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## International business cycle spillovers

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INTERNATIONAL BUSINESS CYCLE SPILLOVERS

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# International Business Cycle Spillovers

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We apply Diebold-Yilmaz spillover index methodology to monthly industrial production indices to study business cycle interdependence among G-6 industrialized countries since 1958. The business cycle spillover index fluctuates substantially over time, increasing especially after the 1973-75, 1981-82 and 2001 U.S. recessions. The band within which the spillover index fluctuates has widened since the start of the globalization process in the early 1990s. Our most important result, however, concerns the current state of the world economy: In a matter of four months from September to December 2008, the business cycle spillover index recorded the sharpest increase ever, reaching a record level as of December 2008 (See <http://data.economicresearchforum.org/erf/bcspill.aspx?lang=en> for updates of the spillover plot). Focusing on directional spillover measures, we show that in the current episode the shocks are mostly originating from the United States and spreading to other industrialized countries. We also show that, throughout the period of analysis, the U.S. (1980s and 2000s) and Japan (1970s and 2000s) have been the major transmitters of shocks among the industrialized countries.

**JEL classification:** E32, F41, C32.

**Key words:** Business Cycles, Spillovers, Industrial Production, Vector Autoregression, Variance Decomposition, Unit Roots, Cointegration.

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## I. Introduction

What started in the United States as the sub-prime mortgage crisis in 2007 has since been transformed into a severe global financial crisis that inflicted all major advanced and emerging economies. While it is too early to decide whether the global financial crisis has already reached its climax, it is certainly having a devastating impact on the global economy. Indeed, the global economy is facing the threat of the worst recession in decades, if not a global depression.

It is rather difficult for researchers to explain how the global capitalist system produced such a ‘coordinated’ recessionary outburst after a two-and-half-decade long ‘great moderation’ in business cycles. While the practitioners of the dismal science failed to predict the financial crisis and the ensuing global recession, there has been a great deal of research to shed some light on how the recessionary dynamics will unfold in 2009 and beyond.<sup>1</sup>

Recent developments increased academic and policymakers’ interest in the business cycles research. Actually, the research on international business cycles has generated substantial amount of knowledge that could be of use for policymakers as well. To start with, since the 1990s, research on business cycles across countries has found strong evidence that macroeconomic fluctuations in industrial and developing countries have a lot in common. Using pairwise correlations of GDP, Backus *et al.* (1995) and Baxter (1995) show that output in major industrial countries follow similar short run paths. In addition, empirical studies applying time series and spectral methods to data from different countries and regions also find support for the presence of international business cycles (See Gregory *et al.*, 1997, Lumsdaine and Prasad, 2003). Employing a Bayesian dynamic latent factor model, Kose, Otrok and Whiteman (2003) find strong support for a persistent world common factor that drives business cycles in 60 countries. While they also find support for less persistent country-specific factors, they are not able to find strong evidence in favor of regional factors. In a recent paper, using a

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<sup>1</sup> Analyzing 122 recessions, along with a large number of episodes of credit crunches, house price busts, and stock market busts, Claessens, Kose and Terrones (2008) find evidence that although recessions accompanied with severe credit crunches or house price busts last only three months longer, they typically result in output losses two to three times greater than recessions without these financial stresses. Reinhart and Rogoff (2009), also examine the depth and duration of the real contraction that follows severe financial crises. They show that, on average, output contraction reaches to over 9 percent, while unemployment rate rises an average of 7 percentage points during the slump following severe financial crises.

multicountry Bayesian VAR model with time variations, Canova, Ciccarelli, and Ortega (2007) also find strong evidence for world business cycles among the G-7 countries. They also show that the world- and -country-specific fluctuations are more synchronized in contractions rather than expansions.

While the majority of the studies have found strong support for the presence of an international business cycle, which intensified since the 1990s with the globalization process, there are still some others that question this result. Kose *et al.* (2003), for example, find that with increased globalization, the impact of the world factor on the correlation of GDP across countries increased in the 1990s and after. Doyle and Faust (2005), on the other hand, found no evidence of increased correlation of growth rates of output, consumption and investment across G-7 countries. Furthermore, Eickmeier (2007) emphasizes that the impact of globalization (i.e. real economic and financial integration) on international propagation of macroeconomic shocks is unclear and needs to be addressed empirically.

Rather than linking the international business cycles directly to the globalization process, Stock and Watson (2005) emphasize that documented changes in the volatilities of G-7 business cycles in the 1990s may have altered the correlation among macroeconomic variables across countries. As a result, one has to take the time variation in international business cycle into account.

This paper is intended to contribute to the literature on international business cycle to develop a better understanding of how the macroeconomic shocks are transmitted across countries, with a special interest in output comovements among major industrial countries during the current global recession. In our empirical analysis, we adopt the spillover index methodology, which was recently proposed by Diebold and Yilmaz (2009a) for the analysis of stock return and volatility spillovers across major stock markets around the world, and further developed by Diebold and Yilmaz (2009b) for the measurement of directional spillovers. In particular, we apply the Diebold-Yilmaz spillover index methodology to the seasonally adjusted industrial production indices for G-6 countries (excluding Canada from the G-7 group) to study the business cycle spillovers among these countries.

Diebold-Yilmaz spillover index framework is quite simple to implement. It follows directly from the familiar notion of a variance decomposition associated with an  $N$ -variable

vector autoregression, where all variables in the system are assumed to be endogenous. The time-variation in spillovers is potentially of great interest as the intensity of business cycle spillovers likely to vary over time. Using a rolling windows approach and calculating the spillover index for each window, we allow the business cycle spillovers across G-6 countries to vary over time since 1958. We show that spillovers are important, spillover intensity is indeed time-varying, and the United States and Japan are major transmitters of business cycle shocks to other countries.

The spillover index framework is different from earlier studies of world business cycles, in that, rather than finding a common world factor or indicator that measures world business cycle, we identify how shocks to industrial production in one country affects the industrial output in other countries. Obviously, it is quite plausible to have a common world business cycle if the shocks are common and/or if country-specific shocks spill over across countries in a significant manner. Unlike the previous contributions to the literature, the spillover methodology also allows one to identify directional spillovers transmitted from one country to others, as well as the spillovers across country pairs.

In Section 2, we discuss the Diebold-Yilmaz spillover index methodology, emphasizing in particular the use of generalized variance decompositions and directional spillovers. In Section 3, we first discuss the time series properties of industrial production indices for G-6 countries and then present the results of the business cycle spillovers analysis. In particular we discuss the total spillover plot along with the gross and net directional spillover plots for each of the G-6 countries. We conclude in Section 4.

## **II. The Empirical Model: Spillover Index**

In this section, we provide a brief summary of the Diebold-Yilmaz spillover index. As we have already mentioned in the Introduction, the Diebold-Yilmaz spillover index is built upon the familiar notion of a variance decomposition associated with an  $N$ -variable vector autoregression. Actually the sum of off-diagonal elements of the variance-covariance matrix for the forecast error relative to the sum of all elements is actually what we call the total spillover index.

However, any study of the business cycle spillovers also needs to include directional spillovers across countries. It is a well known fact that Cholesky factorization, upon which the Diebold-Yilmaz spillover index was built, allows one to consider orthogonalized shocks to variables in the model. However, the resulting impulse responses and variance decompositions are not robust to a change in the order of variables. As a result, it is difficult to use the variance decompositions from the Cholesky factor orthogonalization to study the direction of spillovers. With this understanding, Diebold and Yilmaz (2009b) progress by measuring *directional* spillovers in a generalized VAR framework that eliminates the possible dependence of results on ordering.

Consider a covariance stationary  $N$ -variable VAR( $p$ ),  $x_t = \sum_{i=1}^p \Phi_i x_{t-i} + \varepsilon_t$ , where  $\varepsilon \sim (0, \Sigma)$ . The moving average representation is  $x_t = \sum_{i=0}^{\infty} A_i \varepsilon_{t-i}$ , where the  $N \times N$  coefficient matrices  $A_i$  obey the recursion  $A_i = \Phi_1 A_{i-1} + \Phi_2 A_{i-2} + \dots + \Phi_p A_{i-p}$ , with  $A_0$  an  $N \times N$  identity matrix and  $A_i = 0$  for  $i < 0$ . The moving average coefficients (or transformations such as impulse response functions or variance decompositions) are the key to understanding dynamics. We rely on variance decompositions, which allow us to split the forecast error variances of each variable into parts attributable to the various system shocks. Variance decompositions allow us to assess the fraction of the  $H$ -step-ahead error variance in forecasting  $x_i$  that is due to shocks to  $x_j$ ,  $j \neq i$ , for each  $i$ .

Calculation of variance decompositions requires orthogonal innovations, whereas our VAR innovations are generally correlated. Identification schemes such as that based on Cholesky factorization achieve orthogonality, but the variance decompositions then depend on ordering of the variables. We circumvent this problem by exploiting the generalized VAR framework of Koop, Pesaran and Potter (1996), and Pesaran and Shin (1998), which produces variance decompositions invariant to ordering.

Let us define *own variance shares* to be the fractions of the  $H$ -step-ahead error variances in forecasting  $x_i$  due to shocks to  $x_i$ , for  $i=1, 2, \dots, N$  and *cross variance shares*, or

*spillovers*, to be the fractions of the  $H$ -step-ahead error variances in forecasting  $x_i$  due to shocks to  $x_j$ , for  $i, j = 1, 2, \dots, N$ , such that  $i \neq j$ .

The generalized impulse response and variance decomposition analyses also rely on equation (2). Pesaran and Shinn (1998) showed that when the error term ( $\varepsilon_t$ ) has a multivariate normal distribution, the generalized impulse response function scaled by the variance of the variable is defined as:

$$\gamma_j^g(h) = \frac{1}{\sqrt{\sigma_{jj}}} A_h \sum e_j, \quad h = 0, 1, 2, \dots \quad (5)$$

Denoting the generalized  $H$ -step-ahead forecast error variance decompositions by  $\theta_{ij}^g(H)$ , for  $H = 1, 2, \dots$ , we have

$$\theta_{ij}^g(H) = \frac{\sigma_{ii}^{-1} \sum_{h=0}^{H-1} (e_i' A_h \sum e_j)^2}{\sum_{h=0}^{H-1} (e_i' A_h \sum A_h e_i)}.$$

Note that unlike the ones obtained through Cholesky factorization, generalized  $H$ -step-ahead forecast error variance decompositions do not have to sum to one, and in general they do not:

$$\sum_{j=1}^N \theta_{ij}^g(H) \neq 1.$$

To normalize the variance decompositions obtained from the generalized approach, we sum all (own and spillover of shocks) contributions to a country's industrial production (business cycle) forecast error. When we divide each source of industrial production shock by the total of industrial production contributions, we obtain the relative contributions to each country by itself and other countries:

$$\tilde{\theta}_{ij}^g(H) = \frac{\theta_{ij}^g(H)}{\sum_{j=1}^N \theta_{ij}^g(H)}.$$

Now, by construction  $\sum_{j=1}^N \tilde{\theta}_{ij}^g(H) = 1$  and  $\sum_{i,j=1}^N \tilde{\theta}_{ij}^g(H) = N$ .

### Total Spillovers

Using the industrial production contributions from the generalized variance decomposition approach, we can construct a total business cycle spillover index:

$$S^g(H) = \frac{\sum_{\substack{i,j=1 \\ i \neq j}}^N \tilde{\theta}_{ij}^g(H)}{\sum_{i,j=1}^N \tilde{\theta}_{ij}^g(H)} \cdot 100 = \frac{\sum_{\substack{i,j=1 \\ i \neq j}}^N \tilde{\theta}_{ij}^g(H)}{N} \cdot 100.$$

### Directional Spillovers

We now consider directional spillovers in addition to total spillovers. We measure directional business cycle spillovers received by market  $i$  from all other markets  $j$  as:

$$S_{i \cdot}^g(H) = \frac{\sum_{j=1, j \neq i}^N \tilde{\theta}_{ij}^g(H)}{\sum_{j=1}^N \tilde{\theta}_{ij}^g(H)} \cdot 100.$$

In similar fashion, we measure directional business cycle spillovers transmitted by market  $i$  to all other markets  $j$  as:

$$S_{\cdot i}^g(H) = \frac{\sum_{j=1, j \neq i}^N \tilde{\theta}_{ji}^g(H)}{\sum_{j=1}^N \tilde{\theta}_{ji}^g(H)} \cdot 100.$$

One can think of the set of directional spillovers as providing a decomposition of total spillovers into those transmitted by each country in the sample.

### Net Spillovers

Finally, we obtain the net business cycle spillovers transmitted from market  $i$  to all other markets  $j$  as:

$$S_i^g(H) = S_{\cdot i}^g(H) - S_{i \cdot}^g(H).$$

Net spillovers are simply the difference between gross business cycle shocks transmitted to and gross business cycle shocks received from all other markets.

### III. Measuring Business Cycle Spillovers

In our empirical analysis, we use monthly observations of the seasonally adjusted industrial production indices from January 1958 to the latest available observation, December 2008.<sup>2</sup> Even though it is one of the G-7 countries, we do not include Canada in our analysis, because the Canadian IPISA is highly correlated with the IPISA of the United States.<sup>3</sup>

We present the descriptive statistics for the level and log of all 6 industrial production indices in Tables 1a and 1b, and plot the logarithm of industrial production series in Figure 1. As can be seen in Figure 1, IPISA series are trending upwards with occasional downward bumps. Furthermore, the current downturn in industrial production is clearly visible in Figure 1 for all countries. The data indicates that the current downturn is one of the worst recessions (the other one being the 1973-75) since 1957 in the G-6 countries.

#### Log Industrial Production Series: Unit Roots and Cointegration

Before going ahead with the analysis of business cycle spillovers, we first test whether the seasonally adjusted industrial production series for G-6 countries are stationary or not. We use the most-preferred augmented Dickey-Fuller (ADF) test for this purpose. Test results for the whole period (1958:01-2008:12) are presented in Table 2. For all G-6 countries, the augmented Dickey-Fuller test fails to reject the null hypothesis that the log of industrial production series (allowed to have a constant and a linear trend term) possess a unit root. This result obviously implies that none of the six IPISA series are stationary in levels. Applying the tests to the first-differenced log industrial production series, however, we reject the non-stationarity of this series for all six countries. Together these results indicate that all industrial production series are integrated of order one,  $I(1)$ .

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<sup>2</sup> Our sample starts in January 1958, because seasonally adjusted industrial production data for Germany start then., while data for all other countries start in January 1957

<sup>3</sup> The correlation coefficient between the two series is 99.2 percent, the highest among the country pairs. Furthermore, 12-monthly industrial production growth rates for the two countries have a correlation coefficient of almost 75 percent, much higher than the correlation coefficients for other country pairs (See Table A-1). Similarly, the correlation coefficient between the monthly industrial production growth rates of the two countries is much higher than the ones for other pairs of countries (See Table A-2). Artis *et al.* (1997) show that with a value of 85.6%, the contingency correlation coefficient between the US and the Canadian industrial production has been the highest.

Once we show that all industrial production indices in our sample possess a unit root, we then test for the presence of a cointegration relationship among these six series. Johansen cointegration test results (both trace and maximum eigenvalue tests) show that there is a single cointegration relationship among the seasonally adjusted IP series for the G-6 countries over the 1958:01-2008:12 period (See Table 3). Altogether test results imply that, instead of estimating a VAR model for the industrial production series for the G-6 countries, we need to estimate a Vector Error Correction (VEC) model, which is effectively the VAR in first differences with the lagged error correction term from the cointegration equation incorporated.

As VEC is the correct model for the full sample, our spillover analysis relies on variance decomposition from the VEC model estimated over rolling 5-year (60-month) windows. We repeat the unit root tests for each of the 5-year rolling windows in order to have the correct specification of the underlying model. The unit root test results in levels and first differences are presented in Figures 2 and 3. For an overwhelming majority of the rolling windows considered the tests reject the presence of a unit root in first differences but not in levels. We estimate the VEC system with a three month lag over 5-year rolling windows. Once the VEC is estimated, we obtain the variance decompositions based on Cholesky orthogonalization and Generalized VAR approaches for a 10-month forecast horizon.

We estimate the VEC model for the first 5-year sub-sample window (April 1958-March 1963) and obtain the Cholesky and Generalized variance decomposition based spillover indices. Moving the sub-sample window one month ahead, we obtain the spillover indices for the next window and so on. Then we plot the spillover indices for all sub-sample windows and plot them, obtaining the spillover plot.

Before proceeding with the spillover plots, we estimate the VEC model for the full sample and report the generalized variance decomposition as well as the spillover index and the directional spillovers in Table 4. The spillover index for the full sample period is 27%, indicating that approximately 27% of the total variance of the forecast errors for six countries is explained by spillovers of shocks across countries, whereas the remaining 73% is explained by shocks to each individual country itself.

In terms of the directional spillovers transmitted to others (measured by  $S_i^g(H)$ ), Japan is the country which contributed the most to other countries' forecast error variance (52.4,

which is equivalent to 8.7% of the total forecast error variance to be explained), followed by the US (29.5). Italy has contributed the least to other countries' forecast error variance (11.7), followed by the UK (19). In terms of the directional spillovers received from others,  $S_i^s(H)$ , USA appears to be the country that received the least of spillovers from other countries (8.7, equivalent to just 1.5% of the total forecast error variance to be explained) followed by the UK (22.1) and Japan (24.1). Germany received the most (40.4) in terms of spillovers from other countries.

Finally, when we calculate the difference between the column-wise sum (what we call as “contribution from others”) and the row-wise sum (what we call as “contribution to others”) we obtain the net directional spillovers given by  $S_i^s(H)$ . Japan (28.3) and the USA (20.8) are net transmitters of industrial production shocks to other countries, while all European countries in the sample (Italy -18.3, Germany -16.3, France -11.5 and UK -3.1) are net recipients of business cycle spillovers over the full sample.

#### Dynamics I: The Rolling-Sample Business Cycle Spillover Plot

The Spillover Table for the full sample provides important clues as to how the spillover index is calculated and interpreted. In Figure 4, we plot the generalized-based spillover index for rolling windows alone. In Figure 5, we present the generalized-based spillover index along with the Cholesky-based spillover index. We plot the two indices as an area band rather than two different lines. Figure 5 reveals that the difference between the two indices is in general not very large for all sub-sample windows considered, seldom exceeding 10%. Even though the small gap between the two indices varies over time, the two indices tend to move very much in harmony. Therefore, it would not be wrong to focus on the generalized VD based spillover index for the time being.

Our first observation about the spillover plot is the absence of a long-run trend. The spillover plot clearly shows that while there are periods during which shocks to industrial production are transmitted substantially to others, there are yet other periods during which the spillovers of output shocks were much less important. While the spillover index fluctuates

over time, the band within which it fluctuate moves slightly upwards since the current wave of globalization had started in earnest in the early 1990s.

In the first phase of the great moderation period (1985-1994), the index fluctuated within a band of 35-50 percent. As the sample windows are rolled to include 1995, the index reaches close to 60%, but decline down to 40% as the data for the late 1990s and 2000 are included. Towards the end of the mild recession of 2000-2001, the index started to increase reaching to 60% again by the end of 2002. However as the other G-6 countries followed the quickly recovering US economy to a major expansion, the spillover index reached 70% in the second quarter of 2004. The index then declines to 60% again as the window is rolled to include second half of 2004, and then gradually moves down reaching its bottom around 40% from the last quarter of 2006 until the first quarter of 2008.

When we focus on the behavior of the index since 1989, we observe three complete cycles. It is interesting to note that, each time the cycle lasted longer than the previous one and with an increased bandwidth. During the first cycle which lasted from 1989 to the end of 1992, the index fluctuated between 33 and 52, while in the second cycle that lasted from 1993 to 1999, the index fluctuated between 37 and 61. Finally, during the third cycle that lasted from 2000 to 2007, the index fluctuated between 41 and 72 percent.

We think that this finding supports Kose *et al.*'s (2003) finding that with the globalization process the business cycles have become more synchronized. During recessions and strong expansions, the comovement of industrial production fluctuations tends to be more significant since the early 1990s. This result is also consistent with Doyle and Faust's (2005) conclusion. If you were to look at the correlation over a period of time, you may not find strong correlation because the industrial output fluctuations tend to move together especially during recessions compared to expansions.

Going further back in time, we observe that until the oil price shock of 1973, the spillover index fluctuated around 40% range<sup>4</sup>. However, following the oil price hikes, the index increased quickly from 30% to reach 60% by the end of 1974 and stayed close to 60 as the sub-sample window is moved in time to include 1979 (to exclude 1974 data). Once the

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<sup>4</sup> There is a spike in the index in 1968, as the French industrial production makes its largest historical drop. However, this event did not have any lasting impact on industrial output in France and in other G-6 countries.

observations for 1974 are dropped out of the sample the index drops down to 40%. It moves up again as soon as the observations for late 1980s are included in the sub-sample window. The output shock spillovers did not increase much (approximately a 10% jump in the index) during the 1980 recession. The increase in the index towards the end of the 1981-1982 recession was larger (close to 16 percentage points).

The spillover index fluctuates substantially over time from 1960s onwards, without a clear trend. As a rule of thumb, from the 1960s onward, the spillovers contribute between 30% and 60% of the forecast error variance of the industrial production in the G-6 countries. The lowest level of spillovers is observed for the windows ending in 1971 and 1972. The highest level of spillover index, on the other hand, is observed recently towards the end of 2004 and early 2005, during which the US economy was growing at a very high rate, 4 percent per annum. The most significant upward movement in the spillover index started in 2000, even before the 2001 US recession and continued for a long time, to reach close to 65%.

However, as the US economy started to lose pace since 2005, Japan and European economies picked up momentum and grew faster. As a result, the spillover index declined as low as 38% in mid-2007 and stayed around 40% until the end of the first quarter of 2008. As the March 2008 observation is added to the sample, the index increased to reach 47.2%, but declined back to 42-43 in April and May. With the inclusion of observations for June through August in the sample window, the index increased back to a level between 47 and 49.

Now we can turn our focus to the most important part of our results, namely the recent behavior of the index in 2008 and 2009. We want to focus on its most recent behavior, not only because it gives us more clues about the business cycle spillovers since the beginning of the sub-prime crisis in the United States, but also because the index accorded the biggest jump in its history, if we were to leave aside the blip in 1968 due to a 32% decline in French industrial production in May 1968, which was immediately reversed.

The index jumped the most, from 49 to 64, as the observations for September are included in the sample. The index declined slightly in October to 58, but as the November numbers are fed into the VEC model, the spillover index jumped up to 74 percent. While the generalized VD based spillover index jumped by 29 points in a matter of four months, Cholesky-based spillover index jumped by 32 points from 44% to 76%.

The behavior of the index during the current recession episode is in stark contrast with the previous recession episodes. It has increased close to 40 points in a matter of 4 months (September through December). During the worst global recession of the post-war era following the first oil price shock, the spillover index recorded a relatively smaller increase, from a low of 30 to a high of 64, in a matter of four years, from 1972 to 1976.

This jump in the index is an indication of how countries are pulling each other down. In the research paper, I also report the directional spillovers across G-6 countries. It is clear that the United States is leading the way in the current recession. That means the shocks first take place in the United States and spread to other countries. While the United States is the major net transmitter of shocks to others, Italy, with a negative annualized growth rate in the third quarter of 2008, has also been pulling down other countries, albeit with a smaller force. Other countries appear to be net recipients of shocks through the United States and Italy.

After analyzing the more recent developments in the spillover index, we now go back in time to 1970s. Following the rather uneventful spike in the index in 1968, the first major upward move in the spillover index was realized after the first oil price shock and during the ensuing recession in the United States and other G-6 countries. The oil price shock was common to all countries, but different policy responses led to different forms of business fluctuations in different countries. The spillover index gradually increased from around 30% in 1972 to close to 60% by 1976 and stayed in the 50-60% range until the end of 1970s. A similar rise, albeit at a smaller scale and short-lived, was observed in the aftermath of the second oil price shock and during the short 1980 recession in the United States.

Another jump in the spillover index is observed in the aftermath of the 1981-1982 recession; spillover index reaching close to 60% in a matter of months in 1983. This sharp increase in spillovers is followed by a rapid decline in 1984 that took several years to fall down to 30-40% band. Despite a slow rise in the late 1980s, the BC spillovers stayed around 40-50% band until 1994, when it gradually rose to around 60%, followed by a fall towards the end of the 1990s, especially after the East Asian crisis.

So far we have discussed the spillover plot based on 5-year rolling windows. Obviously here the window size is a critical factor that can have an impact on the shape of the spillover plot. For that reason, we present the spillover plots for 4, 6, and 7-year rolling

windows in Figure 6. Irrespective of the window size we choose, the spillover index follows similar patterns. It drops quite rapidly since it reaches a peak in late 2004. As of the start of the current global downturn, the business cycle spillover index across G-6 countries was at its lowest level in more than a decade. With such an initial starting point, the spillovers are less likely to jump up in a matter of less than a year. In all three plots, the spillover index jumps up at least 30+ percentage points since September 2008.

As the window size increased, the spillover plot becomes smoother, giving more clues about the business cycle spillovers. Our result that the band within which the spillover index fluctuates increased during the current globalization process continues to hold with 4, 6 and 7-year rolling windows.

### Dynamics II: The Rolling-Sample Directional Business Cycle Spillover Plots

Following a detailed analysis of the business cycle spillover index, we can now focus on directional spillovers across countries. As described in detail in Section 2, directional spillovers are critical in understanding the respective roles of each of the G-6 countries in spreading domestic shocks to local industry output to other countries.

During the 1970s, Japan has been the most important transmitter of both gross (Figure 7) and net (Figure 9) directional spillovers. During the 1973-1975 recession and during the second half of the 1970s, the spillovers transmitted from Japan to others reached as high as 25% of the total gross spillovers (Figure 7), whereas the spillovers received by Japan from others was only around 8% of the total spillovers (Figure 8), leading the net spillovers from Japan to reach as high as 20% of the total spillovers (Figure 9). Germany was the second most important transmitter of business cycle spillovers during the 1970s. United States, on the other hand, was a net recipient of business cycle spillovers over the most of the 1970s, with the exception of the 1973-1975 recession.

The roles were reversed in the 1980s: the United States has become the major net transmitter of the spillovers, whereas Japan became the net recipient of spillovers. The gross spillovers transmitted by the United States to others jumped above 15%, and as high as 30%, and net spillovers fluctuated between 10-15% after the 1982 U.S. recession. Japan's net spillovers, on the other hand, declined to as low as -11% of total spillovers after the 1982

recession and lasted at low levels until the end of 1987. While Germany and the U.K. were also net positive transmitters of spillovers after the 1982 recession, their roles were rather secondary compared to the United States and Japan (Figure 9).

Throughout the 1990s, Japan was neither a net transmitter nor a net recipient of the business cycle spillovers among the G-6 countries. We think that this result is consistent with the decade-long recession Japan had suffered with almost no effect on other G-6 countries. Neither was the United States nor was Germany major net transmitters of spillovers in the 1990s. It was rather France, Italy and United Kingdom that were net positive transmitters of spillovers, even though the spillovers originating from these countries were not as large and not as persistent as the ones originated from the U.S., Japan and Germany in the 1970s and 1980s. The role these countries played during the 1990s is closely related to the aftermath of the ERM crisis of 1992 and the ensuing slowdown in these economies.

Moving closer to our times, the United States and Japan returned to their locomotive roles in the 2000s with a 10% net spillover transmission to other countries. Germany and France, on the other hand, have been the net recipients of spillovers in the 2000s. Italy's role as a transmitter of gross spillovers also increased in the 2000s, but as a net transmitter its role continued to be rather small along with that of the United Kingdom.

Lately, with a -10% net spillover transmission rate since 2007, Japan has become a net recipient rather than a net transmitter of business cycle spillovers. In the meantime, the net spillovers from the U.S. gradually increased with the intensification of the sub-prime crisis since mid-2007. As emphasized above, since September 2008, the total spillover index jumped substantially up to reach close to 80% and the United States was the most important contributor to the increase in business cycle spillovers, with a net spillover contribution of more than 15%. The gross directional spillovers from the U.S. jumped close to 25 percent since the collapse of the Lehman Brothers in September 2008.

Diebold-Yilmaz Spillover Index methodology also allows us to analyze the net pairwise directional spillovers (Figure 10). To start with the US-Japan pair, it is interesting to note that the US dominated Japan in terms of business cycle spillovers from May 1982 until the end of 1987, with net spillovers reaching as high as the 10% of the total G-6 wide spillovers. After a brief respite the directional spillovers from the US to Japan started in during 1990-1991.

Japan had never had large business cycle spillovers to the US. Net spillovers from Japan to the US reached at most 5% of the total forecast error variance towards the end of the 1973-1975 recession and lasted until the 1980 recession. Japan also had some influence on the US business cycles in the early 1990s as its decade-long recession started. However, since then, spillovers from Japan to the US have been rather limited.

During the 2000s a large portion of the spillovers are generated among the Germany-Japan, Germany-Italy, Japan-Italy and France-Italy pairs. While shocks that hit Japanese industrial production exerted some significant influence on German and Italian industrial production during the early 2000s, shocks to Italian industrial production spilled over to influence the behavior of French and German industrial production series over the same period.

#### **IV. Conclusions**

This paper makes several important contributions to the understanding of international business cycles. First, using the spillover index methodology introduced by Diebold and Yilmaz (2009a and 2009b), the paper introduces an alternative measure of comovement of business cycles across major industrialized countries.

The spillover index methodology employed in this paper is different from factor model approach which is most widely used in the studies of international business cycles. While the factor model approach aims at obtaining a world business cycle measure, the spillover index framework distinguishes between idiosyncratic shocks to industrial production and spillover of industrial production shocks from other countries. Furthermore, we think that the spillover index that is based on a multivariate VAR can better be placed to capture the increased comovement of business fluctuations in more than two countries compared to an analysis based on bi-variate correlation coefficients.

Second, the analysis sheds new light on the nature of business cycles, clearly showing that the cross-country comovement of business fluctuations is not constant over time, nor does it follow an upward trend. Rather, the business cycle spillovers fluctuate substantially over time. However, the band within which the spillover index fluctuates increased since 1990s. This result is consistent with the findings of both Kose *et al.* (2003) and Doyle and Faust

(2005): Major industrialized economies have become more integrated since the 1990s, but their respective real GDPs or industrial productions do not always move together.

Third, the directional spillover index measures help us identify each country as gross and/or net transmitters of business cycle shocks to other countries as well as gross recipients of business cycle shocks from other countries over different time periods.

Last, but not the least, with an unprecedented jump between September and December 2008, the business cycle spillover index captures the global nature of the current recession perfectly and shows that the recovery from the current recession/depression requires coordinated policy actions among the major industrial and emerging economies rather than each country pursuing its own policies.

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**Table 1a. Descriptive Statistics – Log Industrial Production  
(1958:01-2008:12)**

	France	Germany	Italy	Japan	UK	USA
<b>Mean</b>	4.243	4.270	4.175	4.042	4.314	4.033
<b>Median</b>	4.337	4.320	4.301	4.260	4.314	4.024
<b>Maximum</b>	4.665	4.815	4.633	4.719	4.612	4.688
<b>Minimum</b>	3.398	3.409	3.008	2.097	3.792	3.054
<b>Std. Dev.</b>	0.343	0.332	0.416	0.684	0.225	0.430
<b>Skewness</b>	-0.935	-0.772	-1.067	-1.238	-0.463	-0.287
<b>Kurtosis</b>	2.803	2.888	3.220	3.461	2.189	2.249
<b>Jarque-Bera</b>	90.1	61.1	117.5	161.6	38.6	22.8
<b>Probability</b>	0.0	0.0	0.0	0.0	0.0	0.0

**Table 1b. Descriptive Statistics – First-differenced Log Industrial Production  
(1958:01-2008:12)**

	France	Germany	Italy	Japan	UK	USA
<b>Mean</b>	0.0018	0.0021	0.0023	0.0038	0.0011	0.0025
<b>Median</b>	0.0011	0.0023	0.0021	0.0042	0.0010	0.0027
<b>Maximum</b>	0.229	0.116	0.127	0.048	0.095	0.060
<b>Minimum</b>	-0.379	-0.099	-0.160	-0.101	-0.082	-0.042
<b>Std. Dev.</b>	0.024	0.017	0.021	0.015	0.014	0.008
<b>Skewness</b>	-4.054	0.009	-0.155	-0.961	-0.191	-0.197
<b>Kurtosis</b>	119.46	9.31	12.41	8.10	13.21	9.41
<b>Jarque-Bera</b>	346966	1014	2257	756	2655	1050
<b>Probability</b>	0	0	0	0	0	0

**Table 2a. Unit Root Test – Augmented Dickey-Fuller Test Statistics  
(1958:01-2008:12)**

	France	Germany	Italy	Japan	UK	USA
<b>Log Levels (with constant term and intercept)</b>	-1.401	-2.862	-2.010	-1.124	-1.824	-2.680
<b>Log First Differences (with constant term )</b>	-19.767	-13.690	-32.765	-4.116	-29.379	-10.081

**Table 2b. Critical Values for the Augmented Dickey-Fuller Test Statistics**

	1%	5%	10%
<b>Log levels (with constant term and trend)</b>	-3.973	-3.417	-3.131
<b>Log first differences (with constant term)</b>	-3.441	-2.866	-2.569

**Table 3: Johansen Cointegration Test - G-6 Industrial Production Indices  
(logs, 1958:01-2008:12)**

<b>Unrestricted Cointegration Rank Test (Trace)</b>				
Hypothesized		Trace	0.05	
No. of CE(s)	Eigenvalue	Statistic	Critical Value	P-Value
None *	0.0708	102.99	95.754	0.015
At most 1	0.0378	58.397	69.819	0.288
At most 2	0.0315	35.027	47.856	0.447
At most 3	0.0167	15.596	29.797	0.740
At most 4	0.0080	5.350	15.495	0.771
At most 5	0.0008	0.455	3.841	0.500

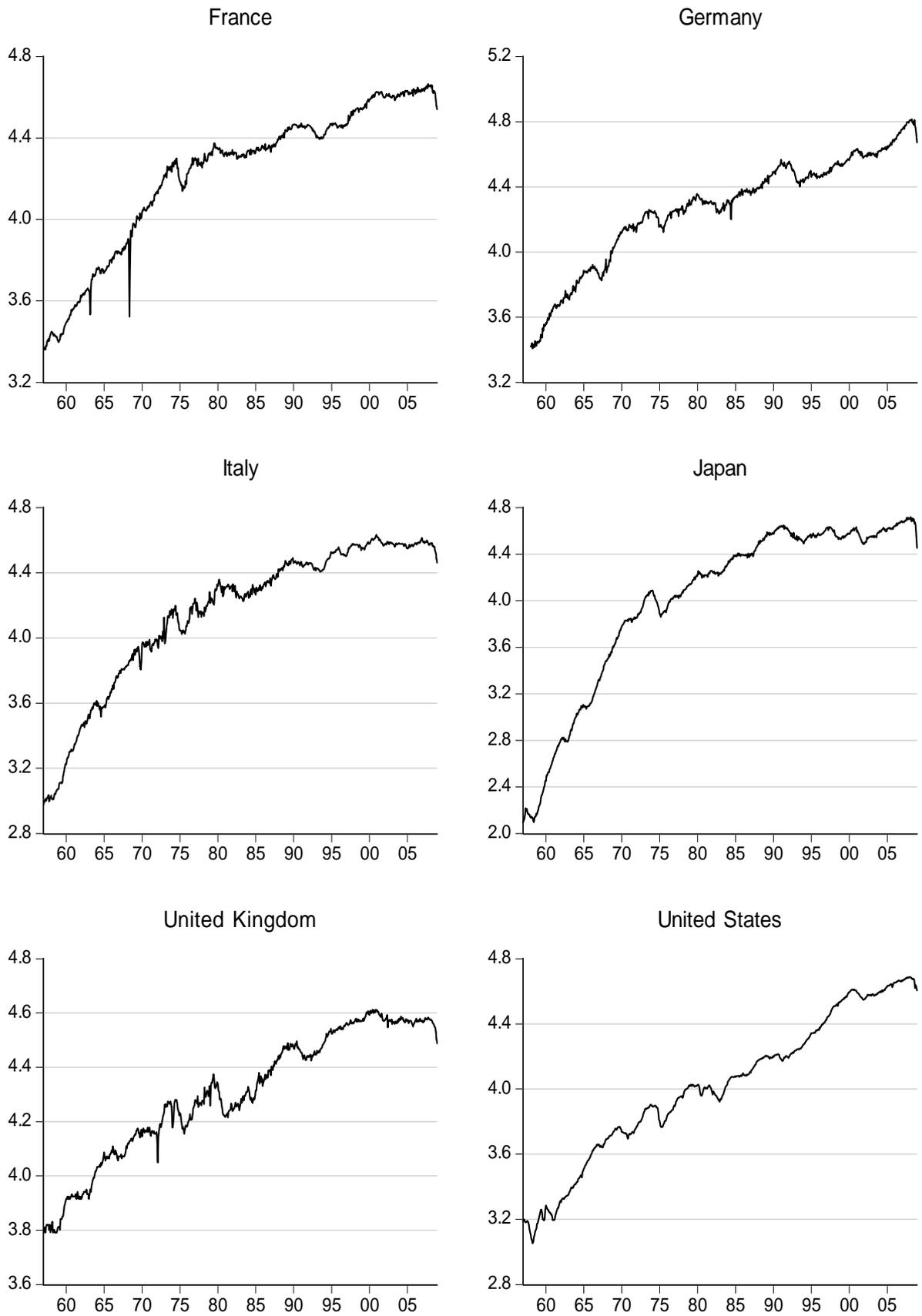
<b>Unrestricted Cointegration Rank Test (Maximum Eigenvalue)</b>				
Hypothesized			0.05	
No. of CE(s)	Maximum Eigenvalue	Statistic	Critical Value	P-value
None *	44.598		40.078	0.015
At most 1	23.370		33.877	0.502
At most 2	19.431		27.584	0.382
At most 3	10.246		21.132	0.721
At most 4	4.895		14.265	0.755
At most 5	0.4552		3.841	0.500

Notes: Linear deterministic trend in the data and an intercept in the cointegrating equation; \* denotes rejection of the hypothesis at the 0.05 level

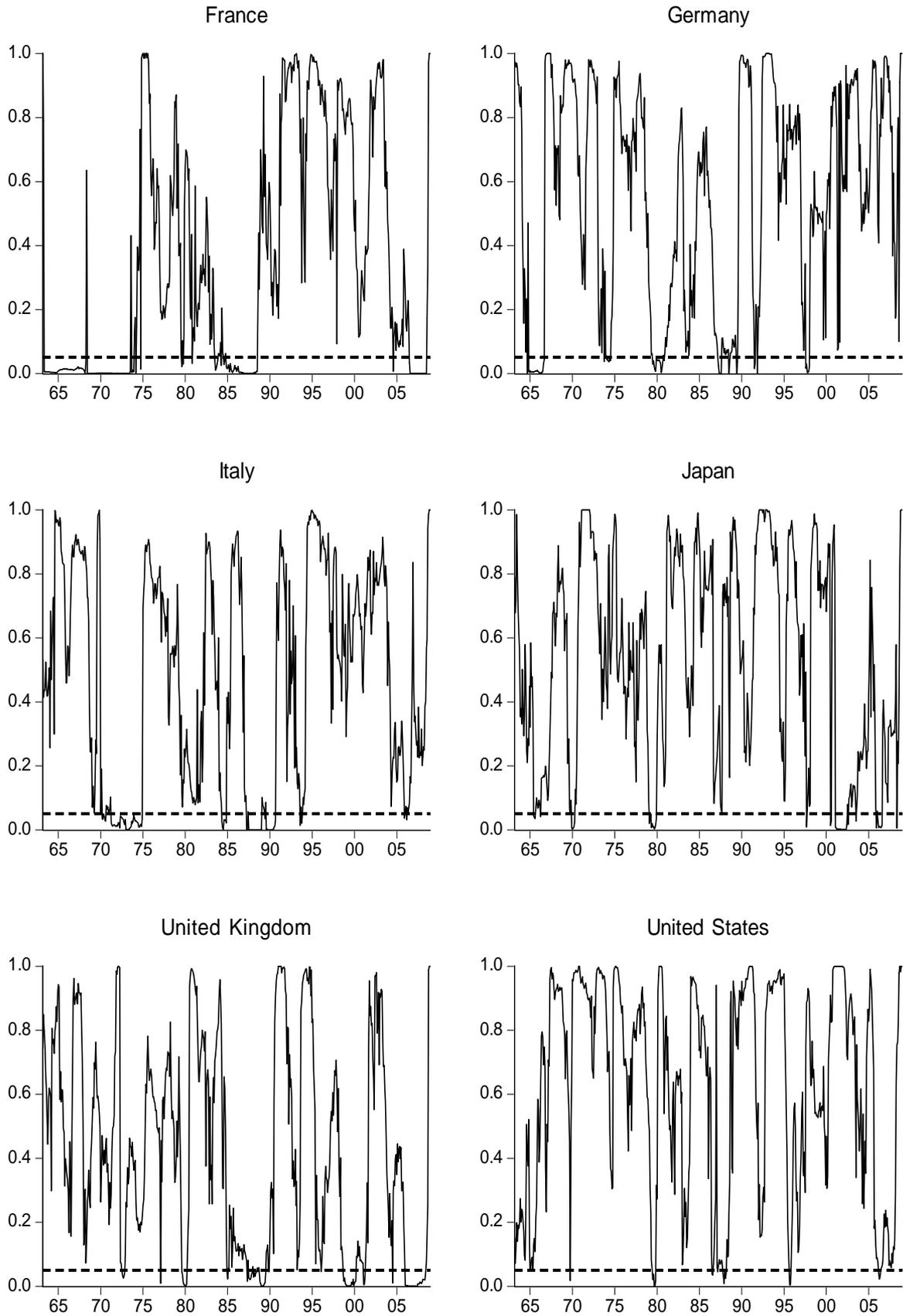
**Table 4: Generalized Business Cycle Spillover Table for G-6 Countries  
(1958:01-2008:12)**

	USA	Germany	Japan	France	UK	Italy	Directional <i>FROM</i> Others
<b>USA</b>	91.3	0.5	2.5	2.6	2.2	0.8	8.7
<b>Germany</b>	4.3	59.6	23.0	6.2	6.8	0.2	40.4
<b>Japan</b>	10.3	6.8	75.9	3.6	2.0	1.3	24.1
<b>France</b>	3.6	11.3	10.2	63.4	3.6	7.9	36.6
<b>UK</b>	7.3	4.8	5.5	3.0	77.9	1.5	22.1
<b>Italy</b>	3.9	0.7	11.2	9.7	4.4	70.0	30.0
<b>Directional TO Others</b>	29.5	24.1	52.4	25.1	19.0	11.7	<b>Index=26.97%</b>
<b>Directional Including Own</b>	120.8	83.7	128.3	88.5	96.9	81.7	
<b>Net Directional Spillovers (FROM – TO)</b>	20.8	-16.3	28.3	-11.5	-3.1	-18.3	

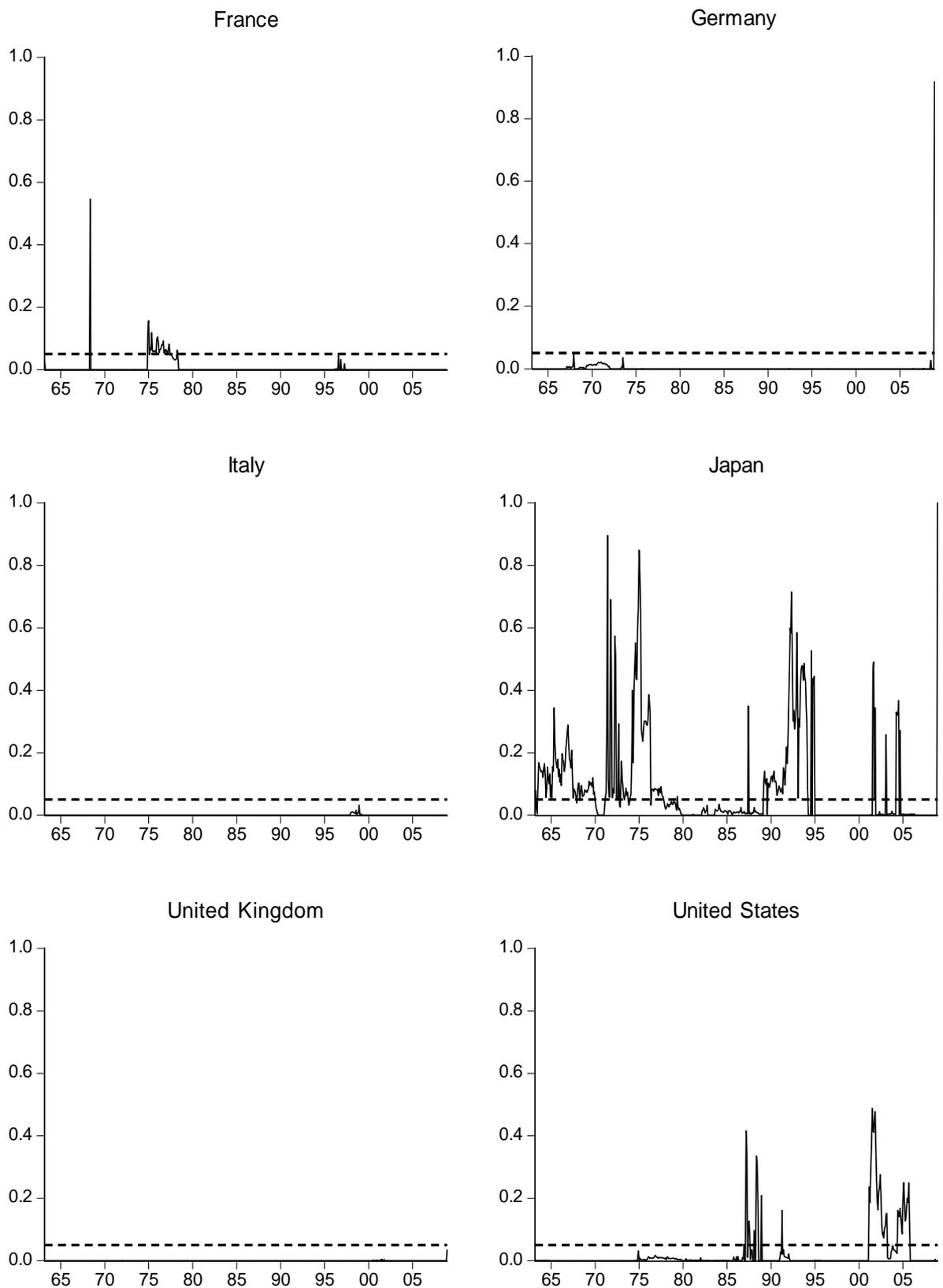
**Figure 1. Seasonally Adjusted Industrial Production Indices for G-6 Countries (1957-2008)**



**Figure 2. Unit Root Tests for SA Log Industrial Production Index in Levels  
(5% significance level)**

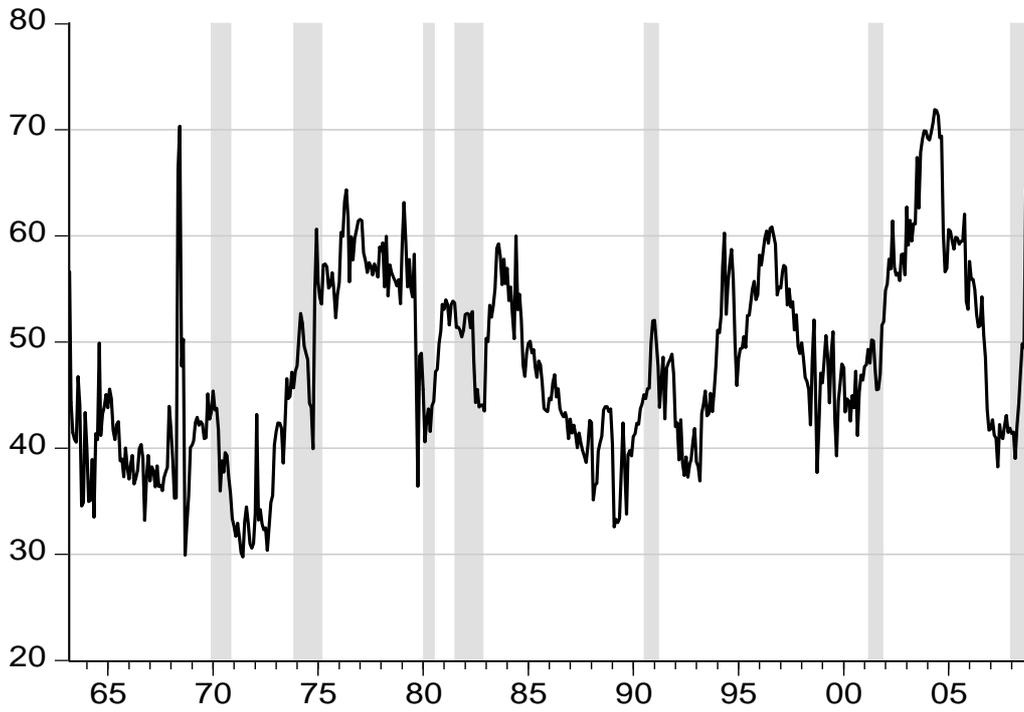


**Figure 3. Augmented Dickey-Fuller Test for Unit Roots in First Differences of SA Log Industrial Production Index (5% significance level)**

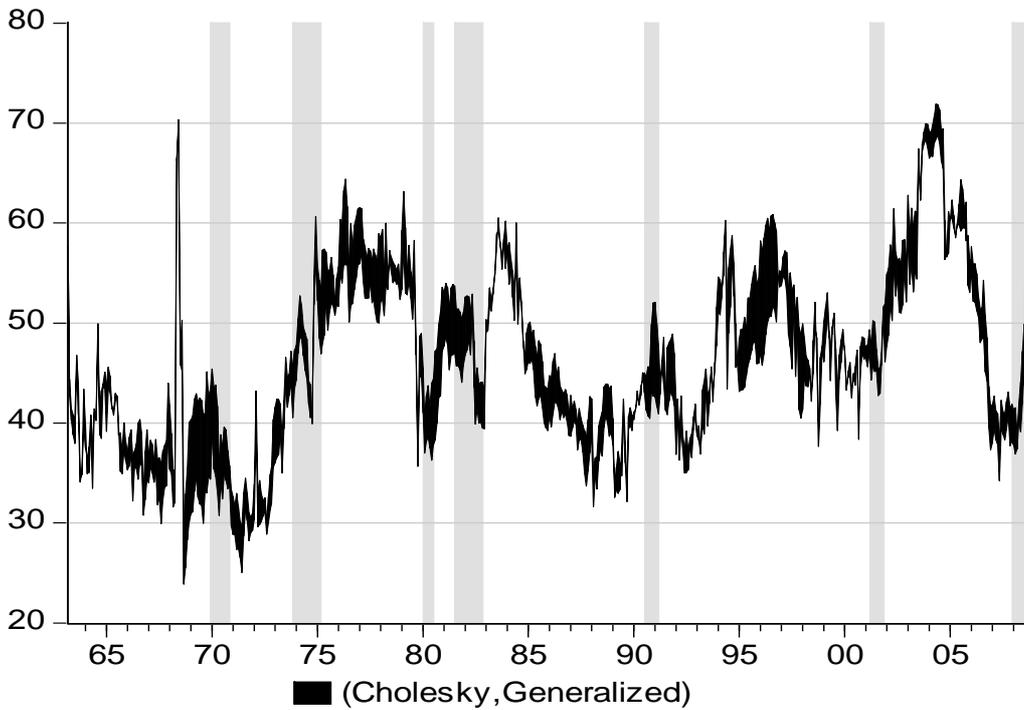


**Figure 4. Generalized Spillovers for G-6 countries**

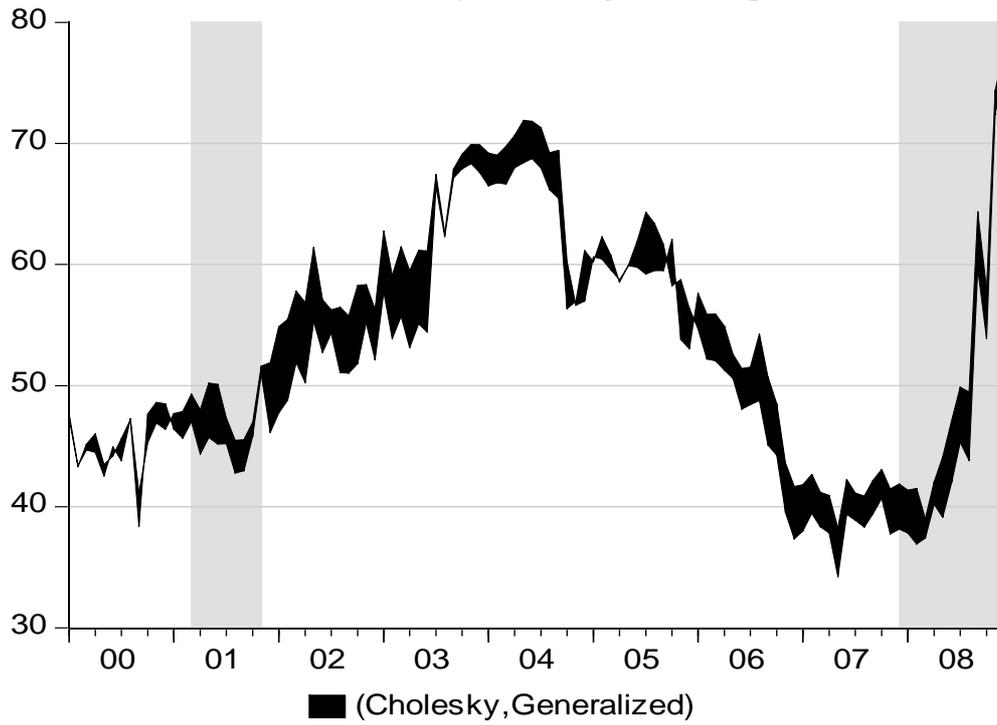
(%, 5-year rolling window, VAR(3))



**Figure 5. Cholesky and Generalized VD based Business Cycle Spillover Indices for G-6 countries (5-year rolling window, percent, VAR(3))**

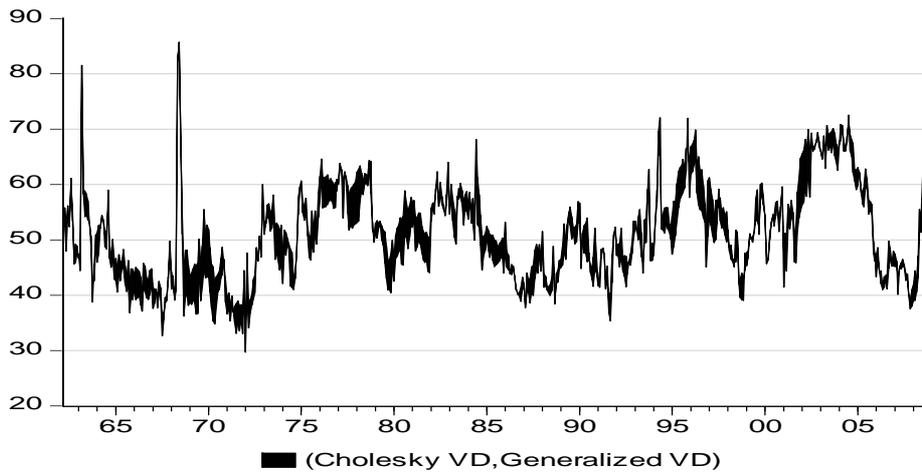


**Figure 5. Cholesky and Generalized VD based Business Cycle Spillover Indices for G-6 countries (2000:01-2008:12, 5-year rolling window, percent, VAR(3))**

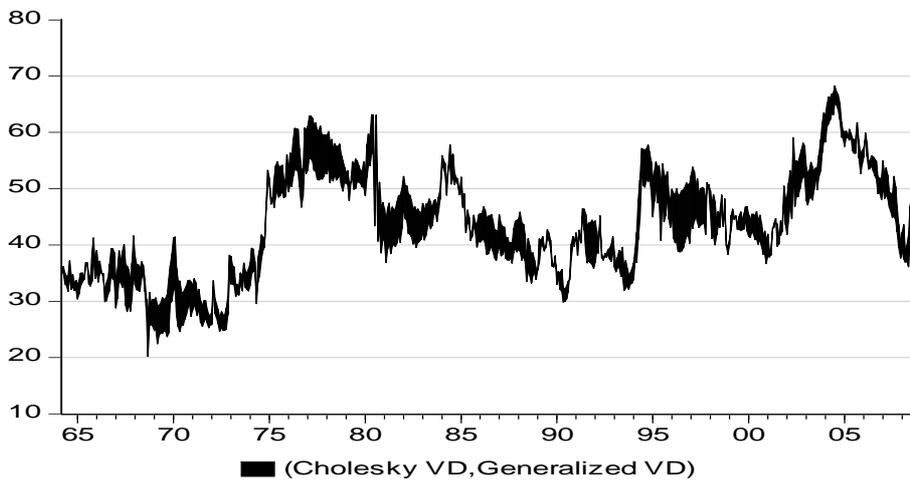


**Figure 6. Business Cycle Spillover Indices for G-6 countries**

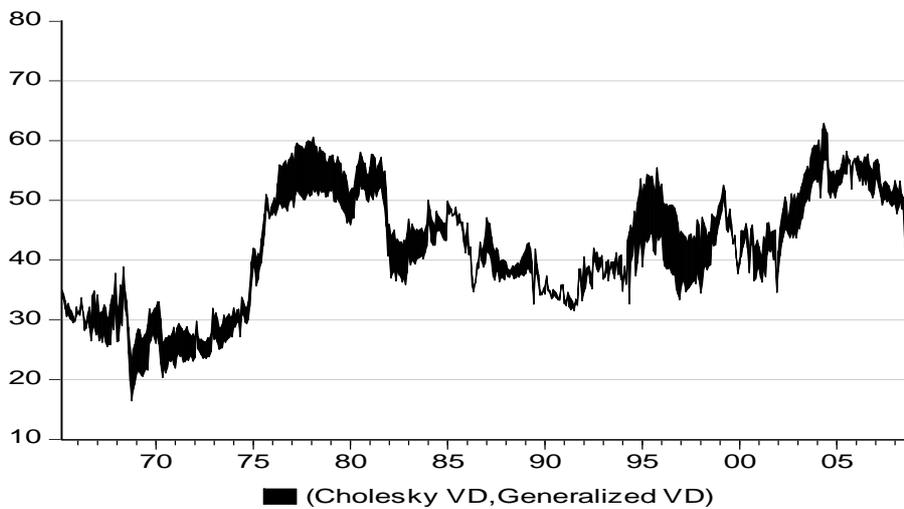
**a) 4-year rolling window**



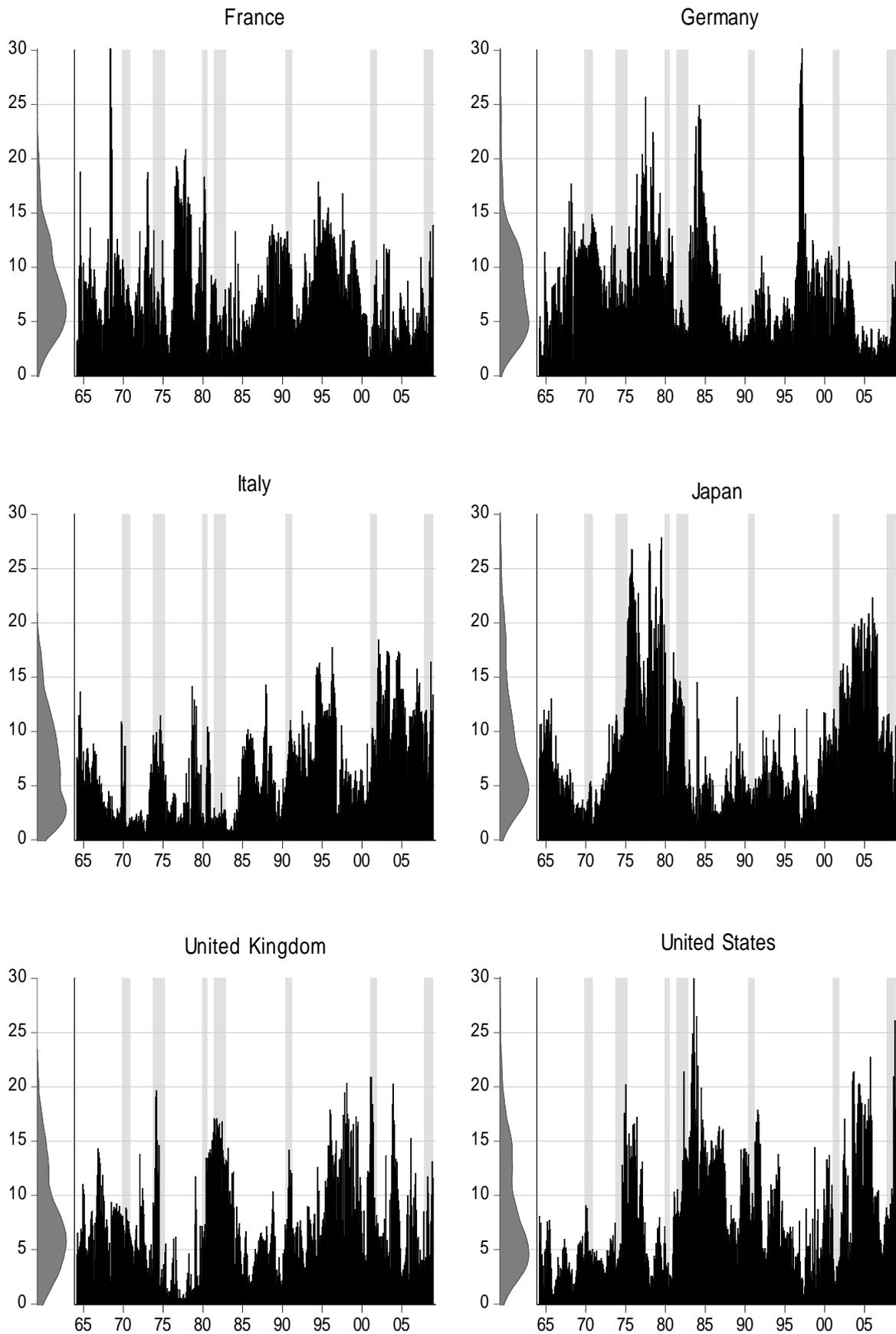
**b) 6-year rolling window**



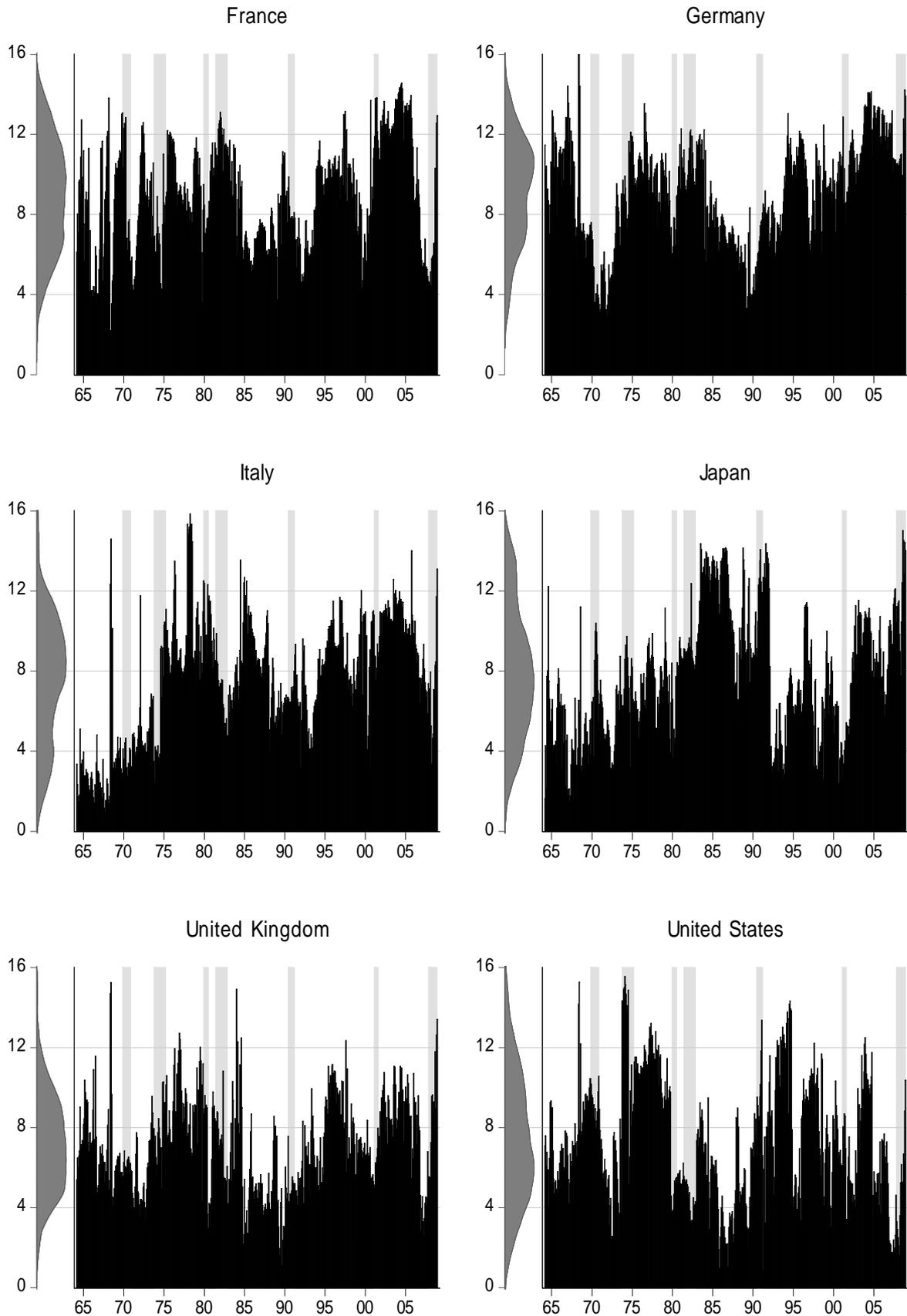
**c) 7-year rolling window**



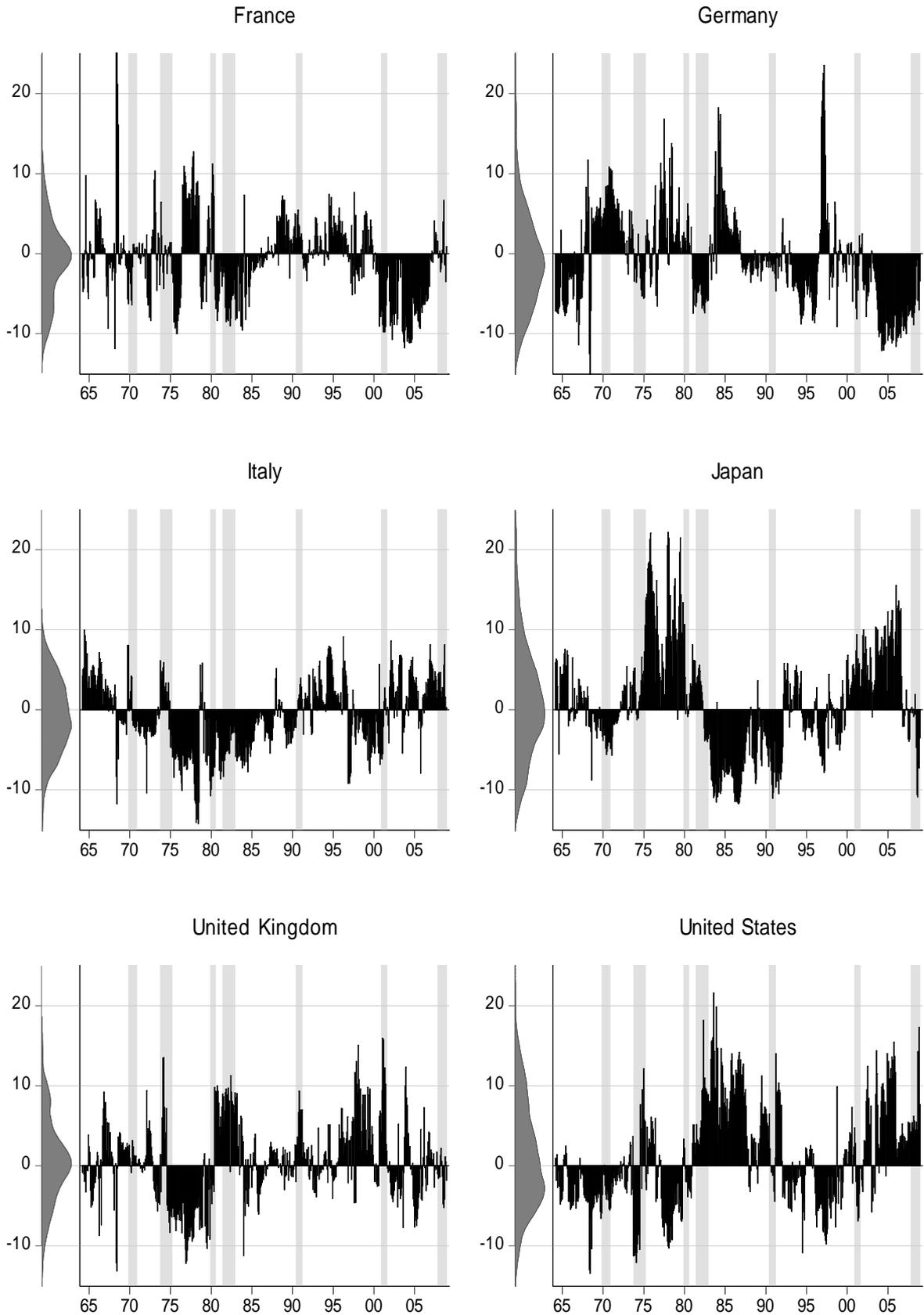
**Figure 7. Gross Directional Business Cycle Spillovers Transmitted to Others  
(5-year rolling window, VAR(3); with official US recession episodes)**



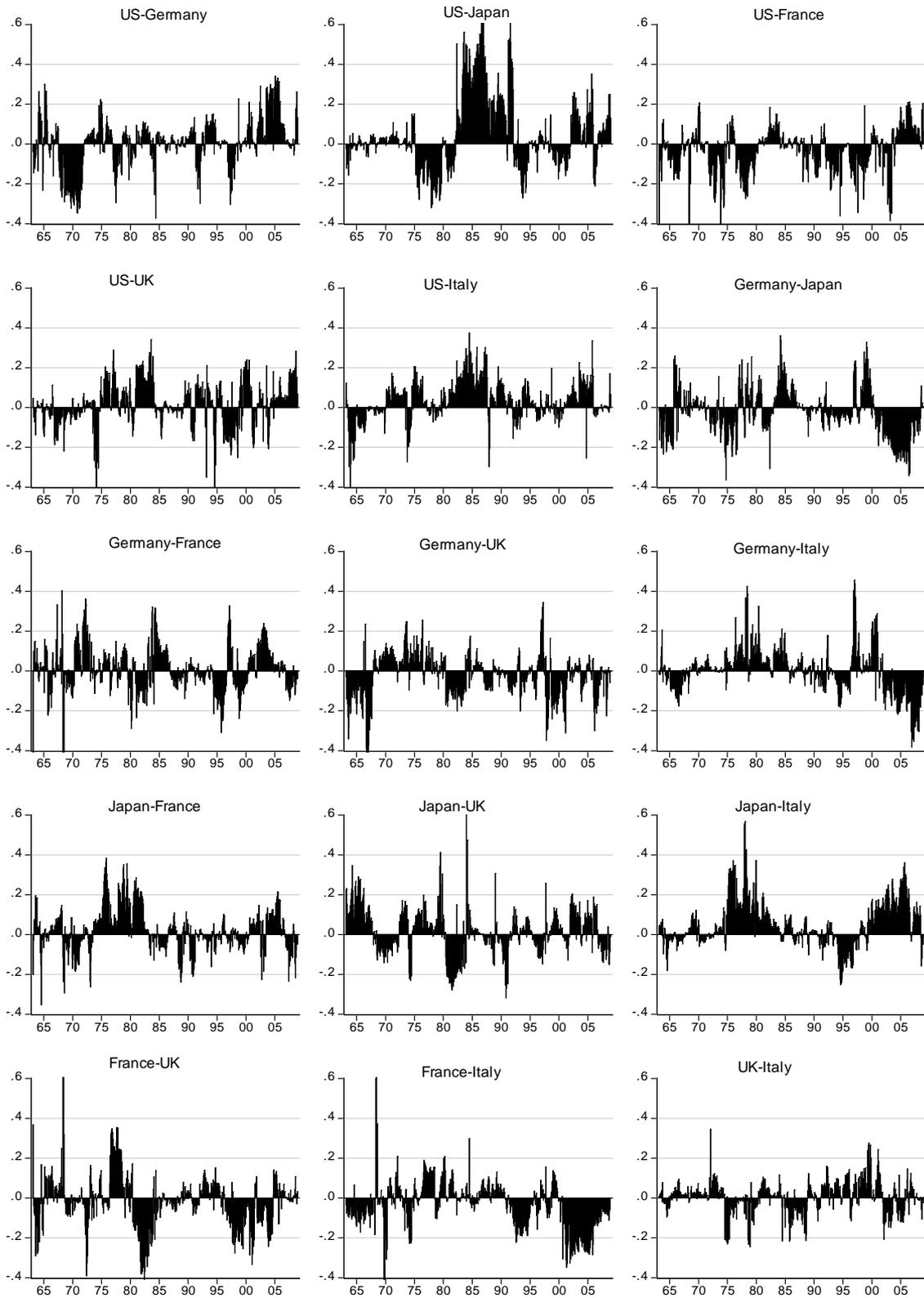
**Figure 8. Gross Directional Business Cycle Spillovers Received from Other s  
(5-year rolling window, VAR(3); with official US recession episodes)**



**Figure 9. Net Directional Business Cycle Spillovers Transmitted to Others  
(5-year rolling window, VAR(3); with official US recession episodes)**



**Figure 10. Net Directional Business Cycle Spillovers  
(5-year rolling window, VAR(3))**



## APPENDIX

**Table A-1: Correlation Coefficient 12-monthly Growth Rates of Industrial Production  
(1957:01-2008:12)**

	Canada	France	Germany	Italy	Japan	UK	USA
<b>Canada</b>	1						
<b>France</b>	0.411	1					
<b>Germany</b>	0.383	0.582	1				
<b>Italy</b>	0.450	0.593	0.487	1			
<b>Japan</b>	0.411	0.545	0.620	0.651	1		
<b>UK</b>	0.440	0.437	0.483	0.374	0.437	1	
<b>USA</b>	0.747	0.379	0.365	0.461	0.426	0.472	1

**Table A-2: Correlation Coefficients Monthly Growth Rates of Industrial Production  
(1957:01-2008:12)**

	Canada	France	Germany	Italy	Japan	UK	USA
Canada	1						
France	0.048	1					
Germany	-0.053	0.089	1				
Italy	0.060	0.026	0.047	1			
Japan	0.111	0.085	0.146	0.004	1		
UK	0.159	0.027	0.150	0.167	0.064	1	
USA	0.297	0.015	0.091	0.090	0.166	0.147	1