UNDERSTANDING SOURCES OF THE CHANGE IN INTERNATIONAL BUSINESS CYCLES

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Abstract

Macroeconomic activity has become less volatile over the past three decades in most G7 economies. Current literature focuses on the characterization of the volatility reduction and explanations for this so called "moderation" in each G7 economy separately. In opposed to individual country analysis and individual variable analysis, this paper focuses on common characteristics of the reduction and common explanations for the moderation in G7 countries. In particular, we study three explanations: structural changes in the economy, changes in common international shocks and changes in domestic shocks. We study these explanations in a unified model structure. To this end, we propose a Bayesian factor structural vector autoregressive model. Using the proposed model, we investigate whether we can find common explanations for all G7 economies when information is pooled from multiple domestic and international sources. Our empirical analysis suggests that volatility reductions can largely be attributed to the decline in the magnitudes of the shocks in most G7 countries while only for the U.K., the U.S. and Italy they can partially be attributed to structural changes in the economy. Analyzing the components of the volatility, we also find that domestic shocks rather than common international shocks can account for a large part of the volatility reduction in most of the G7 countries. Finally, we find that after mid-1980s the structure of the economy changes substantially in five of the G7 countries: Germany, Italy, Japan, the U.K. and the U.S..

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1 Introduction

Macroeconomic fluctuations have moderated over the past three decades in G7 economies. Particularly, the volatility of output growth in most of the G7 countries has markedly lowered since 1980s. The first papers on this moderation are Kim and Nelson (1999) and McConnell and Perez-Quiros (2000). They study the growing stability of the U.S. economy, which is characterized by a large decline in the vector autoregression (VAR) innovation variances after the mid-1980s. Since the identification of this "great moderation," there has been a great deal of research on the moderation and its possible causes. Although the moderation is also evident in international business cycles, the magnitude of the volatility reduction is considerably different in each economy (see Del Negro and Otrok (2004), Doyle and Faust (2002), Stock and Watson (2004)).

The reduction in the volatility of output growth is not specific to one country but common within most G7 countries; moreover, the volatility reduction is not specific to output growth, but evident in most macroeconomic variables. Considering these two facts, it makes sense to collect the information from multiple variables and multiple countries, and search for the common sources that cause the moderation in all G7 economies. Therefore, in this study, we investigate whether there are common explanations for all G7 economies while pooling the information from multiple domestic and international sources – specifically, in this study inflation, output and interest rates from G7 countries together with their domestic and international components. Three explanations, which are broad in the sense that they cover a wide range of more specific explanations for the volatility decline, are studied in this paper: structural changes in the economy, changes in common international shocks and changes in domestic shocks. In opposed to the current literature, we study these explanations in a unified model structure. To this end, we develop a Bayesian factor structural vector autoregressive (FSVAR) model. In this model structure, while each of the G7 economies is characterized by three macroeconomic variables, these economies are linked to each other through common international shocks.

From the methodological perspective, this paper is closely related to the fairly well developed literature on modeling common and specific shocks in the economy. Examples of the papers that use different structured FSVAR models are Stock and Watson (2004), Norrbin and Schlagenhauf (1996) and Clark and Shin (2000); however, each of these papers employs different assumptions to identify the factor structure that can answer their economic question. The major distinction between this paper and the FSVAR papers in the literature is the estimation methodology. We propose a Bayesian approach for the estimation. Another difference is how we identify the factor structure to estimate the common and domestic components. To identify the recursive structure of the economy, we apply a similar dynamic structure for the vector autoregressive (VAR) model to the ones employed in Ahmed, Levin and Wilson (2004) and Primiceri (2005). The proposed FSVAR structure provides the estimated structure of the economy and decompositions of the exogenous shocks into international and domestic components. This FSVAR setup also allows us to study the domestic spillover effects from one variable to the others.

From the perspective of the empirical application, this study is related to a broad collection of recent literature that analyzes the effects of changes in the economy and the effects of changes in the exogenous shocks on the volatilities. Recent papers show that there are changes in the policy activism of central banks and substantial changes in the magnitudes of exogenous shocks over time. For example, Cogley and Sargent (2001, 2003) and Primiceri (2005) find remarkable changes in the Federal Reserve's policy activism after 1980. Moreover, reductions in the magnitudes of exogenous shocks in the U.S. economy are largely presented in the recent literature such as Stock and Watson (2003) and Ahmed, Levin and Wilson (2004). On the other hand, Stock and Watson (2004), Cotis and Coppel (2004), Dalsgaard, Elmeskov and Park (2002), Cecchetti, Flores-Lagunes and Krause (2005) and Mills and Wang (2000) provide evidences of the change in the monetary policy and the volatility reductions in the international data. In this paper, we study the common characteristics of the volatility reduction and investigate whether we can find common explanations for the moderation in the G7 business cycle fluctuations. We find that although for some countries like the U.K., the U.S. and Italy volatility reductions can partially be attributed to structural changes in the economy, this is not true for all G7 countries, and the drop in the magnitudes of exogenous shocks is the leading explanation for the volatility reduction in output growth.

We further ask which exogenous shocks contribute the most to the volatility reduction of G7 output growth. Among the recent explanations for the moderation, the drop in the magnitude of international shocks is fairly a new one as a leading cause of the moderation. Working only with the output data, Stock and Watson (2004) provide quantitative estimates for the sources of the change in G7 output volatilities and find that the decline in the volatility of output growth is mainly a result of the decline in common international shocks. Collecting the information from multiple sources (particularly inflation, output and interest rates to construct a small economy), we investigate whether it is the change in international shocks or the change in domestic shocks that can account for this moderation. We find that it is the change in domestic shocks that accounts for a large part of the moderation in most of the G7 countries.

In addition to the moderation in the fluctuations of output growth, most of the G7 countries have also experienced a decline in the volatility of inflation since the mid-1980s. The recent papers attempt to explain the shifts in the inflation volatility (for example, Ahmed, Levin and Wilson (2004)). Applying the same methodology to detect and analyze the changes in inflation volatility, we find that a substantial part of the change in the volatility of inflation in three of the G7 economies (Japan, the U.K. and the U.S.) can be attributed to policy changes while for others changes in the exogenous shocks, particularly the domestic shocks, can account for most of the changes in the inflation volatility.

Here is how this paper is organized: Section 2 provides the data and some empirical facts about the moderation. Section 3 presents the proposed Bayesian FSVAR methodology. Empirical findings are discussed in section 4. In the final section, you can find the concluding remarks.

2 Data and Reductions in Volatilities

This section documents volatility reductions throughout G7 economies. The data is provided first and then changes in volatilities are discussed.

2.1 Data

In this study, the small economy VAR model for each country consists of three variables: inflation (constructed from consumer prices), output growth (real GDP growth) and interest rates (short term nominal interest rates). Several papers in the literature also apply VAR models with small data sets (for example, Cogley and Sargent (2001) and (2003), Primiceri (2005)). The data are collected on these three series for each G7 country (Canada, France, Germany, Italy, Japan, the U.K. and the U.S.) from 1970:Q1 to 2001:Q4. Output data for all G7 countries are the same as the one used in Stock and Watson (2004).[1] For the U.S., data sets for prices and interest rates are taken from the Federal Reserve's FRED database. For the other G7 countries, all the interest rates data are obtained from International Monetary Fund's IFS database.[2] Lastly, the consumer price index (CPI) is used for prices. CPI for the U.K. is taken from the IFS database while for the other five countries it is obtained from OECD Economic Outlook database. Output series and price series are seasonally adjusted.

The data are subject to some transformations. For the monthly available data sets (prices and interest rates), the data are aggregated to obtain the quarterly observations. Quarterly aggregates for interest rates are formed as the last monthly values of the

[1] *This data is available at http://www.wws.princeton.edu/mwatson/publi.html.*

[2] *I wish to thank Ayhan Kose for his help completing the missing years of the data.*

quarters while quarterly aggregates for the CPI are obtained as averages of the monthly values. Then output growth and inflation, which are taken as the quarterly growth at an annual rate, are computed using the transformation $400(log(x_t/x_{t-1}))$ where x_t is either output or CPI. Lastly, two series contain incredibly large outliers (inflation and output growth for Germany) at the fourth quarter of 1990 because of the reunification of Germany. These outliers are replaced with interpolated values constructed as the median of the values, within three periods, on either side of the outlier.

2.2 Reductions in Volatilities

This section presents the “moderation” in the G7 economies. G7 economies have experienced many changes in the last three decades. One of the most striking changes in most G7 economies is the moderation of macroeconomic fluctuations, and most importantly the moderation of output fluctuations.

In order to study the high volatility and low volatility years of the economies, we split the data into two periods at the quarter 1984:1 which is the same break date as in Stock and Watson (2004) and Blanchard and Gali (2007). Therefore we have pre-1984, representing the quarters from 1970:1 to 1983:4 and post-1984, representing the quarters from 1984:1 to 2001:4. This common break date is just a compromise used in the literature and not based on thorough scientific work. Determining the common break date based on a scientific model is still an open question for future research.

Table 1 summarizes the standard deviations of GDP growth, inflation and interest rates for Canada, France, Germany, Italy, Japan, U.K. and U.S. over the periods 1970:1–1983:4 and 1984:1–2001:4. For each of the series, the ratio of the standard deviations for the period 1984:1–2001:4 to the ones for the period 1970:1–1983:4, $\frac{Post-1984}{Pre-1984}$, is also reported. The standard deviation of GDP growth for all countries but Japan over the post-1984 period is almost less than three-fourths what it had been during the pre-1984 period. The drop in standard deviation of inflation in the second period ranges from 32% to 68%; the only exception is Germany, for which the standard deviation rises 6%. Similarly, the standard deviations of interest rates for Canada, France, Germany, Italy, the U.K. and the U.S. drop during the post-1984 period while the standard deviation for Japan increases. Here we just give a simple picture of the idea analyzed in this paper, however a complete discussion of the high volatility and low volatility years of the economies can be found in the literature such as Blanchard and Simon (2001) and Cogley and Sargent (2003). It is widely accepted that there has been a substantial decline in the volatility of GDP growth and inflation in the last two decades after high volatility years of 1970s.

Final words as a summary of the previous paragraph: Most of the G7 economies have experienced a substantial decline in the volatility of output after the mid-1980s. On the other hand, the volatilities of inflation and interest rates have also dropped as well during that period of time.

3 The Methodology

The objective of this study is to portray the nature of change and to understand the sources of change in volatilities of output growth and inflation. To this end, we develop a Bayesian factor structural vector autoregressive model. We first introduce the model and then give further analysis of the model framework in the later section.

3.1 The Model

The proposed model is the Bayesian factor structural vector autoregressive model. Let i be the country index (seven countries), j be the data index (inflation, output growth, interest rates) and t be the observed quarter. Superscripts represent the data index, j, and subscripts represent the country, i, and t is time.

For each of the seven countries ($i = 1, ..., 7$), the VAR structure of the model is

$$\mathbf{B}_i(L)\mathbf{y}_{it} = \boldsymbol{\alpha_i} + \boldsymbol{\varepsilon}_{it} \quad (i = 1, ..., 7) \tag{1}$$

where $\mathbf{y}_{it} = (y^1_{it}, y^2_{it}, y^3_{it})'$ is a 3×1 vector of observables, $\mathbf{B}_i(L)$ is a 3×3 matrix of lag operators, $\boldsymbol{\alpha_i}$ is a 3×1 vector of constants and $\boldsymbol{\varepsilon}_{it} = (\varepsilon^1_{it}, \varepsilon^2_{it}, \varepsilon^3_{it})'$ is a 3×1 vector of innovations. In this structure for each country i, inflation is ordered first (y^1_{it}), output is second (y^2_{it}), and the interest rate is last (y^3_{it}). Thus the exogenous shocks are the inflation shock (price shock, ε^1_{it}), the output shock (ε^2_{it}), and the interest rate shock (ε^3_{it}). Moreover, $\mathbf{B}_i(0)$ is a lower triangular matrix with 1s along the principal diagonal and $Var(\boldsymbol{\varepsilon}_{it}) = \boldsymbol{\Omega}_i = diag(\omega^1_i, \omega^2_i, \omega^3_i)$. Also $\boldsymbol{\varepsilon}_{it}$ is uncorrelated with its own lags and with lagged values of $\mathbf{y}_{it}$. For $i \neq j$, $\boldsymbol{\varepsilon}_{it}$ is also uncorrelated with lagged values of $\mathbf{y}_{jt}$.

We assume that there are three common shocks and three idiosyncratic shocks in each country VAR. The three common international shocks are a common output shock, a common inflation shock, and a common interest rate shock. Similarly, three idiosyncratic shocks in each VAR are idiosyncratic output shock, idiosyncratic inflation shock, and idiosyncratic interest rate shock. These shocks are all mutually independent because each country VAR is recursively identified. To estimate these shocks, we assume that each country VAR have a factor structure:

$$\varepsilon_{it} = \mathbf{\Lambda}_i \mathbf{f}_t + \mathbf{e}_{it} \quad (i = 1, ..., 7) \tag{2}$$

where $\mathbf{\Lambda}_i = diag(\Lambda_i^1, \Lambda_i^2, \Lambda_i^3)$, $\mathbf{e}_{it} = (e_{it}^1, e_{it}^2, e_{it}^3)'$ and $Cov(\mathbf{e}_{it}) = \mathbf{D}_i = diag(d_i^1, d_i^2, d_i^3)$. There is one international factor for each of the three macro variables. One can notice that the factors f_t^j, $j = 1, 2, 3$, are common in all seven countries. Note that after factor derivation, the decomposition of the variance-covariance matrix of the error terms is $\mathbf{\Omega}_i = \mathbf{\Lambda}_i \mathbf{\Lambda}_i' + \mathbf{D}_i$, and also $\omega_i^j = (\Lambda_i^j)^2 + d_i^j$. Moreover, it is assumed that, for each country i,

$$\underset{3\times 1}{\mathbf{e}_{it}} \overset{i.i.d.}{\sim} N(\mathbf{0}, \mathbf{D}_i) \quad (i = 1, ..., 7) \tag{3}$$

Since there is only one factor estimated for each set of the disturbances (inflation disturbances, output disturbances, interest rate disturbances),

$$\underset{3\times 1}{\mathbf{f}_t} \overset{i.i.d.}{\sim} N(\mathbf{0}, \mathbf{I}_3) \quad (t = 1, ..., T) \tag{4}$$

where $\mathbf{I}_3$ is the 3×3 identity matrix. For $s = 1, ..., t$, $\mathbf{f}_t$ and $\mathbf{f}_{t-s}$ are uncorrelated.

Let

$$\mathbf{y}_i^j = (y_{i1}^j, \ldots, y_{i,T-1}^j, y_{iT}^j)', \quad \mathbf{f}^j = (f_1^j, \ldots, f_{T-1}^j, f_T^j)'$$
$$\mathbf{\Lambda}^j = (\Lambda_1^j, \ldots, \Lambda_6^j, \Lambda_7^j)', \quad \mathbf{e}_i^j = (e_{i1}^j, \ldots, e_{i,T-1}^j, e_{iT}^j)'$$

Also for each country i, let $\boldsymbol{\beta}_i^j$ be the $(3p+j) \times 1$ vector of deterministic components and autoregressive coefficients for dependent variable j and $\mathbf{Z}_i^j$ denote the $T \times (3p+j)$ matrix of explanatory variables with the vector of 1s in the first column. Notice that contemporaneous values of inflation, $y_{i1}^1, \ldots, y_{iT}^1$, appear in the second column of matrix of the explanatory variables, $\mathbf{Z}_i^2$, in output equation. Similarly, the contemporaneous values of both inflation, $y_{i1}^1, \ldots, y_{iT}^1$, and output, $y_{i1}^2, \ldots, y_{iT}^2$, are in the set of explanatory variables, $\mathbf{Z}_i^3$, in interest rate equation.

For each dependent variable j (inflation, output and interest rates) of each country i, we can write the model as in the following form:

$$\mathbf{y}_i^j = \mathbf{Z}_i^j \boldsymbol{\beta}_i^j + \Lambda_i^j \mathbf{f}^j + \mathbf{e}_i^j \tag{5}$$

Then the conditional distribution of $\mathbf{y}_i^j$ is

$$\underset{T\times 1}{\mathbf{y}_i^j} |(\mathbf{Z}_i^j, \boldsymbol{\beta}_i^j, \Lambda_i^j, \mathbf{f}^j, d_i^j) \sim N(\mathbf{Z}_i^j \boldsymbol{\beta}_i^j + \Lambda_i^j \mathbf{f}^j, d_i^j \mathbf{I}_T) \quad (i = 1, ..., 7; j = 1, 2, 3) \tag{6}$$

There is another alternative representational form of the model which is useful for the posterior derivation. First the notation in this form is as follows:

$$\mathbf{Y}^j = (\mathbf{y}_1^j, \dots, \mathbf{y}_6^j, \mathbf{y}_7^j)', \quad \boldsymbol{\beta}^j = (\boldsymbol{\beta}_1^j, \dots, \boldsymbol{\beta}_6^j, \boldsymbol{\beta}_7^j)'$$

$$\boldsymbol{\Lambda}^j = (\Lambda_1^j, \dots, \Lambda_6^j, \Lambda_7^j)', \quad \mathbf{e}^j = (e_1^j, \dots, e_6^j, e_7^j)'$$

$$\mathbf{F}^j = \mathbf{I}_7 \otimes \mathbf{f}^j, \quad \mathbf{Z}^j = diag(\mathbf{Z}_1^j, ..., \mathbf{Z}_7^j)$$

The model in this alternative representation is a compact form:

$$\mathbf{Y}^j = \mathbf{Z}^j \boldsymbol{\beta}^j + \mathbf{F}^j \boldsymbol{\Lambda}^j + \mathbf{e}^j \tag{7}$$

Thus, the conditional distribution of the observable variable j is

$$\underset{7T\times 1}{\mathbf{Y}^j} | (\mathbf{Z}^j, \boldsymbol{\beta}^j, \mathbf{F}^j, \boldsymbol{\Lambda}^j, \mathbf{D}^j) \sim N(\mathbf{Z}^j \boldsymbol{\beta}^j + \mathbf{F}^j \boldsymbol{\Lambda}^j, \mathbf{D}^j \otimes \mathbf{I}_T) \quad (j = 1, 2, 3) \tag{8}$$

3.2 Analysis of the Model

Each G7 economy is characterized by three macroeconomic variables. Although large data sets are widely used in VAR models these days, there are also articles with small data sets, too (for example, Cochrane (1994), Cogley and Sargent (2001) and (2003), Primiceri (2005), Rotemberg and Woodford (1997)). A small set of data used in this paper is output (representing the private sector reactions), inflation (representing the price fluctuations), and interest rates (representing the monetary policy responses). Rotemberg and Woodford (1997) call this three-variable data set a “minimal set” for the analysis of the relation between policy variables and macro variables.

While each of the G7 economies is represented by three macro variables in a VAR setup, we know that these seven economies are not independent of each other. Outputs are linked to each other at least through international trade, and interest rates are linked to each other at least through financial linkages. We assume that a country’s macro variable is not explained by other countries’ macro variables. Each economy is linked to the others through exogenous shocks that hit the economies. These exogenous shocks could be either common between countries or specific to that country. In the proposed structure, the common shocks are interpreted as international shocks regardless of whether they are transmitted through the channels of financial linkages and the channels of commodity trade, or they are direct world wide shocks. In this sense, this structure has the same spirit as parametric dynamic factor models used by several authors (for example, Kose, Otrok and Whiteman (2003)). Hence, we have got the factor structure in the model to estimate the common international shocks. There are three common international shocks that affect these seven economies: common output shock , common inflation shock, and common interest rate shock.

In this study, we apply a model that requires a minimal set of variables and a minimal set of assumptions for the identification of the structure of the economy in order to make the analysis simple for dealing with seven-country international analysis. In order to identify the relations between the policy actions and the actions of the private sector, policy actions as an endogenous response to current developments in the economy must be separated from exogenous policy movements. In addition, the economy's responses to the policy actions must be separated from the exogenous macroeconomic movements. For the identification of the monetary policy shocks, it is assumed that monetary policy shocks are identified with the movements in the interest rates that cannot be predicted given the past values of interest rates, or by current and past values of other macro time series such as output and inflation in this paper. Identifying the monetary policy shocks requires a further assumption about the period t monetary shock and the period t endogenous variables. The assumption is that the monetary policy shock at date t has no contemporaneous effect on either inflation or output.[3] The intuition behind this is that both purchasing and pricing decisions are made prior to the realization of the shock, i.e., before the period t interest rate is observed. The use of such decision lags to identify the relation between policy variables and macro variables is common in the VAR literature which begins with Sims (1986). Any contemporaneous correlation should reflect causation from macro economy variables to the policy variable, and policy shocks should have no contemporaneous impact on inflation and output. Hence, in the proposed VAR structure, there is an ordering of the variables to reflect this causal relationship. In this causal ordering, inflation is listed the first, the real variable is in the middle, and the interest rate is the last. A further assumption for identification of the shocks is that VAR innovations are orthogonal after the recursive identification.

3.3 Priors

a. Priors on VAR Coefficients

Priors on the elements of $\boldsymbol{\beta}_i^j$ have a structure similar to Litterman (1986) priors. Recall that the indexing is country i, variables (j, k) and lag of the variable s. In addition to this, prior hyperparameters are denoted by letters with lower bar and posterior parameters are denoted by letters with upper bar. So priors on the VAR coefficients are, for $s = 2, ..., p$ and $j \neq k$,

$$\alpha_i^j \sim N(0, \underline{\sigma}_{ij}^2), \quad \boldsymbol{\beta}_{i1}^{jj} \sim N(1, (\frac{\underline{\gamma}_i}{s})^2), \quad \boldsymbol{\beta}_{is}^{jj} \sim N(0, (\frac{\underline{\gamma}_i}{s})^2)$$

[3]Some of the papers that apply the same identification structure are Bernanke and Mihov (1998), Cochrane (1994), Bagliano and Favero (1998), Leeper, Sims and Zha (1996), Primiceri (2005), Rotemberg and Woodford (1997).

$$\boldsymbol{\beta}_{i1}^{jk} \sim N(0, (\frac{\underline{w}_i \underline{\gamma}_i \underline{\tau}_{ij}}{\underline{\tau}_{ik}})^2), \quad \boldsymbol{\beta}_{is}^{jk} \sim N(0, (\frac{\underline{w}_i \underline{\gamma}_i \underline{\tau}_{ij}}{s\underline{\tau}_{ik}})^2), \quad \boldsymbol{\beta}_{i0}^{jk} \sim N(0, (\frac{\underline{w}_i \underline{\gamma}_i \underline{\tau}_{ij}}{\underline{\tau}_{ik}})^2)$$

where the hyperparameter $\underline{\gamma}_i$ controls overall tightness of beliefs around the random walk prior, the ratio of the hyperparameters $\frac{\underline{\tau}_{ij}}{\underline{\tau}_{ik}}$ is a correction for the units of the variables and $\underline{w}_i$ controls the tightness of the parameters on the lags of the variables other than the dependent variable to reflect the idea that own lags account for most of the variation of a given variable. The last density above is the prior for the coefficients on the contemporaneous values of the inflation and output growth that appear in the output growth and interest rate equations. Also note that $\underline{\gamma}_i$ is the standard deviation of the first lag of the dependent variable in each equation. Here, $\underline{\tau}_{ij}$ is estimated from the standard deviation of the residuals from an OLS regression of y_{it}^j on a constant and on p of its own lagged values. Also $\underline{\tau}_{ik}$ is estimated in the same manner. Like in Doan (1990), $\underline{w}_i$ is set equal to 0.2 in the VAR for each country i. Values of 0.1, 0.2, 0.4, 0.6, 0.8 and 1 are tried for $\underline{\gamma}_i$, and then $\underline{\gamma}_i$ is chosen to be 0.2. Finally, we need to set the hyperparameter $\underline{\sigma}_{ij}^2$. However, we can say just a little about the distribution of the parameters of the deterministic component before observing the data. This ignorance is represented by setting $\underline{\sigma}_{ij}^2$ equal to $10^5 \underline{\tau}_{ij}$ in equation j for country i.

The variance-covariance matrix for the prior distribution of the coefficients is diagonal; thus

$$\underset{k_j \times 1}{\boldsymbol{\beta}_i^j} \sim N(\underline{\boldsymbol{\mu}}_i^j, (\underline{\mathbf{H}}_i^j)^{-1}) \quad (i = 1, ..., 7; j = 1, 2, 3) \tag{9}$$

where $\underline{\mathbf{H}}_i^j$ is the precision matrix, diagonal elements of which are the inverse of the prior variances given above. Each element of $\underline{\boldsymbol{\mu}}_i^j$ also comes from these same equations. The prior on the coefficients is also truncated by applying stationarity conditions for the VAR model in order to exclude nonstationary VAR's. The stationarity conditions for the VAR model can be found in detail in section 10.1 of the Hamilton (1994)'s book, therefore we do not provide the details here.

b. Priors on the Parameters of Factor Analysis

Priors on the factor loadings, $\boldsymbol{\Lambda}^j$, are normal densities:

$$\underset{7\times 1}{\boldsymbol{\Lambda}^j} \sim N(\mathbf{0}, (\underline{\mathbf{H}}_\Lambda^j)^{-1}) \quad (j = 1, 2, 3) \tag{10}$$

where $\underline{\mathbf{H}}_\Lambda^j$ is a diagonal positive definite precision matrix. There is an identification problem we need to solve here: If we replace $\boldsymbol{\Lambda}^j$ by $-\boldsymbol{\Lambda}^j$, the posterior is unaffected. Thus, we assume $\Lambda_1^j \geq 0$ so that the model is uniquely identified.

Priors on the residual variances, d_i^j, are inverted gamma distributions:

$$\frac{\underline{s}_{ij}^2}{d_i^j} \sim \chi^2(\underline{\nu}_i^j) \tag{11}$$

Running a prior predictive analysis, we choose to use the following set of prior hyperparameters in the empirical analysis: $\underline{\mathbf{H}}_\Lambda^1 = \frac{1}{3}\mathbf{I}_N$, $\underline{s}_{i1}^2 = 3$ and $\underline{\nu}_i^1 = 5$ for inflation; $\underline{\mathbf{H}}_\Lambda^2 = \frac{1}{4}\mathbf{I}_N$, $\underline{s}_{i2}^2 = 4$ and $\underline{\nu}_i^2 = 5$ for output; and $\underline{\mathbf{H}}_\Lambda^3 = \mathbf{I}_N$, $\underline{s}_{i3}^2 = 2$ and $\underline{\nu}_i^3 = 5$ for interest rates. Detailed discussions about the prior predictive analysis can be found in section 8.3 of Geweke (2005).

3.4 Posteriors

The model, priors, derivation of posteriors and the Markov chain Monte Carlo blocks are fully summarized in Appendix A. In this section we just give posterior distributions.

a. Conditional Posteriors for the VAR Coefficients

The conditional posterior density for $\boldsymbol{\beta}_i^j$, $i = 1, \ldots, 7$, is

$$\underset{k_j \times 1}{\boldsymbol{\beta}_i^j} |(\mathbf{y}_i^j, \mathbf{Z}_i^j, \mathbf{f}^j, d_i^j, \Lambda_i^j) \sim N(\overline{\boldsymbol{\mu}}_i^j, (\overline{\mathbf{H}}_i^j)^{-1}) \quad (i = 1, ..., 7; j = 1, 2, 3) \tag{12}$$

where

$$\overline{\mathbf{H}}_i^j = \underline{\mathbf{H}}_i^j + \frac{1}{d_i^j}(\mathbf{Z}_i^j)'(\mathbf{Z}_i^j)$$

$$\overline{\boldsymbol{\mu}}_i^j = (\overline{\mathbf{H}}_i^j)^{-1}[\underline{\mathbf{H}}_i^j \underline{\boldsymbol{\mu}}_i^j + \frac{1}{d_i^j}(\mathbf{Z}_i^j)'\widetilde{\mathbf{y}}_i^j]$$

The reader should refer to Geweke (2005) to learn more about the derivations.

b. Conditional Posteriors for the Latent Factors and the Parameters of the Factor Structure

We need to make some modifications to derive the conditional posterior of latent factors, let ε_{it}^j be the innovation for variable j of country i. Let $\boldsymbol{\varepsilon}_t^j = (\varepsilon_{1t}^j, ..., \varepsilon_{7t}^j)'$ for each of the three variables $j = 1, 2, 3$. From (1), (2), (3) and (4)

$$\underset{7 \times 1}{\boldsymbol{\varepsilon}_t^j} |(\boldsymbol{\Lambda}^{\boldsymbol{j}}, f_t^j, \mathbf{D}^j) \sim N(\boldsymbol{\Lambda}^{\boldsymbol{j}} f_t^j, \mathbf{D}^j) \quad (j = 1, 2, 3) \tag{13}$$

where $\mathbf{D}^j = diag(d_1^j, ..., d_7^j)$. Then the conditional distribution of the latent factors is a normal distribution:

$$f_t^j|(\varepsilon_t^j, \mathbf{\Lambda^j}, \mathbf{D}^j) \sim N(\overline{\mu}_t, \overline{h}^{-1}) \tag{14}$$

where

$$\overline{\mu}_t = \mathbf{\Lambda^j}'(\mathbf{\Lambda^j}\mathbf{\Lambda^j}' + \mathbf{D}^j)^{-1}\varepsilon_t^j$$
$$\overline{h} = [1 - \mathbf{\Lambda^j}'(\mathbf{\Lambda^j}\mathbf{\Lambda^j}' + \mathbf{D}^j)^{-1}\mathbf{\Lambda^j}]^{-1}$$

Since the kernel for the factor components of the model factors across the T observations, these components condition only on contemporaneous terms in the expression for the posterior.

The conditional posterior of d_i^j is an inverted gamma density:

$$\frac{\overline{s}_{ij}^2}{d_i^j}|(\mathbf{y}_i^j, \mathbf{Z}_i^j, \boldsymbol{\beta}_i^j, \mathbf{f}^j, \Lambda_i^j) \sim \chi^2(\underline{\nu}_i^j + T) \tag{15}$$

where $\overline{s}_{ij}^2 = \underline{s}_{ij}^2 + (\mathbf{y}_i^j - \mathbf{Z}_i^j\boldsymbol{\beta}_i^j - \Lambda_i^j\mathbf{f}^j)'(\mathbf{y}_i^j - \mathbf{Z}_i^j\boldsymbol{\beta}_i^j - \Lambda_i^j\mathbf{f}^j)$.

The conditional posterior of $\mathbf{\Lambda}^j$ is

$$\underset{7\times1}{\mathbf{\Lambda}^j}|(\mathbf{Y}^j, \mathbf{f}^j, \mathbf{D}^j) \backsim N(\overline{\boldsymbol{\mu}}_\Lambda^j, (\overline{\mathbf{H}}_\Lambda^j)^{-1}) \quad (j = 1, 2, 3) \tag{16}$$

where

$$\overline{\mathbf{H}}_\Lambda^j = \underline{\mathbf{H}}_\Lambda^j + \mathbf{f}^{j\prime}(\mathbf{D}^j \otimes \mathbf{I}_T)^{-1}\mathbf{F}^j$$
$$\overline{\boldsymbol{\mu}}_\Lambda^j = (\overline{\mathbf{H}}_\Lambda^j)^{-1}[\underline{\mathbf{H}}_\Lambda^j.\underline{\boldsymbol{\mu}}_\Lambda^j + \mathbf{f}^{j\prime}(\mathbf{D}^j \otimes \mathbf{I}_T)^{-1}(\mathbf{Y}^j - \mathbf{Z}^j\boldsymbol{\beta}^j)].$$

The derivation of this posterior is the same as the derivation of the posterior of seemingly unrelated regressions model as discussed in Geweke (2005).

After deriving these posteriors and writing the code for the posterior simulator, we need to verify the accuracy of the analytic derivations given above and computer coding for the posterior simulator. All of these must be error-free to get correct empirical results. To this end, we conduct the joint distribution test described in Geweke (2004). This test can detect the errors both in the analytic derivations and in the computer coding of the posterior simulator. We need to have two sets of simulations to run this test: one from the draws applied to prior distributions and data distribution, and the other one from the draws applied to the data distribution and conditional posterior distributions. The former is called the marginal-conditional simulator and the latter is called successive-conditional simulator. Let $g(\boldsymbol{\beta}, \mathbf{\Lambda}, \mathbf{D}, \mathbf{Y})$ be the test function of interest. This test function is evaluated using simulated data sets from both the marginal-conditional simulator and the successive-conditional simulator. Since these two samples must come from the same distribution, two-sample joint tests for the means should be passed. Several joint tests are conducted; none of them is rejected at the 5% significance level. Some sample test results are presented in Table 2. In these tests, the length of the simulated sample is 2, the number of data series is 3 and the number of countries is 2. In these simulations, the number of iterations is 16000.

4 Empirical Results

Empirical results based on the proposed Bayesian FSVAR model are presented in this section. We first investigate whether there is a substantial change in the volatility of output growth and inflation in the post-1984 period and then explore possible sources of the volatility reduction, if there is any. In the empirical analysis given in this section, we estimate the changes in three components of the variance (international, domestic spillover and idiosyncratic components), and then study whether they account for the volatility reduction in the output growth and inflation. After the analysis of these three possible sources of volatility reduction, we explore whether the change in any of these three components is a result of a change in the magnitude of international shocks, spillover effects of domestic shocks and idiosyncratic shocks (that is, impulses) or a change in the sensitivity of the economy to these three shocks (that is, propagation mechanism). In this paper, we also study which component of the volatility is more important in understanding international business cycle fluctuations.

One way of observing sources of the reductions in volatilities is to analyze the change in the variance decompositions. In the proposed VAR structure, the forecast error variance decomposition at the horizon H for country i is

$$\mathbf{\Gamma}_i(H) = \mathbf{\Omega}_i + \mathbf{\Psi}_{i1}\mathbf{\Omega}_i\mathbf{\Psi}'_{i1} + \cdots + \mathbf{\Psi}_{i,H-1}\mathbf{\Omega}_i\mathbf{\Psi}'_{i,H-1} \tag{17}$$

where $\mathbf{\Omega}_i = (\mathbf{A}_{i0}^{-1})\mathbf{D}_i(\mathbf{A}_{i0}^{-1})'$ is the disturbance variance-covariance matrix, $\mathbf{\Gamma}_i = (\gamma_{i,kl})$ for $k, l = 1, 2, 3$ is the forecast error variance-covariance matrix, and $\mathbf{\Psi}_{ih} = (\psi_{i,kl}^{(h)})$ for $k, l = 1, 2, 3$ and $h = 1, \ldots, (H-1)$ is the impulse-response coefficient matrix at lag h. Moreover, $\mathbf{\Omega}_i = \mathbf{\Omega}_i^{int} + \mathbf{\Omega}_i^{dom}$ where $\mathbf{\Omega_i}^{int} = (\mathbf{A}_{i0}^{-1})\mathbf{\Lambda}_i\mathbf{\Lambda}'_i(\mathbf{A}_{i0}^{-1})'$ and $\mathbf{\Omega}_i^{dom} = (\mathbf{A}_{i0}^{-1})\mathbf{\Sigma}_i(\mathbf{A}_{i0}^{-1})'$. Thus, the variance-covariance matrix, $\mathbf{\Gamma}_i(H)$, has two components: international and domestic. Based on equation (4), decomposition of the international component of the variance is

$$\mathbf{\Gamma}_i^{int}(H) = \mathbf{\Omega_i}^{int} + \mathbf{\Psi}_{i1}\mathbf{\Omega_i}^{int}\mathbf{\Psi}'_{i1} + \cdots + \mathbf{\Psi}_{i,H-1}\mathbf{\Omega_i}^{int}\mathbf{\Psi}'_{i,H-1} \tag{18}$$

and decomposition of the domestic component of the variance is

$$\mathbf{\Gamma}_i^{dom}(H) = \mathbf{\Omega}_i^{dom} + \mathbf{\Psi}_{i1}\mathbf{\Omega}_i^{dom}\mathbf{\Psi}'_{i1} + \cdots + \mathbf{\Psi}_{i,H-1}\mathbf{\Omega}_i^{dom}\mathbf{\Psi}'_{i,H-1} \tag{19}$$

The unconditional variance of the data, $Var(\mathbf{y}_{it})$, can be approximately computed using (17) and decomposed using (18) and (19). Since equation (17) is the variance decomposition from MA(∞) representation when H goes to ∞,

$$Var(\mathbf{y}_{it}) = \mathbf{\Gamma}_i(\infty) \tag{20}$$

If H is sufficiently large, $Var(\mathbf{y}_{it})$ can be approximately evaluated by (17). After the analysis, we find that forty quarters would be a sufficiently long horizon to achieve an approximation for the unconditional variance. Therefore, all of the analysis in the following sections and the related tables are based upon $H = 40$ for an approximation of the unconditional variance.

We now present how results in all the tables in the following sections are computed. International components of the variance decompositions and impulse-propagation decompositions are all based on equation (18), while domestic components follow from equation (19); that is, domestic spillover effects (spillover effects of domestic shocks) and idiosyncratic components (country specific components of the variance) are all based on (19). Computations of international, domestic spillover and idiosyncratic components (with their contributions to variances) are provided in Appendix B.

As it is provided above, we first study the variance decompositions to determine each component's contribution to the moderation of the business cycle fluctuations. Then the next step is the more detailed analysis of these contributions; that is, whether they come from changes in the sizes of the shocks (impulses) or from changes in the structure of the economy (propagation). In the context of this study, impulses are basically functions of the VAR innovation variances (shock variances), and the propagation is a function of the VAR coefficients. Computations of impulses and propagations are presented in Appendix B. Impulses reflect the magnitudes of the shocks while the propagation reflects the sensitivity of the economy to the shocks or the effects of the shocks on the economy. Let $\widetilde{\gamma}_1$ and $\widetilde{\gamma}_2$ be the variances of the 40-quarter-ahead forecast errors for output growth (in a specific country) in the first and second period, respectively. While the variance of the 40-quarter-ahead forecast error for output growth is the second diagonal element of $\mathbf{\Gamma}_i(H)$ at $H = 40$, that is $\gamma_{i,22}$, we use $\widetilde{\gamma}_1$ and $\widetilde{\gamma}_2$ to simplify the notation because we now need two more superscripts (or subscripts) to denote the periods and the components of the variance. These variances in each period are decomposed into contributions from three international shocks (international components of output, inflation and interest rate shocks) and contributions from three domestic shocks (domestic components of output, inflation and interest rate shocks). Each of these contributions makes a part of $\widetilde{\gamma}_1$ and $\widetilde{\gamma}_2$. So the change in the variance between two periods is $\widetilde{\gamma}_2 - \widetilde{\gamma}_1 = \sum_{k=1}^{6}(\widetilde{\gamma}_{2,k} - \widetilde{\gamma}_{1,k})$ where $\widetilde{\gamma}_{2,k} - \widetilde{\gamma}_{1,k}$, $k = 1, \ldots, 6$, are the changes in contributions from six international and domestic shocks. Any of these six components of the volatility change, $\widetilde{\gamma}_{1,k}$ and $\widetilde{\gamma}_{2,k}$, can be written as $\beta_{1k}\tau_{1k}^2$ and $\beta_{2k}\tau_{2k}^2$, respectively, where β_{1k} and β_{2k} are the squared cumulative impulse responses, and τ_{1k}^2 and τ_{2k}^2 are the variances of the shocks. Please see Appendix B for computations of three international and three domestic shocks, and computations of their contributions to volatility change, and explicit expressions of β_{1k}, β_{2k}, τ_{1k}^2 and τ_{2k}^2. Hence the change in the contribution of shock k can be decomposed as $\widetilde{\gamma}_{2,k} - \widetilde{\gamma}_{1,k} = (\frac{\beta_{1k}+\beta_{2k}}{2})(\tau_{2k}^2 - \tau_{1k}^2) + (\frac{\tau_{1k}^2+\tau_{2k}^2}{2})(\beta_{2k} - \beta_{1k})$: the former part is the change in the contribution from the shock variance, and the latter part is the change in the contribution from the impulse-response. These discussions also apply to the variance decompositions for the inflation. Results in Tables 5 and 9 are all based on these computations.

We also ask from which component the largest contribution to the volatility change comes. We can illustrate this using statistical notation: Let a, b and c be the changes in the three components of the variances or, in other words, the changes in the contributions from three shocks; for example, the changes in the contributions from international, domestic spillover and idiosyncratic shocks in Table 3. Posterior probabilities of the largest contribution to the volatility change in output growth displayed in the last three columns of Table 4 are $P[|a| \geq |b|, |a| \geq |c||Y]$ and $P[|b| \geq |a|, |b| \geq |c||Y]$ and $P[|c| \geq |a|, |c| \geq |b||Y]$ where Y is the observed data.

In this section, we also provide a criterion that help us better understand the numerical results given in the tables. We define a reduction in the variance or a component of the variance as an *important* reduction if this reduction is less than -4. For example, let a be the decline in the contributions from idiosyncratic shocks reported in the last column of Table 3. Then the probability that this decline is important is given by $P[a < -4|Y]$. We also call this the *importance criterion* in the rest of this study. In the current analysis, we choose -4 only as an illustration. However it is easy to substitute a different number to study the sources of the volatility change in each country. Also we should point out that variance of 4 is standard deviation of 2, and a 2% change in output growth would be regarded as substantial by most macroeconomists.

4.1 Understanding Sources of the Volatility Change

This section presents empirical results based on the Bayesian FSVAR model described in section 3. The factor structure permits the decomposition of the volatilities of output growth and inflation in a given country into the contributions from the following three sources: international shocks, domestic spillover effects and idiosyncratic shocks. We investigate whether changes in these three sources can account for a substantial part of the changes in the volatilities of output growth and inflation. Moreover, the contribution from either of these shocks to the volatility can decrease because the variance of the shock (impulses) might decrease or because the sensitivity of the economy to that shock might become smaller (propagation). Said differently, the volatility can drop because the magnitude of a shock might drop or because there is a structural change in the economy. In the following two sections, we investigate these possibilities.

In Tables 3, 5, 7 and 9 posterior medians as well as 5% and 95% quantiles are reported for each country; that is, posterior median and 90% posterior probability region centered at this median are displayed in the first three entries for the analysis of the changes in these four tables. The fourth entry is the probability that there is an *important* reduction (in the variance or in a component of the variance); that is, the probability that the reduction is less than -4. The fifth entry is the probability of a reduction (again in the variance or in a component of the variance). Please note that medians do not add up across decompositions whereas means do. We need to clarify one important point here. We are imposing stationarity conditions in the posterior analysis; however there are still some roots arbitrarily close to the unit circle. As some roots approach the unit circle from the stationary side, the variance of the output and inflation goes infinity. Thus, the posterior expectation of the variance does not exist. Therefore, we report the median and quantiles instead of the mean and the standard deviation. Finally, in all the analysis of the following two sections, the number of draws from the posterior simulator is 145,000 (5000 of which are used for burn-in period).

4.1.1 Sources of The Volatility Change in Output Growth

a. International Shocks, Domestic Spillover Effects or Idiosyncratic Shocks?

Using the Bayesian FSVAR model we decompose the volatility of the GDP growth in each country into three components: international, domestic spillover and idiosyncratic components. Table 3 reports the change in the variance and its decomposition into changing international components, changing domestic spillover components and changing idiosyncratic components.

After mid-1984, is there a reduction in the volatility of output growth in the G7 economies? The results in Table 3 indicate that there is a decline in the volatility for Canada, France, Italy, the U.K. and the U.S. with at least 96% posterior probability. The posterior probability that this reduction is important is 90% and higher in these countries, only with an exceptional result for France. In all of the five countries listed above, again with at least 94% posterior probability idiosyncratic shocks (GDP-related country specific shocks) contribute to the reduction in the GDP variance. However, only for Canada, Italy, the U.K. and the U.S. this contribution is important with high probability. This is the largest contribution among the three shocks in all of these countries. Table 4 supports this result. As the last column of Table 4 shows, the largest contribution to 74% probability).

Do domestic spillover effects account for any of the change in the variance? Only for Italy the posterior probability of a contribution from domestic spillover effects to the variance reduction is greater than 90%. Furthermore, we can deduce from Table 4 that probability of the importance of the contribution from this component to the decline in the variance is quite small for all of the countries. Thus, the second component, domestic spillover effects, is the least helpful in understanding the volatility reduction in the output growth.

Finally, with at least 82% posterior probability the decline in common international shocks contributes to the decline in the variance in Canada, Germany, U.S. and the U.K. while the other three countries this probability is relatively small. The probability that there is an important contribution from international shocks to the volatility reduction is 83% for Germany and 85% for the U.K. whereas for all other countries the probabilities are quite small.

Based on the evidences we find so far, we can summarize the results as follows: There is substantial reduction in the volatility of output growth for Canada, Italy, the U.K. and the U.S. after 1984 while on the contrary there is little evidence to support the volatility reduction belief for France, Germany and Japan. The volatility reduction in these four countries can largely be attributed to the decline in domestic shocks, particularly the decline in GDP-related country specific shocks, rather than the decline in international shocks. We find strong evidence that the largest contribution to a change in the volatility (either a decrease or an increase in the volatility) is again from changes in GDP-related country specific shocks.

b. Impulse or Propagation?

We now take a close look at the changes in the three components of the volatility. Table 5 displays a detailed examination of these three components. Entries are the decomposition of changes in the variance into changing impulses and changing propagation. Impulses and propagations are also decomposed into international, domestic spillover and idiosyncratic components. Changes in impulses and propagations from Table 5 make up the changes in the contribution of the shocks given in Table 3. For example, international component of the impulse and international component of the propagation together make up the changes in the contributions from international shocks. On the other hand, total changes in impulses (second column) and total changes in propagation (sixth column) make up the changes in the variance of output growth.

There is a drop in impulses (that is, magnitudes of the shocks) with quite high probabilities in six countries excluding Japan. With at least 90% posterior probability, total changes in the magnitudes of the shocks contribute to the variance reduction in six countries while the probability of a contribution from propagation mechanism is substantially high only for Italy. However, the contribution of the shock magnitudes to the variance reduction is important with at least 90% posterior probability only for four of the G7 countries, Canada, Italy, the U.K. and the U.S.; on the other hand total changes in propagation can account for a substantial portion of the reduction for just one country, Italy. In addition to these results, Table 6 reports the probability that each component of the impulse or the propagation has the largest contribution to the variance reduction. One lesson from Table 6 is that explanatory power of the changes in impulses (column two) for the changes in the volatilities is quite higher than that of the changes in propagation (column six).

Next we ask which component of the impulse or the propagation is more important in understanding the change in the volatility. Reductions in international shocks contribute to the moderation of international business cycle fluctuations with relatively large probabilities in Canada, Germany, the U.K. and the U.S.; however, only for Germany and the U.K. this contribution is important with quite high probabilities 87% and 96%, respectively. Although probability of the contribution from domestic spillover effects to the variance reduction is quite high in all of the countries except Canada, the size of the contribution to the reduction is unimportant with really large probabilities. Idiosyncratic shocks contribute the most to the change in variances in all of the economies except for the German economy, which can be seen from the probabilities of the importance of these idiosyncratic shocks and also from Table 6. In the case of the propagation, while Italy is the only country that seems to have relatively high contribution from total changes in the propagation to the drop in the variance, for all countries changes in the components of the propagation seems to be highly unimportant.

The results discussed above lead us to the following major conclusions: Volatility reductions in output growth can largely be attributed to the decline in the magnitude of the shocks; more specifically the largest contribution to the volatility reduction in Canada, Italy, the U.K. and the U.S. are from the magnitudes of the shocks. Considering that changes in the propagation mechanism reflects changes in the structure of the economy, the results indicate that for most of the G7 economies, except Italy, there is not much evidence to support that the change in the monetary policy can explain the volatility reduction. One final lesson from the analysis of the output growth is that explanatory power of the changes in the magnitudes of the shocks for the changes in the volatilities (both decrease and increase) is quite higher than that of the changes in the structure of the economy.

4.1.2 Sources of the Volatility Change in Inflation

a. International Shocks, Domestic Spillover Effects or Idiosyncratic Shocks?

As in the case of output growth, using the Bayesian FSVAR model, we can decompose the changes in the inflation volatility in each country into three components. Table 7 reports the change in the inflation variance and its decomposition into changing international components, changing domestic spillover effects and changing idiosyncratic components.

Except for Germany, all G7 economies experience reductions in inflation variances. Among these economies, the reductions for France, Italy, Japan, the U.K. and the U.S. are important with at least 91% posterior probability. Idiosyncratic shocks contribute to the decline in inflation variance with 74% probability and higher in all seven countries while only for France, Italy, the U.K. and the U.S. is the posterior probability that this contribution is important, at least 83%. There are also contributions from international shocks and domestic spillover effects to the decline in the variance with various probability levels; however the posterior probability of the importance of these contributions is less than half (only exception is international shocks for Japan). Also we can see from Table 8 that except for Germany the largest contribution to the change in the variance is from idiosyncratic shocks in all other countries whereas for Germany it is mainly the international shocks that contribute the most.

Based on the discussions above, we can conclude as follows: We find strong evidences for substantial reductions in the volatility of inflation for France, Italy, Japan, the U.K. and the U.S.. Most of these volatility reductions are attributed to domestic shocks, mainly the price related country specific shocks, rather than international shocks. The largest contribution among the three shocks to any change in the volatility comes from these country specific shocks for all countries except Germany whereas it is the common international shocks that contribute the most to any change in the volatility for Germany.

b. Impulse or Propagation?

In the previous section, we discuss which one among the three components of the inflation variance (international, domestic spillover and idiosyncratic components) can explain volatility reductions in the G7 economies. Now we ask if a change in the magnitude of the shock (impulse) or a change in the structure of the economy (propagation) lead to a change in the three components of the variance; hence we can also answer whether, over all, changes in the magnitudes of the shocks or the change in the structure of the economy can account for the reduction in the volatilities. Table 9 and Table

10 reports the results for impulse-propagation analysis of the volatility.

The variance reduction in G7 economies is associated with a decline in the total magnitude of the shocks with quite high probabilities. This decline in the magnitude is highly important (with at least 85% posterior probability) for five countries excluding only Canada and Germany. On the other hand, except for Germany total change in the propagation mechanism contributes to the decline in the variance with at least 62% for all other countries. However the probability of the importance of this contribution is not high in most of the G7 economies; only for three countries it is greater than 50% with the maximum of 82%.

Among the three components of the impulses, both international shocks and domestic spillover effects are quite unimportant with high probabilities in understanding the variance reduction in most of the G7 economies. Also as in the case of the total change in the propagation mechanism the contributions from its three components to the decline in the variance are also unimportant with high probabilities.

One interesting point here is that the inflation volatility increases only in Germany. Why does it increase in Germany? We can see from Table 9 (column six) and Table 10 (column eight) that this increase can be due to changes in the propagation mechanism, in particular changes in the domestic spillover component of the propagation. This result is consistent with the changes in the macroeconomic structure of Germany after the reunification in the post-1984 period.

Based on the evidences in Table 9 and Table 10, we can summarize the results of this section as follows: The reduction in inflation volatility is associated with an important decline in the magnitudes of the shocks for most of the G7 economies. Since the contribution from the propagation mechanism to the decline in the volatility is not very much likely for Canada, France and Italy, these results do not support the idea that the monetary policy change can explain the volatility reduction in these countries. Lastly, the reduction in the magnitudes of the idiosyncratic shocks contributes the most to movements in the volatility of inflation for all countries but Germany.

5 Conclusion

In this paper, we study the common characteristics of the volatility reductions in G7 macroeconomic variables and investigate possible sources of this moderation. Our particular interest is the reduction in the volatility of output growth and also the inflation. We study three explanations for this moderation: changes in the structure of the economy and changes in exogenous shocks, particularly common international shocks and domestic shocks. First, we investigate three sources of the moderation: changes in international shocks, changes in domestic spillover effects and changes in idiosyncratic shocks. Then we further study whether the volatility reductions in G7 economies can be attributed to a change in the magnitudes of the shocks (impulses) or to a change in the structure of the economy (propagation).

The major findings from the analysis of output growth can be summarized as follows: First, there is strong evidence that Canada, Italy, the U.K. and the U.S. experience a substantial reduction in the volatility of output growth after mid-1980s whereas there is not much evidence to support the volatility reduction belief for France, Germany and Japan. Second, domestic shocks, mainly the GDP related country specific shocks (idiosyncratic shocks), rather than common international shocks can explain the volatility reduction. Except for Germany, the largest contribution to the volatility change (either a reduction or an increase in the volatility) is from idiosyncratic shocks. Third, volatility reductions in Canada, Italy, the U.K. and the U.S. can largely be attributed to the decline in the magnitudes of the shocks whereas they can hardly be attributed to changes in the structure of the economy.

As regards the volatility of inflation, we find strong evidences of reductions in France, Italy, Japan, the U.K. and the U.S. in the post-1984 period. Second, for Canada, France, Italy, the U.K. and the U.S. domestic shocks can be a major source of decline in inflation volatility. Once again the largest contribution to the volatility reduction comes from idiosyncratic shocks. Third, although for most of the G7 economies changes in the volatility of inflation are due to changes in the magnitudes of the shocks, they can partially be attributed to changes in the structure of the economy for Japan, the U.K., the U.S. and Germany.

From the methodological perspective, this paper proposes a Bayesian FSVAR model, which is useful in making inference about the common and idiosyncratic parts of both the predictable and unpredictable components of the VAR model together with their probability distributions (hence, uncertainty levels). This model utilizes a set of priors on the coefficients similar to Litterman (1986) priors. The major advantages of this Bayesian FSVAR framework are that this model structure permits us to make inferences about the changes in the structure of the economy, common international shocks and domestic shocks in a unified model setup, and to assess the importance of the changes in the components of the volatility in understanding the moderation in international business cycles using the posterior probability distributions.

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Appendix A

This appendix provides the joint distribution of the parameters, latent variables and observables in the Bayesian FSVAR model. Derivations of the conditional posterior distributions are also presented in this appendix.

1. Fixed hyperparameters of the prior distribution:

   (a) $\underline{\boldsymbol{\mu}}_i^j$, $\underline{\mathbf{H}}_i^j$: Prior distribution of $\boldsymbol{\beta}_i^j$.

   (b) $\underline{\boldsymbol{\mu}}_\Lambda^j$, $\underline{\mathbf{H}}_\Lambda^j$: Prior distribution of $\boldsymbol{\Lambda}^j$.

   (b) $\underline{s}_{ij}^2$, $\underline{\nu}_i^j$: Prior distribution of d_i^j.

2. Prior distributions of parameters:

   (a) $\underset{k_j \times 1}{\boldsymbol{\beta}_i^j} \sim N(\underline{\boldsymbol{\mu}}_i^j, (\underline{\mathbf{H}}_i^j)^{-1}) \quad (i = 1, ..., 7; j = 1, 2, 3)$

   (b) $\underset{7 \times 1}{\boldsymbol{\Lambda}^j} \sim N(\underline{\boldsymbol{\mu}}_\Lambda^j, (\underline{\mathbf{H}}_\Lambda^j)^{-1}) \quad (j = 1, 2, 3)$

   (c) $\frac{\underline{s}_{ij}^2}{d_i^j} \sim \chi^2(\underline{\nu}_i^j) \quad (i = 1, ..., 7; j = 1, 2, 3)$

3. Distributions of latent variables:

   (a) $f_t^j \overset{i.i.d.}{\sim} N(0, 1) \quad (j = 1, 2, 3; t = 1, ..., T)$

4. Prior density kernels:

   (a) $p(\boldsymbol{\beta}_i^j) \propto exp\{-\frac{1}{2}(\boldsymbol{\beta}_i^j - \underline{\boldsymbol{\mu}}_i^j)' \underline{\mathbf{H}}_i^j (\boldsymbol{\beta}_i^j - \underline{\boldsymbol{\mu}}_i^j)\} \quad (i = 1, ..., 7; j = 1, 2, 3)$

   (b) $p(\boldsymbol{\Lambda}^j) \propto exp\{-\frac{1}{2}(\boldsymbol{\Lambda}^j - \underline{\boldsymbol{\mu}}_\Lambda^j)' \underline{\mathbf{H}}_\Lambda^j (\boldsymbol{\Lambda}^j - \underline{\boldsymbol{\mu}}_\Lambda^j)\} \quad (j = 1, 2, 3)$

   (c) $p(d_i^j) \propto exp\{-\underline{s}_{ij}^2/(2d_i^j)\}(d_i^j)^{-(\underline{\nu}_i^j+2)/2} \quad (i = 1, ..., 7; j = 1, 2, 3)$

5. Latent factor density kernels:

   (a) $p(f_t^j) \propto exp\{-\frac{1}{2}(f_t^j)^2\} \quad (j = 1, 2, 3; t = 1, ..., T)$

5. Observables:

   (a) $\mathbf{y}_i^j = (y_{i1}^j, \ldots, y_{i,T-1}^j, y_{iT}^j)' \quad (i = 1, ..., 7; j = 1, 2, 3)$

   (b) $\mathbf{Y}^j = (\mathbf{y}_1^{j'}, \ldots, \mathbf{y}_6^{j'}, \mathbf{y}_7^{j'})' \quad (j = 1, 2, 3)$

   (c) $\mathbf{Z}_i^j = (\mathbf{Z}_{i1}^{j'}, ..., \mathbf{Z}_{iT}^{j'})' \quad (i = 1, ..., 7; j = 1, 2, 3).$

6. Conditional density of observables, $(i = 1, ..., 7; j = 1, 2, 3)$:

   (a) $p(\mathbf{y}_i^j|\mathbf{Z}_i^j, \boldsymbol{\beta}_i^j, \mathbf{f}^j, d_i^j, \boldsymbol{\Lambda}_i^j) \propto exp\{-\frac{1}{2}\frac{1}{d_i^j}(\mathbf{y}_i^j - \mathbf{Z}_i^j\boldsymbol{\beta}_i^j - \Lambda_i^j\mathbf{f}^j)'(\mathbf{y}_i^j - \mathbf{Z}_i^j\boldsymbol{\beta}_i^j - \Lambda_i^j\mathbf{f}^j)\}$

7. Conditional posterior distributions of parameter blocks, $(i = 1, ..., 7; j = 1, 2, 3)$:

   (a) From (4a) and (6a),

   $$p(\boldsymbol{\beta}_i^j|\mathbf{y}_i^j, \mathbf{Z}_i^j, \mathbf{f}^j, d_i^j, \Lambda_i^j) \propto exp\{-\frac{1}{2d_i^j}(\mathbf{y}_i^j - \Lambda_i^j\mathbf{f}^j - \mathbf{Z}_i^j\boldsymbol{\beta}_i^j)'(\mathbf{y}_i^j - \Lambda_i^j\mathbf{f}^j - \mathbf{Z}_i^j\boldsymbol{\beta}_i^j)\}$$
   $$\times exp\{-\frac{1}{2}(\boldsymbol{\beta}_i^j - \underline{\boldsymbol{\mu}}_i^j)'\underline{\mathbf{H}}_i^j(\boldsymbol{\beta}_i^j - \underline{\boldsymbol{\mu}}_i^j)\}$$

   Thus,

   $$\underset{k_j\times 1}{\boldsymbol{\beta}_i^j}|(\mathbf{y}_i^j, \mathbf{Z}_i^j, \mathbf{f}^j, d_i^j, \Lambda_i^j) \sim N(\overline{\boldsymbol{\mu}}_i^j, (\overline{\mathbf{H}}_i^j)^{-1}) \quad (i = 1, ..., 7; j = 1, 2, 3)$$

   where

   $$\overline{\mathbf{H}}_i^j = \underline{\mathbf{H}}_i^j + \frac{1}{d_i^j}(\mathbf{Z}_i^j)'(\mathbf{Z}_i^j)$$
   $$\overline{\boldsymbol{\mu}}_i^j = (\overline{\mathbf{H}}_i^j)^{-1}[\underline{\mathbf{H}}_i^j\underline{\boldsymbol{\mu}}_i^j + \frac{1}{d_i^j}(\mathbf{Z}_i^j)'(\mathbf{y}_i^j - \Lambda_i^j\mathbf{f}^j)]$$

   (b) From (4b) and (6a),

   $$p(\boldsymbol{\Lambda}^j|\mathbf{Y}^j, \mathbf{Z}^j.\boldsymbol{\beta}^j, \mathbf{f}^j, \mathbf{D}^j) \propto exp\{-\frac{1}{2}(\mathbf{Y}^j - \mathbf{Z}^j\boldsymbol{\beta}^j - \mathbf{f}^j\boldsymbol{\Lambda}^j)'(\mathbf{D}^j \otimes \mathbf{I}_T)^{-1}(\mathbf{Y}^j - \mathbf{Z}^j\boldsymbol{\beta}^j - \mathbf{f}^j\boldsymbol{\Lambda}^j)'\}$$
   $$\times exp\{-\frac{1}{2}(\boldsymbol{\Lambda}^j - \underline{\boldsymbol{\mu}}_\Lambda^j)'\underline{\mathbf{H}}_\Lambda^j(\boldsymbol{\Lambda}^j - \underline{\boldsymbol{\mu}}_\Lambda^j)\}$$

   Thus,

   $$\underset{7\times 1}{\boldsymbol{\Lambda}^j}|(\mathbf{Y}^j, \mathbf{Z}^j.\boldsymbol{\beta}^j, \mathbf{f}^j, \mathbf{D}^j) \backsim N(\overline{\boldsymbol{\mu}}_\Lambda^j, (\overline{\mathbf{H}}_\Lambda^j)^{-1}) \quad (j = 1, 2, 3)$$

where

$$\overline{\mathbf{H}}_{\Lambda}^{j} = \underline{\mathbf{H}}_{\Lambda}^{j} + \mathbf{F}^{j'}(\mathbf{D}^{j} \otimes \mathbf{I}_{T})^{-1}\mathbf{F}^{j}$$

$$\overline{\boldsymbol{\mu}}_{\Lambda}^{j} = (\overline{\mathbf{H}}_{\Lambda}^{j})^{-1}[\underline{\mathbf{H}}_{\Lambda}^{j}.\underline{\boldsymbol{\mu}}_{\Lambda}^{j} + \mathbf{f}^{j'}(\mathbf{D}^{j} \otimes \mathbf{I}_{T})^{-1}(\mathbf{Y}^{j} - \mathbf{Z}^{j}\boldsymbol{\beta}^{j})].$$

(c) From (4c) and (6a),

$$p(d_i^j|\mathbf{y}_i^j, \mathbf{Z}_i^j, \boldsymbol{\beta}_i^j, \mathbf{f}^j, \Lambda_i^j) \propto |d_i^j|^{-\frac{T}{2}} exp\{-\frac{1}{2d_i^j}(\mathbf{y}_i^j - \mathbf{Z}_i^j\boldsymbol{\beta}_i^j - \Lambda_i^j\mathbf{f}^j)'(\mathbf{y}_i^j - \mathbf{Z}_i^j\boldsymbol{\beta}_i^j - \Lambda_i^j\mathbf{f}^j)\}$$

$$\times exp\{-\frac{\underline{s}_{ij}^2}{2d_i^j}\}(d_i^j)^{-(\underline{\nu}_i^j+2)/2}$$

Hence,

$$\frac{\overline{s}_{ij}^2}{d_i^j}|(\mathbf{y}_i^j, \mathbf{Z}_i^j, \boldsymbol{\beta}_i^j, \mathbf{f}^j, \Lambda_i^j) \sim \chi^2(\underline{\nu}_i^j + T) \quad (i = 1, ..., 7; j = 1, 2, 3)$$

where $\overline{s}_{ij}^2 = \underline{s}_{ij}^2 + (\mathbf{y}_i^j - \mathbf{Z}_i^j\boldsymbol{\beta}_i^j - \Lambda_i^j\mathbf{f}^j)'(\mathbf{y}_i^j - \mathbf{Z}_i^j\boldsymbol{\beta}_i^j - \Lambda_i^j\mathbf{f}^j)$.

8. Conditional posterior distributions of latent variables, $(i = 1, ..., 7; j = 1, 2, 3)$:

(a) From (5a) and (6a),

$$p(f_t^j|\boldsymbol{\varepsilon}_t^j, \boldsymbol{\Lambda^j}, \mathbf{D}^j) \propto exp\{-\frac{1}{2}\sum_{t=1}^{T}(\boldsymbol{\varepsilon}_t^j - \boldsymbol{\Lambda^j} f_t^j)'(\mathbf{D}^j)^{-1}(\boldsymbol{\varepsilon}_t^j - \boldsymbol{\Lambda^j} f_t^j)\}exp\{-\frac{1}{2}\sum_{t=1}^{T}(f_t^j)^2\}$$

where $\boldsymbol{\varepsilon}_t^j = (\varepsilon_{1t}^j, ..., \varepsilon_{7t}^j)'$ and, moreover, $\boldsymbol{\varepsilon}_{it}^j = y_{it}^j - \mathbf{Z}_{it}^j\boldsymbol{\beta}_i^j$.

Therefore

$$f_t^j|(\boldsymbol{\varepsilon}_t^j, \boldsymbol{\Lambda^j}, \mathbf{D}^j) \sim N(\overline{\mu}_t, \overline{h}^{-1}) \quad (j = 1, 2, 3)$$

where

$$\overline{\mu}_t = \boldsymbol{\Lambda^j}'(\boldsymbol{\Lambda^j}\boldsymbol{\Lambda^j}' + \mathbf{D}^j)^{-1}\boldsymbol{\varepsilon}_t^j$$

$$\overline{h} = [1 - \boldsymbol{\Lambda^j}'(\boldsymbol{\Lambda^j}\boldsymbol{\Lambda^j}' + \mathbf{D}^j)^{-1}\boldsymbol{\Lambda^j}]^{-1}.$$

Appendix B

Computations of the contributions from international, domestic spillover and idiosyncratic shocks to variances are presented in this appendix. For each country i, let

$$\mathbf{R} = \begin{pmatrix} 1 & 0 & 0 \\ r_{i,21} & 1 & 0 \\ r_{i,31} & r_{i,32} & 1 \end{pmatrix}$$

In the variance decomposition for output growth, coefficients are defined as follows:

$$\alpha^1_{i,22} = r_{i,21} + \sum_{h=1}^{H-1} [(\psi^{(h)}_{i,21})^2 + (r_{i,21}\psi^{(h)}_{i,22})^2 + (r_{i,31}\psi^{(h)}_{i,23})^2]$$

$$\alpha^2_{i,22} = 1 + \sum_{h=1}^{H-1} [(\psi^{(h)}_{i,22})^2 + (r_{i,32}\psi^{(h)}_{i,23})^2]$$

$$\alpha^3_{i,22} = \sum_{h=1}^{H-1} (\psi^{(h)}_{i,23})^2$$

The variance of output growth is decomposed into three components: contribution from international shocks, contribution from domestic spillovers and contribution from idiosyncratic shocks. That is,

$$\gamma_{i,22} = \gamma^{int}_{i,22} + \gamma^{domsp}_{i,22} + \gamma^{idio}_{i,22}$$

where

$$\gamma^{int}_{i,22} = \alpha^1_{i,22}\Lambda^1_i\Lambda^{1'}_i + \alpha^2_{i,22}\Lambda^2_i\Lambda^{2'}_i + \alpha^3_{i,22}\Lambda^3_i\Lambda^{3'}_i$$

$$\gamma^{domsp}_{i,22} = \alpha^1_{i,22}\sigma^1_i + \alpha^3_{i,22}\sigma^3_i$$

$$\gamma^{idio}_{i,22} = \alpha^2_{i,22}\sigma^2_i$$

In the last three equations, coefficients ($\alpha^1_{i,22}$, $\alpha^2_{i,22}$, $\alpha^3_{i,22}$) are the "propagations" while the magnitudes of the shocks ($\Lambda^1_i\Lambda^{1'}_i$, $\Lambda^2_i\Lambda^{2'}_i$, $\Lambda^3_i\Lambda^{3'}_i$, σ^1_i, σ^2_i, σ^3_i) are the "impulses."

In the case of output growth, the variances of the shocks, τ^2_{1k} and τ^2_{2k} in section 4, are $\Lambda^1_i\Lambda^{1'}_i$, $\Lambda^2_i\Lambda^{2'}_i$, $\Lambda^3_i\Lambda^{3'}_i$, σ^1_i, σ^2_i, σ^3_i as they are computed for pre-1984 and post-1984 periods, respectively. Similarly, squared cumulative impulse responses, β_{1k} and β_{2k}, are $\alpha^1_{i,22}$, $\alpha^2_{i,22}$, $\alpha^3_{i,22}$ evaluated for pre-1984 and post-1984 periods, respectively.

Similarly, coefficients for the variance decomposition of inflation are

$$\alpha^1_{i,11} = 1 + \sum_{h=1}^{H-1} [(\psi^{(h)}_{i,11})^2 + (r_{i,21}\psi^{(h)}_{i,12})^2 + (r_{i,31}\psi^{(h)}_{i,13})^2]$$

$$
\begin{aligned}
\alpha_{i,11}^2 &= \sum_{h=1}^{H-1} [(\psi_{i,12}^{(h)})^2 + (r_{i,32}\psi_{i,13}^{(h)})^2] \\
\alpha_{i,11}^3 &= \sum_{h=1}^{H-1} (\psi_{i,13}^{(h)})^2
\end{aligned}
$$

Then the variance of inflation can be decomposed into contributions from international shocks, domestic spillovers and idiosyncratic shocks:

$$
\gamma_{i,11} = \gamma_{i,11}^{int} + \gamma_{i,11}^{domsp} + \gamma_{i,11}^{idio}
$$

where

$$
\begin{aligned}
\gamma_{i,11}^{int} &= \alpha_{i,11}^1 \Lambda_i^1 \Lambda_i^{1'} + \alpha_{i,11}^2 \Lambda_i^2 \Lambda_i^{2'} + \alpha_{i,11}^3 \Lambda_i^3 \Lambda_i^{3'} \\
\gamma_{i,11}^{domsp} &= \alpha_{i,11}^2 \sigma_i^2 + \alpha_{i,11}^3 \sigma_i^3 \\
\gamma_{i,11}^{idio} &= \alpha_{i,11}^1 \sigma_i^1
\end{aligned}
$$

Again coefficients are the propagations and magnitudes of the shocks are the impulses in the last three equations.

In the case of inflation, the variances of the shocks, τ_{1k}^2 and τ_{2k}^2 in section 4, are again $\Lambda_i^1 \Lambda_i^{1'}$, $\Lambda_i^2 \Lambda_i^{2'}$, $\Lambda_i^3 \Lambda_i^{3'}$, σ_i^1, σ_i^2, σ_i^3 computed for pre-1984 and post-1984 periods, respectively. However, squared cumulative impulse responses, β_{1k} and β_{2k}, are $\alpha_{i,11}^1$, $\alpha_{i,11}^2$, $\alpha_{i,11}^3$ evaluated for pre-1984 and post-1984 periods, respectively, which are different from the ones in the output growth.

Table 1: Changes in volatilities

		CAN	*FRA*	*GER*	*ITA*	*JAP*	*U.K.*	*U.S.*
Inflation	Pre-84	10.85	8.99	3.04	32.67	28.66	35.80	11.73
	Post-84	5.03	2.67	3.39	5.88	3.01	6.56	2.20
	Ratio	0.46	0.30	1.12	0.18	0.11	0.18	0.19
GDP growth	Pre-84	16.62	7.32	25.86	21.68	17.19	30.51	22.57
	Post-84	7.96	4.29	14.14	5.24	17.74	5.06	4.98
	Ratio	0.48	0.59	0.55	0.24	1.03	0.17	0.22
Interest rate	Pre-84	16.57	10.75	7.87	29.03	6.36	9.44	14.92
	Post-84	8.88	8.62	4.14	17.24	7.11	9.04	4.08
	Ratio	0.54	0.80	0.53	0.59	1.12	0.96	0.28

For each variable (GDP growth, inflation, interest rates), variances for the time periods of 1970–1983 (Pre-1984) and 1984–2001 (Post-1984) are reported in the first two rows and their ratio, $\frac{Post-1984}{Pre-1984}$, is reported in the third row.

Table 2: Testing for derivation and coding errors

Test Functions	P-values for equality of means
1. eigenvalue of (YY')	0.16
2. eigenvalue of (YY')	0.50
$(\Lambda^{j'}\Lambda^j)_{21}$	0.69
$(\Lambda^{j'}\Lambda^j)_{22}$	0.69
d_1^j	0.19
d_2^j	0.69
β_{12}^{j2}	0.33
β_{21}^{j2}	0.86

The test proposed in Geweke (2004) is conducted to check for analytic solution and coding errors. Some selected samples of the test functions are presented. All results pass the test at the 5% level.

Table 3: OUTPUT: Decomposition of changes in the variance into changing shocks

Country	Pre-1984 Var	Post-1984 Var	Change	*Int'l*	*D.spill.*	*Own*
CAN	(13.07)	(5.74)	(-21.95)	(-8.69)	(-1.06)	(-16.55)
	18.82	8.39	-10.17	-3.28	0.01	-6.57
	(30.29)	(14.78)	(-1.89)	(-0.33)	(1.08)	(0.65)
			(*0.96*)	(*0.39*)	(*0.00*)	(*0.73*)
			(*1.00*)	(*0.97*)	(*0.48*)	(*0.94*)
FRA	(5.49)	(3.46)	(-9.76)	(-5.07)	(-1.01)	(-6.98)
	8.29	4.78	-3.45	-0.35	-0.08	-2.94
	(14.54)	(7.24)	(0.24)	(2.78)	(0.46)	(0.10)
			(*0.43*)	(*0.09*)	(*0.00*)	(*0.29*)
			(*0.97*)	(*0.57*)	(*0.67*)	(*0.95*)
GER	(13.78)	(11.19)	(-13.24)	(-20.11)	(-2.25)	(-2.77)
	19.05	15.52	-3.41	-9.77	-0.27	7.40
	(27.84)	(23.62)	(6.06)	(-0.23)	(1.01)	(14.82)
			(*0.47*)	(*0.83*)	(*0.02*)	(*0.04*)
			(*0.76*)	(*0.95*)	(*0.72*)	(*0.11*)
ITA	(13.33)	(4.52)	(-30.83)	(-1.06)	(-5.18)	(-28.71)
	20.18	6.10	-13.95	1.66	-0.80	-14.49
	(37.05)	(8.71)	(-6.64)	(4.50)	(-0.00)	(-7.92)
			(*0.99*)	(*0.01*)	(*0.08*)	(*1.00*)
			(*1.00*)	(*0.12*)	(*0.95*)	(*1.00*)
JAP	(12.41)	(15.28)	(-12.93)	(-4.17)	(-2.38)	(-10.81)
	18.53	21.36	2.74	-0.38	0.01	3.49
	(33.49)	(33.65)	(16.27)	(1.33)	(2.51)	(15.90)
			(*0.19*)	(*0.06*)	(*0.02*)	(*0.15*)
			(*0.35*)	(*0.68*)	(*0.49*)	(*0.30*)
UK	(23.55)	(3.73)	(-44.80)	(-22.80)	(-2.83)	(-32.71)
	33.12	5.47	-27.27	-8.58	-0.31	-17.36
	(50.53)	(9.92)	(-16.79)	(-2.18)	(0.54)	(-5.01)
			(*1.00*)	(*0.85*)	(*0.03*)	(*0.96*)
			(*1.00*)	(*1.00*)	(*0.75*)	(*0.97*)
U.S.	(17.73)	(3.96)	(-41.90)	(-4.22)	(-4.88)	(-37.38)
	26.62	5.69	-20.64	-0.74	-0.38	-18.69
	(47.92)	(9.51)	(-11.12)	(0.56)	(0.34)	(-9.85)
			(*1.00*)	(*0.06*)	(*0.07*)	(*1.00*)
			(*1.00*)	(*0.82*)	(*0.80*)	(*1.00*)

Second and third columns are the pre-1984 and post-1984 variances for output growth. Changes in variances [(Post-1984 Variance)-(Pre-1984 Variance)] are reported in the fourth column. Contributions from international shocks, domestic spillovers and idiosyncratic shocks to these changes are given in the last three columns. Posterior medians as well as 5% and 95% quantiles are presented in the first three entries. The fourth entry is the probability that the reduction (in the variance or in its components) is *important* (less than -4). The fifth entry is the probability of observing a reduction.

Table 4: OUTPUT: The largest contribution to the volatility change

Country	Pre-1984 Var	Post-1984 Var	Change	*Int'l*	*D.spill.*	*Own*
CAN	18.82	8.39	-10.17	0.25	0.01	0.74
FRA	8.29	4.78	-3.45	0.25	0.01	0.74
GER	19.05	15.52	-3.41	0.69	0.01	0.30
ITA	20.18	6.10	-13.95	0.00	0.01	0.99
JAP	18.53	21.36	2.74	0.09	0.07	0.84
UK	33.12	5.47	-27.27	0.19	0.01	0.80
U.S.	26.62	5.69	-20.64	0.00	0.01	0.99

Second and third columns are the pre-1984 and post-1984 variances for output growth. Changes in variances [(Post-1984 Variance)-(Pre-1984 Variance)] are reported in the fourth column. The probability that a shock has the largest contribution to a change in the volatility is provided in the last three columns.

Table 5: OUTPUT: Decomposition of changes in the variance into changing impulses and changing propagation

	Impulses				*Propagation*				
Country	*Total*	*Int'l*	*D.spill.*	*Own*	*Total*	*Int'l*	*D.spill.*	*Own*	*Change*
CAN	(-24.59)	(-10.76)	(-0.32)	(-17.95)	(-2.18)	(-0.62)	(-0.88)	(-1.59)	(-21.95)
	-13.81	-4.37	-0.02	-8.99	2.94	0.81	0.03	1.95	-10.17
	(-7.42)	(-1.11)	(0.21)	(-3.48)	(12.56)	(4.35)	(1.02)	(8.65)	(-1.89)
	(*1.00*)	(*0.59*)	(*0.00*)	(*0.99*)	(*0.02*)	(*0.00*)	(*0.00*)	(*0.01*)	(*0.96*)
	(*1.00*)	(*1.00*)	(*0.66*)	(*1.00*)	(*0.16*)	(*0.18*)	(*0.49*)	(*0.17*)	(*1.00*)
FRA	(-7.37)	(-4.26)	(-1.09)	(-5.78)	(-3.72)	(-1.87)	(-0.46)	(-1.79)	(-9.76)
	-3.21	-0.12	-0.26	-2.69	-0.36	-0.21	0.10	-0.26	-3.45
	(-0.37)	(2.91)	(-0.06)	(0.07)	(2.29)	(0.86)	(1.26)	(0.65)	(0.24)
	(*0.36*)	(*0.06*)	(*0.00*)	(*0.22*)	(*0.04*)	(*0.01*)	(*0.00*)	(*0.01*)	(*0.43*)
	(*1.00*)	(*0.54*)	(*1.00*)	(*0.97*)	(*0.64*)	(*0.68*)	(*0.34*)	(*0.74*)	(*0.97*)
GER	(-16.67)	(-20.49)	(-9.10)	(-2.66)	(-1.77)	(-0.81)	(-0.78)	(-0.84)	(-13.24)
	-5.69	-10.26	-1.14	7.0801	1.34	0.29	0.56	0.22	-3.41
	(2.07)	(-0.69)	(-0.19)	(13.97)	(12.35)	(2.30)	(9.65)	(1.86)	(6.06)
	(*0.65*)	(*0.87*)	(*0.16*)	(*0.03*)	(*0.01*)	(*0.00*)	(*0.00*)	(*0.00*)	(*0.47*)
	(*0.91*)	(*0.99*)	(*1.00*)	(*0.11*)	(*0.24*)	(*0.29*)	(*0.27*)	(*0.31*)	(*0.76*)
ITA	(-17.48)	(-0.03)	(-2.40)	(-18.99)	(-15.03)	(-2.65)	(-3.12)	(-10.76)	(-30.83)
	-8.66	2.51	-0.57	-10.54	-5.32	-0.82	-0.29	-3.93	-13.95
	(-3.46)	(6.29)	(-0.13)	(-5.64)	(-1.61)	(-0.18)	(0.67)	(-1.38)	(-6.64)
	(*0.93*)	(*0.00*)	(*0.02*)	(*0.99*)	(*0.69*)	(*0.02*)	(*0.03*)	(*0.49*)	(*0.99*)
	(*1.00*)	(*0.05*)	(*1.00*)	(*0.99*)	(*0.99*)	(*0.99*)	(*0.72*)	(*1.00*)	(*1.00*)
JAP	(-6.27)	(-4.15)	(-2.55)	(-4.16)	(-10.64)	(-0.58)	(-1.22)	(-10.07)	(-12.93)
	3.40	-0.49	-0.55	5.05	-0.63	0.02	0.39	-1.25	2.74
	(13.29)	(1.27)	(-0.01)	(14.76)	(6.95)	(0.82)	(4.29)	(3.77)	(16.27)
	(*0.10*)	(*0.05*)	(*0.02*)	(*0.05*)	(*0.20*)	(*0.00*)	(*0.01*)	(*0.21*)	(*0.19*)
	(*0.27*)	(*0.72*)	(*0.96*)	(*0.17*)	(*0.58*)	(*0.44*)	(*0.29*)	(*0.70*)	(*0.35*)
UK	(-58.79)	(-29.23)	(-2.79)	(-42.62)	(1.49)	(0.16)	(-1.21)	(1.09)	(-44.80)
	-36.36	-10.81	-0.73	-23.71	7.71	1.87	0.20	5.19	-27.27
	(-24.13)	(-2.86)	(-0.11)	(-10.05)	(24.14)	(8.04)	(2.39)	(16.57)	(-16.79)
	(*1.00*)	(*0.96*)	(*0.02*)	(*1.00*)	(*0.01*)	(*0.00*)	(*0.01*)	(*0.00*)	(*1.00*)
	(*1.00*)	(*1.00*)	(*1.00*)	(*1.00*)	(*0.03*)	(*0.03*)	(*0.37*)	(*0.02*)	(*1.00*)
U.S.	(-40.94)	(-8.31)	(-2.22)	(-35.07)	(-7.44)	(-0.92)	(-2.79)	(-5.62)	(-41.90)
	-23.25	-1.73	-0.36	-20.21	1.48	0.57	-0.11	0.89	-20.64
	(-14.24)	(0.07)	(-0.05)	(-12.18)	(12.64)	(6.80)	(0.80)	(7.45)	(-11.12)
	(*1.00*)	(*0.21*)	(*0.02*)	(*1.00*)	(*0.11*)	(*0.00*)	(*0.03*)	(*0.08*)	(*1.00*)
	(*1.00*)	(*0.98*)	(*1.00*)	(*1.00*)	(*0.36*)	(*0.28*)	(*0.64*)	(*0.38*)	(*1.00*)

Entries are the decomposition of changes in the variance into changing impulses and changing propagation. Impulses and propagations are also decomposed into international, domestic spillover and idiosyncratic (own) components. Posterior medians as well as 5% and 95% quantiles are presented in the first three entries. The fourth entry is the probability that the reduction (in the variance or in its components) is *important* (less than -4). The fifth entry is the probability of observing a reduction.

Table 6: OUTPUT: The largest contribution to the volatility change from impulses and the propagation

	Impulses				*Propagation*				
Country	*Total*	*Int'l*	*D.spill.*	*Own*	*Total*	*Int'l*	*D.spill.*	*Own*	*Change*
CAN	0.97	0.18	0.00	0.82	0.03	0.21	0.04	0.75	-10.17
FRA	0.87	0.25	0.01	0.74	0.13	0.37	0.29	0.34	-3.45
GER	0.79	0.72	0.07	0.21	0.21	0.20	0.61	0.19	-3.41
ITA	0.79	0.00	0.00	0.99	0.21	0.00	0.04	0.96	-13.95
JAP	0.62	0.09	0.05	0.86	0.38	0.02	0.25	0.73	2.74
UK	1.00	0.16	0.00	0.84	0.00	0.08	0.03	0.89	-27.27
U.S.	1.00	0.01	0.00	0.99	0.00	0.27	0.10	0.63	-20.64

Entries are the decomposition of changes in the variance into changing impulses and changing propagation. Impulses and propagations are also decomposed into international, domestic spillover and idiosyncratic (own) components. The probability of the largest contribution to the volatility change from impulses and propagation is provided in the second and the sixth columns, respectively. The same probabilities are also reported for the three components of both impulses and propagation.

Table 7: INFLATION: Decomposition of changes in the variance into changing shocks

Country	Pre-1984 Var	Post-1984 Var	Change	*Int'l*	*D.spill.*	*Own*
CAN	(6.06)	(3.78)	(-15.53)	(-4.19)	(-0.11)	(-14.27)
	9.61	5.35	-4.15	-0.01	0.20	-4.15
	(21.00)	(8.69)	(0.63)	(1.19)	(0.97)	(0.78)
			(*0.55*)	(*0.05*)	(*0.00*)	(*0.52*)
			(*0.99*)	(*0.50*)	(*0.13*)	(*0.92*)
FRA	(5.34)	(1.21)	(-20.44)	(-2.69)	(-1.62)	(-18.17)
	8.82	1.78	-6.96	0.33	-0.10	-6.91
	(22.31)	(2.99)	(-3.27)	(1.49)	(0.24)	(-3.58)
			(*0.91*)	(*0.03*)	(*0.01*)	(*0.92*)
			(*1.00*)	(*0.37*)	(*0.73*)	(*1.00*)
GER	(2.54)	(3.02)	(-4.33)	(-1.29)	(-0.29)	(-5.28)
	4.04	4.88	0.80	1.41	0.39	-0.96
	(9.11)	(11.12)	(6.98)	(4.61)	(2.65)	(2.00)
			(*0.06*)	(*0.01*)	(*0.00*)	(*0.09*)
			(*0.36*)	(*0.14*)	(*0.16*)	(*0.74*)
ITA	(22.52)	(2.50)	(-97.24)	(-20.85)	(-11.87)	(-76.98)
	37.55	3.78	-33.34	-2.33	-0.98	-27.85
	(101.37)	(7.54)	(-17.89)	(1.08)	(0.21)	(-12.64)
			(*1.00*)	(*0.39*)	(*0.17*)	(*0.98*)
			(*1.00*)	(*0.76*)	(*0.90*)	(*0.99*)
JAP	(20.77)	(2.33)	(-93.05)	(-46.30)	(-8.88)	(-70.39)
	34.53	3.29	-31.05	-9.66	-0.66	-17.23
	(96.56)	(5.33)	(-17.11)	(-0.02)	(0.44)	(2.46)
			(*1.00*)	(*0.63*)	(*0.13*)	(*0.66*)
			(*1.00*)	(*0.96*)	(*0.82*)	(*0.75*)
UK	(28.31)	(4.31)	(-113.88)	(-61.89)	(-10.14)	(-85.58)
	46.89	6.36	-40.01	-1.89	-0.70	-29.72
	(120.85)	(11.89)	(-20.66)	(1.40)	(0.44)	(4.29)
			(*1.00*)	(*0.42*)	(*0.15*)	(*0.83*)
			(*1.00*)	(*0.70*)	(*0.81*)	(*0.85*)
U.S.	(7.96)	(1.73)	(-44.89)	(-8.23)	(-0.55)	(-40.11)
	14.07	2.46	-11.49	-0.44	-0.02	-10.61
	(47.48)	(3.97)	(-5.19)	(1.14)	(0.18)	(-3.02)
			(*1.00*)	(*0.14*)	(*0.00*)	(*0.93*)
			(*1.00*)	(*0.62*)	(*0.59*)	(*0.99*)

Second and third columns are the pre-1984 and post-1984 variances for inflation. Changes in variances [(Post-1984 Variance)-(Pre-1984 Variance)] are reported in the fourth column. Contributions from international shocks, domestic spillovers and idiosyncratic shocks to these changes are given in the last three columns. Posterior medians as well as 5% and 95% quantiles are presented in the first three entries. The fourth entry is the probability that the reduction (in the variance or in its components) is *important* (less than -4). The fifth entry is the probability of observing a reduction.

Table 8: INFLATION: The largest contribution to the volatility change

Country	Pre-1984 Var	Post-1984 Var	Change	*Int'l*	*D.spill.*	*Own*
CAN	9.61	5.35	-4.15	0.11	0.01	0.88
FRA	8.82	1.78	-6.96	0.01	0.00	0.99
GER	4.04	4.88	0.80	0.48	0.09	0.43
ITA	37.55	3.78	-33.34	0.04	0.01	0.95
JAP	34.53	3.29	-31.05	0.43	0.00	0.57
UK	46.89	6.36	-40.01	0.23	0.01	0.76
U.S.	14.07	2.46	-11.49	0.07	0.00	0.93

Second and third columns are the pre-1984 and post-1984 variances for inflation. Changes in variances [(Post-1984 Variance)-(Pre-1984 Variance)] are reported in the fourth column. The probability that a shock has the largest contribution to a change in the volatility is provided in the last three columns.

Table 9: INFLATION: Decomposition of changes in the variance into changing impulses and changing propagation

	Impulses				*Propagation*				
Country	*Total*	*Int'l*	*D.spill.*	*Own*	*Total*	*Int'l*	*D.spill.*	*Own*	*Change*
CAN	(-8.33)	(-4.22)	(-0.24)	(-6.85)	(-9.03)	(-0.98)	(-0.08)	(-8.65)	(-15.53)
	-3.25	-0.60	-0.03	-2.35	-1.06	0.36	0.23	-1.79	-4.15
	(0.04)	(0.87)	(0.12)	(1.15)	(2.81)	(2.22)	(1.05)	(0.68)	(0.63)
	(0.40)	*(0.06)*	*(0.00)*	*(0.25)*	*(0.18)*	*(0.01)*	*(0.00)*	*(0.21)*	*(0.55)*
	(1.00)	*(0.82)*	*(0.73)*	*(0.94)*	*(0.75)*	*(0.27)*	*(0.10)*	*(0.95)*	*(0.99)*
FRA	(-11.67)	(-1.49)	(-0.85)	(-11.84)	(-9.45)	(-2.07)	(-0.97)	(-6.84)	(-20.44)
	-5.55	0.65	-0.15	-5.83	-1.54	-0.31	-0.01	-1.18	-6.96
	(-3.14)	(2.00)	(-0.02)	(-3.37)	(0.97)	(0.24)	(0.62)	(0.55)	(-3.27)
	(0.85)	*(0.01)*	*(0.00)*	*(0.90)*	*(0.19)*	*(0.02)*	*(0.01)*	*(0.12)*	*(0.91)*
	(1.00)	*(0.24)*	*(1.00)*	*(1.00)*	*(0.88)*	*(0.86)*	*(0.54)*	*(0.90)*	*(1.00)*
GER	(-17.21)	(-1.55)	(-16.99)	(-3.64)	(-1.28)	(-0.82)	(0.09)	(-2.68)	(-4.33)
	-3.43	1.08	-3.07	-1.10	3.83	0.30	3.42	0.00	0.80
	(0.56)	(3.47)	(-0.19)	(1.05)	(22.13)	(2.35)	(19.43)	(2.51)	(6.98)
	(0.45)	*(0.01)*	*(0.42)*	*(0.04)*	*(0.02)*	*(0.01)*	*(0.00)*	*(0.03)*	*(0.06)*
	(0.93)	*(0.19)*	*(1.00)*	*(0.85)*	*(0.10)*	*(0.25)*	*(0.02)*	*(0.51)*	*(0.36)*
ITA	(-69.04)	(-17.80)	(-3.83)	(-60.26)	(-35.52)	(-5.28)	(-8.11)	(-23.85)	(-97.24)
	-32.84	-1.96	-0.51	-28.44	-2.00	-0.20	-0.54	-0.77	-33.34
	(-20.32)	(1.34)	(-0.09)	(-15.05)	(13.51)	(2.00)	(0.68)	(12.27)	(-17.89)
	(1.00)	*(0.36)*	*(0.05)*	*(0.98)*	*(0.40)*	*(0.07)*	*(0.11)*	*(0.31)*	*(1.00)*
	(1.00)	*(0.71)*	*(1.00)*	*(0.98)*	*(0.62)*	*(0.65)*	*(0.79)*	*(0.56)*	*(1.00)*
JAP	(-49.29)	(-34.09)	(-2.14)	(-40.02)	(-45.12)	(-13.46)	(-6.99)	(-31.67)	(-93.05)
	-22.56	-7.34	-0.25	-12.82	-8.68	-1.65	-0.46	-4.27	-31.05
	(-13.87)	(0.08)	(0.06)	(3.90)	(-1.37)	(-0.03)	(0.84)	(-0.35)	(-17.11)
	(1.00)	*(0.59)*	*(0.02)*	*(0.63)*	*(0.82)*	*(0.29)*	*(0.10)*	*(0.52)*	*(1.00)*
	(1.00)	*(0.92)*	*(0.91)*	*(0.69)*	*(0.98)*	*(0.97)*	*(0.74)*	*(0.98)*	*(1.00)*
UK	(-73.82)	(-50.95)	(-5.47)	(-60.68)	(-46.34)	(-15.09)	(-5.43)	(-31.40)	(-113.88)
	-35.33	-1.37	-1.08	-27.36	-5.97	-0.42	0.05	-3.52	-40.01
	(-21.48)	(1.91)	(-0.23)	(5.71)	(9.88)	(1.69)	(2.30)	(7.00)	(-20.66)
	(1.00)	*(0.41)*	*(0.09)*	*(0.86)*	*(0.62)*	*(0.19)*	*(0.07)*	*(0.50)*	*(1.00)*
	(1.00)	*(0.70)*	*(1.00)*	*(0.88)*	*(0.81)*	*(0.74)*	*(0.50)*	*(0.82)*	*(1.00)*
U.S.	(-20.68)	(-6.16)	(-0.38)	(-19.77)	(-25.19)	(-4.50)	(-0.29)	(-20.83)	(-44.89)
	-7.94	-0.16	-0.08	-7.26	-3.81	-0.43	0.03	-3.43	-11.49
	(-4.12)	(2.14)	(-0.01)	(-2.19)	(0.69)	(1.51)	(0.38)	(-0.27)	(-5.19)
	(1.00)	*(0.10)*	*(0.00)*	*(0.92)*	*(0.50)*	*(0.06)*	*(0.00)*	*(0.45)*	*(1.00)*
	(1.00)	*(0.57)*	*(1.00)*	*(1.00)*	*(0.96)*	*(0.75)*	*(0.36)*	*(1.00)*	*(1.00)*

Entries are the decomposition of changes in the variance into changing impulses and changing propagation. Impulses and propagations are also decomposed into international, domestic spillover and idiosyncratic (own) components. Posterior medians as well as 5% and 95% quantiles are presented in the first three entries. The fourth entry is the probability that the reduction (in the variance or in its components) is *important* (less than -4). The fifth entry is the probability of observing a reduction.

Table 10: INFLATION: The largest contribution to the volatility change from impulses and the propagation

	Impulses				*Propagation*				
Country	*Total*	*Int'l*	*D.spill.*	*Own*	*Total*	*Int'l*	*D.spill.*	*Own*	*Change*
CAN	0.63	0.23	0.00	0.77	0.37	0.19	0.01	0.80	-4.15
FRA	0.95	0.01	0.00	0.99	0.05	0.02	0.10	0.88	-6.96
GER	0.31	0.16	0.68	0.16	0.69	0.02	0.80	0.18	0.80
ITA	0.99	0.03	0.00	0.97	0.01	0.03	0.16	0.82	-33.34
JAP	0.95	0.44	0.00	0.56	0.05	0.38	0.04	0.58	-31.05
UK	0.98	0.24	0.00	0.76	0.02	0.19	0.10	0.71	-40.01
U.S.	0.82	0.08	0.00	0.92	0.18	0.09	0.00	0.90	-11.48

Entries are the decomposition of changes in the variance into changing impulses and changing propagation. Impulses and propagations are also decomposed into international, domestic spillover and idiosyncratic (own) components. The probability of the largest contribution to the volatility change from impulses and propagation is provided in the second and the sixth columns, respectively. The same probabilities are also reported for the three components of both impulses and propagation.