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# Output Volatility, Economic Growth, and Cross-Country Spillovers: New Evidence for the G7 Countries

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**Abstract**

This paper considers the linkages between output growth and output volatility for the sample of G7 countries over the period 1958M2-2011M7, thereby paying particular attention to spillovers within and between countries. Using the VAR-based spillover index approach by Diebold and Yilmaz (2012), we identify several empirical regularities: i) output growth and volatility are highly intertwined, with spillovers taking place into all four directions; ii) the importance of spillovers has increased after the mid 1980s and reached unprecedented levels during the recent financial and economic crisis; iii) the US has been the largest transmitter of output and volatility shocks to other countries. Generalized impulse response analyses point to moderate growth-growth spillovers and sizable volatility-volatility spillovers across countries, suggesting that volatility shocks quintuplicate in the long run. The cross-variable effects turn out negative: volatilty shocks lead to lower economic growth, growth shocks tend to reduce output volatility. Our findings underline the increased vulnerability of the G7 countries to destabilizing shocks and their detrimental effects on economic growth, which are sizeably amplified through international spillover effects and the associated repercussions.

**Key words:** Output growth, Output growth volatility, Spillover, Vector autoregression, Variance decomposition, Impulse response

**JEL codes:** C32, E32, F41, F43, F44

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# 1 Introduction

The theoretical literature on the relation between output volatility and economic growth is controversial. According to Bernanke (1983), output volatility raises economic uncertainty and thus hampers investment due to its irreversible nature, which in turn leads to lower economic growth. Aghion and Howitt (2006) argue that volatility has a negative effect on growth under credit market imperfections that constrain investments during recessions. On the contrary, higher volatility (economic uncertainty) could increase precautionary saving and therefore lead to higher growth rates (Mirman, 1971; Lensink et al., 1999). Optimal portfolio theory suggests that volatile sectors command high investment rates (Imbs, 2007). Finally, a positive effect of volatility on growth could also be due to a Schumpeterian 'cleansing effect' of recessions (Caballero, 1991).[1]

The empirical literature on the relation between output volatility and economic growth, which has used cross-section and panel data models as well as time series analyses of individual countries, adds to this controversy. Ramey and Ramey (1995), Lensink et al. (1999), Martin and Ann Rogers (2000), Badinger (2010) and Posch and Wälde (2011) find that output growth tends to be lower during periods of higher volatility. On the other hand, Grier and Tullock (1989), Caporale and McKiernan (1996), Fountas and Karanasos (2006) and Lee (2010) find that countries with higher output volatility tend to experience higher economic growth rates.[2]

Identifying the relationship between economic growth and volatility is aggravated by their complex and intricate linkages. First, causality may run not only from volatility to growth but also from growth to volatility, a point already made by Stiglitz (1993). The empirical literature on this linkage is rather sparse. Fountas and Karanasos (2006) find that higher output growth leads to significantly lower output volatility in two out of the G3 countries (Germany and the US) between the mid-19th century and 1999, while Lee (2010), who uses a panel-GARCH approach for the G7 countries over the 1965-2007 period, finds no significant relationship.

Second, in a world of highly interdependent economies, economic growth and output volatility spillovers from foreign countries are relevant determinants of a country's own economic growth and output volatility. Due to their high degree of economic integration, this holds particularly true for developed countries, for which a strong role of growth spillovers (Antonakakis and Scharler, 2012) and volatility spillovers (Antonakakis and Badinger, forthcoming) has been found.

The aim of this paper is to shed more light on this controversy by examining the linkages between output volatility and economic growth both within and across the G7 countries. As a first study on the linkages between growth and volatility, we use the VAR-based spillover index approach recently introduced by Diebold and Yilmaz (2009, 2012), which is particularly suited for the investigation of systems of highly interdependent variables. In particular, it enables an encompassing analysis to unravel the two-way relationships between output growth and volatility, both within countries and accounting for spillovers between countries. Moreover, it allows an assessment of the evolution of spillovers between output volatility and economic growth over time, the identification of net receivers and transmitters of shocks, and the quantification of their magnitude using impulse response analyses.

The remainder of the paper is organized as follows. Section 2 discusses the application of the spillover index approach to disentangle the intricate relationships between volatility and growth and describes the data used. Section 3 presents the empirical findings. Section 4 summarizes the results and concludes.

[1]See Imbs (2007) for an extended discussion of the link between volatility and growth.

[2]For a comprehensive review and discussion of empirical studies, see Döpke (2004) and Norrbin and Yigit (2005).

# 2 Empirical Model, Methodology, and Data

## 2.1 Definition of Spillover Indices for Output Growth and Volatility

In the following, we outline our application of the spillover index approach introduced by Diebold and Yilmaz (2009). Building on the seminal work on VAR models by Sims (1980) and the well-known notion of variance decompositions, it allows an assessment of the contributions of shocks to variables to the forecast error variances of both the respective and the other variables of the model. Using rolling-window estimation, the evolution of spillover effects can be traced over time and illustrated by spillover plots.

For the purpose of the present study, we use the variant of the spillover index in Diebold and Yilmaz (2012), which extends and generalizes the method in Diebold and Yilmaz (2009) in two respects. First, they introduce refined measures of directional spillovers and net spillovers, providing an 'input-output' decomposition of total spillovers into those coming from (or to) a particular source (variable) and allowing to identify the main recipients and transmitters of spillovers.

Second, in line with Koop et al. (1996) and Pesaran and Shin (1998), Diebold and Yilmaz (2012), we use a generalized vector autoregressive framework, in which forecast-error variance decompositions are invariant to the ordering of the variables (in contrast to Cholesky-factor identification used (Diebold and Yilmaz, 2009)). In the context of the present study, this is particularly important since it is hard if not impossible to justify one particular ordering of the variables on output growth and volatility among the countries. Of course, the generalized VAR framework has advantages and drawbacks. A disadvantage is that it aggravates the identification of causal effects in a strict sense in the impulse response analysis. On the other hand, by fully accounting for the pattern of observed correlation between shocks it increases the relevance from a policy perspective in light of the increased synchronization of shocks and the growing importance of a 'world component' in countries' business cycles (Kose et al., 2003).

Starting point for the analysis is the the following $P$-th order, $K$-variable VAR

$$y_t = \sum_{p=1}^{P} \Theta_i y_{t-p} + \varepsilon_t \tag{1}$$

where $y_t = (y_{1t}, y_{2t}, \ldots, y_{Kt})$ is a vector of $K$ endogenous variables, $\Theta_i, i = 1, ..., P$, are $K \times K$ parameter matrices and $\varepsilon_t \sim (0, \Sigma)$ is vector of disturbances that are independently distributed over time; $t = 1$, ..., $T$ is the time index and $k = 1$, ..., $K$ is the variable index. For each of the G7 countries considered $(CAN, FRA, GER, ITA, JPN, UK, US)$, the VAR given by Equation (1) contains observations on output growth ($g_{n,t}$), and output growth volatility ($\sigma_{n,t}$, $n = 1, ..., 7$), with $n$ denoting the country index. Hence, with 7 countries and 2 variables, our VAR is made up of $K = 14$ variables, i.e., $y_t = [g_t' \; \sigma_t']'$, where $g_t$ and $\sigma_t$ are 7x1 vectors with observation on output growth and output volatility for each of the 7 countries respectively. For notational simplicity, both variables $g_{n,t}$ and $\sigma_{n,t}$ in (1), are referred to as $y_{i,t}$ and indexed by $i = 1$, ..., $K = 14$ in the following.

The two key variables, output growth and output volatility[3], are derived from monthly, seasonally adjusted data on industrial production for the G7 countries over the period from January 1958 to July 2011. (Data source is the IMF's International Financial Statistics.) Monthly growth rates of real industrial production are obtained using the first difference of their logarithms. Given the lack of data at a higher than monthly frequency, precluding the use of

[3]Throughout the paper, the terms output growth volatility, output volatility, or simply volatility are used interchangeably.

within-period realized volatility measures, we use the standard approach to calculate economic uncertainty in terms of (conditional) volatility of industrial production growth, using univariate GARCH models (see, for instance, Fountas and Karanasos, 2006; Fountas et al., 2004; Caporale and McKiernan, 1998).[4,5] Results from the Augmented Dickey-Fuller (ADF) tests, which are reported in Table 1 below, reject the null hypothesis of a unit root for each (country-specific) series $g_n$ and $\sigma_n$, justifying the use of a VAR model for the subsequent analysis.

Key to the dynamics of the system is the moving average representation of model (1), which is given by $y_t = \sum_{j=0}^{\infty} A_j \varepsilon_{t-j}$, where the $K \times K$ coefficient matrices $A_j$ are recursively defined as $A_j = \Theta_1 A_{j-1} + \Theta_2 A_{j-2} + \ldots + \Theta_p A_{j-p}$, where $A_0$ is the $K \times K$ identity matrix and $A_j = 0$ for $j < 0$.

To avoid the use of identification schemes (such as Cholesky factorization) that make the variance decompositions dependent on the ordering of the variables, Diebold and Yilmaz (2012) use the generalized VAR framework of Koop et al. (1996) and Pesaran and Shin (1998), which produces variance decompositions invariant to the variable ordering. According to this framework, the $H$-step-ahead forecast error variance decomposition is

$$\phi_{ij}(H) = \frac{\sigma_{ii}^{-1} \sum_{h=0}^{H-1} (e_i' A_h \Sigma e_j)^2}{\sum_{h=0}^{H-1} (e_i' A_h \Sigma A_h' e_i)}, \tag{2}$$

where $\Sigma$ is the (estimated) variance matrix of the error vector $\varepsilon$, $\sigma_{ii}$ the (estimated) standard deviation of the error term for the $i$-th equation and $e_i$ a selection vector with one as the $i$-th element and zeros otherwise. This yields a $K \times K$ matrix $\phi(H) = [\phi_{ij}(H)]_{i,j=1,\ldots 14}$, where each entry gives the contribution of variable $j$ to the forecast error variance of variable $i$. The main diagonal elements contains the (own) contributions of shocks to the variable $i$ to its own forecast error variance, the off-diagonal elements show the (cross) contributions of the other variables $j$ to the forecast error variance of variable $i$.

Since the own and cross-variable variance contribution shares do not sum to one under the generalized decomposition, i.e., $\sum_{j=1}^{K} \phi_{ij}(H) \neq 1$, each entry of the variance decomposition matrix is normalized by its row sum, such that

$$\tilde{\phi}_{ij}(H) = \frac{\phi_{ij}(H)}{\sum_{j=1}^{K} \phi_{ij}(H)} \tag{3}$$

with $\sum_{j=1}^{K} \tilde{\phi}_{ij}(H) = 1$ and $\sum_{i,j=1}^{K} \tilde{\phi}_{ij}(H) = K$ by construction.

This ultimately allows to define a total (volatility) spillover index, which is given by

$$S(H) = \frac{\sum_{i,j=1, i\neq j}^{K} \tilde{\phi}_{ij}(H)}{\sum_{i,j=1}^{K} \tilde{\phi}_{ij}(H)} \times 100 = \frac{\sum_{i,j=1, i\neq j}^{K} \tilde{\phi}_{ij}(H)}{K} \times 100 \tag{4}$$

which gives the average contribution of spillovers from shocks to all (other) variables to the total forecast error variance.

This approach is quite flexible and allows to obtain a more differentiated picture by considering directional spillovers: Specifically, the directional spillovers received by variable $i$ from all other variables $j$ are defined as

$$S_{i\leftarrow j}(H) = \frac{\sum_{j=1, j\neq i}^{K} \tilde{\phi}_{ij}(H)}{\sum_{i,j=1}^{K} \tilde{\phi}_{ij}(H)} \times 100 = \frac{\sum_{j=1, j\neq i}^{K} \tilde{\phi}_{ij}(H)}{K} \times 100 \tag{5}$$

[4]The optimal lag-length of each GARCH model is determined by the Schwarz information criterion and overfitting tests.

[5]Our results are robust the the use of alternative measures of (unconditional) volatility, such as serial correlation filtered squared residuals of output growth series as used, e.g., by (Lee, 2002). In fact, the correlation between the unconditional and the conditional volatility measure is 0.82.

and the directional spillovers transmitted by variable $i$ to all other variables $j$ as

$$S_{i\to j}(H) = \frac{\sum_{j=1,j\neq i}^{K} \tilde{\phi}_{ji}(H)}{\sum_{i,j=1}^{K} \tilde{\phi}_{ji}(H)} \times 100 = \frac{\sum_{j=1,j\neq i}^{K} \tilde{\phi}_{ji}(H)}{K} \times 100. \qquad (6)$$

Notice that the set of directional spillovers provides a decomposition of total spillovers into those coming from (or to) a particular source. In the present application this means that our spillover matrix $\phi(H)$ is made up of four blocks: the two main diagonal blocks ($i, j = 1, ..., 7$; and $i, j = 8, .., 14$) reflecting growth-growth and volatility-volatility spillovers respectively; and the off-diagonal blocks ($i = 1, ..., 7$, $j = 8, ...14$; and $i = 8, ..., 14$, $j = 1, ...7$), reflecting growth-volatility and volatility-growth spillovers.

Finally, subtracting Equation (5) from Equation (6) we obtain the net spillover from variable $i$ to all other variables $j$ as

$$S_i(H) = S_{i\to j}(H) - S_{i\leftarrow j}(H), \qquad (7)$$

providing information on whether a country (variable) is a receiver or transmitter of shocks in net terms.

The spillover index approach provides measures of the intensity of interdependence across countries and variables and allows a decomposition of spillover effects by source and recipient. The magnitude of the spillovers will then be quantified using impulse response analyses.

### 2.2 Descriptive statistics

Before turning to the estimation results, Table 1 provides summary statistics of our monthly output growth and volatility series. Results are reported for the full sample from 1958M2-2011M7 (642 observations), and for two subperiods from 1958M2-1984M12 (323 observations) and from 1985M1-2011M7 (319 observations), which will be used in the econometric analysis below. For the full sample, average output growth was highest in Japan with 0.38% (followed by Canada and the US) and lowest in the UK with 0.1%. The largest volatilities are observed for Italy and France, whereas Canada and US showed the most stable growth of industrial production.

[Insert Table 1 here]

A look at the unconditional (contemporaneous) correlations in Table 1 reveals several interesting features of our data. First, as expected, the correlations among growth rates and volatilities are positive in the vast majority of cases, both within and between countries. Second, correlations between volatility and growth are positive within countries (except for the US) and negative between countries. Generally, these correlation are more pronounced in the post-1985 period. Specifically, 86% of the correlations between volatility and growth are negative in the post-1985 period, compared with only 49% in the pre-1985 period.

## 3 Empirical findings

In the following we report the results from our empirical analysis, starting with the estimates of the spillover index and its subindices, defined in Equations (4)-(7). We then consider the evolution of spillovers indices over time and finally turn to the results from the impulse response function analyses.

In the estimation of model (1), a lag-length of 3, 2 and 1 is chosen for the full sample, pre-1985 and post-1985 sample, respectively, based on the Akaike (AIC) and Schwarz Bayesian information (BIC) criteria, and overfitting methods in the spirit of Ng and Perron (2005). Lagrange-multiplier (LM) tests for autocorrelation in the residuals for each estimated VAR model do not reject the null hypothesis of uncorrelated residuals up to 12 lags. To check for structural stability we used the Bai and Perron (2003) test, which identifies a break at the end of 1984 for all series. The occurence of a structural break in the mid-1980s is also confirmed by a standard Chow test. Hence, we will report separate estimation results for the pre- and post-1985 periods in the following.

### 3.1 Spillover Indices

Tables 2 and 3 report the estimates of the spillover indices for the pre-1985 and post-1985 sample period based in 12-months ahead forecast error variance decompositions. Before discussing the results, let us describe the elements of these two tables. In Panel A of Tables 2 and 3, the $ij-$th entry is the estimated contribution *to* the forecast error variance of variable $i$ coming *from* innovations to variable $j$ (see Equation (2)). Note that each variable (index) is associated with one of the G7 countries' output growth or output volatility. Hence, the diagonal elements ($i = j$) measure own-variable spillovers of output growth and volatility within countries, while the off-diagonal elements ($i \neq j$) capture cross-variable spillovers between output growth and volatility within and between countries. In addition, the row sums excluding the main diagonal elements (labeled 'Contributions from others', see Equation (5)) and the column sums (labeled 'Contributions to others', see Equation (6)) report the total volatility spillovers 'to' (received by) and 'from' (transmitted by) each variable. The difference between each (off-diagonal) column sum and row sum, respectively, gives the net spillovers from variable $i$ to all other variables $j$ (see Equation (7)). The total volatility spillover index defined in Equation (4), given in the lower right corner of panel A in Tables 2 and 3, is approximately[6] equal to the grand off-diagonal column sum (or row sum) relative to the grand column sum including diagonals (or row sum including diagonals), expressed in percentage points.

[Insert Table 2 here]

[Insert Table 3 here]

Summarizing the rich information in Tables 2 and 3, we identify several empirical regularities. In general, growth-to-growth spillovers and volatility-to-volatility spillovers are larger within countries than between countries. For instance, in the pre-1985 (post-1985) period, innovations in US output growth are responsible for 78.7% (64.9%) of the 12-month ahead forecast error variance of output growth in the US, but only for 7.7% (7.2%) of Canada. The same holds true for spillovers from growth to volatility (and vice versa). For instance, innovations to output growth in France explain 35.2% (5.7%) of the 12-month ahead forecast error variance of volatility in France, but only 0.1% (1.2%) for Canada.

Comparing the results for the two time periods, we generally observe an increased importance of spillovers effects in the more recent period as of 1985. The total spillover index, which is reported in the lower right part of panel A and essentially distills all spillovers effects between and within countries into a single measure, has increased from 18.5% in the pre-1985 period to 40.1% in the post-1985 period.

[6]The approximate nature of the claim stems from the fact that the contributions of the variables in the variance decompositions do not sum to one and have to be normalized (see Equation (3)).

On the one hand, this result is certainly driven to some extent by the recent financial and economic crisis over the period 2008-2009. Restricting our estimates of the post-1985 sample to the period up to June 2008 the change in the spillover index turns out more moderate with an increase to 20%. On the other hand, one could argue that the large variation in the data during the crises helps to identify the actual extent of spillovers (rather than overestimating their extent). In this respect, notice that the spillover index captures shares in the contributions to forecast error variances and is thus invariant to changes in the overall level of the volatility.[7] Moreover, it should also be borne in mind that the post-1985 period (excluding the crisis) coincides with the great moderation of output volatility.[8] Hence, if the estimated increase in spillovers for the period including the crisis is in fact partly driven by the increase in the overall level of volatility, then one could argue that the increase from 18.5% to 20% (obtained for the period of the great moderation excluding the crisis) underestimates the actual increase in spillovers that would have occurred if volatility had remained constant.

The finding of an increased importance of spillover effects is particularly pronounced for volatility spillovers originating in the US: The average contribution of US volatility spillovers to other countries volatility amounted to 1% in the pre-1985 period and surged to an average share of 9% (ranging from 0.02% to 17.6%) for the more recent period. This result is further supported by the gross and net spillover indices by country reported in Panels A of Tables 2 and 3. Overall, the contribution to and from others has increased. Moreover, in terms of net spillovers (see Equation (7)), the US hold the dominant position as transmitter of output growth and volatility spillovers in the post-1985 period.

Our results are in line with Eickmeier et al. (2011). Focusing on the role of financial shocks originating in the US during the recent financial and economic crisis, they find that the 'global financial crisis shock' was very large by historical standards and that US shocks explain one third of the variation in GDP growth on average over all countries in 2008-2009, compared with a little less than 10% over the 1971-2007 period. While the results are not directly comparable since they focus on financial rather than real shocks and use an alternative method (time-varying factor-augmented VARs), the large vulnerability of countries due to the increased interconnectedness of the world economy is a common finding.

In order to provide a more differentiated picture, Panels B in Tables 2 and 3 further parse the directional spillovers into growth-growth spillovers and volatility-growth spillovers ('Contribution to others' $g$'), as well as growth-volatility spillovers and volatility-volatility spillovers ('Contribution to others' $\sigma$'). We can see that in the post-1985 (pre-1985) period, 32.56% (41.73%) of all four gross directional spillovers are from growth to growth, with France (US) and Italy (Canada) being the biggest contributors to output growth to the remaining G7 countries. The share of volatility-growth and growth-volatility spillovers is smaller with an average of 13.66% (15.23%), with the US (UK) being the main contributor, followed by Germany (France) and UK (Italy). Finally, with a share of 28.42%, volatility-volatility spillovers make up a substantival fraction of total spillovers, with the US (Canada) being the largest transmitter to the other G7 countries.

### 3.2 Spillover Plots

While we have split our sample according to the results of the structural break tests, the use of an average measure of growth and volatility spillovers over a fairly long period might mask

[7] The increased volatility in the early 1980s is not equally reflected in an increase in spillovers during that period (see also the results from the rolling-window estimates in section 3.2).

[8] The G7's average output volatility in the pre-1985 period and the post-1985 period (up to 2008M6, excluding the crises) amounted to 0.0307% and 0.0152%, respectively.

potentially interesting information on secular or cyclical movements in spillover effects. Hence, we estimate the model in Equation (1) using 180-month rolling windows and calculate the variance decompositions and spillover indices for each subsample. As a result, we obtain time series of estimated spillover indices, allowing us to judge the evolution of total and directional growth and volatility spillover within and between countries over time.

[Insert Figure 1 here]

Figure 1 presents the results for the time-varying total spillovers indices obtained from the 180-months rolling windows estimation for each of the subsamples. In the pre-1985 period output growth and output volatility spillovers in the G7 countries remained relatively stable and below 30%. In the post-1985 period the spillover indices also remained stable around around 30% and surged to unprecedented levels above 50% following the recent global financial and economic crisis. Overall these results are in line with the average estimates for the subperiods, suggesting an increased in the role of spillovers (in spite of the great moderation) and a surge during the recent crisis period.

The results for the total total volatility spillover index are suggestive but they might discards directional information that is contained in the "Contribution to others" row (Equation (5)) and the "Contribution from others" column (Equation (6)) in Panel A of Tables 2 and 3. Figure 2 presents the estimated 180-month rolling windows directional spillovers from each of the variables to others (corresponding to the "Contribution to others" row in Panel A of Tables 2 and 3) in the pre- and post- 1985 period, respectively. According to this figure, in the pre-1985 period, spillovers arise basically from output growth, with France, US and Canada holding the dominant position as transmitters of output growth spillovers, while spillovers originating from output volatility are smaller in magnitude. Specifically, the share of directional spillovers from output growth sometimes reaches the 5% threshold, while the share of directional spillovers from output volatility is below 2.5%. In the post-1985 period, in contrast, the contribution of directional volatility spillovers increases to a share of 10% and receives the largest values for US volatility and growth spillovers. In other words, there is increased influence of directional spillovers in the post-1985 period, with the US lying at the epicenter of spillovers during the recent economic crisis through its dominant role as transmitter of output volatility and growth spillovers to the other G7 countries.

[Insert Figure 2 here]

[Insert Figure 3 here]

A similar pictures emerges when looking at the net directional spillover indices obtained from the rolling window estimation. According to Figure 3, which plots the time-varying net directional spillovers, we see that during the pre-1985 period France and US were the strongest transmitters of growth spillovers in net terms. During the post-1985 period and especially during the recent crisis, US output volatility constitutes the main source of net spillovers.

### 3.3 Impulse Responses

Having established the strong role and growing importance of spillover effects we next turn to an impulse response analysis in order to shed more light on the intricate relationships between volatility and growth. As already outlined above the results should be interpreted with care. In particular, the effects of shocks to single variables should not be interpreted as causal (in the sense of 'all else being equal'), given that the generalized impulse responses account for the observed correlation of shocks across countries. This is a limitation on the one side. However, given the increased synchronization of shocks and business cycles across countries, we do not expect shocks to countries to appear in isolation from each other; and since there is no strong reason to assume that the correlation pattern of shocks to countries will change fundamentally in the short- to the medium-run, we argue that the generalized impulse responses can be regarded as indicative for the effects of future shocks.

Results of the generalized impulse response analysis are reported for the post-1985 period, using one standard deviation shocks to each of the G7 countries' output growth and volatility (see Pesaran and Shin, 1998). We first report the results for shocks to the US in light of its dominant role as transmitter of spillover effects[9] and then provide a broader picture in terms of cross-country averages of impulse response effect of shocks to single countries.

Generalized impulse responses (GIR) of shocks to the US in the post-1985 period are illustrated in Figure 4. Panel a) of Figure 4 shows that output growth shocks to the US have positive, but relatively short-lived effects on growth, compared with the relatively more persistent effects of volatility shocks in panel b) of Figure 4. Specifically, the effects of output growth shocks to the US on own and other countries' output growth dissipate after some 12 months, whereas the effects of shocks to volatility on own- and other countries' volatility fade away after some 2 years.

[Insert Figure 4 here]

Turning the cross-variable (i.e., growth-volatility and volatility-growth) spillovers, panel c) of Figure 4 shows that overall, volatility shocks to the US have negative effects on growth, which fade away after some 2 years. A qualitatively similar picture emerges for the effects of growth shocks to the US on own- and other countries' volatility in panel d) of Figure 4.

In order to provide a broader picture on the bottom line effect of growth and volatility shocks we next calculate for each country the cumulative effects of a one-standard deviations shock to growth (volatility) on the respective country's growth (volatility), referred to as 'within-country' response in the following.[10] Table 4 reports the averages of the cumulative effects i) of growth shocks on growth and on volatility (first column), and ii) of volatility shocks on growth and on volatility (second column). The cumulative effects are reported for time horizons of 6, 12, and 24 months. Since the effects of shocks have fully materialized after 2 years (compare Figure 4), the cumulative 24-months responses can be interpreted as overall bottom line effect of incipient shocks including spillover effects and the associated repercussions.

Regarding the direction of the effects, notice first that - as expected - volatility and growth shocks have positive and multiplied effects on 'themselves'. Of particular interest are the impulse response effects across variables, i.e., the response of a country's growth rate (volatility) to shocks to volatility (growth) of the respective country. As evident from Table 4 we find a negative effect of volatility shocks on economic growth, and also a negative effect of output growth shocks on volatility. It worth emphasizing once more that the long-term cumulative impulse responses reflect level rather than permanent growth rate effects.

The magnitude of the cumulative response effects has to be judged against the size of the incipient shock, which corresponds to the standard deviation of the error term in the respective equation of the VAR. In order to facilitate the interpretation and to make our results comparable with other studies, Table 4 reports (country-specific averages of) the implied response multipliers, defined as the cumulative impulse response effect divided by the size of the incipient

[9] Impulse responses of shocks to other countries are qualitatively similar and not presented for the sake of brevity.

[10] Notice that with a stationary VAR the cumulative growth rate effects of one-time shocks have to be interpreted as level effects and should not be confused with permanent effects on the growth rate.

shock. In the discussion of the results we focus on the multiplier effects in the following. We start with a discussion of growth-growth and volatility-volatility spillovers and then turn to the cross-variable effects, i.e., the spillovers from growth to volatility and vice versa.

Notice first that the long-run multiplier effects of growth shocks are fairly small with a value slightly above one (see the third column of Table 4). This result masks a bit that there are substantial spillover effects to other countries. The 'cross-country' multiplier of shocks to other countries (not reported in Table 4), which is defined as average multiplier of the six G7 countries' growth in response to growth shocks to the other country amounts to 0.41. What the rather small 'within-country' multiplier thus suggests is that that growth spillovers appear to mainly materialize in 'one wave' and that the repercussions and feedback effects to the country of origin are moderate.

[Insert Table 4 here]

In contrast, the long-run multiplier effects of volatility shocks are sizeable with an average 'within-country' response multiplier of 5.51. In line with previous studies this highlights the role of international volatility spillovers as a crucial determinant of countries' output volatility. Carare and Mody (2010), who use factor-structural vector autoregressive models for a sample of 22 countries over the period 1960-2007, find that 50-75% of total volatility in the post-1995 period is due to international spillovers. Our multiplier of 5.51 in response to volatility shocks suggests that one fifth of the total increase in volatility is due to the incipient shock and that the 80% are triggered by international spillover effects.[11] Since our sample also includes the 2008-2009 crises, during which spillover effects have surged according to our estimates and those of Eickmeier et al. (2011), we would expect somewhat larger effects of volatility shocks. This result is also confirmed by the large 'cross-country' multiplier of shocks to volatility amounting to 1.04. Volatility shocks and uncertainty appear to be highly contagious, persistent, and self-enforcing through large feedback effects.

Turning to the cross-variable effects, we find a multiplier of -0.1451 for the effect of growth on volatility. As one of the rare studies on this link, Fountas and Karanasos (2006) obtain smaller coefficients of -0.034 for Germany and -0.018 for the USA, using univariate time series analyses. The larger magnitude of our estimates that are based on more countries and account for cross-country spillovers is plausible. And while the point estimates should not be overstressed, our findings are qualitatively in line with intuitive theoretical arguments: According to the Phillips curve, an increase in output growth raises inflation. Given the negative association between inflation and output growth uncertainty ('Taylor effect'), output volatility would be expected to fall in response to positive growth shocks (Fountas and Karanasos, 2007).

Regarding the effects of shocks to volatility on economic growth, the multiplier effect amounts to -1.0847. Hence, output volatility exerts a negative and sizeable effect on economic activity. Comparing our results to previous studies that have estimated the effect of volatilty of growth using large cross-sections of countries, our effects turn out larger in magnitude. Ramey and Ramey (1995) obtain coefficients for the effect of volatility on economic growth in a range of -0.4 to -0.5. The estimates by Fatás and Mihov (2003) are closer to ours with a coefficient of -0.8. Given the uncertainty involved in our point estimates, this discrepancy should not be overemphasized. However, the larger magnitude implied by our estimates could be due to the

[11] Although the impulse response effects are not directly comparable with the variance decompositions in section 3.1, the multiplier effects are consistent with the spillover indices reported in Table 3. The average contribution of volatility shocks to other countries' volatility (in terms of the forecast error variance) for a 12-month horizon amounts to 28.42%; the multiplier effect for the cumulative response after 12 months amounts to 4.08, also suggesting a share of around one quarter.

fact that the cross-sectional estimates of the aforementioned studies (relating country-specific growth to country-specific volatility) do not fully capture the reinforcing effects of international growth and volatility spillovers that are captured through the dynamics of our system.

## 4 Conclusions

The present paper considers the linkages between output growth and output volatility for the sample of the G7 countries over the period 1958M2-2011M7, thereby paying particular attention to spillovers within and between countries. Using spillover index estimates in the spirit of Diebold and Yilmaz (2012), we identify several empirical regularities: i) In line with theoretical arguments, volatility and growth turn out empirically highly intertwined, with spillovers taking place into all four directions, i.e., both from growth to growth (volatility to volatility) between countries as well as from volatility to growth within and between countries (and vice versa). ii) The importance of spillovers has increased after the mid 1980s and reached unprecedented levels during the recent financial and economic crisis. iii) Among the G7 countries, the US turn out as the largest transmitter of output and volatility shocks to other countries.

Generalized impulse response analyses point to positive though moderate growth to growth spillovers and sizeable volatility to volatility spillovers, suggesting that volatility shocks quintuplicate in the long run through international contagion effects and the associated repercussions. Regarding the cross-variable effects, we find a negative effect of growth on volatility in line with the theoretical arguments that higher growth triggers higher inflation which is in turn associated with lower output volatility (Taylor effect). Finally, volatility shocks turn out to have negative effects on economic output. Qualitatively, our results are in line with previous studies that have considered one-way linkages between volatility and growth within countries. However, the magnitude of the estimated effects turns out larger, since our encompassing approach appears to more completely capture the reinforcing propagation effects and dynamics of growth and volatility spillovers, both within and between countries.

Our findings underline the increased vulnerability of the G7 countries to local and joint destabilizing shocks and their detrimental effects on economic growth, which are sizeably amplified due to the high degree of economic integration. On the positive side, they highlight the potentially huge gains (in terms of stabilization and growth multipliers) from international policy coordination in the implementation of macroprudential stabilization policies, which may result in a virtuous cycle of higher growth and lower volatility.

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Table 1: Descriptive statistics of output growth and output growth volatility

| Full sample, 1958M2-2011M7 | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $g$CAN | $g$FRA | $g$GER | $g$ITA | $g$JPN | $g$UK | $g$US | $\sigma$CAN | $\sigma$FRA | $\sigma$GER | $\sigma$ITA | $\sigma$JPN | $\sigma$UK | $\sigma$US |
| Mean | 0.2807 | 0.1698 | 0.2204 | 0.2188 | 0.3759 | 0.0997 | 0.2367 | 0.0133 | 0.0333 | 0.0273 | 0.0466 | 0.0255 | 0.0182 | 0.0067 |
| Std | 1.1558 | 2.4006 | 1.7829 | 2.1656 | 1.7373 | 1.3500 | 0.8473 | 0.0133 | 0.1869 | 0.0248 | 0.0521 | 0.0544 | 0.0297 | 0.0085 |
| ADF | -30.93** | -31.35** | -34.03** | -33.10** | -23.51** | -29.68** | -17.21** | -3.965** | -15.47** | -15.77** | -4.333** | -14.67** | -11.67** | -14.40** |
| | | | | | | | Correlations | | | | | | | |
| $g$CAN | 1.0000 | | | | | | | | | | | | | |
| $g$FRA | 0.0529 | 1.0000 | | | | | | | | | | | | |
| $g$GER | -0.0362 | 0.1134 | 1.0000 | | | | | | | | | | | |
| $g$ITA | 0.0680 | 0.0496 | 0.0847 | 1.0000 | | | | | | | | | | |
| $g$JPN | 0.1005 | 0.1133 | 0.1795 | 0.0645 | 1.0000 | | | | | | | | | |
| $g$UK | 0.1619 | 0.0382 | 0.1567 | 0.1775 | 0.0816 | 1.0000 | | | | | | | | |
| $g$US | 0.3047 | 0.0379 | 0.1241 | 0.1114 | 0.1706 | 0.1542 | 1.0000 | | | | | | | |
| $\sigma$CAN | 0.0689 | 0.0129 | 0.0322 | 0.0570 | 0.1182 | 0.0578 | 0.0963 | 1.0000 | | | | | | |
| $\sigma$FRA | 0.0280 | 0.4136 | 0.0695 | 0.0002 | -0.0119 | 0.0105 | 0.0008 | 0.0041 | 1.0000 | | | | | |
| $\sigma$GER | -0.1242 | -0.0219 | 0.0276 | -0.0606 | -0.1724 | -0.0598 | -0.0743 | 0.1260 | 0.0392 | 1.0000 | | | | |
| $\sigma$ITA | -0.0146 | -0.0045 | -0.0384 | 0.0133 | 0.0023 | 0.0080 | -0.0897 | 0.1164 | -0.0328 | 0.0672 | 1.0000 | | | |
| $\sigma$JPN | -0.0322 | -0.0197 | -0.0236 | -0.0358 | 0.0246 | -0.0685 | -0.0974 | -0.0835 | 0.0065 | 0.1506 | 0.0487 | 1.0000 | | |
| $\sigma$UK | -0.0087 | -0.0063 | -0.0475 | 0.0160 | -0.0662 | 0.2149 | -0.0197 | 0.0588 | -0.0169 | 0.0349 | 0.1978 | 0.0064 | 1.0000 | |
| $\sigma$US | -0.0042 | -0.0289 | -0.0005 | -0.0209 | -0.0697 | 0.0005 | -0.0066 | 0.1351 | -0.0096 | 0.0635 | 0.0352 | 0.0484 | -0.0035 | 1.0000 |
| Pre-1985, 1958M2-1984M12 | | | | | | | | | | | | | | |
| | $g$CAN | $g$FRA | $g$GER | $g$ITA | $g$JPN | $g$UK | $g$US | $\sigma$CAN | $\sigma$FRA | $\sigma$GER | $\sigma$ITA | $\sigma$JPN | $\sigma$UK | $\sigma$US |
| Mean | 0.3486 | 0.2722 | 0.2839 | 0.3922 | 0.6951 | 0.1535 | 0.3012 | 0.0192 | 0.0490 | 0.0286 | 0.0669 | 0.0197 | 0.0236 | 0.0082 |
| Std | 1.4615 | 3.1840 | 1.9609 | 2.6836 | 1.4190 | 1.6219 | 1.0096 | 0.0110 | 0.2626 | 0.0273 | 0.0644 | 0.0082 | 0.0403 | 0.0110 |
| ADF | -23.01** | -21.91** | -26.28** | -24.14** | -18.24** | -20.26** | -11.16** | -3.784** | -10.98** | -12.02** | -3.459** | -13.57** | -8.278** | -10.45** |
| | | | | | | | Correlations | | | | | | | |
| $g$CAN | 1.0000 | | | | | | | | | | | | | |
| $g$FRA | 0.0213 | 1.0000 | | | | | | | | | | | | |
| $g$GER | -0.0953 | 0.0499 | 1.0000 | | | | | | | | | | | |
| $g$ITA | 0.0407 | -0.0266 | -0.0069 | 1.0000 | | | | | | | | | | |
| $g$JPN | 0.0944 | 0.0727 | 0.2049 | -0.0740 | 1.0000 | | | | | | | | | |
| $g$UK | 0.1380 | -0.0190 | 0.1370 | 0.1467 | 0.0028 | 1.0000 | | | | | | | | |
| $g$US | 0.3256 | 0.0122 | 0.0794 | 0.0527 | 0.1880 | 0.1693 | 1.0000 | | | | | | | |
| $\sigma$CAN | 0.0307 | -0.0261 | 0.0369 | 0.0046 | 0.0735 | -0.0076 | 0.1268 | 1.0000 | | | | | | |
| $\sigma$FRA | 0.0274 | 0.4387 | 0.0908 | -0.0055 | -0.0372 | 0.0104 | -0.0033 | -0.0569 | 1.0000 | | | | | |
| $\sigma$GER | -0.1317 | 0.0071 | 0.1740 | 0.0022 | -0.0254 | -0.0329 | -0.0018 | 0.2512 | 0.0316 | 1.0000 | | | | |
| $\sigma$ITA | -0.0417 | -0.0161 | -0.0486 | -0.0014 | -0.1229 | 0.0048 | -0.1166 | -0.2103 | -0.0796 | -0.0501 | 1.0000 | | | |
| $\sigma$JPN | 0.0365 | 0.0287 | 0.0289 | -0.0370 | 0.0051 | 0.0248 | 0.0566 | 0.1599 | 0.0839 | -0.0255 | -0.0291 | 1.0000 | | |
| $\sigma$UK | -0.0103 | -0.0081 | -0.0397 | 0.0089 | -0.1187 | 0.2515 | -0.0121 | -0.1182 | -0.0361 | -0.0415 | 0.1231 | 0.0197 | 1.0000 | |
| $\sigma$US | 0.0026 | -0.0074 | 0.0410 | -0.0036 | 0.0129 | 0.0455 | -0.0190 | 0.1403 | -0.0298 | 0.0004 | -0.0670 | 0.1522 | -0.0559 | 1.0000 |
| Post-1985, 1985M1-2011M7 | | | | | | | | | | | | | | |
| | $g$CAN | $g$FRA | $g$GER | $g$ITA | $g$JPN | $g$UK | $g$US | $\sigma$CAN | $\sigma$FRA | $\sigma$GER | $\sigma$ITA | $\sigma$JPN | $\sigma$UK | $\sigma$US |
| Mean | 0.2121 | 0.0662 | 0.1560 | 0.0431 | 0.0527 | 0.0453 | 0.1714 | 0.0073 | 0.0175 | 0.0260 | 0.0260 | 0.0315 | 0.0127 | 0.0053 |
| Std | 0.7215 | 1.1530 | 1.5829 | 1.4491 | 1.9589 | 1.0020 | 0.6376 | 0.0127 | 0.0072 | 0.0219 | 0.0204 | 0.0763 | 0.0090 | 0.0044 |
| ADF | -18.24** | -24.49** | -21.16** | -21.83** | -16.66** | -23.04** | -14.95** | -3.917** | -8.892** | -9.824** | -3.456** | -10.42** | -10.67** | -9.884** |
| | | | | | | | Correlations | | | | | | | |
| $g$CAN | 1.0000 | | | | | | | | | | | | | |
| $g$FRA | 0.2179 | 1.0000 | | | | | | | | | | | | |
| $g$GER | 0.1025 | 0.3559 | 1.0000 | | | | | | | | | | | |
| $g$ITA | 0.1503 | 0.4275 | 0.2937 | 1.0000 | | | | | | | | | | |
| $g$JPN | 0.1164 | 0.2451 | 0.1620 | 0.2330 | 1.0000 | | | | | | | | | |
| $g$UK | 0.2361 | 0.2923 | 0.1966 | 0.2621 | 0.1755 | 1.0000 | | | | | | | | |
| $g$US | 0.2305 | 0.1392 | 0.2083 | 0.2648 | 0.1532 | 0.1062 | 1.0000 | | | | | | | |
| $\sigma$CAN | 0.0884 | 0.0349 | -0.0022 | 0.0576 | 0.0183 | 0.1240 | -0.0035 | 1.0000 | | | | | | |
| $\sigma$FRA | -0.1163 | -0.0912 | -0.2389 | -0.1466 | -0.2790 | -0.1209 | -0.2038 | -0.0340 | 1.0000 | | | | | |
| $\sigma$GER | -0.1284 | -0.1394 | -0.2058 | -0.2260 | -0.3448 | -0.1229 | -0.2337 | -0.0311 | 0.6016 | 1.0000 | | | | |
| $\sigma$ITA | -0.0413 | -0.0869 | -0.1118 | -0.1328 | -0.0367 | -0.0773 | -0.2289 | 0.2578 | 0.4736 | 0.4704 | 1.0000 | | | |
| $\sigma$JPN | -0.0675 | -0.0536 | -0.0358 | -0.0507 | 0.0565 | -0.1285 | -0.1798 | -0.0673 | 0.2512 | 0.2572 | 0.3448 | 1.0000 | | |
| $\sigma$UK | -0.1136 | -0.0949 | -0.1824 | -0.0624 | -0.2009 | 0.0181 | -0.2111 | 0.2998 | 0.3671 | 0.4232 | 0.3766 | 0.1148 | 1.0000 | |
| $\sigma$US | -0.1030 | -0.2434 | -0.1580 | -0.1855 | -0.3743 | -0.2198 | -0.0258 | -0.0716 | 0.3242 | 0.2398 | 0.2182 | 0.1449 | 0.1857 | 1.0000 |

Notes: $g_n$ is industrial production growth of country $n$, $\sigma_n$ is the (conditional) volatility of industrial production growth in country $n$, where $n = CAN, FRA, GER, ITA, JPN, UK, US$. Means and standard deviations have been multiplied by 100 and are expressed in %. ADF denotes augmented Dickey Fuller tests with 5%(1%) critical values of -2.87(-3.44). * and ** indicate significance at 5% and 1% level respectively.

Table 2: Spillover table, pre-1985 (1958M2-1984M12)

| Panel A | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *From (j)* | | | | | | | | | | | | | | |
| *To (i)* | $g$CAN | $g$FRA | $g$GER | $g$ITA | $g$JPN | $g$UK | $g$US | $\sigma$CAN | $\sigma$FRA | $\sigma$GER | $\sigma$ITA | $\sigma$JPN | $\sigma$UK | $\sigma$US | Contr. from Others |
| $g$CAN | 82.5 | 0.1 | 2.2 | 1.3 | 1.1 | 1.4 | 7.7 | 0.5 | 0.1 | 0.9 | 0.4 | 0.2 | 0.5 | 0.8 | 17 |
| $g$FRA | 0.9 | 88.2 | 0.5 | 0.9 | 1.7 | 0.6 | 0.3 | 0.4 | 4.9 | 0.3 | 0.1 | 0.5 | 0.5 | 0.1 | 12 |
| $g$GER | 1.9 | 1.0 | 85.4 | 0.3 | 3.4 | 2.2 | 0.7 | 0.3 | 2.5 | 1.2 | 0.3 | 0.2 | 0.5 | 0.2 | 15 |
| $g$ITA | 2.2 | 0.5 | 0.4 | 84.8 | 2.2 | 1.8 | 0.5 | 0.4 | 0.2 | 1.5 | 1.9 | 0.5 | 3.0 | 0.1 | 15 |
| $g$JPN | 1.7 | 0.5 | 3.6 | 5.1 | 76.1 | 1.4 | 4.0 | 0.6 | 2.5 | 0.3 | 2.0 | 0.1 | 1.0 | 1.1 | 24 |
| $g$UK | 2.0 | 0.8 | 2.2 | 2.4 | 2.3 | 80.1 | 2.8 | 0.9 | 0.6 | 0.4 | 1.0 | 0.4 | 4.0 | 0.3 | 20 |
| $g$US | 8.3 | 0.5 | 0.4 | 3.4 | 0.5 | 2.3 | 78.7 | 1.0 | 0.1 | 0.4 | 1.3 | 0.2 | 0.6 | 2.3 | 21 |
| $\sigma$CAN | 0.4 | 0.1 | 1.0 | 0.2 | 5.5 | 0.2 | 0.6 | 79.2 | 0.2 | 11.4 | 0.4 | 0.2 | 0.4 | 0.3 | 21 |
| $\sigma$FRA | 0.8 | 35.2 | 1.1 | 0.3 | 1.0 | 0.5 | 0.2 | 0.5 | 58.3 | 0.7 | 0.4 | 0.1 | 0.4 | 0.5 | 42 |
| $\sigma$GER | 2.1 | 1.1 | 4.5 | 0.9 | 0.4 | 0.2 | 0.9 | 10.1 | 2.3 | 76.5 | 0.1 | 0.2 | 0.0 | 0.7 | 24 |
| $\sigma$ITA | 1.1 | 0.8 | 0.3 | 0.8 | 2.0 | 0.1 | 0.4 | 2.1 | 0.1 | 0.2 | 90.3 | 0.2 | 1.3 | 0.1 | 10 |
| $\sigma$JPN | 1.3 | 1.7 | 0.4 | 0.3 | 1.3 | 1.0 | 1.3 | 2.2 | 0.1 | 0.8 | 0.6 | 86.9 | 0.3 | 1.7 | 13 |
| $\sigma$UK | 0.2 | 0.7 | 0.2 | 1.6 | 0.8 | 5.1 | 0.1 | 2.2 | 0.3 | 0.3 | 0.9 | 0.2 | 87.1 | 0.2 | 13 |
| $\sigma$US | 2.1 | 0.2 | 0.5 | 0.9 | 0.8 | 0.3 | 4.6 | 1.7 | 0.5 | 0.5 | 0.4 | 0.4 | 0.1 | 86.9 | 13 |
| Contr. to others | 25 | 43 | 17 | 19 | 23 | 17 | 24 | 23 | 14 | 19 | 10 | 3 | 13 | 8 | Total Spillover |
| Contr. incl. own | 108 | 131 | 103 | 103 | 99 | 97 | 103 | 102 | 73 | 95 | 100 | 90 | 100 | 95 | Index= 18.5% |
| Net spillovers | 8 | 31 | 2 | 4 | -1 | -3 | 3 | 2 | -28 | -5 | 0 | -10 | 0 | -5 | |
| Panel B | | | | | | | | | | | | | | | |
| Contr. to others' $g$ | 17 | 3.4 | 9.3 | 13.4 | 11.2 | 9.7 | 16 | | | | | | | | 80.0 (41.73%) |
| Contr. to others' $\sigma$ | 7.6 | 4.6 | 3.5 | 4.2 | 10.5 | 2.3 | 3.5 | | | | | | | | 36.2 (18.88%) |
| Contr. to others' $g$ | | | | | | | | 3.6 | 6 | 3.8 | 5.1 | 2 | 6.1 | 2.6 | 29.2 (15.23%) |
| Contr. to others' $\sigma$ | | | | | | | | 18.8 | 3.5 | 13.9 | 2.8 | 1.3 | 2.5 | 3.5 | 46.3 (24.15%) |

Notes: Spillover indices, given by Equations (2)-(7), calculated from variance decompositions based on 12-step-ahead forecasts.

Table 3: Spillover table, post-1985 (1985M1-2011M7)

| Panel A | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *From (j)* | | | | | | | | | | | | | | |
| *To (i)* | $g$CAN | $g$FRA | $g$GER | $g$ITA | $g$JPN | $g$UK | $g$US | $\sigma$CAN | $\sigma$FRA | $\sigma$GER | $\sigma$ITA | $\sigma$JPN | $\sigma$UK | $\sigma$US | Contr. from Others |
| $g$CAN | 74.3 | 2.9 | 0.4 | 4.0 | 1.6 | 3.7 | 7.2 | 0.1 | 0.1 | 0.1 | 0.2 | 0.4 | 3.3 | 1.7 | 26 |
| $g$FRA | 2.3 | 62.2 | 6.6 | 9.4 | 3.0 | 4.0 | 3.1 | 1.4 | 0.2 | 1.3 | 0.8 | 1.8 | 0.7 | 3.2 | 38 |
| $g$GER | 0.4 | 7.5 | 64.4 | 5.6 | 5.1 | 2.0 | 1.8 | 0.0 | 1.7 | 2.0 | 2.7 | 1.9 | 0.9 | 3.9 | 36 |
| $g$ITA | 2.7 | 10.7 | 5.7 | 61.4 | 3.2 | 2.8 | 4.3 | 0.4 | 0.9 | 1.5 | 1.6 | 1.1 | 0.9 | 2.9 | 39 |
| $g$JPN | 0.7 | 3.3 | 2.1 | 2.6 | 60.0 | 2.6 | 4.3 | 0.0 | 2.3 | 7.1 | 1.5 | 3.9 | 2.0 | 7.6 | 40 |
| $g$UK | 3.0 | 4.2 | 2.2 | 3.9 | 3.0 | 75.1 | 2.3 | 0.4 | 0.3 | 0.4 | 0.6 | 0.6 | 1.1 | 2.9 | 25 |
| $g$US | 7.0 | 3.2 | 1.7 | 6.2 | 4.6 | 1.9 | 64.9 | 0.2 | 0.9 | 1.0 | 2.0 | 0.9 | 2.1 | 3.4 | 35 |
| $\sigma$CAN | 10.4 | 1.2 | 0.2 | 0.7 | 0.1 | 0.1 | 0.5 | 83.6 | 0.1 | 0.0 | 2.6 | 0.0 | 0.3 | 0.0 | 16 |
| $\sigma$FRA | 0.7 | 5.7 | 5.2 | 3.7 | 4.4 | 2.5 | 4.4 | 0.3 | 39.0 | 4.7 | 7.7 | 2.4 | 1.5 | 17.6 | 61 |
| $\sigma$GER | 0.7 | 4.4 | 7.5 | 2.9 | 12.2 | 3.2 | 4.5 | 0.1 | 8.8 | 37.2 | 4.5 | 1.5 | 5.0 | 7.5 | 63 |
| $\sigma$ITA | 0.7 | 5.9 | 8.3 | 6.5 | 7.7 | 3.3 | 7.7 | 0.2 | 10.3 | 5.8 | 28.0 | 3.1 | 2.5 | 10.0 | 72 |
| $\sigma$JPN | 0.8 | 2.0 | 2.5 | 2.1 | 9.8 | 1.2 | 3.5 | 0.2 | 1.4 | 1.0 | 4.4 | 59.9 | 1.1 | 10.2 | 40 |
| $\sigma$UK | 0.2 | 1.8 | 2.3 | 2.7 | 4.3 | 11.3 | 2.7 | 1.1 | 1.9 | 3.3 | 2.7 | 1.1 | 56.4 | 8.3 | 44 |
| $\sigma$US | 1.1 | 1.7 | 1.4 | 1.8 | 5.1 | 1.3 | 9.8 | 0.1 | 0.4 | 0.3 | 1.6 | 2.5 | 0.5 | 72.4 | 28 |
| Contr. to others | 31 | 55 | 46 | 52 | 64 | 40 | 56 | 5 | 29 | 29 | 33 | 21 | 22 | 79 | Total Spillover |
| Contr. incl. own | 105 | 117 | 110 | 113 | 124 | 115 | 121 | 88 | 68 | 66 | 61 | 81 | 78 | 152 | Index= 40.1% |
| Net spillovers | 5 | 17 | 10 | 13 | 14 | 15 | 21 | -9 | -32 | -34 | -39 | -19 | -22 | 51 | |
| Panel B | | | | | | | | | | | | | | | |
| Contr. to others' $g$ | 16.1 | 31.8 | 18.7 | 31.7 | 20.5 | 17 | 23 | | | | | | | | 158.8 (32.56%) |
| Contr. to others' $\sigma$ | 4.2 | 17 | 19.9 | 13.9 | 33.8 | 11.6 | 23.3 | | | | | | | | 123.7 (25.36%) |
| Contr. to others' $g$ | | | | | | | | 2.4 | 6.2 | 11.4 | 7.8 | 6.7 | 9.9 | 22.2 | 66.6 (13.66%) |
| Contr. to others' $\sigma$ | | | | | | | | 2 | 22.9 | 15.1 | 23.5 | 10.6 | 10.9 | 53.6 | 138.6 (28.42%) |

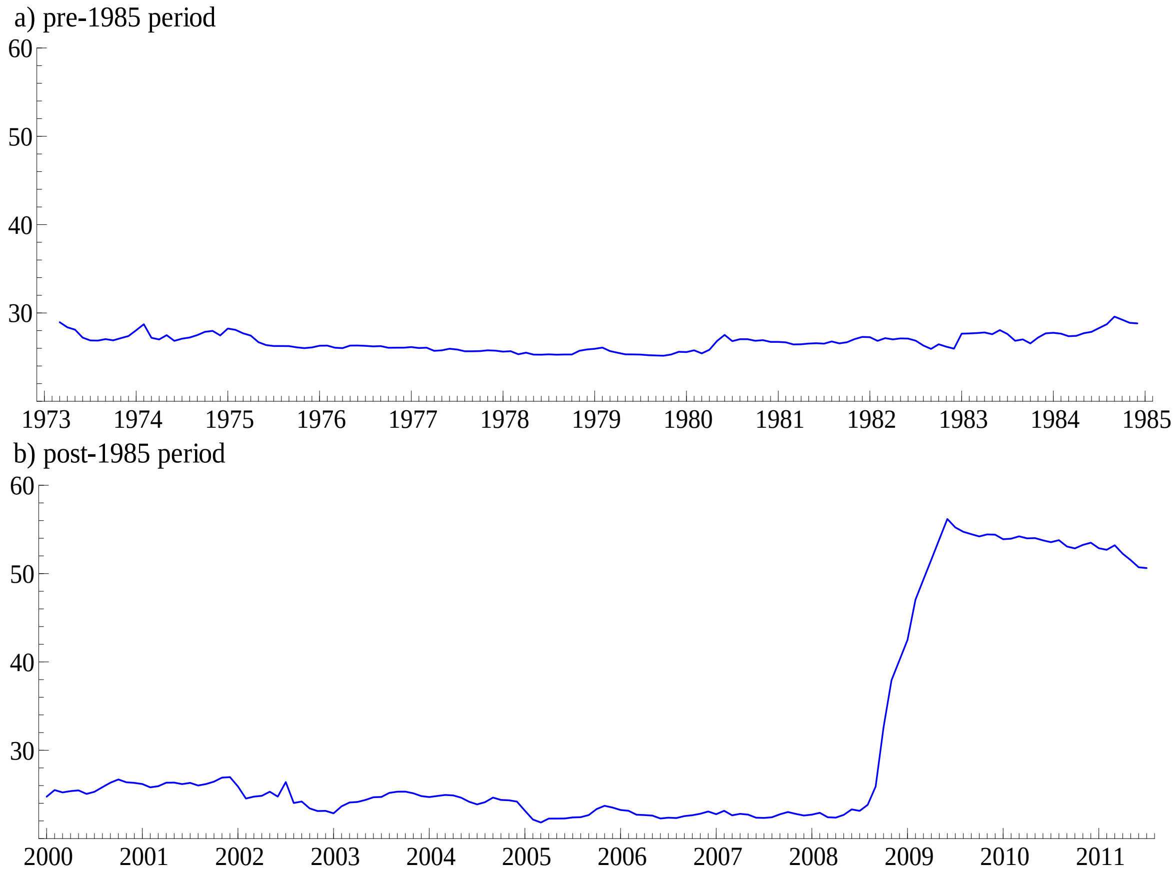
Notes: Spillover indices, given by Equations (2)-(7), calculated from variance decompositions based on 12-step-ahead forecasts.

Table 4: Cumulative impulse responses and multiplier effects, post-1985

| | | Cumulative response[1] | | Implied multiplier effect[2] | |
|---|---|---|---|---|---|
| | | *From (j)* | | *From (j)* | |
| | *To(i)* | $g$ | $\sigma$ | $g$ | $\sigma$ |
| 6-months | $g$ | 1.0566 | -1.0129 | 1.0159 | -0.6589 |
| | $\sigma$ | -0.0437 | 2.3079 | -0.0842 | 2.8332 |
| 12-months | $g$ | 1.0643 | -1.4486 | 1.0375 | -0.9281 |
| | $\sigma$ | -0.0717 | 2.5786 | -0.1181 | 4.0828 |
| 24-months | $g$ | 1.0481 | -1.8381 | 1.0370 | -1.0847 |
| | $\sigma$ | -0.0986 | 2.8712 | -0.1451 | 5.5058 |

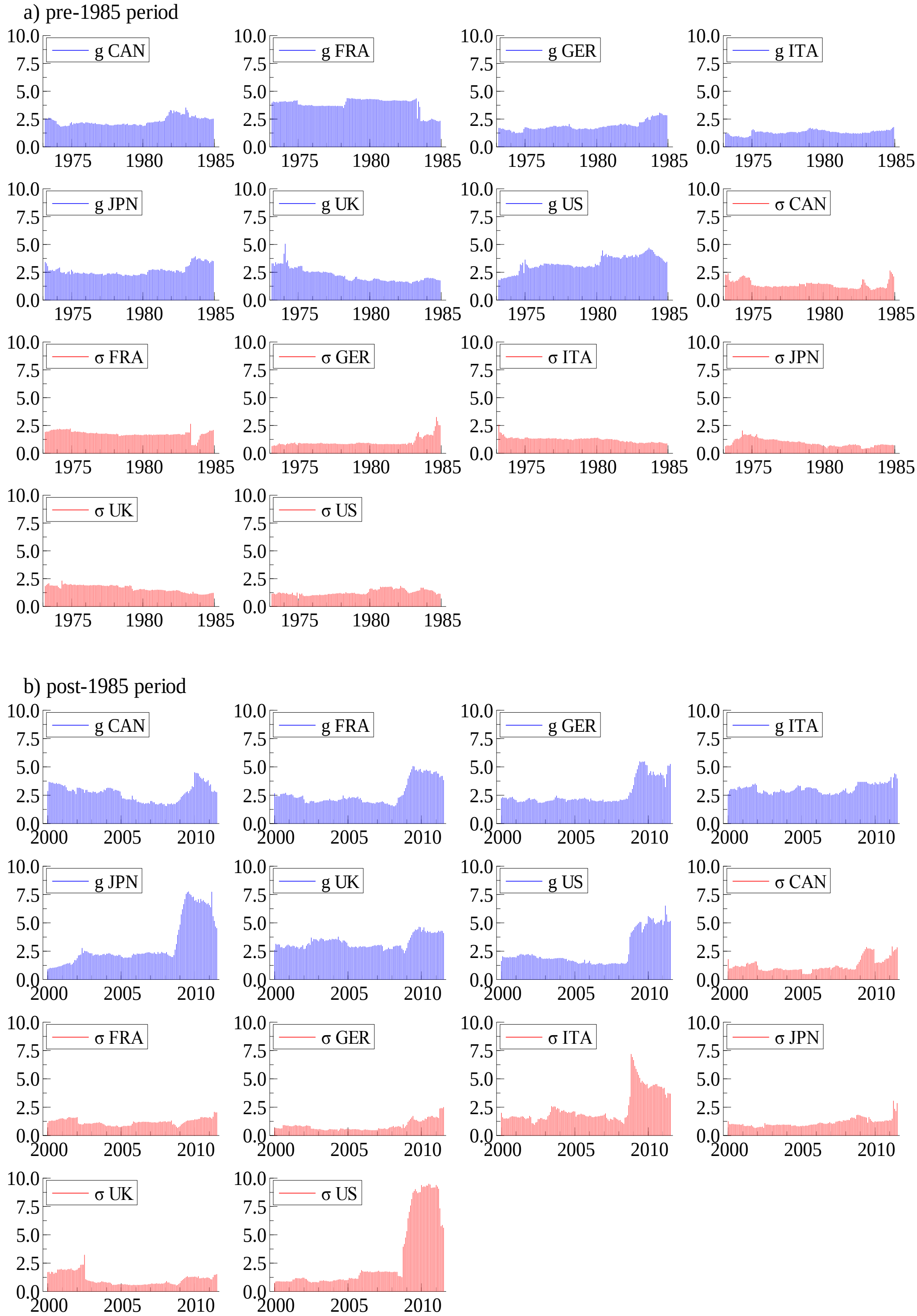
Notes: [1] Cumulative generalized impulse response to one standard deviation shock, multiplied by 100 (in %).
[2] Multiplier effect, calculated as ratio of cumulative response to incipient shock to the respective country.
All entries are averages over country-specific shocks to the respective variable.

Figure 1: Total spillover indices



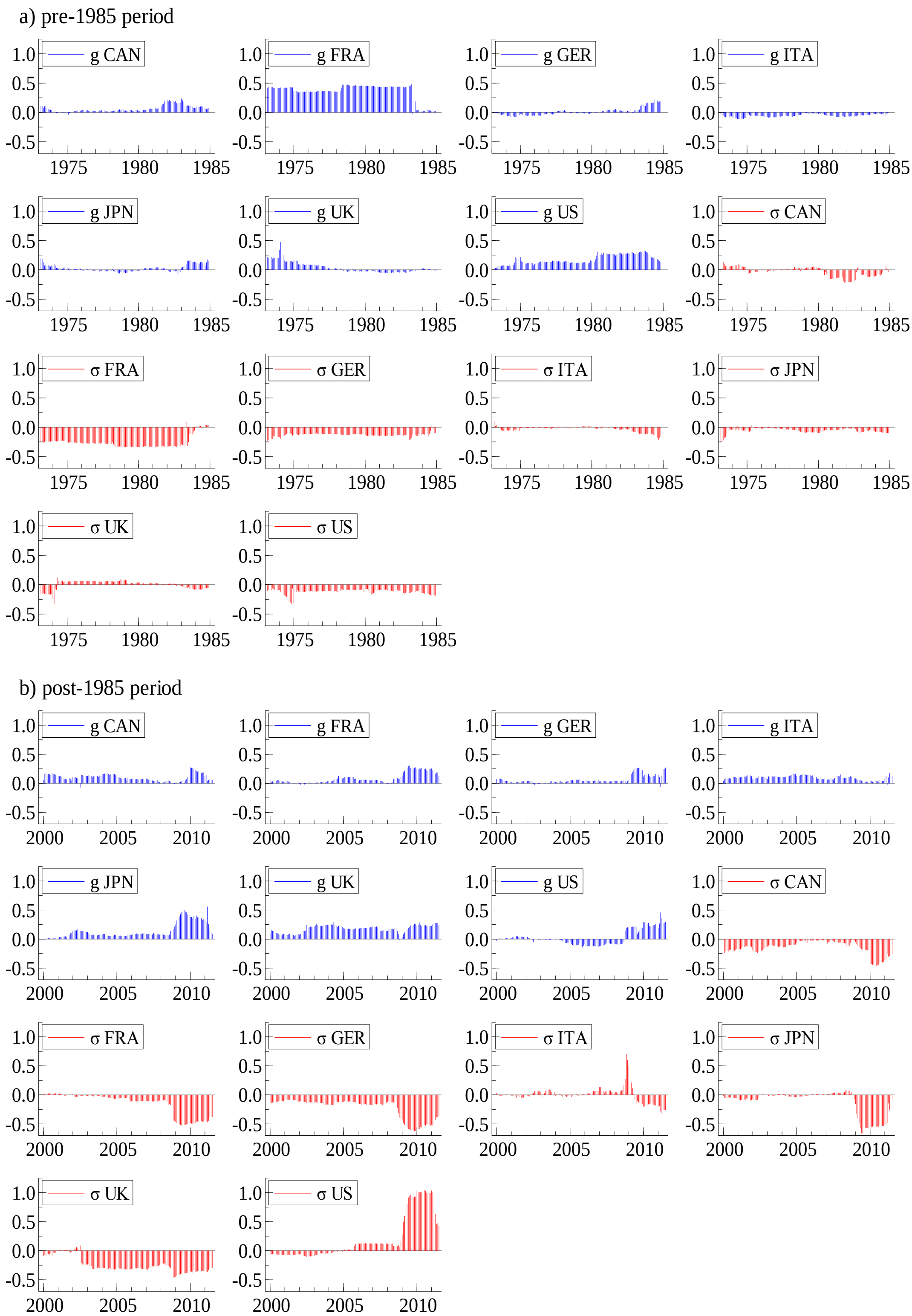

Notes: Plots of moving total spillover indices estimated using 180-month rolling windows.

Figure 2: Directional spillovers *from* each countries' output growth and volatility



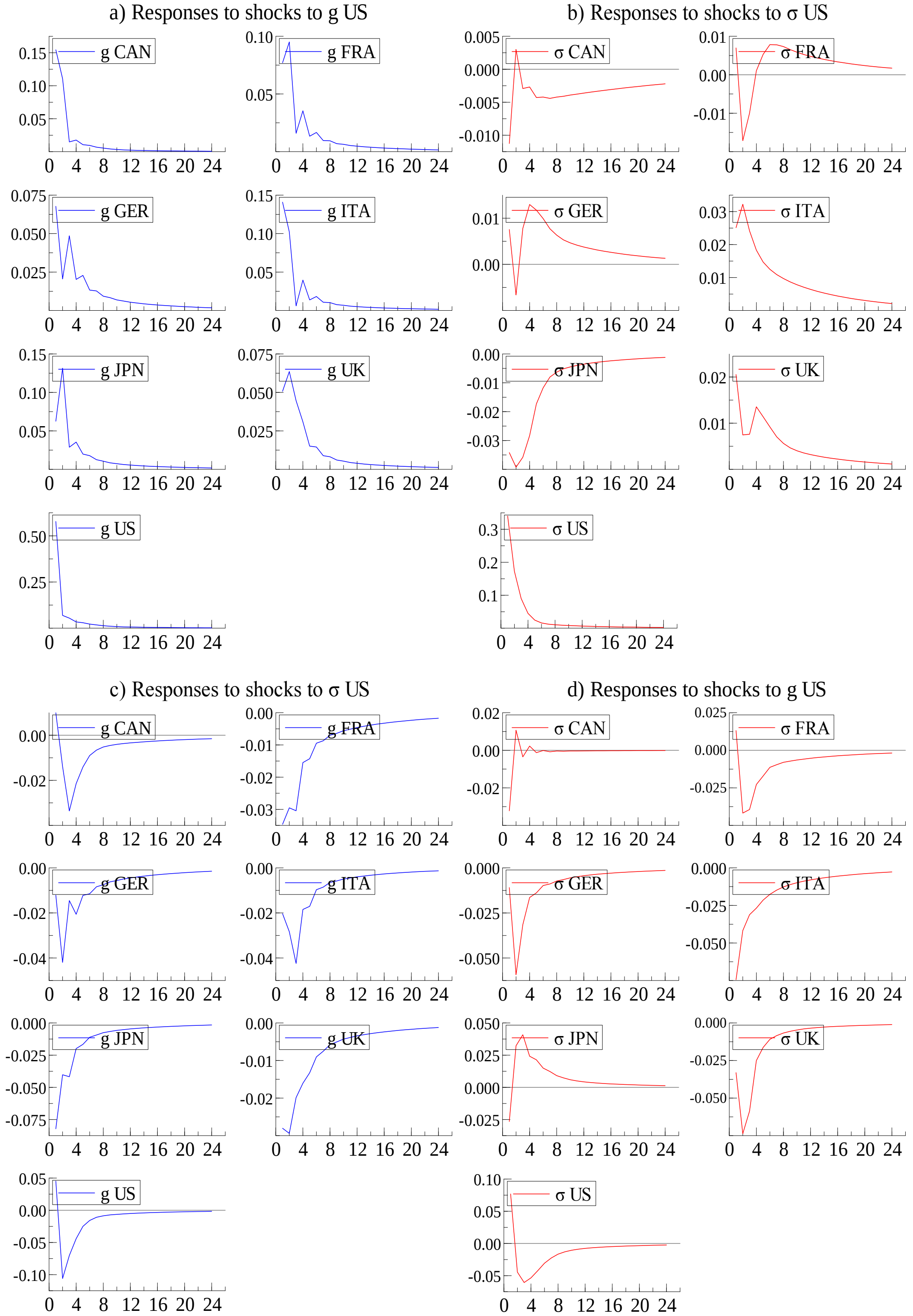

Notes: Plots of moving directional spillovers estimated using 180-month rolling windows. Blue bars indicate output growth; red bars indicate output volatility.

Figure 3: Net spillovers of output growth and volatility shocks for each country




Notes: Plots of moving net spillover indices estimated using 180-month rolling windows. Blue bars indicate output growth; red bars indicate output volatility. Countries with positive (negative) values are net transmitters (receivers) of shocks.

Figure 4: Generalized impulse responses to US shocks, post-1985 period




Notes: Generalized impulse responses to one standard deviation shock to output growth (output volatility) of the US. Blue lines indicate responses of output growth; red lines indicate responses of output volatility.