth, little is known about output growth volatility spillovers among countries. Besides, the empirical literature on output growth dynamics during the latest recession is limited. Antonakakis and Scharler (2010) examined output growth dynamics during US recessions and found that the 2007 to 2009 recession was associated with unusually highly synchronized output growth dynamics in the G7 countries. The source of such high synchronization may be attributed to financial integration and contagion (Mendoza and Quadrini, 2009). As a result of the high level of integration of the economies, shocks experienced by one country have increasingly important implications for other countries.

The motivation for this study is to investigate the interdependencies of GDP growth rates and their volatilities across the G7 countries. Put differently, the interaction of GDP growth of one country with the others is examined. More importantly, we investigate GDP growth volatility spillovers across countries by examining how own-country shocks and volatilities as well as cross-country shocks and volatility co-movements impact on GDP growth volatility of one country and how they are transmitted across countries.

In particular, the contribution of this paper is twofold. First, we obtain time-varying measures of variances and covariances by the use of the BEKK-MGARCH model proposed by Engle and Kroner (1995).[1] Even though this model has been applied solely to financial data so far, we argue that this approach is a strong candidate for the subject of the present paper, yielding more elaborated measures than rolling-time windows to construct time-varying measures of variances and co-variances. Second, we extend the period sample up to the third quarter of 2009 thereby providing an up-to-date evidence of output growth volatility spillovers.

The remainder of this paper is organized as follows. Section 2 describes the methodology employed and data used. Section 3 presents and discusses the estimated results. Section 4 summarizes the results and concludes.

2 Methodology and data

The dataset consists of quarterly observations of real GDP per capita in the G7 countries over the period 1960q1 - 2009q3 obtained from OECD Main Economic Indicators database. We calculate output growth as the fourth quarter difference of the log of quarterly real GDP per capita, yielding stationary series of annualized output growth in the G7 countries.[2] These series are plotted in Figure 1 where it can be seen that, in general, the largest decline of GDP was recorded in the most recent downturn. Table 1 presents the descriptive statistics of these series. Generally, annual GDP growth rate in the G7 countries during the sample is 2% with Japan the only exception with an annual GDP growth rate of 3%. Yet, Japan is subject to higher shocks as it experiences the largest deviations in output growth (3.6%) compared to the remaining G7 countries (where standard deviation is around 2%).

According to the pairwise unconditional correlations in Table 1, GDP growth of all G7 countries is positively interrelated. The highest correlations are between countries that are in close geographical proximity such as Canada and US (0.7731), and France and Italy (0.7728), whereas, the lowest correlation is between Japan and Canada (0.3541). In addition, in Table 1 the Lagrange Multiplier (LM) test of Engle (1982) indicates the

[1]The acronym BEKK stems from the joint work of Baba, Engle, Kraft and Kroner.

[2]According to the Augmented Dickey Fuller (ADF) test results in Table 1, the null hypothesis of a unit root is rejected at the 0.01 level of significance in all cases.

presence of ARCH effects with the squared residuals of GDP growth.

[insert Figure 1 here]

[insert Table 1 here]

To address the transmission of GDP growth and GDP growth volatility among the G7 countries we employ the BEKK-MGARCH model originally proposed by Engle and Kroner (1995). This is a novel contribution of the present study as, to the best of our knowledge, this model has not been applied to investigate output growth volatility transmission.

The following conditional expected GDP growth equation relates each country's GDP growth to its own and other countries' GDP growth, lagged one period:

$$Y_t = \alpha + BY_{t-1} + \epsilon_t, \tag{1}$$

where Y_t is a 7×1 vector of fourth quarter difference of the log of quarterly real GDP per capita at time t for each of the G7 countries; the residual vector, ϵ_t, given the information set available at time $t-1$, Ω_{t-1}, is normally distributed, $\epsilon_t|\Omega_{t-1} \sim (0, H_t)$, with its corresponding 7×7 conditional variance-covariance matrix, H_t. The 7×1 vector, α, accounts for long-term drift parameters. The elements b_{ij} of matrix B measure the degree of output growth spillover effects across countries, with the diagonal elements, $i = j$, of matrix B representing the own-country spillovers and the off-diagonal elements, $i \neq j$, representing the cross-country spillovers. The multivariate structure of model 1 allows the identification of the effects of the innovations in output growth of one country on its own output growth and those of the output growth of other countries ... with a lag of one period.

There exist various parameterizations of the conditional variance-covariance matrix, H_t, of the BEKK-MGARCH model such as the full, diagonal and the scalar BEKK-MGARCH model. For the purpose of the present study the full BEKK-MGARCH model is employed in which the conditional variance-covariance matrix H_t depends on the lagged squares and cross-products of innovations, ϵ_{t-1}, and its lag, H_{t-1}. An important feature of this parameterization is that it allows the conditional variances and covariances of output growth in the G7 to influence each other.[3] The full BEKK-MGARCH specification is

[3]Positive semi-definiteness of the conditional variance-covariance matrix is ensured by construction which is a necessary condition for the variances to be positive.

given by:

$$H_t = C^{'}C + A^{'}\epsilon_{t-1}\epsilon_{t-1}^{'}A + G^{'}H_{t-1}G \tag{2}$$

where c_{ij} are the elements of an upper-triangular matrix of constants C, the elements a_{ij} of the $n \times n$ symmetric matrix A measure the degree of innovation from country i to country j and the elements g_{ij} of the $n \times n$ symmetric matrix G measure the persistence in conditional volatility between country i and country j. For instance, in the bivariate case the BEKK-MGARCH can be written as:

$$\begin{aligned}\begin{bmatrix} H_{11,t} & H_{12,t} \\ H_{21,t} & H_{22,t} \end{bmatrix} = C'C \; &+ \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}' \begin{bmatrix} \epsilon_{1t-1}^2 & \epsilon_{1t-1}\epsilon_{2t-1} \\ \epsilon_{2t-1}\epsilon_{1t-1} & \epsilon_{2t-1}^2 \end{bmatrix} \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \\ &+ \begin{bmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{bmatrix}' \begin{bmatrix} H_{11,t-1} & H_{12,t-1} \\ H_{21,t-1} & H_{22,t-1} \end{bmatrix} \begin{bmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{bmatrix} \end{aligned} \tag{3}$$

Under the assumption of normally distributed random errors, the log-likelihood function for the BEKK-MGARCH model is given by:

$$L(\theta) = -\frac{TN}{2} + \ln(2\pi) - \frac{1}{2}\sum_{t=1}^{T}(\ln|H_t(\theta)| + \epsilon_t(\theta)^{'}|H_t(\theta)^{-1}|\epsilon_t(\theta)), \tag{4}$$

where T is the number of observations, N is the number of countries, θ is the vector of parameters to be estimated and all other variables are as previously defined (Kearney and Patton, 2000). Optimization is performed using BFGS (Broyden, Fletcher, Goldfarb and Shanno) algorithm, and the robust variance–covariance matrix of the estimated parameters is computed from the last BFGS iteration. The proposed model has $\frac{N(5N+1)}{2}$ parameters in the conditional variance and $N \times (N+1)$ parameters in the conditional mean equation, giving 182 parameters in total.

3 Empirical findings

The estimated conditional mean and variance equations with the associated robust standard errors and likelihood function values for the G7 countries' output growth are presented in Table 2.[4]

[4]All estimations are made using RATS Version 7.20.

3.1 Output growth spillovers

According to the conditional mean output growth equations reported at panel A in Table 2, all countries exhibit significantly positive and high own mean spillovers from their own lagged output growth. The estimated coefficient for the own mean spillover ranges from 0.6173 in France to 0.9103 in Japan indicating a high degree of persistence.

[insert Table 2 here]

Importantly, there are significant lagged mean spillovers from many of the G7 countries to many of the others. In the case of Canada, output growth in U.S. and Germany in the current year will significantly Granger-cause an increase and decrease, respectively, of output growth in Canada in the following year. Put differently, current output growth changes in Germany de-synchronize its business cycle with that of Canada in the following year whereas, current output growth changes in U.S. tend to synchronize its business cycle with that of Canada in the upcoming year. In the case of France, output growth in Canada, Italy, Japan and UK in the current year will significantly Granger-cause an increase of output growth in France in the following year. In Germany, only current output growth in Japan has a positive direct impact on output growth in the former country in the upcoming year.

This means that on average short-run output growth changes in many of the G7 countries are associated with significant output growth changes in many of the remaining countries, indicating the presence of high degree of business cycle synchronization with a year lag which is in line with the results in Stock and Watson (2005). This is likely due to the highly integrated goods and financial markets of these specific countries (Mendoza and Quadrini, 2009).

3.2 Output growth volatility spillovers

Having evaluated the dynamics of output growth spillovers we now present the results of the BEKK-GARCH model for output growth volatility spillovers across the G7 countries.

The conditional variance-covariance equations of the BEKK-GARCH model effectively capture the own-volatility and cross-volatility spillovers of output growth among the G7 countries. Panel B in Table 2 presents the estimated coefficients for the conditional variance-covariance matrix, H_t, of equations. These quantify the effects of the lagged own and cross-country output growth innovations and lagged own and cross-volatility output growth persistence on the own and cross-volatility of output growth in the G7 countries. In general, the estimated coefficients of the conditional variance-covariance matrix for own and cross-innovations and own and cross-volatility spillovers are significant in most of G7 countries, indicating the presence of ARCH and GARCH effects. Specifically, 59% (29 out of 49) of the estimated ARCH coefficients and 71% (32 out of 49) of the estimated GARCH coefficients are significant at the 0.10 level or lower.

Own-innovations spillovers in all G7 countries are significant indicating the presence of ARCH effects. The own innovation spillover effects range from 0.1614 in France to 0.4169 in Canada. That is, the past output growth shocks in Canada will have the strongest impact on its own future volatility compared to country-specific output growth shocks in the other six countries. Turning to cross-innovation effects of GDP growth in the G7 countries, past innovations in most countries exert an influence on GDP growth volatility of the remaining countries. Nevertheless, the cross-volatility shocks are generally lower than the own-volatility shocks. This means, that cross-volatility shocks have a weaker effect on future conditional volatility than the one from past country-specific volatility shocks on future volatility. For instance, in the case of Canada, cross-innovations in Germany (0.3349), Italy (0.2266), Japan (0.3246), UK (0.3366) and US (0.1476) are significantly positive, of which UK has the largest effect. While, in the case of US, cross-innovations in Canada (0.2441) are significantly positive and cross-innovations in Germany (-0.2016), Italy (-0.2250), Japan (-0.2848) and UK (-0.1017) are significantly negative. In the case of Italy, cross-innovations in Japan (-0.3706) and in UK (-0.4637) exert a significantly negative influence while, cross innovations in France (0.1153) exert a significantly positive influence. This suggest the existence of asymmetries in the cross-innovation spillovers across the G7 countries.

In the GARCH set of parameters one can observe that own-country and cross-country volatility spillovers vary in magnitude and magnitude and sign, respectively, across countries. Own-country volatility spillovers range from 0.4772 in UK to 0.9272 in Germany.

This suggests own-past output growth volatility spillover in UK has the weakest effect on its own-future conditional output growth volatility than the own-volatility spillover in each of the remaining countries. In addition, future conditional volatility in Germany and Italy is positively intensified by past volatility persistence in all other countries apart from cross-volatility spillovers in Italy and Germany, respectively. Nevertheless, in the remaining countries, cross-volatility spillovers exert asymmetric effects on future country-specific conditional volatility. For example, in the case of Canada, cross-volatility spillovers in France (-0.0925) and Italy (-0.2537) exert a negative influence whereas, cross-volatility spillovers in US (0.3366) exert a significantly positive influence.

An additional important finding is that U.S. exerts unidirectional volatility spillovers to all other countries' output growth volatility (except to Canada, as Canada's volatility persistence also exert a significant influence to US).[5] This suggest that US is the dominant country in output growth volatility transmission across the G7 countries. Put differently, output growth volatility persistence in the US is transmitted to all other countries but the opposite does not hold. An example of such transmission is the most recent crisis originated (in the housing market and caused increased negative changes in GDP growth) in the US that caused uncertainty and abrupt changes in countries' GDP growth around the world.

It should be noted that the coefficients reported in Table 2 reflect direct effects of innovations in the error process, whereas the simultaneous structure of the empirical model implies that incipient shocks propagate through the whole system of equations and thus countries. Overall, our results point to strong, potentially asymmetric linkages, both direct and indirect, between output growth and volatility between all countries of our sample, where the US appears to be a key source of international spillover effects.

Figures 2 and 3 which plot the conditional variances and covariances of the BEKK model reveal couple important features. First, in line with the empirical literature (see, for instance, Stock and Watson, 2005), international volatility and business cycles synchronization declined in the mid-1980s a period known as the great moderation. Nevertheless, international volatility and business cycles co-movements generally reached a peak during

[5] Our results are robust to difference transformation of the GDP growth, such as the band-pass filter.

the most recent worldwide crisis (Antonakakis and Scharler, 2010). These results suggest a probable end to the Great Moderation and a beginning of a new era of more closely tight business cycle co-movements and spillovers. Put differently, the global economy seems to have passed from the period of the Great Moderation to the period of the Great Integration.

[insert Figure 2 here]

[insert Figure 3 here]

4 Conclusion

This paper examines the international spillovers of GDP growth and GDP growth volatility among the G7 countries over the period 1960 - 2009. The multivariate generalized autoregressive conditional heteroskedasticity (MGARCH) BEKK model of Engle and Kroner (1995) was employed to identify the source and magnitude of GDP growth and GDP growth volatility spillovers. The results indicate the presence of positive own mean spillovers in each country and of mean spillovers among most of the G7 countries, the latter being in line with the fact that business cycles among countries are rather synchronized with a time lag (see, for instance, Stock and Watson, 2005). In addition, the large number of significant output growth own-volatility and cross-volatility spillovers indicates that output growth shocks in many of the G7 countries affect future output growth volatility in the remaining others. An additional important finding is that U.S. is the dominant country in GDP growth volatility transmission, as its volatility exerts a significant unidirectional spillover to all remaining G7 countries.

Even though evidence of asymmetries in output growth volatility spillovers across the G7 countries was reported, those asymmetries were originated from symmetric shocks. An important avenue for future research is to examine whether asymmetric shocks of output growth exert dissimilar effects on output growth volatility across countries.

An additional avenue which we leave for future research is to check whether and how conditional output growth volatility affects output growth. This can be performed under a GARCH-in-mean multivariate framework.

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Figure 1: GDP growth rates in the G7 countries: 1960q1 - 2009q3

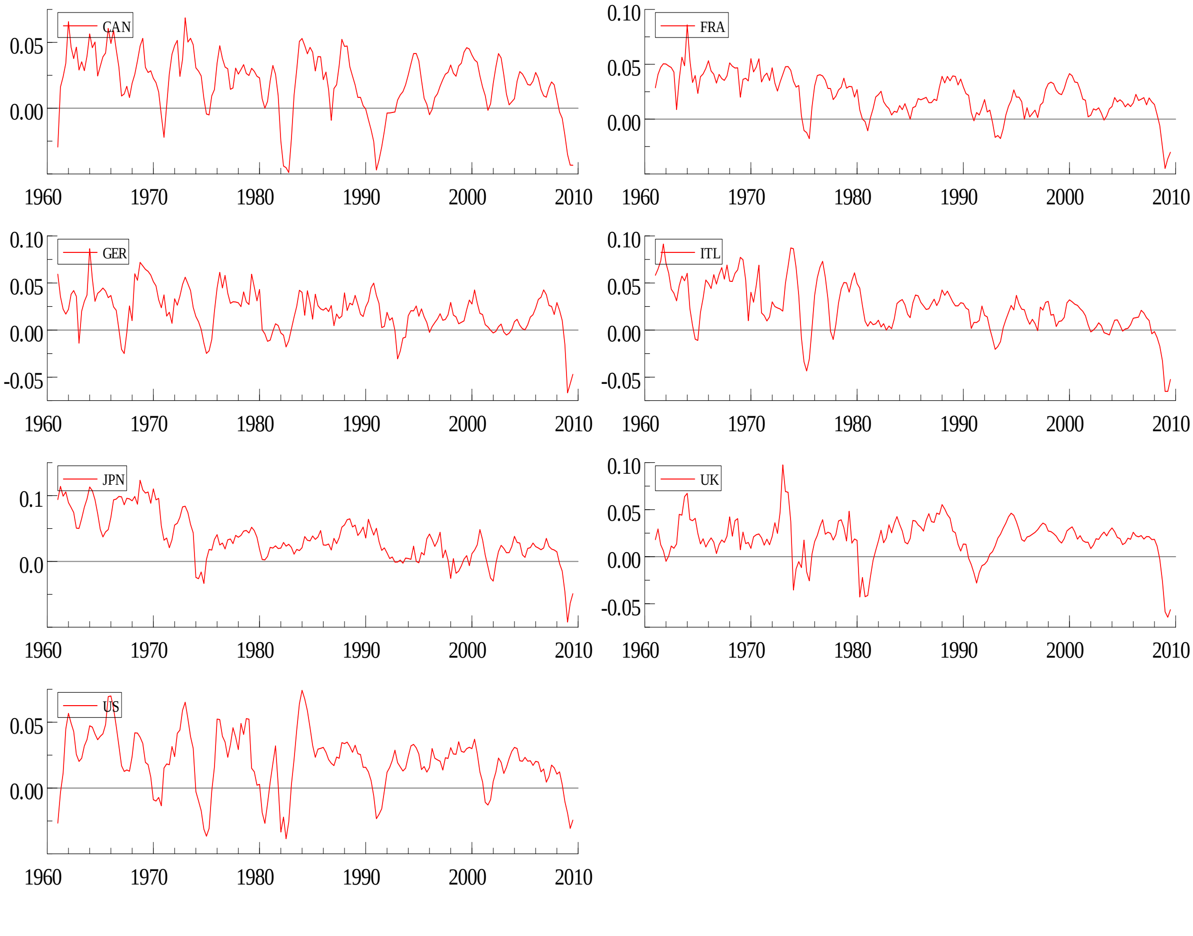

Figure 2: Conditional Variances of GDP growth in the G7 countries from BEKK-GARCH model

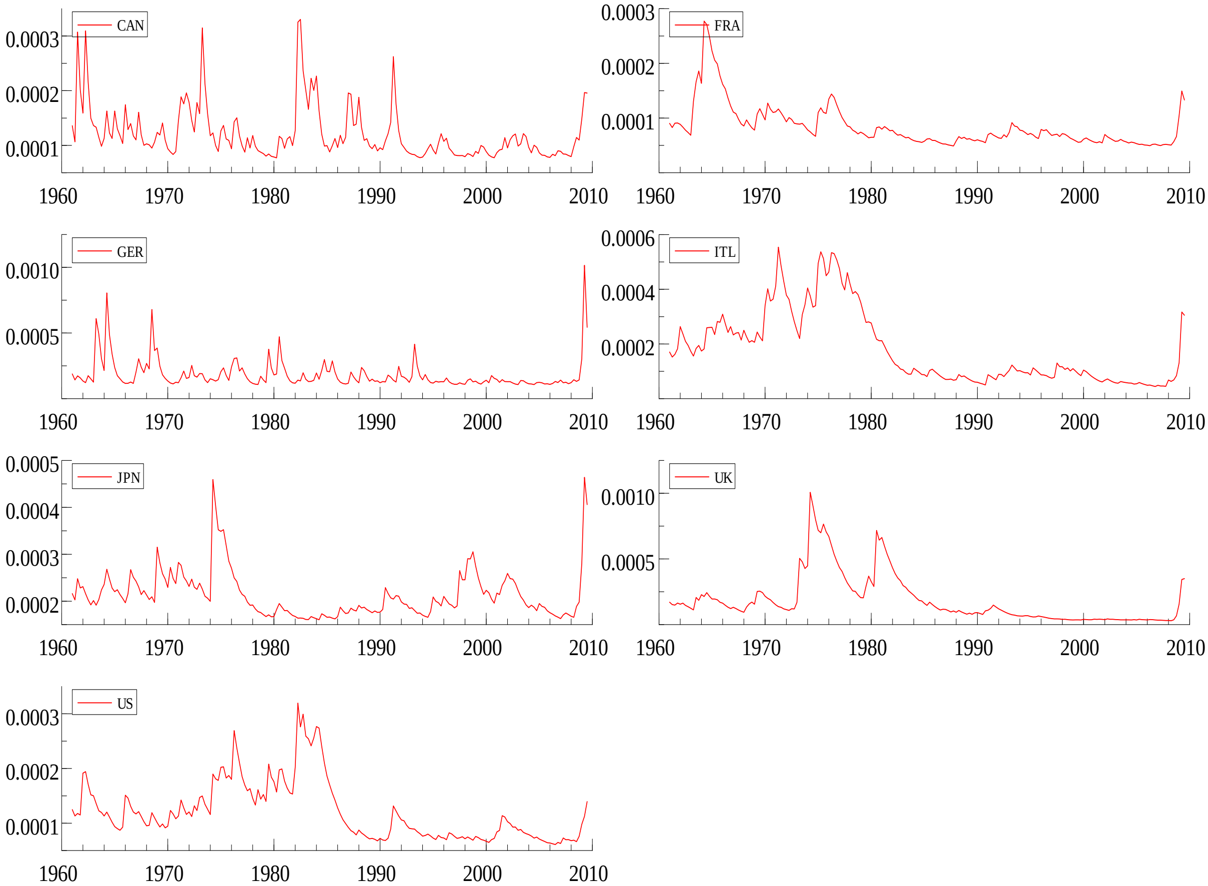

Figure 3: Conditional Covariances of GDP growth in the G7 countries from BEKK-GARCH model

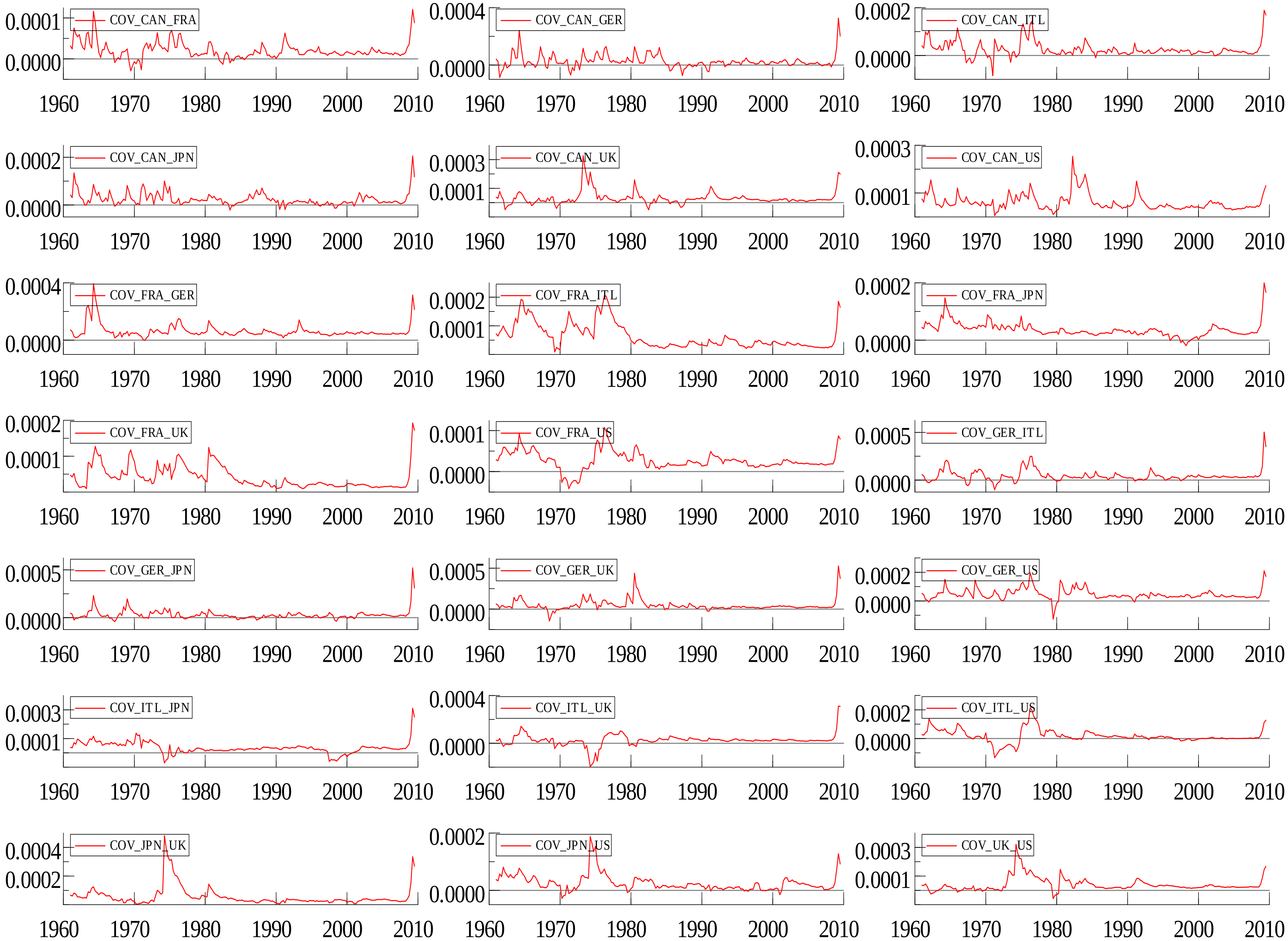

Table 1: Descriptive statistics of GDP growth in G7 countries

	CAN	FRA	GER	ITL	JPN	UK	US
Mean	0.0201	0.0221	0.0200	0.0235	0.0345	0.0193	0.0204
Minimum	-0.0489	-0.0450	-0.0667	-0.0652	-0.0921	-0.0643	-0.0385
Maximum	0.0686	0.0858	0.0865	0.0914	0.1232	0.0976	0.0741
Standard deviation	0.0231	0.0190	0.0227	0.0267	0.0363	0.0220	0.0223
Skewness	-0.8320	-0.3629	-0.3907	-0.1587	0.1458	-0.8518	-0.3702
Excess Kurtosis	0.7767	0.7823	1.2322	0.7684	0.4427	2.9227	0.2245
Jarque-Bera	27.397	9.2524	17.298	5.6165	2.2837	92.987	4.8638
JB probability	0.0000	0.0097	0.0002	0.0603	0.3192	0.0000	0.0879
ARCH-LM F(5,184)	37.613	58.515	27.151	83.360	171.70	28.203	84.231
ARCH-LM prob.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
ADF test	-3.6237	-3.5323	-4.1059	-3.6002	-3.8376	-3.8427	-3.4797
Unconditional correlations							
CAN	1.0000						
FRA	0.5221	1.0000					
GER	0.4876	0.6822	1.0000				
ITL	0.4869	0.7728	0.5888	1.0000			
JPN	0.3541	0.6958	0.5966	0.6276	1.0000		
UK	0.5066	0.5042	0.5119	0.3556	0.4081	1.0000	
US	0.7731	0.4409	0.4984	0.3575	0.3620	0.5471	1.0000

Notes: ADF test: H_0, unit root; H_α, no unit root. The lag orders in the ADF equations are determined by the significance of the coefficient for the lagged terms. Only intercepts are included. Critical values are -2.88 at 0.05 and -3.47 at 0.01 levels.

Table 2: Results of BEKK MGARCH model for GDP growth in the G7: 1960q1 - 2009q3

	CAN (i=1)		FRA (i=2)		GER (i=3)		ITL (i=4)		JPN (i=5)		UK (i=6)		US (i=7)	
Panel A: Estimated coefficients for conditional mean GDP growth equations														
	Estimated coefficient	Standard error	Estimated coefficient	Standard error	Estimated coefficient	Standard error	Estimated coefficient	Standard error	Estimated coefficient	Standard error	Estimated coefficient	Standard error	Estimated coefficient	Standard error
Cons.	-0.0005	0.0013	0.0008	0.0010	-0.0019	0.0013	-0.0044***	0.0013	-0.0011	0.0018	0.0018	0.0015	0.0003	0.0011
b_{iCAN}	0.6822***	0.0513	0.1329***	0.0436	0.0260	0.0648	0.1351***	0.0500	-0.0111	0.0721	0.0182	0.0567	-0.0662	0.0552
b_{iFRA}	0.0477	0.0711	0.6173***	0.0483	-0.0331	0.0776	-0.2215***	0.0678	-0.0104	0.1181	0.0115	0.0795	0.1407**	0.0723
b_{iGER}	-0.0790*	0.0441	-0.0286	0.0349	0.7244***	0.0616	0.0649	0.0447	-0.0992	0.0728	-0.1408**	0.0555	-0.1498***	0.0424
b_{iITL}	0.0359	0.0440	0.0859***	0.0326	-0.0042	0.0455	0.8461***	0.0050	0.0398	0.0830	-0.0024	0.0635	-0.0299	0.0352
b_{iJPN}	0.0344	0.0269	0.0686**	0.0298	0.1609***	0.0317	0.0828**	0.0288	0.9103***	0.0446	0.1180***	0.0270	0.0699***	0.0264
b_{iUK}	0.0535	0.0453	0.0786**	0.0364	0.0369	0.0645	0.1758***	0.0434	0.1007*	0.0575	0.7836***	0.0519	0.1097***	0.0466
b_{iUS}	0.2344***	0.0362	-0.0436	0.0310	0.1317	0.0810	0.0016	0.0443	0.1772**	0.0812	0.1068	0.0653	0.8349***	0.0721
Panel B: Estimated coefficients for conditional variance GDP growth equations														
	CAN (j=1)		FRA (j=2)		GER (j=3)		ITL (j=4)		JPN (j=5)		UK (j=6)		US (j=7)	
	Estimated coefficient	Standard error	Estimated coefficient	Standard error	Estimated coefficient	Standard error	Estimated coefficient	Standard error	Estimated coefficient	Standard error	Estimated coefficient	Standard error	Estimated coefficient	Standard error
a_{CANj}	0.4169***	0.0692	-0.1467	0.0897	0.0386	0.0926	0.0209	0.0478	-0.0702	0.0479	-0.0577	0.0737	0.2441***	0.0783
a_{FRAj}	-0.0618	0.0610	0.1614**	0.0691	0.0026	0.0501	0.1153**	0.0408	-0.0041	0.0338	-0.0574	0.0369	0.0417	0.0579
a_{GERj}	0.3349***	0.0758	0.0627	0.0971	0.3472***	0.0641	-0.0595	0.0880	0.0361	0.0612	-0.0176	0.0811	-0.2016***	0.0578
a_{ITLj}	0.2266***	0.0716	0.1320**	0.0643	0.1841***	0.0650	0.2547***	0.0825	0.0591	0.0382	-0.2568***	0.0510	-0.2250***	0.0613
a_{JPNj}	0.3246***	0.1256	0.0900	0.1019	0.1694**	0.0801	-0.3706***	0.0933	0.2443***	0.0525	0.0768	0.0660	-0.2848***	0.1084
a_{UKj}	0.3366***	0.0758	0.4832***	0.0842	-0.0316	0.0723	-0.4637***	0.0687	-0.1315***	0.0450	0.2260***	0.0791	-0.1017*	0.0534
a_{USj}	0.1476**	0.0643	-0.1036	0.0743	0.1193**	0.0580	0.0730	0.0710	-0.0740**	0.0325	-0.1797***	0.0641	0.2989***	0.0735
g_{CANj}	0.8547***	0.0975	-0.1934	0.1739	0.2063**	0.0830	0.2995***	0.0907	0.0425	0.0468	-0.0717	0.0546	-0.5614***	0.0807
g_{FRAj}	-0.0925*	0.0502	0.5499***	0.0729	0.2231***	0.0397	0.1383**	0.0587	0.0214	0.0266	0.1545*	0.0798	-0.0045	0.0804
g_{GERj}	-0.1548	0.1403	-0.0949	0.0720	0.9272***	0.0531	0.0050	0.0463	-0.1666***	0.0376	-0.2765***	0.0965	0.0189	0.0499
g_{ITLj}	-0.2537***	0.0576	0.1174**	0.0596	-0.0554	0.0425	0.8545***	0.0482	-0.0945***	0.0323	-0.0844	0.0809	0.0367	0.0569
g_{JPNj}	-0.0901	0.1161	0.1169	0.1163	0.1690**	0.0743	0.1283**	0.0545	0.8833***	0.0305	-0.5173***	0.0810	-0.0312	0.1031
g_{UKj}	-0.2163	0.1836	-0.8273***	0.0768	0.3760***	0.0713	0.4793***	0.0824	0.1715***	0.0373	0.4772***	0.0431	0.0224	0.1516
g_{USj}	0.3366**	0.1370	-0.4380***	0.1121	0.2119***	0.0526	0.2723***	0.0759	0.0521*	0.0306	-0.1895*	0.1004	0.5145***	0.0776
LogLik								4529.61						

Notes: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.