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Abstract

This paper studies business cycle interdependence among the industrialized countries since 1958. Using the spillover index methodology recently proposed by Diebold and Yilmaz (2009a) and based on the generalized VAR framework, we develop an alternative measure of comovement of macroeconomic aggregates across countries. We have several important results. First, the spillover index fluctuates over time, increasing substantially following the post-1973 U.S. recessions. Secondly, the band within which the spillover index fluctuates follows an upward trend since the start of the globalization process in the early 1990s. Thirdly, the spillover index recorded the sharpest increase ever following the peak of the global financial crisis in September 2008, reaching a record level as of December 2008 (See http://data.economicresearchforum.org/erf/bcspill.aspx?lang=en for updates of the spillover plot). We also derive measures of directional spillovers and show that the U.S. (1980s and 2000s) and Japan (1970s and 2000s) are the major transmitters of shocks to other countries. Finally, during the current global economic recession shocks mostly originated from the United States and spread to other industrialized countries.

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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. Indeed, the global economy is experiencing the worst recession in decades, if not a global depression. As expected, the global recession increased the academic and policy interest in the business cycles research.

There has been quite an extensive literature on international business cycles that dates back to early 1990s. Since then, research on business cycles across countries has displayed ample evidence that macroeconomic fluctuations in industrial and developing countries have a lot in common. Using pair-wise correlations of GDP, Backus et al. (1995) and Baxter (1995) show that output in major industrial countries follow similar short run paths. 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. In a recent paper, using a multicountry Bayesian VAR model with time variations, Canova, Ciccarelli, and Ortega (2007) also find evidence in favor of 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.[1]

As the evidence on international business cycles accumulated, the literature started to focus on the effect of globalization on international business cycles. Kose et al. (2003) find that with increased globalization, the impact of the world factor on the correlation of macroeconomic aggregates (output, consumption and investment) across countries increased in the 1990s and after. More recently, Kose et al. (2008) extend their previous findings to the second moments of output, consumption and investment. Doyle and Faust (2005), on the other hand, found no evidence of increased correlation of growth rates of output in the United States and in other G-7 countries over time. Stock and Watson (2005) show

[1] In addition, empirical studies employing time series and spectral methods also find support for the presence of international business cycles (See Gregory et al., 1997, Lumsdaine and Prasad, 2003).

that the comovement of macroeconomic aggregates has declined in the globalization era of 1984-2002. However, rather than linking their results directly to the globalization process, Stock and Watson (2002) conclude that their results are likely due to diminished importance of common shocks among the G-7 countries. Eickmeier (2007) emphasizes that the impact of globalization on international propagation of macroeconomic shocks is unclear and needs to be studied further.

This paper develops a business cycle spillover index across G-6 countries using forecast-error variance decompositions obtained from a Vector Error Correction (VEC) model to differentiate between own-shocks versus spillover of shocks. Diebold and Yilmaz (2009a) recently proposed this methodology to study return and volatility spillovers across major stock markets around the world. We apply the spillover index methodology to the seasonally adjusted monthly industrial production indices for G-6 countries (excluding Canada from the G-7 group).

The spillover index framework is simple to implement. It follows directly from the variance decomposition associated with an *N*-variable vector autoregression, where all variables in the system, in our case industrial production indices, are assumed to be endogenous. The time-variation in spillovers is potentially of great interest as the intensity of business cycle spillovers is 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 business cycle spillovers across G-6 countries are important; spillover intensity is indeed time-varying; and the United States and Japan are the major transmitters of business cycle shocks to other countries.

The spillover index framework is different from earlier studies of international business cycles, in that, rather than finding a common world factor or indicator that measures international business cycles we identify how shocks to industrial production in one country affect the industrial output in other countries. Obviously, one is likely to find evidence for international business cycles either if the shocks are common and/or 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 (see Diebold and Yilmaz, 2009b).

Finally, our study differs from the majority of earlier contributions to the literature in terms of the data used. We use industrial production indices at monthly frequency rather than the quarterly data from the national income accounts. There are two reasons for this choice. First, the use of monthly data allows us to capture the spillovers of shocks much faster, as seen in the latest economic crisis. Second, the use of monthly data allows us to have more observations in calculating the spillover index for each rolling sample window.

In the rest of the paper we proceed as follows. In Section 2, we discuss the 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. Section 4 concludes the paper.

II. The Spillover Index Methodology

In this section, we provide a brief summary of the the spillover index. As we have already mentioned in the Introduction, the 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 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*x*N* coefficient matrices A_i obey the recursion $A_i = \Phi_1 A_{i-1} + \Phi_2 A_{i-2} + ... + \Phi_p A_{i-p}$, with A_0 an *N*x*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 the 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,..,*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,.., *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 (ε_t) has a multivariate normal distribution, the generalized impulse response function scaled by the variance of the variable is defined as:

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

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

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

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:

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

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

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

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:

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

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

III. The Empirics of Business Cycle Spillovers

In our empirical analysis, we use monthly observations of the seasonally adjusted industrial production (IPSA) indices from January 1958 to May 2009. Even though it is one of the G-7 countries, we do not include Canada in our analysis, because the Canadian IPSA is highly correlated with the IPSA of the United States.[2]

Seasonally Adjusted 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 (1958:01-2009:05) are presented in Table 1. For all G-6 countries, the augmented Dickey-Fuller test fails to reject the null hypothesis that the log of IPSA series (allowed to have a constant and a linear trend term) possess a unit root even at the ten percent level of significance. This result obviously implies that none of the six IPSA series are stationary in levels. Applying the tests to the first-differenced log IPSA series, however, we reject the non-stationarity of this series for all six countries at the one percent level of significance. Together these results indicate that all IPSA series included in our analysis are integrated of order one, I(1).

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[2] Year-on-year industrial production growth rates for the two countries have a correlation coefficient of almost 86 percent, much higher than the correlation coefficients for other country pairs (See Table A-1). Similarly, the correlation coefficient between the monthly IPSA industrial production growth rates of the two countries is much higher than the ones for other pairs of countries (See Table A-2, 0.38 vs. 0.26 the next higher correlation coefficient between the US and Japan). Artis *et al.* (1997) show that with a value of 85.6% the contingency correlation coefficient between the US and the Canadian industrial production is 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 1958:01-2009:05 (See Table 2). 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 included.

The Business Cycle Spillover Table

In the empirical analysis of business cycle spillovers we first estimate the VEC model for the full sample and report the spillover index and the directional spillovers in Table 3 along with the underlying generalized variance decomposition.

The spillover index for the full sample period is 68.7%, indicating that more than two-thirds of the total variance of the forecast errors for G-6 countries is explained by spillovers of shocks across countries, whereas the remaining 31% is explained by idiosyncratic shocks. It is important at this stage to note that the rather high value of the spillover index is driven by the observations in 2009. In a previous version of the paper, the spillover index for the period from 1958:01 to 2008:12 was only 27%. The inclusion of just 5 observations leads to a significant jump in the index.

In terms of the directional spillovers transmitted to others (measured by $S_{\bullet i}^{g}(H)$) throughout the full sample, the US is the country that contributed the most to other countries' forecast error variance (170.3 points, which is equivalent to 28.3% of the total forecast error variance to be explained), followed by Italy (116.6). According to the full sample directional spillover measures, Japan and Germany contributed the least to other countries' forecast error variance (19.8 and 20.5 points, respectively), followed by the UK (30.5).

In terms of the directional spillovers received from others, $S_{i\bullet}^{g}(H)$, the US appears to be the country that received the least of spillovers from other countries (26, equivalent to just 4.3% of the total forecast error variance to be explained) followed by Italy (56.5) and the UK (74.2). Germany received the most (91.7) 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 $S_{i}^{g}(H)$. The US (144.2) and Italy (60) are net transmitters of industrial production shocks to other countries, while Japan and other European countries in the sample (Germany -71.2, Japan -66.9, UK -43.6 and France -22.5) 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. However, as we emphasized in the introduction, our focus is more on the dynamics of business cycle spillovers over time. The fact that the inclusion of Jan-May 2009 observations in the data set led to a substantial jump in the spillover index definitely highlights the need to study the dynamics of spillovers over time.

As VEC is the correct model for the full sample, our dynamic analysis of spillovers also relies on the variance decomposition from the VEC model estimated over rolling 5-year windows. Here is how we obtain the spillover plot: We estimate the VEC model for the first 5-year sub-sample window (April 1958-March 1963) and obtain the value for the generalized variance decomposition-based spillover index (from now on, the spillover index). Moving the sub-sample window one month ahead, we obtain the spillover index for the next window and so on. Graphing the spillover index values for all sub-sample windows gives us the spillover plot.

In Figure 1, we present the rolling sample generalized spillover index plot alone. In Figure 2, we present the spillover index along with the spillover index based on the Cholesky variance decomposition (from now on, the Cholesky VD-based spillover index). We plot the two indices as an area band rather than two different lines. Figure 2 reveals that the difference between the two indices is in general not very large for all sub-sample windows considered, seldom exceeding 10 percentage points. 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 be sufficient to focus on the generalized VD-based spillover index for the time being.

Let us now focus on Figure 1 again. 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. Actually, during or after all U.S. recessions (indicated by shaded bars in Figures 1 through 7), the spillover index recorded significant upward movements. The only exception is the 1969-70 recession, during which the index moves down. In addition, the index goes up in late 1993, and after a brief correction in late 1994, it goes up again in 1995. While there is no U.S. recession during this period, France, Germany, Italy and Japan experienced recessions ending in late 1993 or early 1994 (See ECRI, 2008). As a result, the upward move in the spillover index is most likely due to the spillovers originating from these countries.

Second, while the spillover index fluctuates over time, we can differentiate between several trends. First, during the 1973-75 recession the spillover index increases by almost 20-25 percentage points and fluctuates around 50 percent after the 1981-82 recession. Starting in 1984, the spillover index declines all the way down to 35 percent. This result is consistent with findings of McConnell and Perez-Quiros (2000), and Blanchard and Simon (2001) that the volatility of U.S. GDP declined after 1984 (great moderation). As the volatility of GDP declines, the spillover index declines down to pre-1973 levels.

Third, after the great moderation era of the late 1980s, the behavior of the spillover index reflects the influence of globalization. From 1989 onwards, the band within which the spillover index fluctuates starts to move upwards with the current wave of globalization which started in earnest in early 1990s. As the sample windows are rolled to include 1996, the index reaches 60%, but declines down to 40% as the data for the late 1990s and 2000 are included. The index starts to increase again towards the end of the mild recession of 2000-2001, reaching 60% 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 65% 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 lasts longer and has a larger bandwidth than the previous one. During the first cycle which lasts from 1989 to the end of 1992, the index fluctuates between 33% and 45%, while in the second cycle that lasts from 1993 to 1999 the index fluctuates between 37% and 56%. Finally, during the third cycle from 2001 to 2007, the index fluctuates between 44% and 65% percent.

This result supports Kose et al.'s (2003) finding that with the globalization process the business cycles have become more synchronized. It basically indicates that the comovement of industrial production fluctuations tends to be more significant since the late 1980s. This result is also consistent with Doyle and Faust's (2005) conclusion that the correlation coefficients among the industrial production series are not high since the late 1980s. The output fluctuations tend to move more together during periods of high spillover index, compared to the periods with low spillover index. When one analyzes the period since the late 1980s as a whole, he/she may not obtain high correlation coefficients.

Next we focus on the most important part of our results, namely the behavior of the spillover index since June 2008. We want to focus on its most recent behavior, not only because it gives us more clues about business cycle spillovers since the beginning of the sub-prime crisis in the United States, but also because the index reccorded the biggest jump in its history. The index jumped from 53% in June to 71% in September, and then to 80% as the December observation is included in the sample. With the inclusion of January-May 2009 observations, the index declined slightly down to 69%.

The behavior of the index during the 2008-09 global recession is in stark contrast to previous recession episodes. It has increased 42 percentage points from April to December 2009. During the recession following the first oil price hikes, the spillover index recorded a relatively smaller increase, from a low of 30 to a high of 61, in a matter of four years, from 1972 to 1976. The jump in the index during the current global recession is an indication of how G-6 countries are pulling each other down.

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 4. Irrespective of the window size we choose, the spillover index follows similar patterns. For example, in all three plots the spillover index jumps between 30 and 40 points since the start of the 2008-09 global recession.

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

[3] There is a spike in the index in May 1968, as the French industrial production makes its largest (38%) historical drop in May 1968, which was followed by 23% and 19% increases in June and July. However, the sudden drop in May 1968 did not have any lasting impact on industrial output in France and in other G-6 countries.

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 source country of spillovers (measured both gross (Figure 7) and net (Figure 9) terms). During the 1973-1975 recession and during the second half of the 1970s, the spillovers originated 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 source 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 stayed 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 that 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 25%. The gross directional spillovers from the U.S. jumped close to 33% since the collapse of the Lehman Brothers in September 2008. 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.

The spillover index methodology also allows us to analyze the net pair-wise 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 were 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 industrial production in Germany and Italy 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

Using the spillover index methodology introduced by Diebold and Yilmaz (2009a and 2009b), we develop an alternative measure of comovement of macroeconomic aggregates across major industrialized countries. We use forecast-error variance decompositions from Vector Error Correction (VEC) model to calculate the business cycle spillover index across G-6 countries.

We make several important contributions to the literature on international business cycles. Our spillover index methodology is different from the empirical approaches widely used in the literature. 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 VEC 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 1984. This result is consistent with the findings of both Kose et al. (2003) and Doyle and Faust (2005): When shocks in individual countries are not significant, they can not be expected to spill over to other countries irrespective of the degree of integration among these countries. When the shocks are big enough to spill over to other countries, then the correlation of macroeconomic aggregates across countries will be greater.

Third, the directional spillover 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. The directional spillover measures show that the U.S. (1980s and 2000s) and Japan (1970s and 2000s) are the major transmitters of shocks to other countries.

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. Given how fast the shocks spill over across countries, it is legitimate to argue that the recovery from the current recession/depression requires coordinated policy actions among the major industrial and emerging economies.

In this paper we limited our attention to the study of business cycle spillovers across the G-6 countries only. In our future research, we plan to study the business cycle spillovers across major emerging market economies along with the G-6 countries. It is also interesting to study the spillovers of shocks in labor markets, using the unemployment rates for major industrial countries.

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Table 1. Unit Root Test – G-6 Industrial Production (1958:01-2009:05)

Augmented Dickey-Fuller Test Statistics						
	France	**Germany**	**Italy**	**Japan**	**UK**	**USA**
Log levels (with constant term and trend)	-0.942	-2.440	-1.510	-2.283	-0.869	-2.649
Log first differences (with constant term)	-25.639	-12.946	-32.406	-8.389	-29.137	-10.089

Critical Values for the Augmented Dickey-Fuller Test			
	1%	**5%**	**10%**
Log levels (with constant term and trend)	-3.973	-3.417	-3.131
Log first differences (with constant term)	-3.441	-2.866	-2.569

Notes: In applying the Augmented Dickey-Fuller test to log industrial production we include a constant term and a trend, but only a constant term in the case of first differences of log industrial production. Critical values for the Augmented Dickey-Fuller test are provided in the lower part of the table at the 1%, 5% and 10% level of significance.

Table 2: Johansen Cointegration Test - G-6 Industrial Production (1958:01-2009:05)

Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	P-Value
None *	0.0694	109.18	95.75	0.004
At most 1	**0.0458**	**65.16**	**69.82**	**0.111**
At most 2	0.0262	36.46	47.86	0.374
At most 3	0.0189	20.19	29.80	0.410
At most 4	0.0087	8.51	15.49	0.413
At most 5	0.0052	3.17	3.84	0.075

Unrestricted Cointegration Rank Test (Maximum Eigenvalue)

Hypothesized No. of CE(s)	Maximum Eigenvalue Statistic	0.05 Critical Value	P-value
None *	44.02	40.08	0.017
At most 1	**28.70**	**33.88**	**0.183**
At most 2	16.27	27.58	0.642
At most 3	11.68	21.13	0.579
At most 4	5.34	14.26	0.699
At most 5	3.17	3.84	0.075

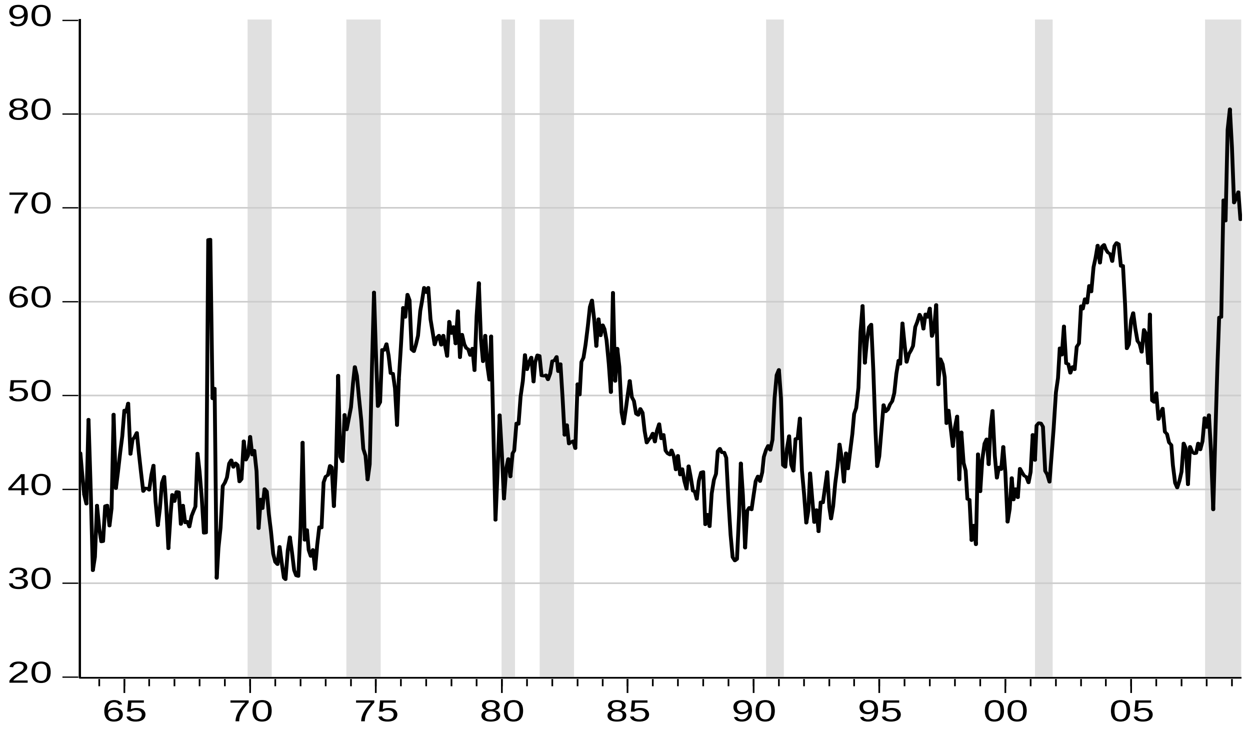
Notes: We assume that there is a linear deterministic trend in the data and an intercept in the cointegrating equation; * denotes rejection of the hypothesis at the 0.05 level

Table 3: Business Cycle Spillover Table for G-6 Countries (1958:01-2009:05)

	USA	Germany	Japan	France	UK	Italy	Directional *FROM* Others
USA	74.0	1.3	3.5	2.5	5.0	13.7	26.0
Germany	33.6	8.3	6.4	16.7	6.0	29.2	91.7
Japan	32.3	6.3	13.2	15.1	9.5	23.7	86.8
France	28.0	7.5	5.2	23.0	7.2	29.0	77.0
UK	38.3	2.4	2.5	10.0	25.8	21.0	74.2
Italy	38.2	3.0	2.4	10.3	2.8	43.5	56.5
Directional *TO* Others	170.3	20.5	19.9	54.5	30.5	116.6	**Index=68.7%**
Directional Including Own	244.2	28.8	33.1	77.5	56.4	160.0	
Net Directional Spillovers (*TO – FROM*)	144.2	-71.2	-66.9	-22.5	-43.6	60.0	

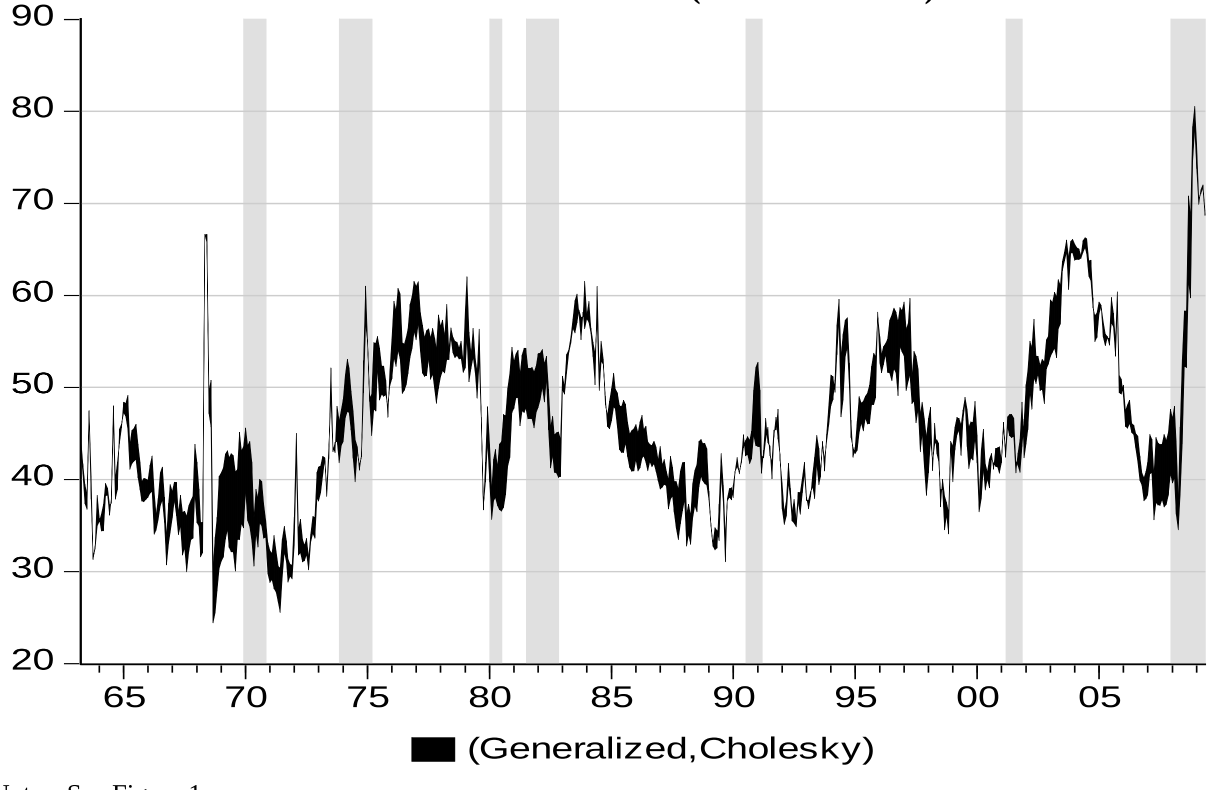
Notes: Each cell in the 6x6 matrix section of the Table reports the relative (n percentage terms) contribution of the "column" country to the variance of the forecast error for the "row" country. "Directional FROM Others" column reports the total variance (of the forecast error) share attributable to other countries. "Directional TO Others" row reports the sum of the contributions of each country to all other countries' variance of forecast errors. "Directional Including Own" row reports the sum of the contributions of each country to the variance of forecast errors for all G-6 countries. Each cell in the "Net Directional Spillovers (TO-FROM)" row reports the difference between the corresponding cells in the "Directional TO Others" row and the ones in the "Directional FROM Others" column. The Index is the sum of the elements of the "Directional FROM Others" column (similarly, the "Directional TO Others" row) divided by the total possible variance contributions, which is by definition equal to 600 for 6 countries.

Figure 1. Business Cycle Spillover Index for G-6 countries (1958:01-2009:05)



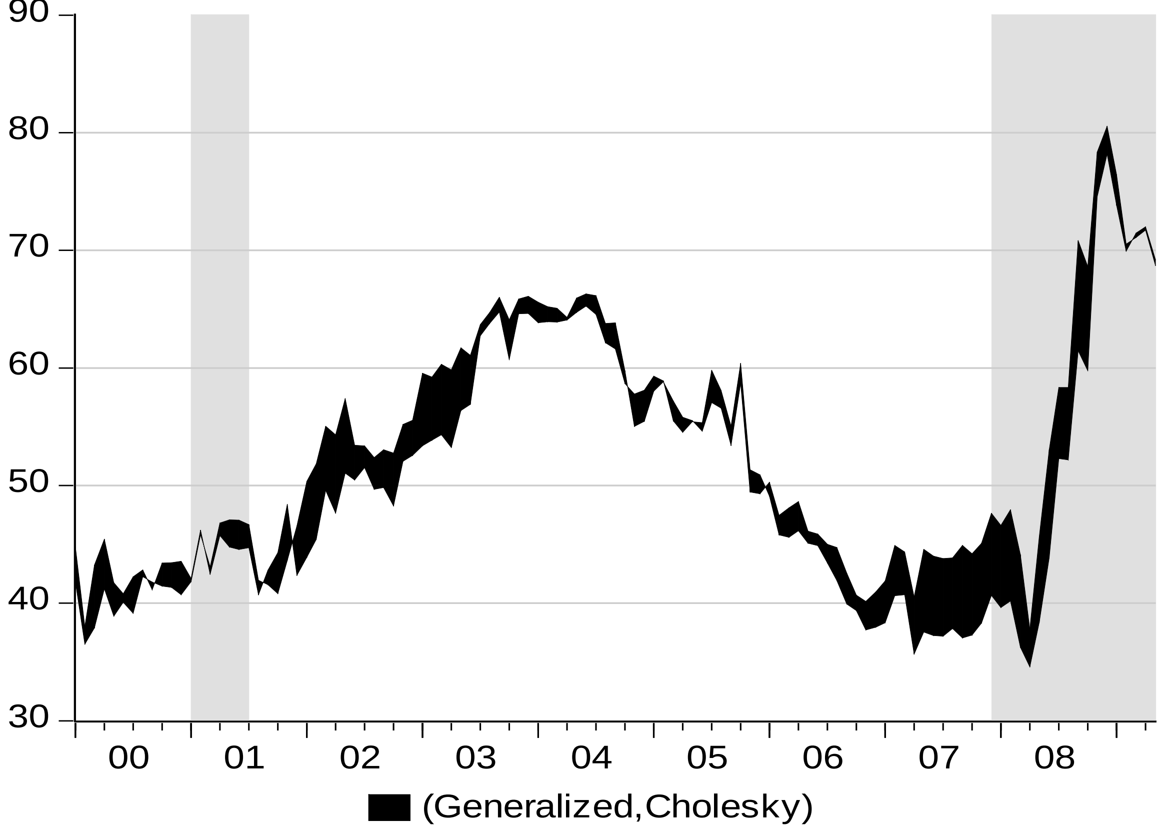
Notes: The spillover index is calculated for 5-year rolling sample windows based on a Vector Error Correction model with 3 lags. The index is denoted in percentage terms. Gray bars indicate the U.S. recessions.

Figure 2. Business Cycle Spillover Index (Generalized VD based) and Cholesky VD Based Index for G-6 countries (1958:01-2009:05)



Notes: See Figure 1.

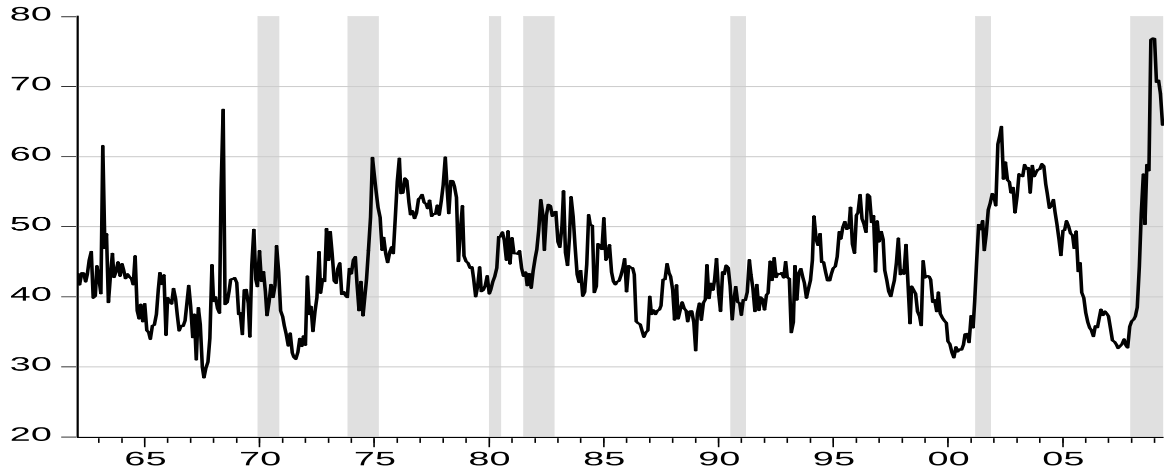
Figure 3. . Business Cycle Spillover Index (Generalized variance decomposition based) and Cholesky VD Based Index for G-6 countries (2000:01-2009:05)



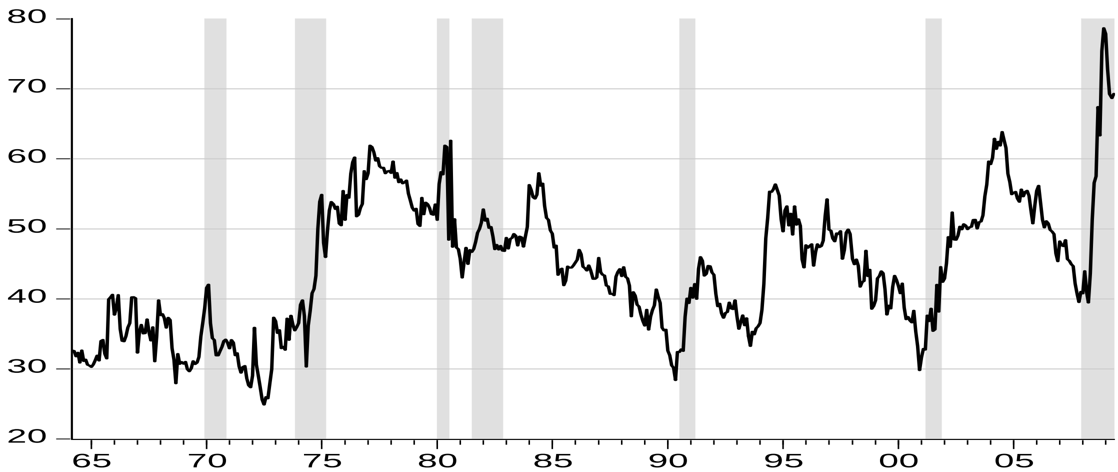
Notes: See Figure 1.

Figure 4. Business Cycle Spillover Indices for G-6 countries (1958:01-2009:05)

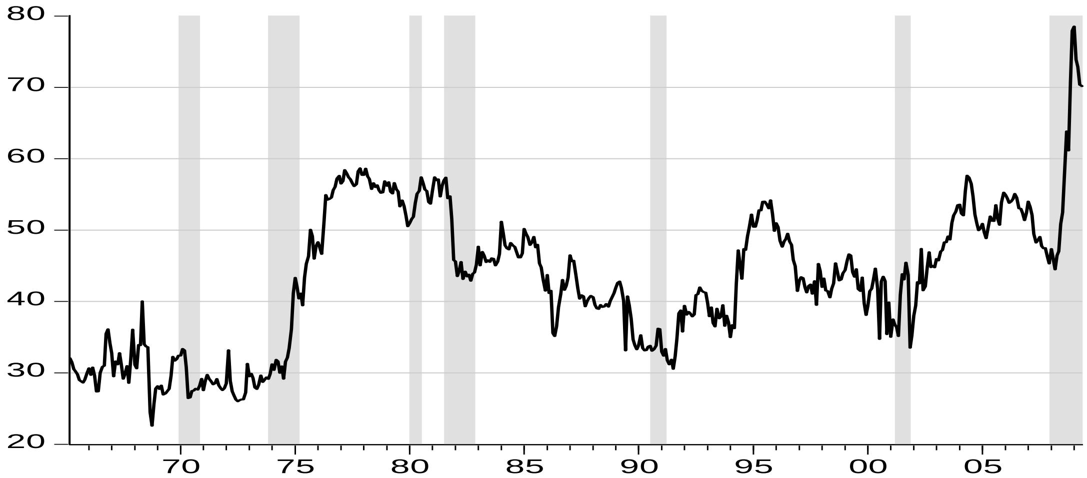
a) 4-year rolling window



b) 6-year rolling window

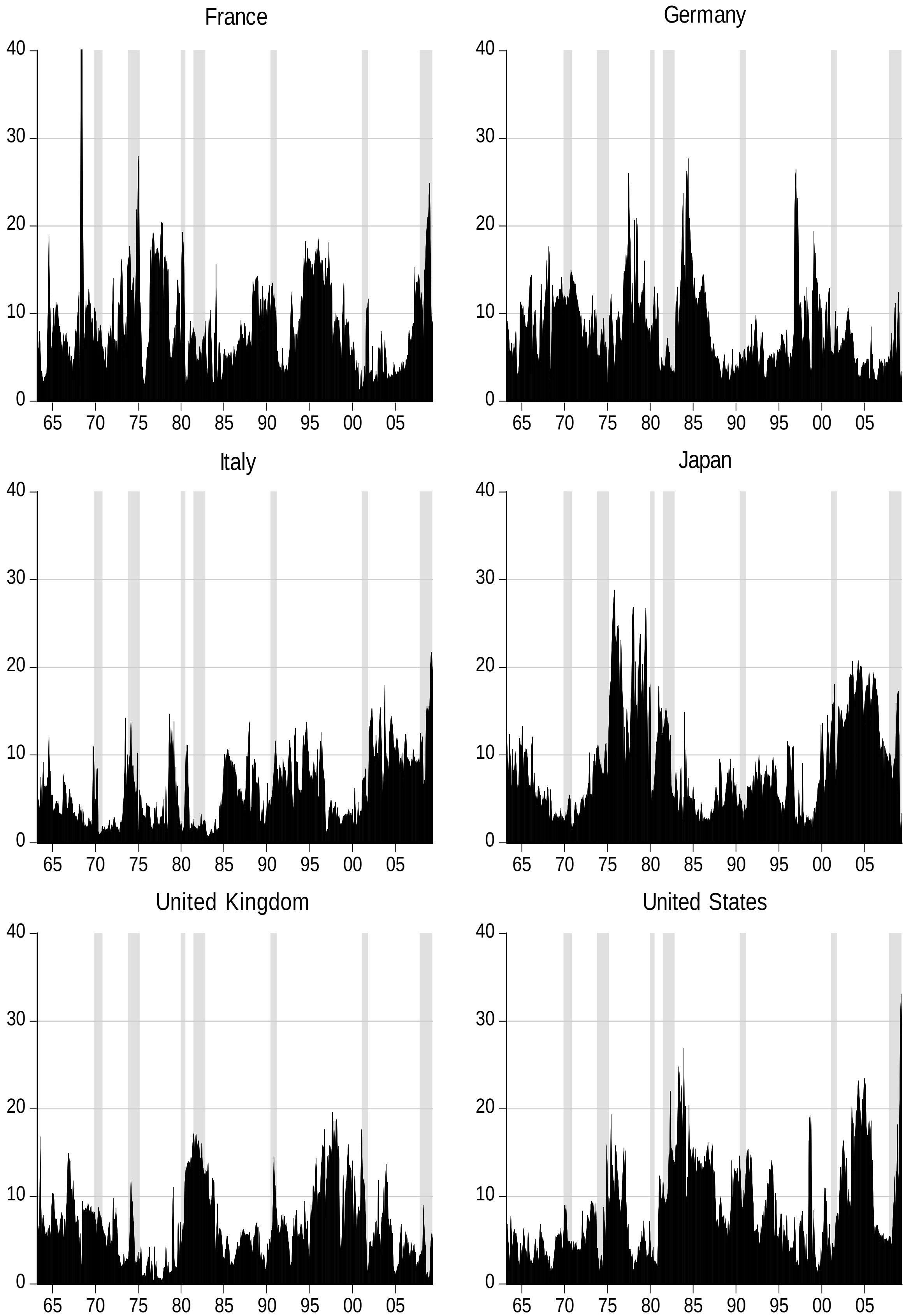


c) 7-year rolling window



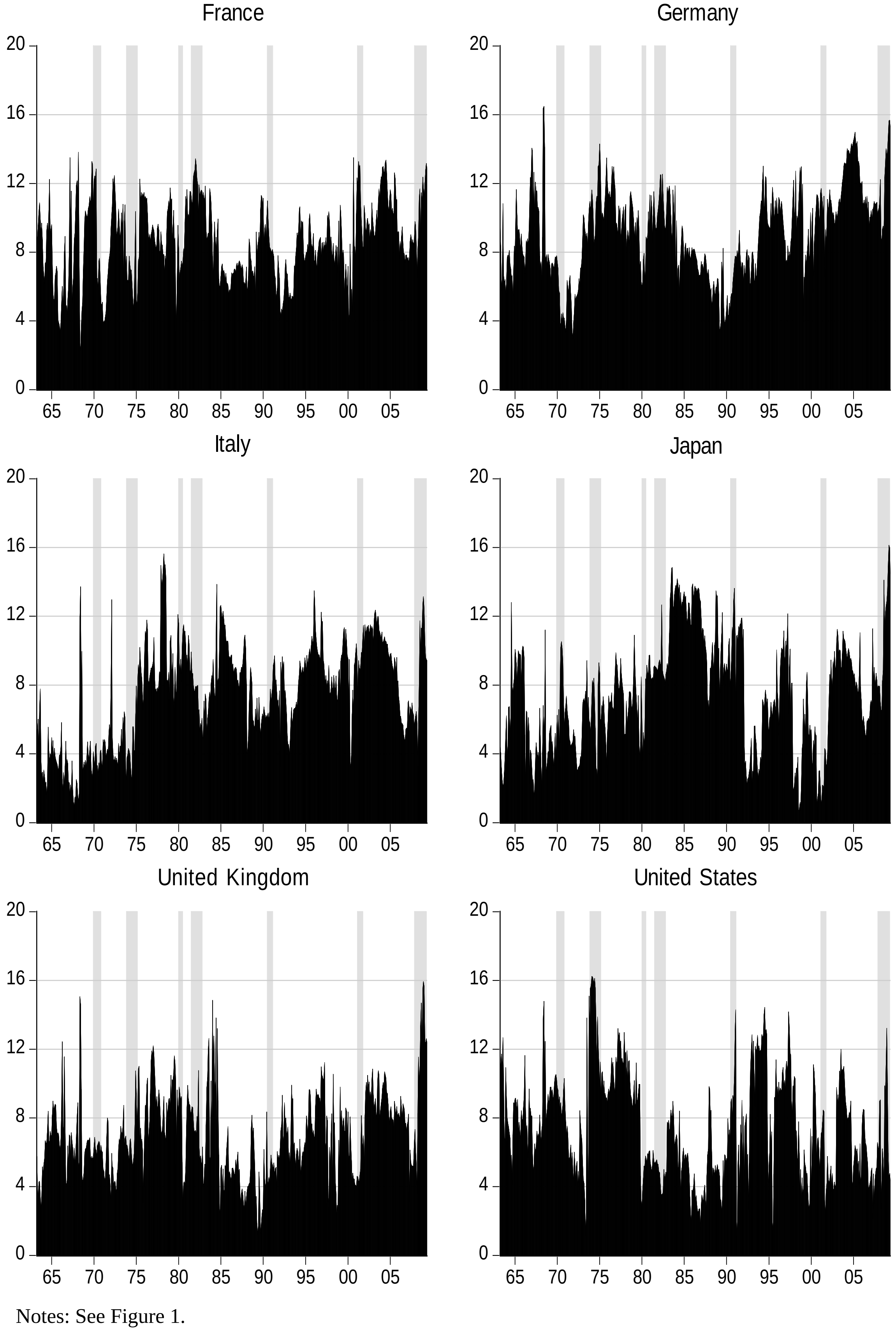
Notes: See Figure 1.

Figure 5. Gross Directional Business Cycle Spillovers Transmitted to Others (1958:01-2009:05)



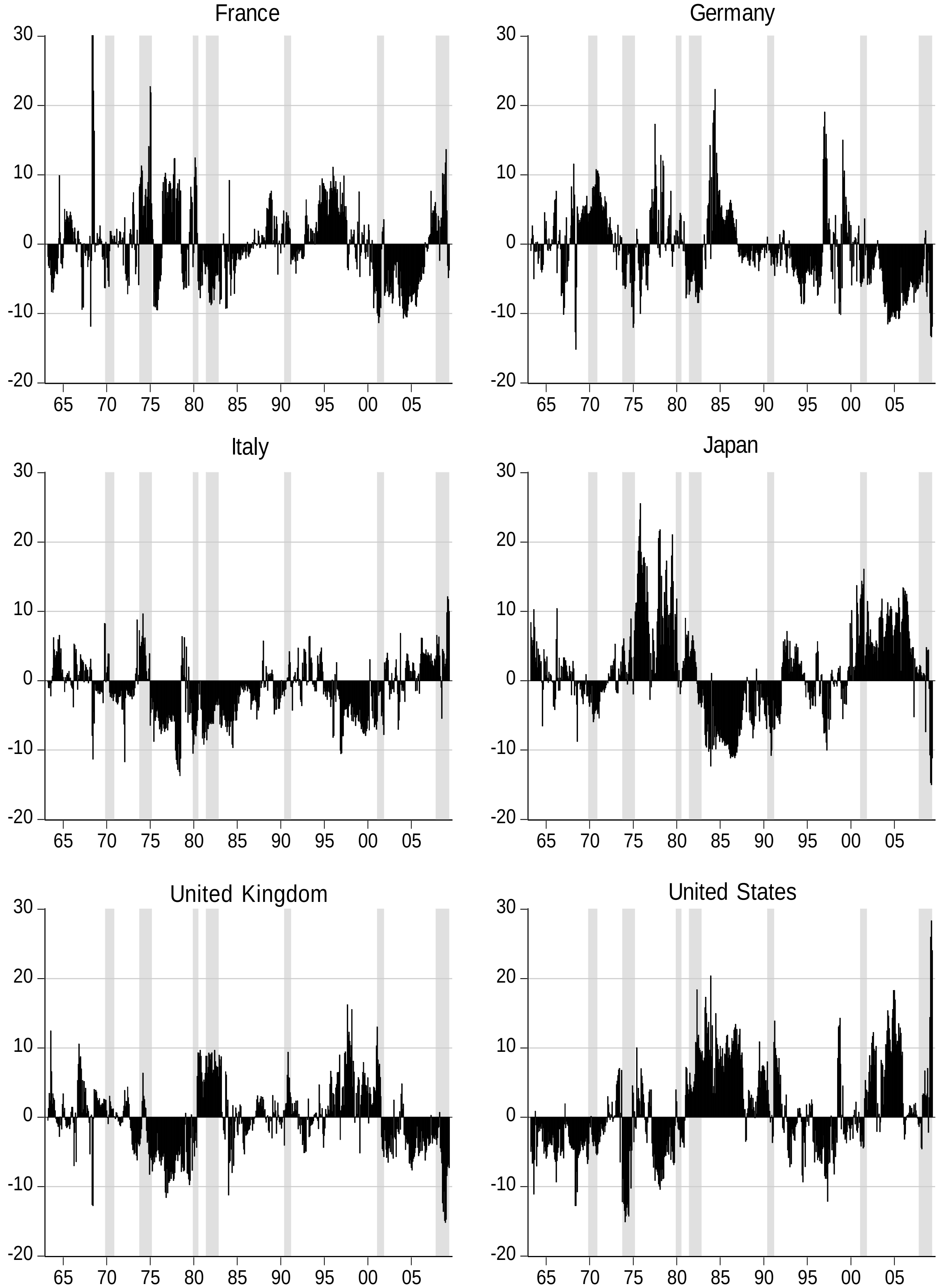
Notes: See Figure 1.

Figure 6. Gross Directional Business Cycle Spillovers Received from Others (1958:01-2009:05)



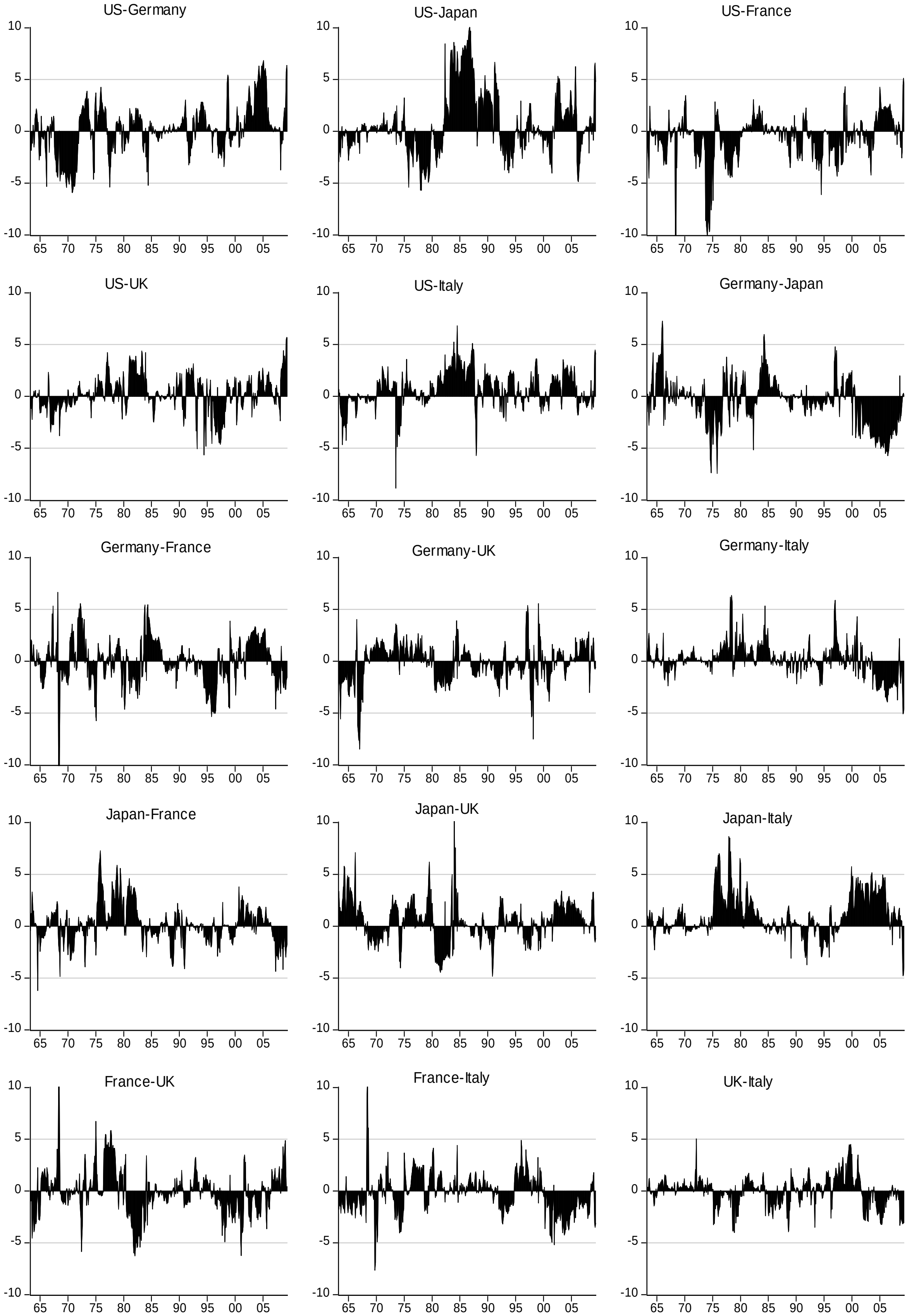
Notes: See Figure 1.

Figure 7. Net Directional Business Cycle Spillovers Transmitted to Others (1958:01-2009:05)



Notes: See Figure 1.

Figure 8. Net Directional Business Cycle Spillovers (1958:01-2009:05)



Notes: See Figure 1.

APPENDIX

Table A-1: Correlation Coefficients - 12-monthly Growth Rates of Industrial Production (1962:01-2009:05)

	Canada	France	Germany	Italy	Japan	UK	USA
Canada	1						
France	0.507	1					
Germany	0.459	0.602	1				
Italy	0.522	0.622	0.505	1			
Japan	0.531	0.583	0.622	0.624	1		
UK	0.531	0.467	0.488	0.380	0.447	1	
USA	0.859	0.501	0.482	0.539	0.533	0.540	1

Table A-2: Correlation Coefficients - Monthly Growth Rates of Industrial Production (1961:02-2009:05)

	Canada	France	Germany	Italy	Japan	UK	USA
Canada	1						
France	0.084	1					
Germany	0.087	0.078	1				
Italy	0.080	0.227	0.047	1			
Japan	0.193	0.165	0.146	0.053	1		
UK	0.151	0.160	0.150	0.185	0.097	1	
USA	0.379	0.044	0.091	0.120	0.261	0.160	1