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The Ties that Bind: Measuring International Bond Spillovers Using Inflation-Indexed Bond Yields

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Measuring International Bond Spillovers Using Inflation-Indexed Bond Yields

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Abstract

This paper explores international bond spillovers using daily and intra-day data on yields on inflation-indexed bonds and associated inflation expectations for the United States, Australia, Canada, France, Sweden, Japan, and the United Kingdom. The analysis starts in 2002, by which point U.S. inflation-indexed markets were fully mature. Real bond yields are found to be closely linked across countries, with developments in U.S. markets determining around half of real foreign yields and no evidence of spillovers back to the United States. Spillovers in inflation expectations are smaller and the direction of causation is less clear.

JEL Classification Numbers: G14, G15, G12, E43

Keywords: Spillovers, Market Efficiency, Real Interest Rates, Inflation-Indexed Bonds.

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[1] We received extremely helpful comments on this paper from two seminars at the IMF, one of which involved a range of U.S. officials, including Nathan Sheets. All errors are, of course, ours.

Contents Page

I. Introduction....3

II. The Theory and Practice of Bond Yields....5
A. Some Theory....5
B. The Data....6

III. Tests for Efficiency and the Existence of Spillovers....12
A. Testing Market Efficiency Using Daily Data....14
B. Intraday Tests of Market Efficiency....18

IV. Quantifying Spillovers....20

V. Conclusions....24

References....26

Figures

1. Long-term Interest Rates and Inflation Expectations, 1997–2006....8
2. Long-term Interest Rates and Inflation Expectations, 2004–2006....9
3. Intraday Price Quote Times....13

Tables

1. Standard Deviations of Daily Bond Yields and Inflation Expectations....10
2. Cross-Country Correlations in Bond Yields and Inflation Expectations....11
3. International Bond Market Spillovers at a Daily Frequency....16
4. International Bond Market Spillovers at a Weekly Frequency....17
5. Intraday Sprillovers in Nominal Bond Markets....20
6. Variance Decompositions After 50 Days....22
7. Variance Decompositions After One Year....23

Appendix Figures

4 Impulse-Response Functions, Australia....29
5. Impulse-Response Functions, Canada....30
6. Impulse-Response Functions, France....31
7. Impulse-Response Functions, Japan....32
8. Impulse-Response Functions, Sweden....33
9. Impulse-Response Functions, United Kingdom....34
10 Impulse-Response Functions for Alternate Ordering, Australia....35
11. Impulse-Response Functions for Alternate Ordering, Canada....36
12. Impulse-Response Functions for Alternate Ordering, France....37
13. Impulse-Response Functions for Alternate Ordering, Japan....38
14. Impulse-Response Functions for Alternate Ordering, Sweden....39
15. Impulse-Response Functions for Alternate Ordering, United Kingdom....40

I. Introduction

One of the many implications of rapid financial market globalization is the likelihood of increasing financial spillovers across countries. This is a particularly important possibility for government bonds, where the standardized characteristics of underlying instruments and rising internationalization of holdings are creating an increasingly interlinked and global market. Yields on government bonds provide the "risk free" interest rate that is the basis for yields in a wide swathe of other markets. Given that yields on long-term securities are generally considered to have a larger impact on activity than the short-term rates that monetary authorities target, this provides an important economic link between countries.

In the past, one limitation in analyzing these links has been that it is difficult to separate real bond yields, which would be expected to be highly linked across countries, from changes in long-term inflation expectations. Fortunately, this decomposition has been greatly assisted by the development of inflation-indexed bonds, which allow prices of these two components of bond yields to be continuously tracked. While indexed bonds were already trading in a number of markets from the early 1990s, it is only with the introduction of inflation-indexed bonds in the United States—the world's largest and most sophisticated bond market—in January 1997 that the potential to identify international spillovers in real interest rates and inflation expectations could be fully realized. With the U.S. inflation-indexed bond market now almost a decade old, there is sufficient information to allow statistical analysis of spillovers in bond yields and inflation expectations.[2]

Accordingly, this paper uses government bonds to examine international spillovers between real interest rates and inflation expectations. It analyzes spillovers between the United States and six other industrial countries with inflation-indexed bond markets—Australia, Canada, France, Japan, Sweden, and the United Kingdom. Given the convergence of euro area bond yields since European Monetary Union, the French data (where inflation-indexed bonds were introduced in November 1998) can be taken as a proxy for the Euro Area as a whole (Italian data, available since early-2004 are almost identical to the French series). As a result, the sample covers bond yields in the vast majority of the industrial world, although in the case of Japan inflation-indexed bonds were only issued starting in 2004.

The focus of this paper is on bilateral links between the U.S. markets and other countries. This reflects the dominant position of the United States in the global bond market. Almost two-thirds of all private bonds are traded in U.S. markets, a significantly more important position than in the real economy, where U.S. GDP represents about one-third of the world using market exchange rates and 20 percent using purchasing parity rates. Financial markets are thus a potentially extremely important conduit for spillovers from the United States to the rest of the world.

Indeed, while this is the first paper we know of to examine international spillovers using inflation-indexed bonds, there is a large literature showing that U.S. macroeconomic news

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[2] See Sack and Elsasser (2004) for an overview of the U.S. inflation-indexed market.

affects returns in foreign markets. Faust et al (2007) is a representative example. Using intraday data, they find that when U.S. economic activity turns out stronger than expected or there is a surprise monetary tightening, the dollar appreciates and interest rates in the United Kingdom and the euro area increase. Other works confirming this evidence on exchange rates include Andersen et al (2003, 2005), Almeida et al (1998), and Fair (2003). Ehrmann and Fratzscher (2003, 2005), Goldberg and Leonard (2003), Christie-David et al (2002), and Kim and Sheen (2000) reach the same conclusions on interest rates. Andersen et al (2005) show how the impact on foreign equity markets varies depending on the state of the economy. Stronger-than-expected U.S. activity raises foreign stock prices during recessions but lowers them during expansions, when concerns about future monetary tightening appear to predominate.

While U.S. economic releases move foreign markets, there are fewer spillovers in the opposite direction. The response of the German Mark or euro-dollar exchange rate is rarely moved by German releases (Anderson et al, 2003, and Almeida et al, 1998), and German and euro area data releases have little impact on U.S. bond yields (Ehrmann and Fratzscher, 2005, and Goldberg and Leonard, 2003). In Becker et al (1995), U.S. news affects the U.K. equity market but U.K. news has no impact on the S&P 500.

The literature on linkages across financial markets also points to the dominance of U.S. spillovers to foreign markets, even when controlling for the role of macreconomic news. U.S. interest rates drive interest rates in the euro area (Ehrmann and Fratzscher, 2005), Germany (Bremnes et al, 2001), Canada (Gravelle and Moessner, 2001), and Australia (Kim and Sheen, 2000). Fatum and Scholnick (2006), show that increased expectations of U.S. monetary tightening, as measured by rates on federal funds futures contracts, are associated with an appreciation in the dollar. And there is a higher degree of dependence of foreign equity markets on U.S. markets than vice versa (Becker et al, 1990, Lin et al, 1994, Diebold and Yilmaz, 2007). In a framework analyzing asset U.S.-euro area linkages across short-term interest rates, long-term bond yields, and equity markets, Ehrmann, Fratzscher, and Rigobon (2007) find that the share of variance in euro area markets explained by U.S. markets is, on average, three times as large as the euro area's importance for U.S. markets.

There is also an active body of work on the interdependence of global real interest rates and their convergence over time, but none using inflation-indexed securities, due to the short period for which data exist. The extant literature typically uses *ex post* real rates based on inflation outturns, or derives real rates using proxies for inflation expectations. Overall, the evidence for real interest parity (RIP) is mixed, while studies that examine the response of interest rates by country find some role for U.S. real rates in determining those of other countries.[3] For example, Chinn and Frankel (2005) find that European rates move so as to

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[3] Jorion (1996) and Breedon et al (1999), who examine longer maturities, find no evidence of RIP across the major industrial countries. Chinn and Frankel (1995), find little evidence of RIP for shorter maturities. Gagnon and Unferth (1995), Goodwin and Grennes (1994), and Awad and Goodwin (1998) do find some support for RIP for short-term interest rates. See Ferreira and León-Ledesma (2007) for recent evidence on RIP for both developed and emerging economies, and for additional references.

restore RIP while U.S. rates do not, though there are preliminary indications that this is changing with the advent of the Euro Area. Cumby and Mishkin (1986) show that European rates respond to movements in U.S. rates, but reject RIP because the passthrough is not one-to-one. Breedon et al (1999) find some evidence that U.S. rates are weakly exogenous for other G7 countries, but cannot reject the same hypothesis for Canada or France. In Chinn and Frankel (1995), U.S. and Japanese real rates have similar influence on emerging Asian markets, but there are no links between the U.S. and Japan or Canada. Thus, the use of more reliable data on real interest rates may clarify the nature of cross-country linkages.

The plan of the rest of the paper is as follows. The next section discusses some theory and characteristics of the underlying data. Section III reports tests for market efficiency, including with respect to international spillovers. Section IV then quantifies spillovers of real interest rates and inflation expectations, followed by conclusions in Section V.

II. The Theory and Practice of Bond Yields

A. Some Theory

For an investor, the annualized yield on a nominal bond can be divided into a "real" return and a component that reflects expected inflation, both of which can be further divided into an expected value and a risk premium associated with investor preferences. Formally:

$$Yield_t = E_t(r_{t,t+k} + \pi_{t,t+k}) + RP_t(r_{t,t+k} + \pi_{t,t+k}), \tag{1}$$

where E is the expectations operator, RP is the risk premium and $r_{t,t+k}$ and $\pi_{t,t+k}$ are the annualized real rate of interest and of inflation between t and $t+k$, respectively. By ensuring that the principal of the bond grows with future inflation, the yield on an inflation-indexed bond eliminates the second and fourth terms. Assuming the risk premium is separable, this implies:

$$Yield\_II_t = E_t(r_{t,t+k}) + RP_t(r_{t,t+k}) \text{ and } Yield_t - Yield\_II_t = E_t(\pi_{t,t+k}) + RP_t(\pi_{t,t+k}). \tag{2}$$

Hence, an inflation-indexed bond allows one to differentiate the real rate of interest and associated risk premium from the equivalent information for inflation expectations. The real rate of interest is simply the quoted yield on the inflation-indexed bond, while the difference between the yields of a nominal and inflation-indexed bond of the same maturity is a measure of expectations of average inflation over that horizon.[4]

[4] The yield on an inflation-indexed bond would also include a premium to compensate investors for its lower liquidity relative to a conventional bond. See Sack (2002) and Shen (2006) for estimates of the size of this liquidity premium.

For a foreign investor the same equations hold, except that there is also foreign exchange risk since the investor is assumed to be concerned about returns in local currency. Using an asterisk to denote foreign variables gives:

$$\begin{aligned} Yield*_t &= E_t(r*_{t,t+k} + \pi*_{t,t+k} + s_{t,t+k}) + RP_t(r_{t,t+k} + \pi_{t,t+k} + s_{t,t+k}) \\ Yield\_II*_t &= E_t(r*_{t,t+k} + rs_{t,t+k}) + RP_t(r*_{t,t+k} + rs_{t,t+k}), \end{aligned} \tag{3}$$

where $s_{t,t+k}$ is the annualized nominal appreciation in the bilateral exchange rate and $rs_{t,t+k}$ is its real equivalent.

Assuming the marginal investor equates real returns across countries, so that $E_t(r_{t,t+k}) = E_t(r*_{t,t+k} + rs_{t,t+k})$, it follows that international differences in nominal yields reflect expected future values of inflation and the exchange rate as well as risk premiums on real rates, inflation, and exchange rates. Those on index-linked bonds isolate the risk premium on real interest rates and exchange rates while cross country differentials in the gap between yields on nominal and inflation-indexed bonds reflect expectations and risk premiums associated with the future path of inflation:

$$\begin{aligned} Yield_t - Yield*_t &= E_t(\pi_{t,t+k} - \pi*_{t,t+k} - rs_{t,t+k}) + RP_t(r_{t,t+k} - r*_{t,t+k} + \pi_{t,t+k} - \pi*_{t,t+k} - rs_{t,t+k}) \\ Yield\_II_t - Yield\_II*_t &= RP_t(r_{t,t+k} - r*_{t,t+k} - rs_{t,t+k}) \\ (Yield_t - Yield\_II_t) - (Yield*_t - Yield\_II*_t) &= E_t(\pi_{t,t+k} - \pi*_{t,t+k}) + RP_t(\pi_{t,t+k} - \pi*_{t,t+k}) \end{aligned} \tag{4}$$

In short, international comparisons of inflation-indexed yields and the differences between conventional and inflation-indexed yields should separate real risk premiums from expected inflation differentials and their associated risk premiums.

B. The Data

We collected daily data on closing prices of both conventional and inflation-indexed bonds for all advanced economies that have issued inflation-linked government securities: the United States, Australia, Canada, France, Italy, Japan, Sweden, and the United Kingdom. Most of our data start in 1997, when the United States issued its first inflation-indexed security, and finishes at end-2006. By the start of 1997, the Australian, Canadian, Swedish, and U.K. markets had already been trading for some time, although due to data limitations in the case of Sweden our series only starts in June 2000.[5] The French inflation-indexed market data are only available from November 1998, when the market opened, while in the case of Italy and Japan the markets opened in 2004.

Given the short sample available for the Italian data, we only use it to confirm that the French markets are a good approximation for the Euro Area as a whole (the correlation coefficient across daily changes in the French and Italian real interest rate series is 0.98). Japanese

[5] Sweden issued its first inflation-indexed bond in March, 1994.

results are reported, however, as the zero interest rate policy being followed through July 2006 means that these results provide potential insights into the impact of the inability to conduct a more typical monetary policy. In addition, we collected data on intraday conventional bonds. Unfortunately, this data is only available for a relatively short window, from December 4, 2006 to April 17, 2007. On the other hand, as discussed below, intraday information allows much more powerful tests of international spillovers.

Figure 1 graphs end-week nominal government bond yields, real yields, and implied inflation expectations for the full sample except Italy and Japan since the start of 1997. Weekly closes are graphed because the daily data are difficult to interpret visually. For the United States the series correspond to the government's benchmark 10-year maturity, while for the other countries the inflation-indexed yield is on the bond maturing closest to 10 years and typically ranges from 8 to 12 years.[6] The nominal yield for those countries is from a bond whose maturity is as close as possible to the indexed bond, which allows for the calculation of expected inflation over that horizon.

The first feature to note in the upper panel of Figure 1 is the high correlation of nominal bond yields across countries. Both the trends and higher-frequency wobbles appear highly correlated across countries. Looking at the start of the sample, for example, nominal yields in all countries in the sample fell steadily from early 1997 through mid- to late-1998 and then rose again through early 2000. Yields then trended downward through 2003 and have generally remained at very low levels. On the other hand, there is some variation. For example, Australia has tended to have higher yields than other countries, while more recently France and Sweden have had the lowest yields. In addition, U.S. yields seem to have been particularly low in 2002 and early 2003, possibly reflecting the aggressive reductions in short-term policy rates at that time.

The middle panel shows real yields (i.e., those on inflation-indexed bonds), using the same size for the vertical scale (6 percentage points) to aid comparison. In addition to being somewhat smoother than their nominal counterparts, their movements are less correlated across countries. For example, while real yields fell significantly through the sample for all countries, this reduction occurred much earlier in the United Kingdom than elsewhere. By contrast, inflation expectations (i.e. the differential between conventional and index-linked bonds), shown in the lower panel of the graph, have shown little evidence of a trend over the sample.

Figure 2 shows the same data since the start of 2004 with Italy and Japan added. The Italian data are virtually identical to the French series, confirming that France is a reasonable proxy for the Euro Area. Movements in Japanese yields and inflation expectations are less correlated with the other countries, a result of particular interest given that country's unique zero short-term interest rate policy to combat deflation.

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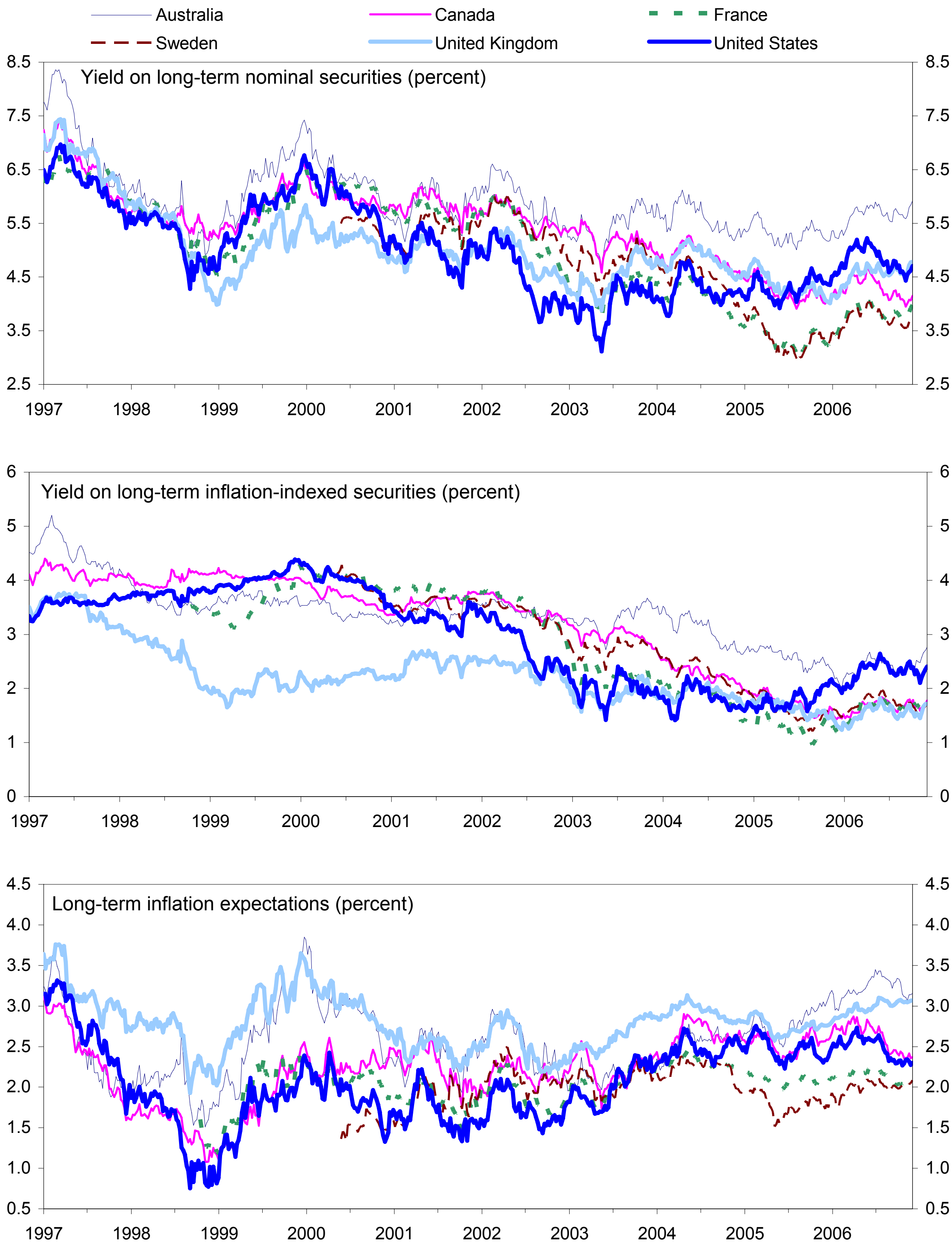
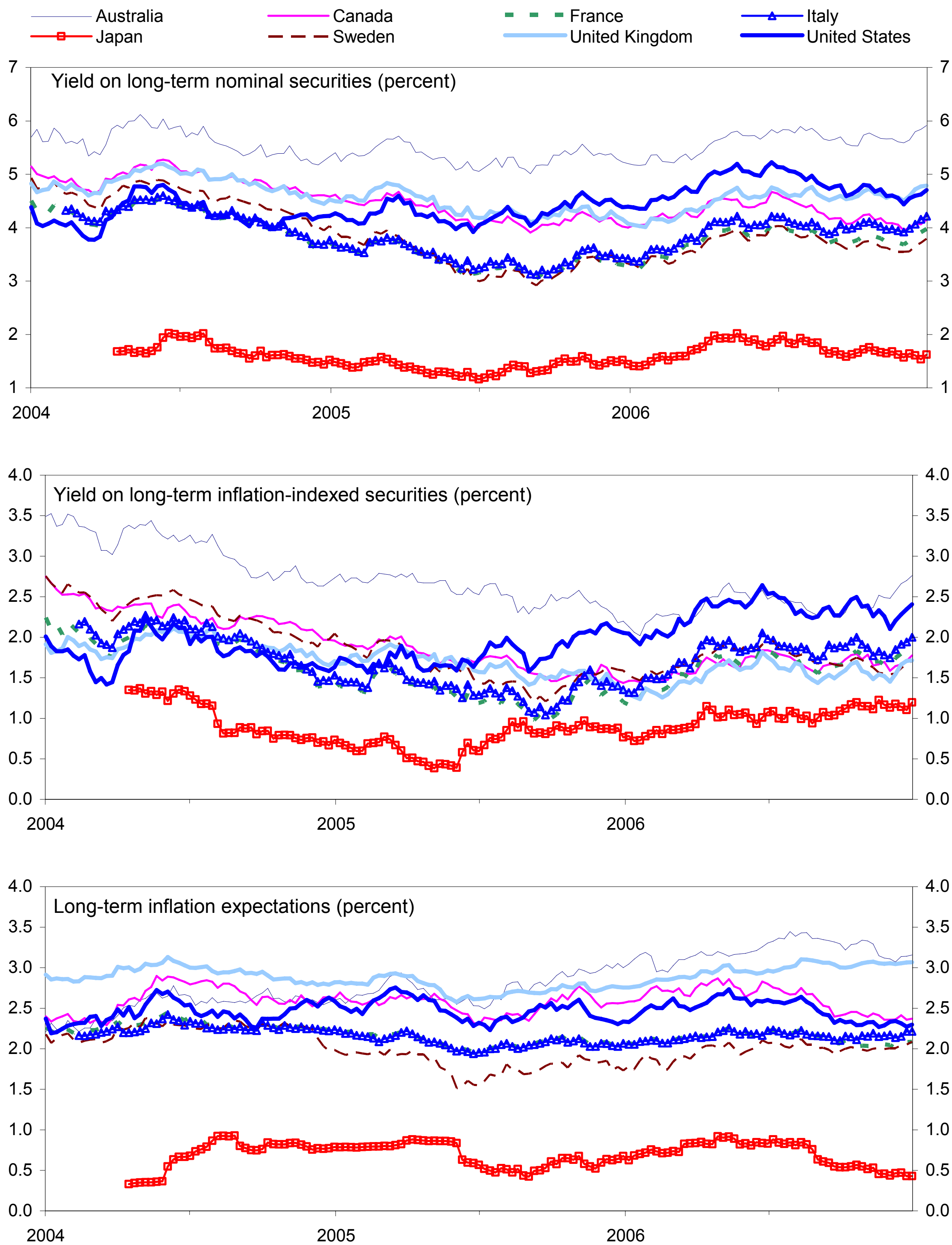
[6] The only significant deviation is in the case of Canada, for which the first inflation-linked bond matures in 2021 and is used throughout the sample.

Figure 1. Long-term Interest Rates and Inflation Expectations, 1997–2006



Sources: Bloomberg, L.P.; and IMF staff calculations.

Figure 2. Long-term Interest Rates and Inflation Expectations, 2004–2006



Sources: Bloomberg, L.P.; and IMF staff calculations.

Table 1. Standard Deviations of Daily Bond Yields and Inflation Expectations
(January 2, 2002 to December 29, 2006)

	Nominal yields		Real yields		Inflation expectations	
	Level	Changes	Level	Changes	Level	Changes
Australia	0.35	0.06	0.45	0.03	0.39	0.04
Canada	0.57	0.04	0.72	0.02	0.25	0.03
France	0.71	0.04	0.75	0.03	0.17	0.02
Japan 1/	0.21	0.03	0.23	0.03	0.16	0.02
Sweden	0.81	0.04	0.70	0.03	0.20	0.03
United Kingdom	0.33	0.04	0.33	0.03	0.23	0.02
United States	0.44	0.06	0.47	0.04	0.35	0.03

Source: IMF staff calculations.
1/ Data begin in April, 2004.

Table 1, which reports standard deviations of daily closes for these markets, confirms some of these observations. For instance, the standard deviations of the *level* of real returns are similar to those for nominal yields, but *changes* in nominal rates are more volatile than either real rates or inflation expectations. The standard deviations of the level of inflation expectations are lower than for either nominal or real yields, an indication of the long-term credibility of the monetary authorities in these countries. As in the remainder of this paper, the calculations use data starting in 2002, as it is only from this period that the U.S. inflation-indexed markets liquid enough for yields to accurately reflect market perceptions of real interest rates and inflation expectations (see Sack and Elsasser, 2004, and Shen, 2006). [7]

Table 2 reports correlations of nominal yields, real yields, and inflation expectations, with correlations of *changes* reported in the lower left triangle and *levels* in the upper right one. Levels of nominal yields are relatively highly correlated: most entries are above ½, with the slightly surprising exception of some of the entries involving the United States, where the low correlations appear to reflect the specific sample used.[8] Correlations of daily changes in nominal yields are generally lower than their counterparts in levels, and partly reflect regional linkages (including greater overlap of trading times, as discussed further below). Correlations are high between the three European markets (France, Sweden, and the United Kingdom), between the two north American markets (Canada and the United States), and, to a less extent, across these two sets of markets.

[7] Analysis using earlier start dates—1998 and mid-2000—find very similar results except that, as expected, there is more evidence of inefficiencies in the U.S. inflation indexed market (and in derived inflation expectations).

[8] Correlations since mid-2000 or early the start of 1998 do not show this anomaly.

Table 2. Cross-Country Correlations in Bond Yields and Inflation Expectations
(January 2, 2002 to December 29, 2006)

		Australia	Canada	France	Japan 1/	Sweden	United Kingdom	United States
Nominal Yields			*Levels*					
Australia		--	0.59	0.77	0.75	0.66	0.89	0.72
Canada	*Changes*	0.12	--	0.94	0.49	0.97	0.59	0.06
France		0.27	0.58	--	0.73	0.97	0.73	0.29
Japan 1/		0.40	0.13	0.22	--	0.60	0.59	0.71
Sweden		0.37	0.44	0.83	0.27	--	0.67	0.09
United Kingdom		0.26	0.51	0.88	0.22	0.76	--	0.56
United States		0.06	0.84	0.58	0.13	0.42	0.51	--
Real Yields			*Levels*					
Australia		--	0.89	0.80	0.26	0.90	0.86	0.36
Canada	*Changes*	0.14	--	0.93	0.23	0.97	0.85	0.52
France		0.19	0.46	--	0.67	0.97	0.90	0.77
Japan 1/		0.33	0.12	0.17	--	0.43	0.21	0.69
Sweden		0.27	0.30	0.54	0.26	--	0.90	0.62
United Kingdom		0.18	0.39	0.71	0.18	0.48	--	0.61
United States		0.08	0.54	0.49	0.12	0.27	0.40	--
Inflation Expectations			*Levels*					
Australia		--	0.58	0.29	0.00	-0.14	0.66	0.58
Canada	*Changes*	0.04	--	0.68	0.48	0.06	0.69	0.86
France		0.13	0.32	--	0.25	0.47	0.81	0.77
Japan 1/		0.08	0.05	0.05	--	0.15	0.00	0.39
Sweden		0.24	0.30	0.49	0.05	--	0.27	-0.06
United Kingdom		0.14	0.31	0.44	0.02	0.37	--	0.81
United States		-0.07	0.51	0.26	0.05	0.20	0.21	--

Source: IMF staff calculations.
Note: Entries above the diagonal are correlations of the data in levels; entries below the diagonal are correlations of daily changes.
1/ Data begin in April, 2004.

Switching to the constituent parts of nominal rates, real rates appear more correlated than inflation expectations in both levels and changes. Correlations of levels of real rates all exceed 0.8 with the exception of those for Japan and, again somewhat surprisingly, the United States (where this result again appears to reflect the specific sample). By contrast, correlations of levels of inflation expectations are almost universally much lower, varying between -0.14 and 0.86. The data on changes in real rates and inflation expectations again show the regional patterns observed for nominal rates. Despite high levels correlations, formal tests reject cointegration between U.S. and other countries for all three series, although given the short sample (only 4 years) these results are not conclusive.

How do these observations accord with the theory outlined earlier? The high correlations across real rates are consistent with the notion that there are significant trends in “world” real rates, and hence the possibility for significant spillovers. The lower correlations among inflation expectations can be explained by the idea that inflation is more likely to be influenced by domestic factors than global factors.

III. Tests for Efficiency and the Existence of Spillovers

This section establishes definitions of market efficiency and spillovers, and carries out tests to distinguish which of the two exist in international bond markets. A financial market is efficient if market prices fully reflect available information.[9] Market efficiency implies that the current period rate of return on a security is the best forecast of the future rate of return:

$$E_t(r_{i,t+1}|\Phi_t) = r_{i,t} \quad (5)$$

or, subtracting $r_{i,t}$ from both sides:

$$E_t(r_{i,t+1} - r_{i,t}|\Phi_t) = 0 \quad (6)$$

where $r_{i,t}$ is the return on asset i at time t and Φ represents the set of available information.[10] If the above equations didn't hold, for example if the expected return in $t+1$ exceeded the return in t, then the price of the security should be bid up in t. No information available at t should systematically predict the asset's return in $t+1$. We test a weak form of this efficiency, in which the only information incorporated in our efficiency tests is of an asset's own historical returns and those of related markets.

Ideally, a test of spillovers would include not only the impact of prior information from foreign markets, but be able to distinguish the extent to which any contemporaneous correlation between the two markets is the result of developments in the foreign market:

$$r_t = f(r_t^*, r_{t-1}^*) \quad (7)$$

If r_t^* is a significant determinant of r_t, then there are spillovers from the foreign to the domestic market, while if it can be determined that r_{t-1}^* matters for r_t, then there is evidence both of spillovers and of domestic market inefficiencies. The difficulty in assigning the contemporaneous correlation between r_t and r_t^* to developments in one market or the other is well known, so this section uses various tests of the impact of r_{t-1}^* on r_t to reach conclusions regarding the most likely driver of the correlation between the two markets.

The complication with this analysis is that international bond markets are open at different times of the day, and hence the definition of prior information can be somewhat tricky

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[9] This is true irrespective of the links across markets. For example, bond yields could be cointegrated if they react to information in a similar manner. Even so, past bond yields should not matter for current movements.

[10] Note that there is a small expected change in the return due to the shift in horizon covered by the bond from t to t+1, but with a 10-year bond, a change of one day makes no noticeable difference.

(Figure 3). The main trading session for U.S. bonds opens at 7 a.m. eastern standard time (EST) and the fix in the data is generally 4.30 p.m.[11] The other countries fall into three categories:

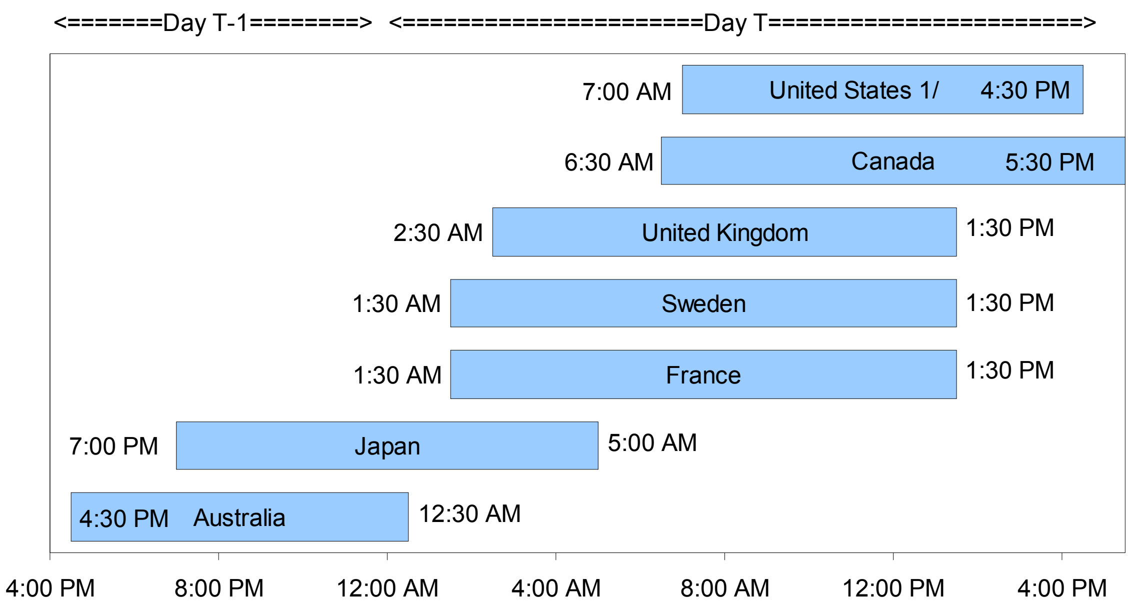
- *Asian markets (no overlap).* The Australian (4.30 p.m. to 12.30 a.m. EST) and Japanese (7 p.m. to 5 a.m. EST) markets have no overlap with the main U.S. trading hours.

- *European markets (significant overlap).* The French, Swedish, and U.K. markets open before the U.S. market (at 1.30 a.m. EST for France and Sweden, 2.30 a.m. for the U.K.) and the closing quote is for 1.30 p.m. EST, about two-thirds of the way through the U.S. session. To add a further complication, the U.S. market is most active during the overlap with the European markets.

- *Canadian market (synchronous)*. The Canadian market has essentially the same trading hours as in the United States.

Below, we report two approaches to testing the degree to which the U.S. market interacts with other markets, based on daily and intraday data.

Figure 3. Intraday Price Quote Times



Source: Bloomberg, L.P.
Note: Shows time in the Eastern United States.
1/ Shows hours for main trading session; price quotes are nearly continuous from 6:30 P.M. Sunday to 5:00 P.M. Friday.

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[11] U.S. bonds are unique in that they are traded more or less continually 24 hours a day, and (in contrast to the other countries in the sample) the fix in our dataset varies slightly depending on the day, varying from 3 p.m. to 7.30 p.m. EST.

A. Testing Market Efficiency Using Daily Data

As discussed above, the daily data comprise changes in yields from the fix on one day to the fix the next day, which means that longer lags are needed on the foreign variables to ensure no overlap of trading times. In particular, as the U.S. market closes later than other markets (except Canada), it is necessary to lag the change in U.S. yields two days versus one day for the foreign markets to ensure no overlap in trading times.

This is an eminently sensible approach for Australia and Japan, where local trading closes before U.S. markets open (in the case of Canadian markets, where the trading sessions cover the same time period, the first lag of U.S. yields can be used). However, for the European markets—where there is a large overlap of the trading sessions—it results in using relatively outdated U.S. information. To see this, consider the test of the degree to which U.S. and U.K. markets interact. In the regression testing the influence of changes in U.S. yields on their U.K. counterparts, the lagged U.S. data are 21 hours "older" than the lagged U.K. yields, whereas in the reverse case the difference is only 3 hours.

The tests use the following specification:

Index – linked bonds and associated Inflation Expectations

$$\Delta r_t \ \ or\ \Delta p_t = \alpha + \beta_1 \Delta r_{t-1} + \beta_2 r_{t-1} + \beta_3 \Delta p_{t-1} + \beta_4 p_{t-1} + \gamma_1 \Delta r^*_{t-1} + \gamma_2 r^*_{t-1} + \gamma_3 \Delta p^*_{t-1} + \gamma_4 p^*_{t-1} + \varepsilon_t \quad (8)$$

$$\Delta r^*_t \ \ or\ \Delta p^*_t = \alpha + \beta_1 \Delta r^*_{t-1} + \beta_2 r^*_{t-1} + \beta_3 \Delta p^*_{t-1} + \beta_4 p^*_{t-1} + \gamma_1 \Delta r_{t-1} + \gamma_2 r_{t-1} + \gamma_3 \Delta p_{t-1} + \gamma_4 p_{t-1} + \varepsilon_t$$

Conventional Bonds

$$\Delta i_t = \alpha + \beta_1 \Delta i_{t-1} + \beta_2 i_{t-1} + \gamma_1 \Delta i^*_{t-1} + \gamma_2 i^*_{t-1} + \varepsilon_t \quad (9)$$

$$\Delta i^*_t = \alpha + \beta_1 \Delta i^*_{t-1} + \beta_2 i^*_{t-1} + \gamma_1 \Delta i_{t-1} + \gamma_2 i_{t-1} + \varepsilon_t$$

where r_t, p_t, and i_t represent the real interest rate, associated inflation expectations, and nominal interest rates and the subscript *t-1* is understood to mean prior data, as discussed above. Both systems involve first lags of the level and the difference of all variables in the system, and are thus a reparameterization of a VAR using two lags of the levels of r_t, r_t^*, p_t and p_t^* or i_t and i_t^*. The lag length was determined by examining standard tests for the optimal lag length of such a levels VAR. As the tests almost universally pointed to zero, one, or two lags, the specification above—which, as noted above, is equivalent to a VAR in levels with two lags except for parts of the lag structure—was adopted.

These specifications allow for a wide range of tests of efficiency. They are most easily explained using the specification for conventional bonds. Clearly, if excluding the change or level of the other countries' yields (setting $\gamma_1 = \gamma_2 = 0$) significantly lowers the regression's fit, then there is evidence for foreign spillovers. Similarly, a significant loss in the regression's explanatory power due to the exclusion of past domestic yields (setting $\beta_1 = \beta_2 = 0$) is a sign of domestic market inefficiency.

In addition, by testing the variables individually one can also gain information as to the form of the inefficiency. If the current change in yield depends on domestic or foreign past levels of yields (the regressions' fit declines significantly if β_1 or γ_1 is excluded) this is a sign of error correction or mean reversion, a phenomenon we will call "long-run inefficiency". Long-run inefficiency indicates that future short-run returns are predictable based on the difference of current returns from the long-run equilibrium.[12] On the other hand, dependence of current changes in yields on past changes implies a more transitory dependence, which we will label "short-term inefficiency".

Results of these tests are presented in Table 3. The table reports the p-values of chi-squared tests of the regressions' likelihood ratios under the coefficient restrictions described above—whether the change in current yields depend significantly on lagged changes in domestic or foreign yields (short-run inefficiency), levels of these yields (long-run inefficiency), or both (overall inefficiency). The results suggest that:

- *For real interest rates there is strong evidence of spillovers from U.S. markets abroad and no evidence of reverse causation*. The tests reveal that past U.S. yields spillover (Granger-cause) current foreign yields in four of the six other countries, the exceptions being Australia (where the test fails only marginally) and Japan (which has a short sample). In addition, consistent with the "old" nature of some of the U.S. lagged data, most of these spillovers reflect "long-run" linkages while in many cases domestic markets fail the "short-term" test of efficiency, suggesting that the more up-to-the-moment domestic data could be capturing some of the spillovers from the United States. By contrast, none of the 36 entries for the United States are significant at conventional levels.

- *For inflation expectations the evidence for spillovers is weaker and more mixed with regard to market efficiency*. U.S. inflation expectations Granger-cause their foreign counterparts in two of six markets. In addition, all of the foreign markets are inefficient with regard to their own past yields. However, these characteristics—domestic inefficiency and some foreign spillovers—also appear prevalent for U.S. expectations, suggesting a more subtle process of international interactions for inflation expectations than for real interest rates. Types of spillovers are also more eclectic for these results.

- *For nominal yields there is strong evidence of U.S. spillovers to foreign markets and some signs of a limited reverse effect*. There are significant U.S. spillovers in four of six foreign markets, while spillovers in the other direction only occur in two markets. The evidence on domestic inefficiency is more surprising. While only two foreign markets show signs that past prices help forecast current ones, several tests indicate domestic inefficiency in the highly liquid U.S. market. The types of spillovers present again reflect a range of linkages.

[12] Note that, since interest rates are a random walk, the presence of cointegration would not influence these results. In any case, standard tests show little evidence of cointegration.

Table 3. International Bond Market Spillovers at a Daily Frequency
(P-values: January 2, 2002 to December 29, 2006)

		Real Interest Rates				Inflation Expectations				Nominal Interest Rates			
		Foreign Market		United States Market		Foreign Market		United States Market		Foreign Market		United States Market	
		United States	Domestic	Foreign	Domestic	United States	Domestic	Foreign	Domestic	United States	Domestic	Foreign	Domestic
Australia	Short-run	0.06	***0.01***	0.97	0.11	**0.03**	0.30	***0.01***	***0.00***	0.12	**0.04**	0.15	0.07
	Long-run	0.28	0.08	0.26	0.14	0.44	**0.04**	0.41	0.17	**0.01**	0.67	0.21	0.37
	Overall	0.12	***0.00***	0.33	0.06	**0.05**	**0.04**	**0.03**	***0.00***	0.08	***0.01***	0.16	0.10
Canada	Short-run	0.50	***0.00***	0.60	0.30	0.13	***0.00***	0.14	***0.00***	**0.03**	0.10	0.38	0.10
	Long-run	***0.00***	***0.00***	0.19	0.18	0.06	**0.01**	0.06	0.58	0.22	0.24	**0.04**	**0.01**
	Overall	**0.04**	***0.00***	0.33	0.25	0.18	***0.00***	0.08	**0.02**	0.10	**0.03**	0.06	**0.01**
France	Short-run	0.96	0.37	0.42	0.21	0.31	**0.02**	0.16	***0.00***	0.62	0.82	0.10	**0.02**
	Long-run	***0.01***	***0.00***	0.91	0.23	0.65	0.25	***0.00***	***0.00***	0.07	0.83	0.25	**0.04**
	Overall	**0.03**	***0.00***	0.67	0.21	0.49	**0.02**	***0.00***	***0.00***	0.95	0.18	0.10	***0.00***
Japan 1/	Short-run	0.99	***0.01***	0.53	0.44	0.14	***0.00***	0.77	0.48	0.97	0.49	0.26	0.14
	Long-run	0.12	**0.01**	0.36	0.51	***0.01***	***0.00***	0.93	0.16	**0.03**	0.12	0.70	0.30
	Overall	0.47	***0.00***	0.51	0.62	0.20	***0.00***	0.89	0.30	0.21	0.06	0.45	0.23
Sweden	Short-run	0.80	***0.00***	0.89	0.30	0.17	***0.01***	0.53	***0.00***	0.61	0.32	0.49	0.06
	Long-run	**0.01**	***0.00***	0.35	0.17	0.84	***0.00***	0.07	***0.01***	0.14	0.73	0.11	**0.02**
	Overall	0.12	***0.00***	0.59	0.22	0.39	***0.00***	0.26	***0.00***	0.58	0.36	0.20	***0.01***
United Kingdom	Short-run	0.80	0.25	0.06	0.16	0.05	0.07	0.14	***0.00***	0.65	0.62	***0.01***	***0.00***
	Long-run	***0.01***	***0.00***	0.22	0.20	0.43	**0.02**	0.07	***0.01***	**0.03**	0.88	0.27	0.10
	Overall	0.06	***0.00***	0.06	0.13	0.14	**0.02**	0.08	***0.00***	0.85	0.09	***0.01***	***0.00***

Source: IMF staff calculations.
Note: Bold = significant at 5 percent level; Bold italic = significant at 1 percent level.
1/ Sample begins April, 2004.

Table 4. International Bond Market Spillovers at a Weekly Frequency
(P-values: January 4, 2002 to December 29, 2006)

		Real Interest Rates				Inflation Expectations				Nominal Interest Rates			
		Foreign Market		United States Market		Foreign Market		United States Market		Foreign Market		United States Market	
		United States	Domestic	Foreign	Domestic	United States	Domestic	Foreign	Domestic	United States	Domestic	Foreign	Domestic
Australia	Short-run	***0.00***	***0.00***	0.52	0.89	***0.00***	**0.01**	0.86	0.74	***0.00***	***0.00***	0.38	0.88
	Long-run	0.10	**0.01**	0.19	0.13	**0.02**	***0.00***	0.54	0.23	***0.00***	0.11	0.16	0.43
	Overall	***0.00***	***0.00***	0.22	0.34	***0.00***	***0.00***	0.80	0.46	***0.00***	***0.00***	0.17	0.73
Canada	Short-run	**0.02**	0.29	0.89	0.70	0.17	0.82	0.70	0.93	0.59	0.30	0.95	0.71
	Long-run	***0.01***	***0.00***	0.23	0.22	**0.03**	***0.00***	0.17	0.78	0.17	0.35	**0.05**	**0.04**
	Overall	***0.01***	***0.01***	0.49	0.45	0.06	***0.01***	0.38	0.94	0.34	0.40	0.11	0.09
France	Short-run	0.46	0.32	0.22	1.00	0.55	0.14	***0.01***	0.19	0.10	0.08	0.62	0.36
	Long-run	**0.01**	***0.00***	0.79	0.34	0.49	0.08	***0.00***	***0.00***	0.05	0.93	0.14	0.09
	Overall	**0.03**	***0.00***	0.37	0.65	0.51	0.08	***0.00***	***0.01***	0.25	0.06	0.38	0.13
Japan 1/	Short-run	0.06	0.54	0.66	0.54	0.67	0.20	0.41	0.52	0.80	***0.01***	0.88	0.78
	Long-run	***0.00***	***0.00***	0.44	0.47	**0.01**	**0.02**	0.62	0.15	***0.00***	**0.02**	0.54	0.55
	Overall	***0.00***	**0.01**	0.37	0.70	0.07	**0.04**	0.79	0.24	***0.01***	0.06	0.82	0.80
Sweden	Short-run	0.08	0.43	0.98	0.89	0.43	***0.00***	0.20	0.44	0.16	**0.02**	0.81	0.48
	Long-run	0.10	**0.02**	0.42	0.19	0.85	**0.01**	0.32	**0.04**	0.17	0.94	0.07	**0.05**
	Overall	0.09	0.10	0.57	0.38	0.78	***0.00***	0.32	0.13	0.10	0.19	0.22	0.08
United Kingdom	Short-run	0.22	0.08	0.72	0.65	0.30	0.52	0.50	0.41	**0.03**	**0.04**	0.22	0.13
	Long-run	**0.04**	***0.00***	0.28	0.30	0.36	**0.04**	0.33	0.13	**0.01**	0.73	0.07	0.25
	Overall	**0.03**	***0.00***	0.54	0.47	0.55	0.19	0.56	0.28	0.18	***0.01***	0.13	0.19

Source: IMF staff calculations.
Note: Bold = significant at 5 percent level; Bold italic = significant at 1 percent level.
1/ Sample begins April, 2004.

To further explore the data, we also examined changes in yields from the close of one week to the close in the next week. As overlapping trading hours are much less of an issue, we use first lags for all series. The results, reported in Tables 4, are broadly similar to the daily data—real interest rate linkages run entirely from the United States to foreign markets. There is somewhat stronger evidence of U.S. spillovers to other countries in inflation expectations, and somewhat weaker evidence of spillovers in nominal bonds and inflation expectations in the opposite direction. It should be emphasized that the absence of significance of these tests does not imply that there are no links between markets, as the effects could occur contemporaneously. Thus, the possibility that foreign markets are of some importance for U.S. interest rates cannot be ruled out completely. However, these data establish that foreign markets do depend significantly on U.S. developments.

B. Intraday Tests of Market Efficiency

The intraday data are particularly useful for analyzing international spillovers as the data allow a more direct test of the influence of foreign markets on domestic returns. The daily data, captured at the close of each day, are affected by events abroad that occur overnight. This obscures the timing of events so as to make difficult the assignment of contemporaneous correlation between markets. However, there is no such barrier with intraday data, as the market can be tracked from the opening bell, which should incorporate developments in foreign markets. As a result, foreign market activity while the domestic market is closed can be used to test for inefficiency.

This advantage of the intraday data, however, has to be weighed against the short data set (the intraday history is only available for 50 days) which puts a premium on relatively simple specifications. In addition, the data for Australia and Japan are expressed as yields and those for other countries are in prices. While the two are closely correlated, it complicates interpretation of the coefficients. Finally, given the importance of market liquidity when measuring changes in bond prices over a few hours, we limit the analysis to conventional bonds, whose markets have higher turnover.

Reflecting these considerations, the specification we use is:

$$\begin{aligned} \Delta i_t &= \alpha + \beta_1 \Delta i_{t-1} + \beta_2 \Delta i^*_{t-1} + \varepsilon_t \\ \Delta i^*_t &= \alpha + \gamma_1 \Delta i^*_{t-1} + \gamma_2 \Delta i_{t-1} + \varepsilon_t \end{aligned} \qquad (10)$$

where i_t is the U.S. bond price, i_t^* is the foreign price (or yield), α, β, and γ are coefficients, and ε_t is a conventional error term. The coefficients β_1 and γ_1 test for dependence on earlier price changes in the home market while β_2 and γ_2 test for dependence international spillovers.

The variables included in each regression depend on the timing of trading across the markets:

- Asian markets:

  - *U.S. regression*: *Dependent variable* is the change in price from opening to close of U.S. markets. *Prior information* is that day's change in yield from opening to close in Asian markets and the previous day's change in price in U.S. markets.

  - *Foreign regression*: *Dependent variable* is the change in yield from opening to close of local markets. *Prior information* is the previous day's change in price from opening to close in U.S. markets and the change in yield in the domestic market.

- European markets:

  - *U.S. regression: Dependent variable* is the change in price from the opening of U.S. markets to close of European markets. *Prior information* is that day's change in price from opening of European markets to the opening of the U.S. market and the previous day's change in prices in U.S. markets.

  - *Foreign regression: Dependent variable* is the change in price from the opening of European markets to opening of U.S. markets. *Prior information* is previous day's change in price in U.S. markets after European markets have closed and the previous day's change in local markets.

- Canadian market: Canada was excluded from the intra-day analysis as trading is simultaneous, so the intraday data provide no useful information.

The results from these regressions, reported in Table 5, indicate strong evidence of U.S. spillovers to other markets and no evidence for spillovers in the other direction. Information from U.S. markets is significant in every case except Japan. Indeed, for those countries with data on prices the coefficients (not reported for the sake of brevity) are insignificantly different from one, suggesting that U.S. news is incorporated one-for-one into foreign markets. There is also some evidence of domestic market inefficiency in Europe. The explanatory power of the U.S. information is not inconsequential, as adding it to a regression including only domestic information raised the R^2 by 5 to 10 percent.

It should be stressed that these opening market yields differ significantly from closing values the day before, and hence should incorporate news that occurred overnight.[13] By contrast, movements in U.S. markets are not affected by developments elsewhere. These results are similar to those in Goldberg and Leonard (2003), Ehrmann and Fratzscher (2003, 2005), and Ehrmann, Fratzscher, and Rigobon (2007), who also find strong spillovers from U.S. interest rates to European rates but extremely weak ones from Europe to the United States.

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[13] One concern is that yields at the opening of a session may not fully reflect events overnight. Accordingly, we also ran the regressions using data from 30 minutes into the European trading sessions—when overnight information should have been fully absorbed—and obtained similar results.

Table 5. Intraday Spillovers in Nominal Bond Markets
(December 4, 2006 to April 17, 2007)

	Foreign market				U.S. market			
	P-value		Adjusted R-squared		P-value		Adjusted R-squared	
	Domestic	United States	Domestic	Both	Domestic	Foreign	Domestic	Both
Asian countries (yields)								
Australia	0.64	***0.02***	-0.01	0.06	0.85	0.19	0.00	-0.01
Japan	0.47	0.22	-0.01	0.00	0.46	0.30	0.00	0.00
European countries (prices)								
France	***0.00***	***0.00***	0.04	0.16	0.61	0.43	0.00	0.00
Italy	***0.00***	***0.00***	0.10	0.22	0.84	0.28	0.00	-0.01
Sweden	***0.00***	***0.00***	0.06	0.12	0.68	0.38	0.00	-0.01
United Kingdom	***0.05***	***0.02***	0.01	0.05	0.87	0.20	0.00	-0.01

Source: IMF staff calculations.
Note: The table reports p-values that the change in U.S. (foreign) bond prices or yields when the other market is closed is significant for the foreign (U.S.) market the next time it is open. The domestic variable is the lagged one-day change in price or yield. P-values in bold italics are significant at the 5 percent level.

Putting together the evidence from the intraday, daily, and weekly data, there is strong evidence of spillovers from U.S. markets to foreign markets. This evidence is most convincing with regard to real interest rates and weakest for inflation expectations. The evidence on reverse causation shows no evidence of spillovers to U.S. real interest rates but some evidence for nominal bonds and inflation expectations. Overall, these results are consistent with a world in which real interest rates are significantly determined by events in U.S. markets.

IV. Quantifying Spillovers

We now move on to test the relative importance of bond spillovers across countries. Our results on efficiency suggest that spillovers for real interest rates and inflation expectations are somewhat different, so we focus on a specification using the daily data set that includes both of these components of nominal yields. Following on from the observation that our specification for testing the efficiency of markets was a reparameterization of a VAR in levels with two lags, we use such a VAR to quantify international spillovers. As the focus is on dynamic responses rather than the efficiency of the markets, first lags of U.S. yields are used. More specifically, the following VAR was estimated using data on the United States and each foreign market:

$$Z_t = A_1 Z_{t-1} + A_2 Z_{t-2} + \varepsilon_t \tag{6}$$

where Z_t is the vector (r_t, p_t, r_t^*, p_t^*), the A vectors are coefficients, and ε_t is a vector of errors.

The order of the Choleski decomposition requires discussion as, given significant contemporaneous correlations, it is central to the results. Due to the predominance of spillovers from the United States to foreign markets, our base specification places the U.S. variables first in the ordering and foreign variables last—r_t, p_t, r_t^*, p_t^*. This assigns any contemporaneous correlation between U.S. and foreign variables to the United States, which appears to be justified given the results of Section III. Given the evidence that there could be feedback from foreign to U.S. markets with regard to inflation expectations, we also report an alternate specification. For the European and Canadian data, U.S. inflation expectations are placed last—r_t, r_t^*, p_t^*, p_t. For the Asian markets, as there is no overlap in trading, we ran r_t^*, p_t^*, r_t, p_t as the alternate ordering, with any contemporaneous correlation assigned to the Asian markets. Elsewhere, overlapping trading sessions make the appropriate ordering based on market trading times less clear, so r^{US} remains before r^*.[14]

We report the results of the VAR in terms of impulse response functions (IRFs, shown in Appendix I, Figures 4-9) and variance decompositions (Table 6). The IRFs indicate that U.S. real interest rates and inflation expectations are extremely close to a random walk. A one standard deviation shock to U.S. real rates moves them up by around 0.045 percent, with a very slight tendency to fall over the next 50 days. None of the other variables in the VARs—U.S. inflation expectations, foreign real rates, and foreign inflation expectations have any significant impact. U.S. inflation expectations show a similar profile, except the decay over time is more pronounced and the French regression finds some significant long-term effects from foreign variables.

By contrast, foreign variables appear subject to significant spillovers from U.S. markets. Domestic shocks in foreign real rates are smaller than in the United States, varying between 0.015 and 0.03 percent, but these are augmented by spillovers from U.S. real interest shocks that vary between 0.01 to 0.025 percent. In round figures, between one-quarter and one-half of U.S. real interest rate shocks are transmitted to foreign markets. These shocks account for a similar proportion of movements in foreign real rates. Finally, changes in U.S. inflation expectations generally have a temporary positive impact on real rates abroad.

Foreign inflation expectations have similarly-sized own shocks to foreign real interest rates (0.015-0.03 percent). They also generally exhibit significant positive spillovers from both U.S. inflation expectations and (to a somewhat lesser extent) U.S. real rates. Finally, they are usually negatively affected by shocks to local real rates. One interpretation of the divergent signs with regard to spillovers from U.S. and domestic real rates is that increases in *U.S.* real rates are seen as a precursor of global inflation pressures (hence the positive relationship) while higher *domestic* real rates are seen as a reflection of monetary tightening, and hence lower expected inflation in the future.

The variance decomposition in Table 6 reports the importance of each shock in the outcome of each variable after 50 days. The results in the left columns, which use the base Choleski decomposition, confirm that outcomes for U.S. real rates and inflation expectations are dominated by local shocks. By contrast, 20-60 percent of foreign real rate variances are determined by U.S. real interest rate shocks, with most of the rest reflecting domestic real interest rate shocks—U.S. and domestic inflation expectations generally play only a minor

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[14] We also ran r^{US}, p^*, r^*, p^{US} for all countries but the results were quite similar to r^{US}, r^*, p^*, p^{US}.

Table 6. Variance Decompositions After 50 Days

(Daily data from January 2, 2002 to December 29, 2006)

VAR Ordering	RUS, PUS, R*, P*					RUS, R*, P*, PUS			
Forecasted	Percent attributed to				Forecasted	Percent attributed to			
variable	RUS	PUS	R*	P*	variable	RUS	PUS	R*	P*
Australia 1/					Australia 1/				
RUS	95.9	0.2	0.1	3.8	RUS	90.2	0.2	1.5	8.1
PUS	1.0	93.0	3.1	3.0	PUS	0.5	94.9	1.1	3.5
R*	29.7	8.1	59.0	3.2	R*	23.2	4.6	70.4	1.8
P*	25.5	20.9	7.7	45.8	P*	20.3	23.3	4.3	52.2
Canada					Canada				
RUS	98.1	0.1	0.0	1.8	RUS	98.1	0.5	0.0	1.5
PUS	1.8	97.7	0.1	0.3	PUS	1.8	59.1	3.8	35.2
R*	44.3	4.1	50.9	0.8	R*	44.3	7.8	46.5	1.4
P*	15.0	41.1	8.1	35.8	P*	15.0	3.5	3.3	78.2
France					France				
RUS	99.8	0.1	0.0	0.1	RUS	99.8	0.0	0.0	0.1
PUS	0.5	80.2	6.7	12.5	PUS	0.5	61.8	2.4	35.2
R*	58.7	1.0	37.2	3.1	R*	58.7	4.8	35.2	1.4
P*	2.5	27.6	1.9	68.0	P*	2.5	7.6	0.2	89.8
Japan 1/ 2/					Japan 1/ 2/				
RUS	96.3	0.1	0.0	3.5	RUS	94.8	0.1	2.0	3.1
PUS	2.8	96.7	0.4	0.1	PUS	2.6	96.2	0.4	0.9
R*	35.8	4.6	47.0	12.7	R*	25.8	4.2	57.1	12.9
P*	1.3	29.3	1.7	67.6	P*	1.6	25.0	1.6	71.8
Sweden					Sweden				
RUS	98.9	0.9	0.2	0.1	RUS	98.9	0.7	0.2	0.2
PUS	0.1	97.3	1.1	1.5	PUS	0.1	87.6	0.4	11.9
R*	37.7	1.2	58.6	2.5	R*	37.7	2.8	58.0	1.5
P*	16.0	12.9	0.8	70.2	P*	16.0	2.5	0.4	81.1
United Kingdom					United Kingdom				
RUS	96.5	0.5	1.8	1.3	RUS	96.5	0.4	2.1	1.0
PUS	1.0	96.4	1.5	1.0	PUS	1.0	87.1	1.4	10.5
R*	32.3	2.3	60.2	5.2	R*	32.3	7.2	57.6	2.9
P*	5.4	19.5	7.5	67.6	P*	5.4	8.3	3.6	82.7
United States average					United States average				
RUS	97.6	0.3	0.4	1.8	RUS	96.4	0.3	1.0	2.3
PUS	1.2	93.6	2.2	3.1	PUS	1.1	81.1	1.6	16.2
Foreign average					Foreign average				
R*	39.7	3.5	52.1	4.6	R*	37.0	5.2	54.1	3.6
P*	10.9	25.2	4.6	59.2	P*	10.1	11.7	2.2	76.0

Source: IMF staff calculations.
1/ Alternate ordering for Australia and Japan is R*, P*, RUS, PUS.
2/ Sample begins in April, 2004.

Table 7. Variance Decompositions After One Year

(Weekly data from January 4, 2002 to December 29, 2006)

VAR Ordering	RUS, PUS, R*, P*					RUS, R*, P*, PUS			
Forecasted	Percent attributed to				Forecasted	Percent attributed to			
variable	RUS	PUS	R*	P*	variable	RUS	PUS	R*	P*
Australia 1/					Australia 1/				
RUS	85.4	4.0	3.9	6.6	RUS	58.2	4.6	12.9	24.3
PUS	6.5	87.5	3.9	2.0	PUS	6.1	88.5	3.2	2.2
R*	21.2	11.2	65.9	1.7	R*	1.8	16.5	78.1	3.5
P*	17.6	19.8	38.5	24.1	P*	8.1	22.2	14.2	55.5
Canada					Canada				
RUS	81.3	9.9	0.9	7.8	RUS	81.3	0.8	1.4	16.5
PUS	12.4	80.9	0.4	6.4	PUS	12.4	69.4	1.7	16.6
R*	44.8	31.5	16.9	6.8	R*	44.8	38.7	14.1	2.4
P*	13.8	59.8	4.0	22.4	P*	13.8	26.1	2.6	57.5
France					France				
RUS	95.4	1.1	0.1	3.5	RUS	95.4	0.3	0.0	4.3
PUS	9.2	73.8	13.9	3.1	PUS	9.2	36.4	7.8	46.6
R*	77.6	1.1	16.4	4.8	R*	77.6	6.3	15.4	0.7
P*	2.9	51.5	8.4	37.2	P*	2.9	5.1	3.9	88.1
Japan 1/ 2/					Japan 1/ 2/				
RUS	79.0	1.2	7.1	12.7	RUS	85.8	3.5	4.4	6.4
PUS	2.8	91.0	5.5	0.7	PUS	6.4	87.7	3.3	2.6
R*	56.1	4.2	23.6	16.1	R*	56.7	1.2	29.3	12.8
P*	3.8	35.6	13.0	47.5	P*	12.2	17.2	9.1	61.4
Sweden					Sweden				
RUS	90.8	5.2	0.1	3.9	RUS	90.8	1.3	0.3	7.6
PUS	6.8	88.9	4.2	0.1	PUS	6.8	73.7	1.3	18.2
R*	60.8	3.4	31.6	4.2	R*	60.8	8.4	29.8	1.1
P*	21.8	23.1	6.0	49.1	P*	21.8	2.5	4.1	71.6
United Kingdom					United Kingdom				
RUS	85.0	1.9	11.2	1.9	RUS	85.0	0.6	12.5	1.9
PUS	6.2	89.7	3.8	0.3	PUS	6.2	64.1	0.7	29.0
R*	41.3	5.0	28.6	25.1	R*	41.3	24.2	26.9	7.6
P*	5.3	46.9	19.3	28.6	P*	5.3	16.5	9.8	68.4
United States average					United States average				
RUS	86.2	3.9	3.9	6.0	RUS	82.8	1.8	5.3	10.2
PUS	7.3	85.3	5.3	2.1	PUS	7.8	70.0	3.0	19.2
Foreign average					Foreign average				
R*	50.3	9.4	30.5	9.8	R*	47.2	15.9	32.3	4.7
P*	10.9	39.5	14.9	34.8	P*	10.7	14.9	7.3	67.1

Source: IMF staff calculations.
1/ Alternate ordering for Australia and Japan is R*, P*, RUS, PUS.
2/ Sample begins in May, 2004.

role.[15] A similar quantitative pattern holds for foreign inflation expectations, except U.S. spillovers involve both U.S. inflation expectations and, to a lesser extent, U.S. real rates.

Results using the alternative Choleski decomposition for the three European markets and Canada are reported in Figures 10-15 (in Appendix I) and the right half of Table 6. Unsurprisingly, results for U.S. real rates remain essentially unchanged, while foreign inflation expectations now play a more important role in determining U.S. inflation expectations, although there continues to be evidence of U.S. spillovers, particularly from real rates, to European and Canadian inflation expectations even under this specification.

An important concern about the VARs using daily data is that the time frame over which the results are projected is only 50 days, a relatively short period for macroeconomic analysis. To analyze the responses over somewhat longer periods, we repeated the VAR analysis using end-week data. The results of the IRFs (not shown for the sake of brevity) indicate that the patterns seen in the daily data are also true for longer periods. Indeed, as can be seen from the variance decompositions for these VARs reported in Table 7, the importance of spillovers appears to rise over longer horizons. After a year, U.S. factors on average comprise more than half of the variation in foreign real interest rates (aside from an anomalous result for Australia, where the importance declines to 2 percent, from 23 percent in the daily data), and spillovers from U.S. to foreign inflation expectations also rise.

V. Conclusions

This paper has used data on inflation-indexed bonds to examine domestic and international spillovers across countries. Given the dominant position of the United States in global bond markets—U.S. markets comprise almost two-thirds of all private bond trading—the focus has been on links between the U.S. and other major industrial countries with inflation-indexed bonds (Australia, Canada, France, which can be seen as a proxy for the Euro Area, Japan, Sweden, and the United Kingdom).

Using a variety of techniques, a relatively uniform picture emerges:

- *Real interest rates appear much more linked across countries than the corresponding inflation expectations*, exactly as would be expected given that real rates are more likely to be affected by global factors while inflation expectations depend more on domestic events.

- *Real interest rate spillovers flow exclusively from the United States to other countries*, and U.S. markets appear to efficiently absorb available information, in contrast to their foreign counterparts. Tests indicate that U.S. factors on average determine about one-half of foreign real interest rates and that, if anything, this proportion rises over time.

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[15] These results are consistent with Chinn and Frankel (2005) and Cumby and Mishkin (1986).

- *There are smaller international spillovers in inflation expectations*, with the results again suggesting that U.S. spillovers tend to be the most important but with more evidence of reverse causation. U.S. market developments account for a quarter to a third of fluctuations in foreign inflation expectations, while reverse spillovers generally account for a smaller proportion of U.S. forecasts although the exact results depend on the chosen specification.

- *Spillovers from the United States to Japan are similar to those for other countries*. The absence of an active monetary policy, given that the Japanese had a zero interest rates over most of the sample period, does not appear to have materially affected the transition mechanism across international bond markets.

In addition to confirming the dominant position of U.S. bond markets in global yields, these results illuminate the underlying sources of these links. In particular, it makes perfect sense that U.S. markets are a major factor in determining global real rates, which should involve arbitrage across destinations, while inflation expectations—which are more domestically determined—are less integrated internationally and involve more complex dynamics. In addition, while U.S. developments are clearly crucial to global bond markets given the importance of its economy and financial markets, U.S. bond yields can and do also reflect international developments, such as the global “saving glut”. Deep and liquid U.S. bond markets are hence also central to global price discovery for long-term real rates.

Given the importance of long-term real interest rates in determining activity, these financial spillovers clearly represent an extremely important conduit from the United States to other industrial countries, particularly as real bond yields are also a key driver of many other financial instruments, such as equities.

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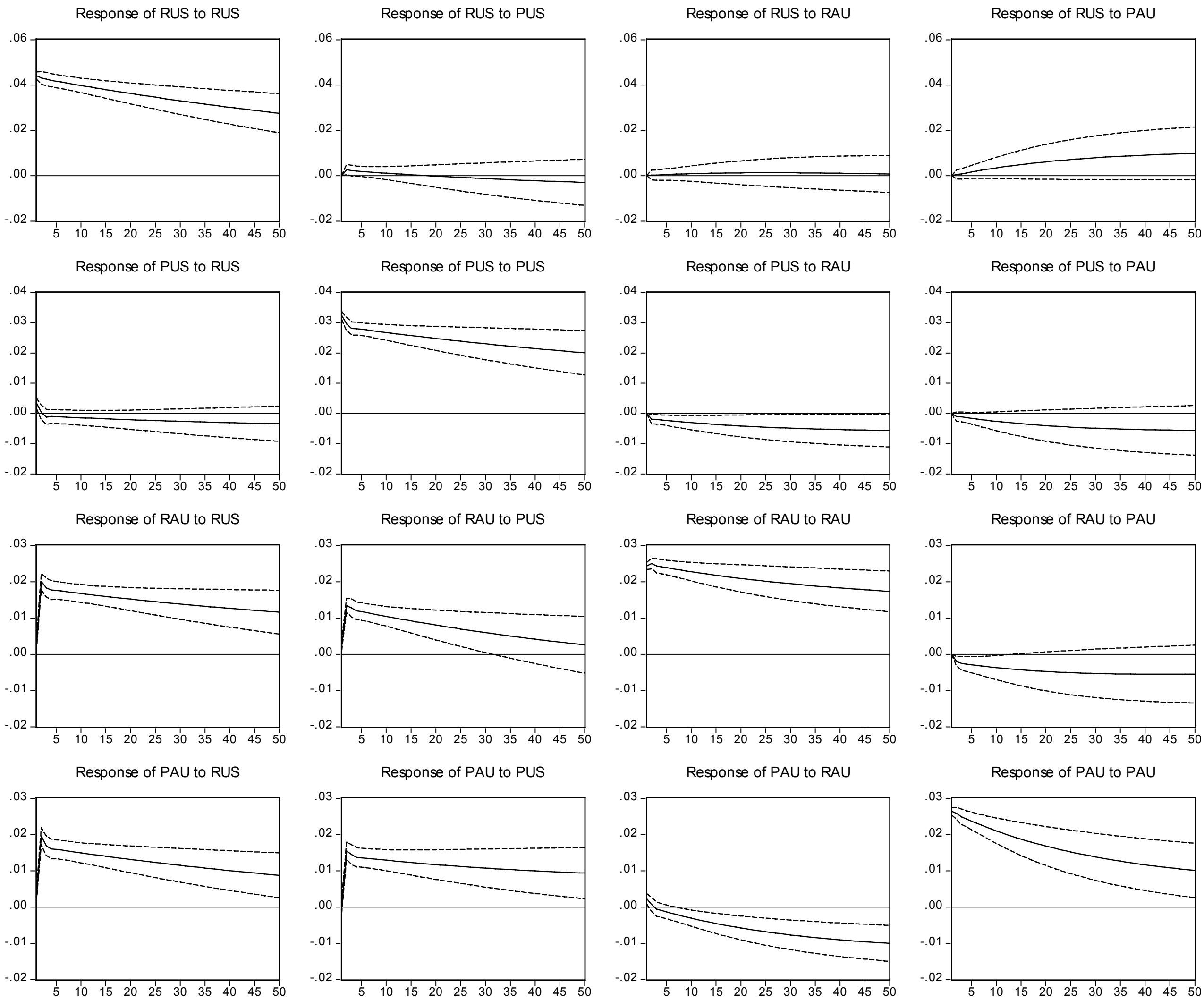
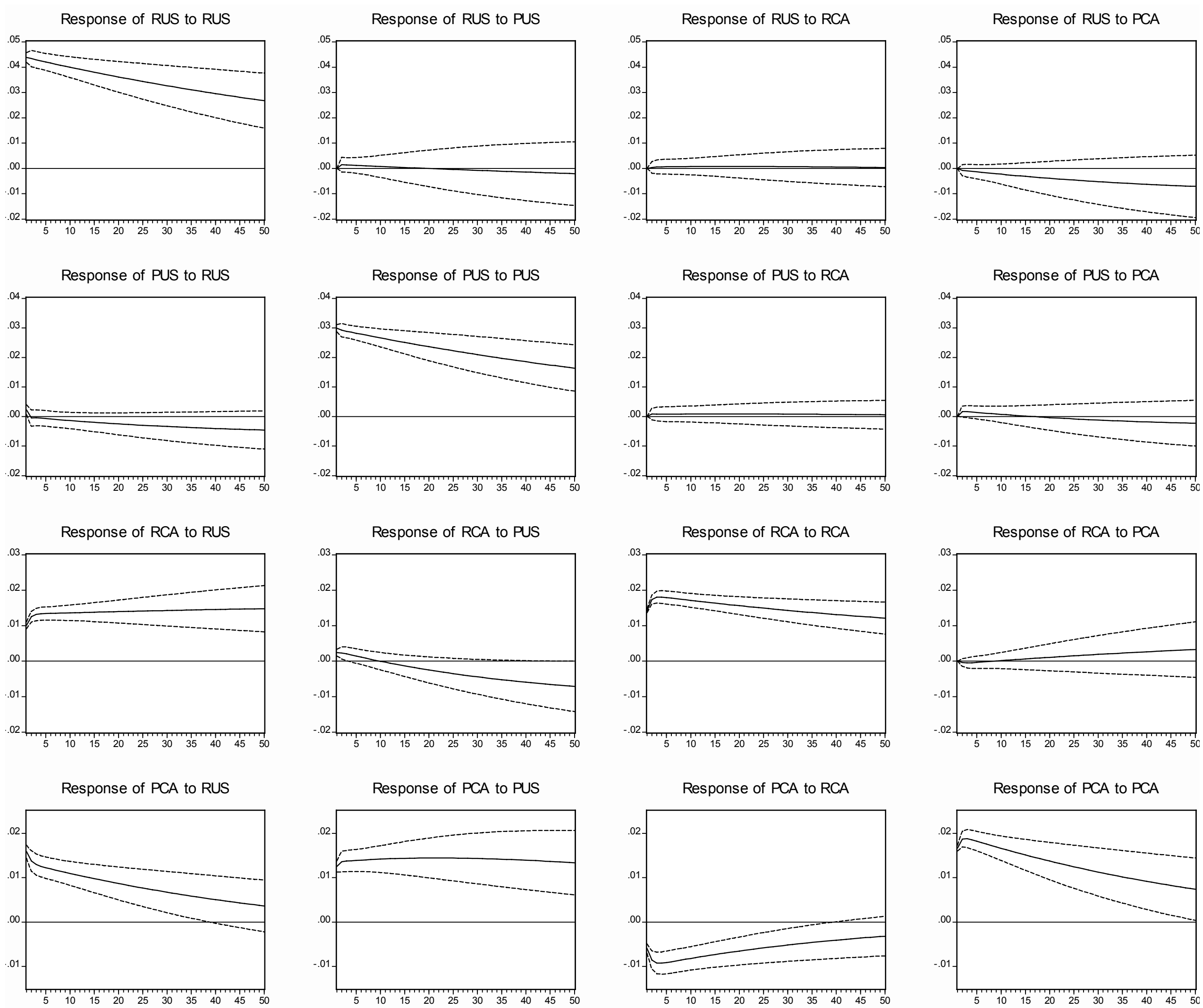
Figure 4. Impulse-Response Functions, Australia



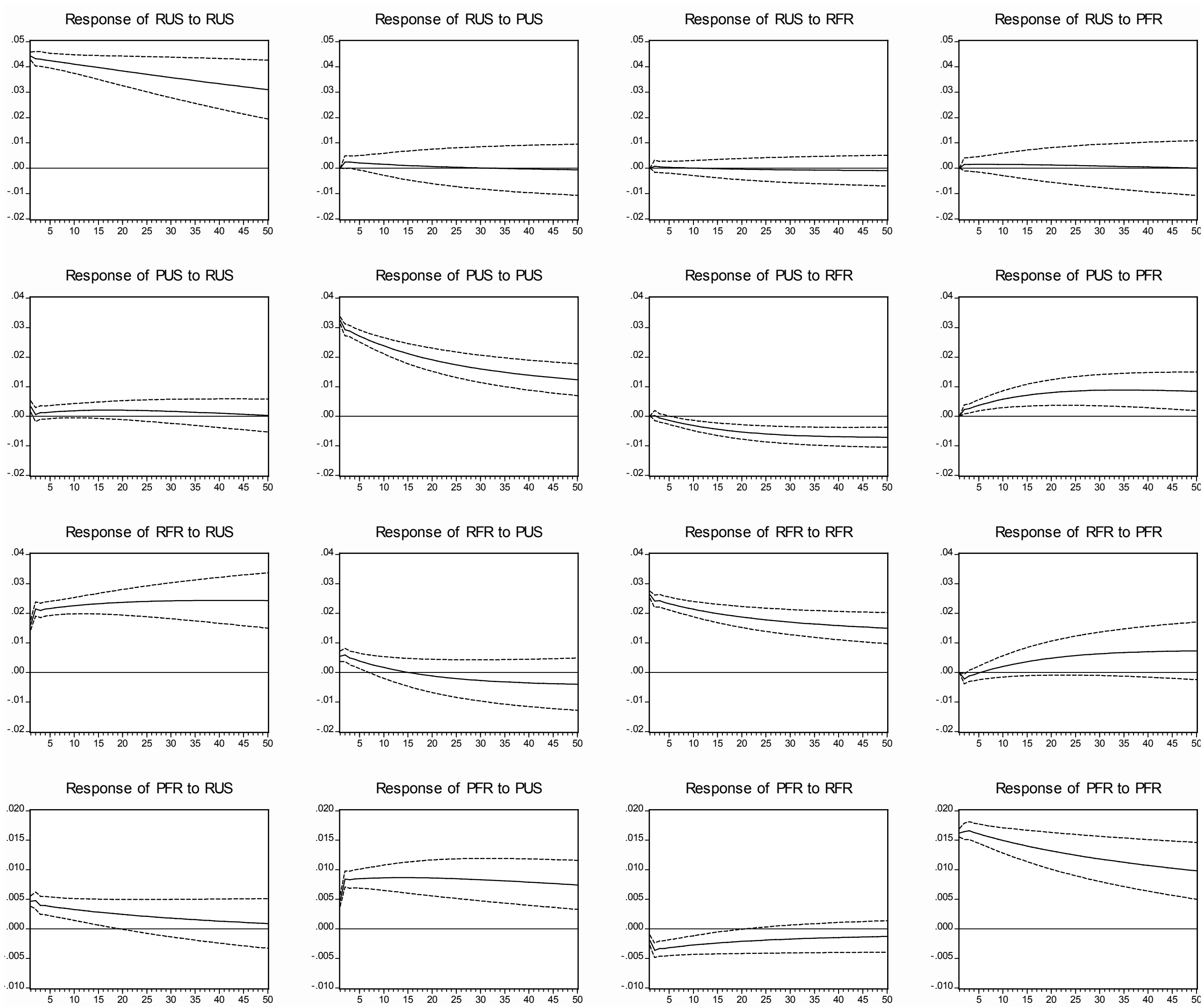
Source: IMF staff calculations.

Figure 5. Impulse-Response Functions, Canada



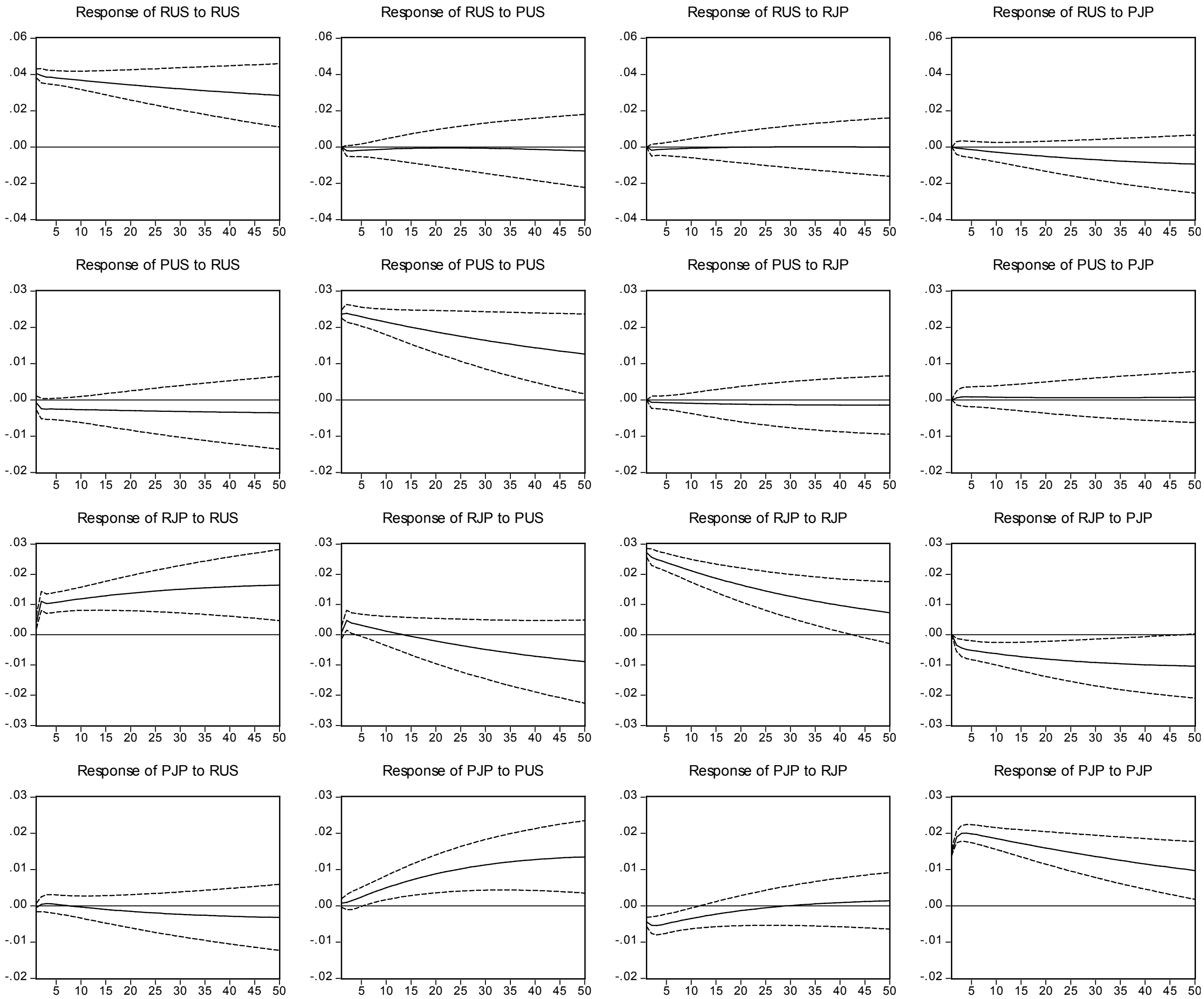
Source: IMF staff calculations.

Figure 6. Impulse-Response Functions, France



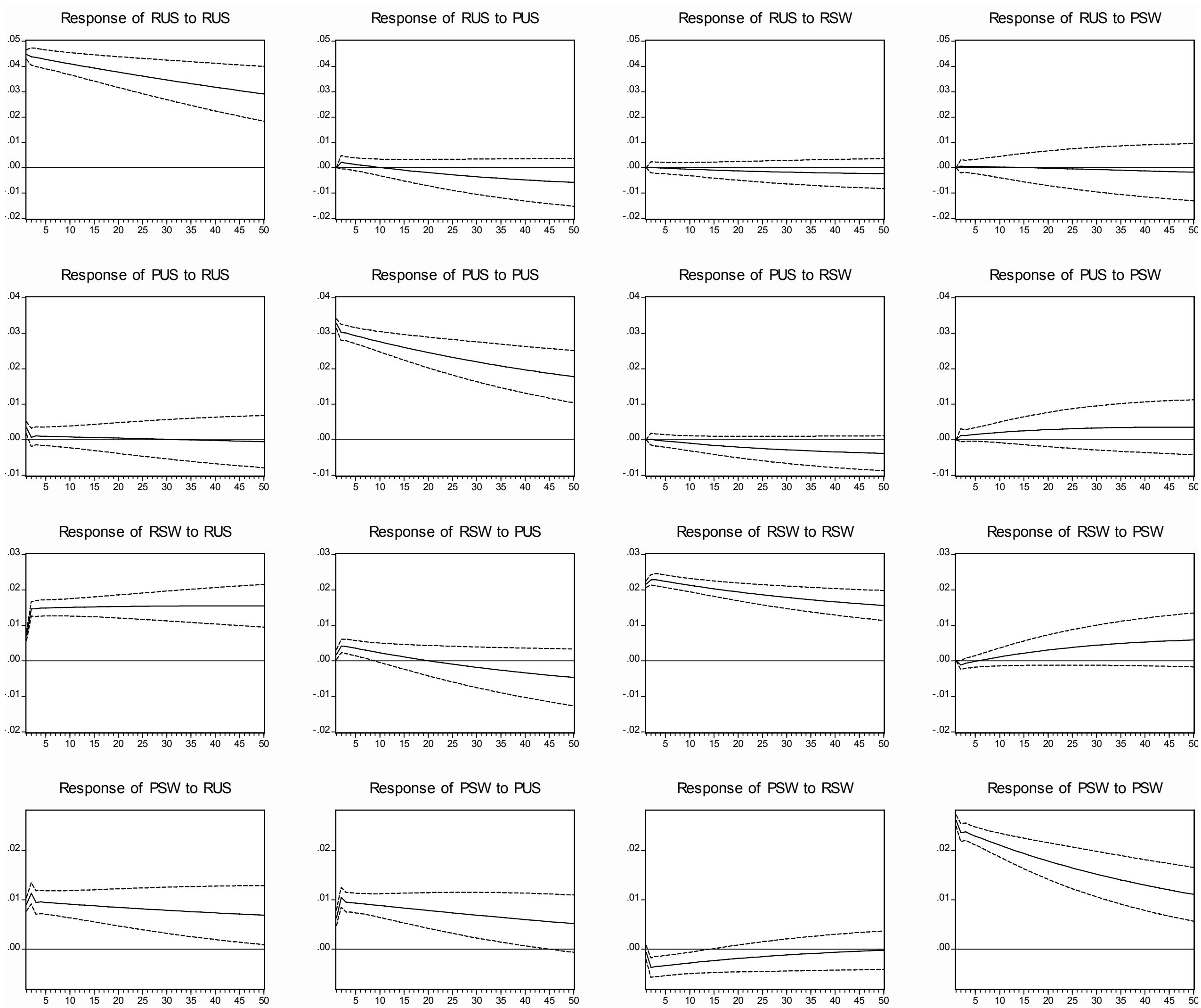
Source: IMF staff calculations.

Figure 7. Impulse-Response Functions, Japan



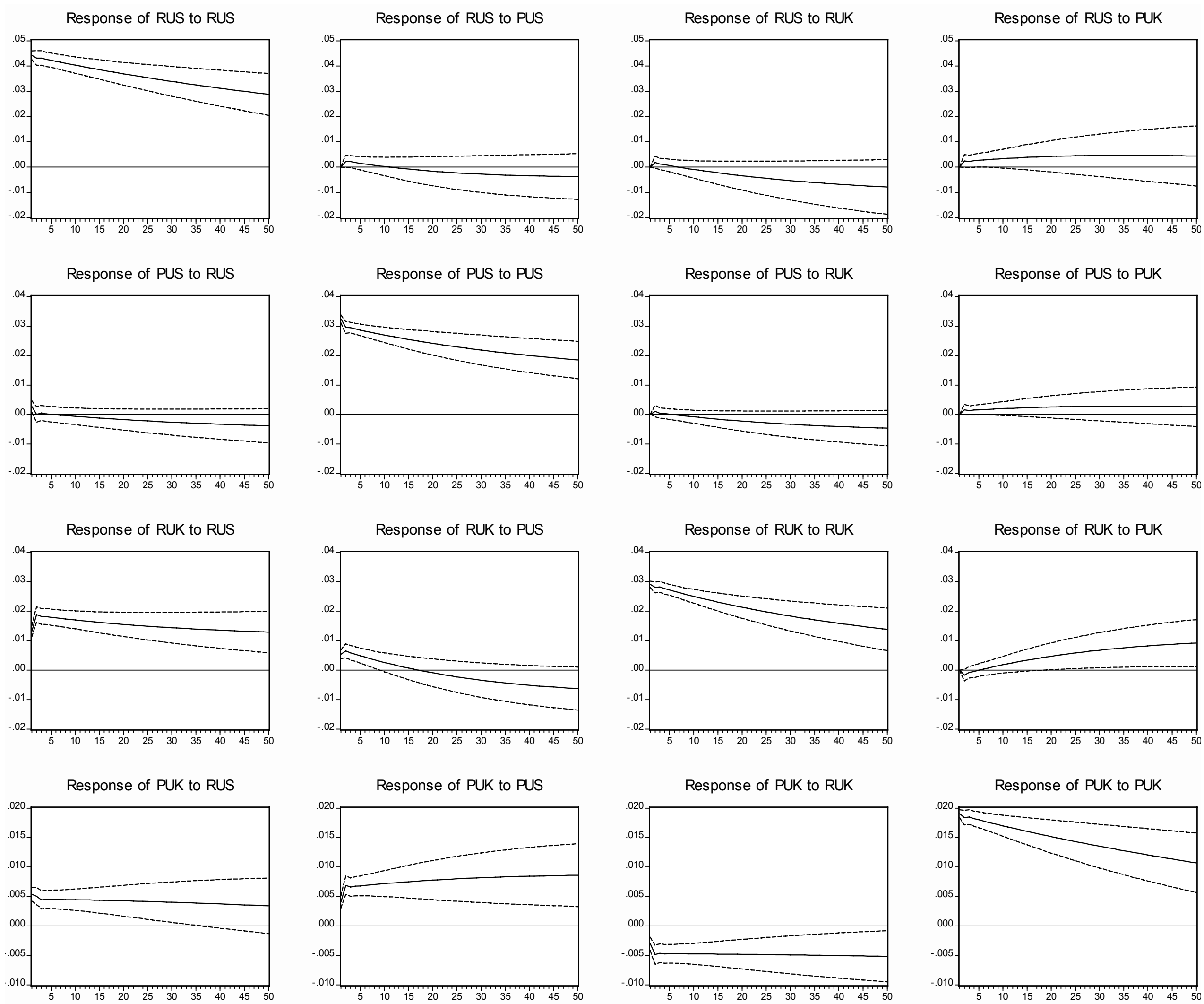
Source: IMF staff calculations.

Figure 8. Impulse-Response Functions, Sweden



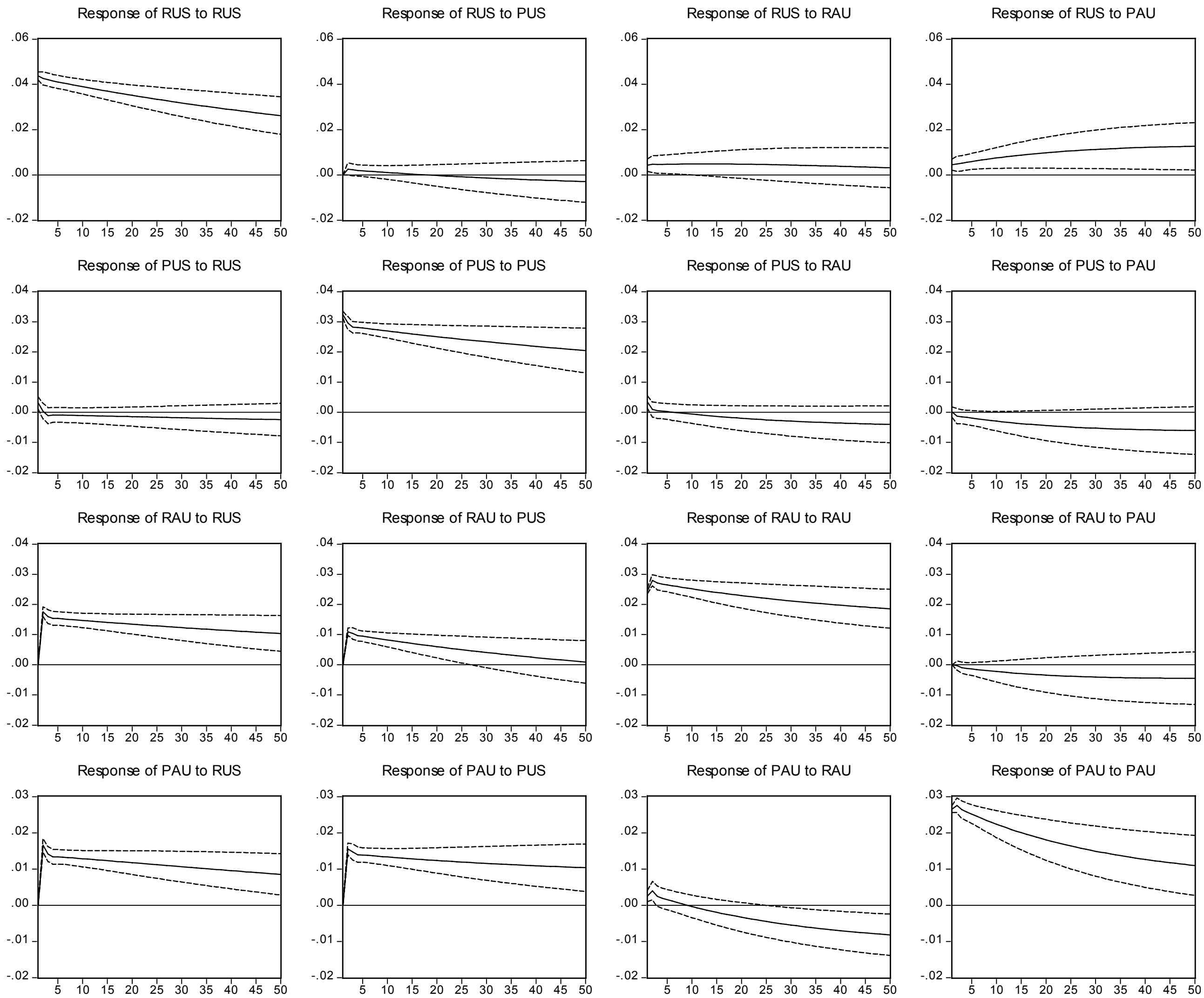
Source: IMF staff calculations.

Figure 9. Impulse-Response Functions, United Kingdom



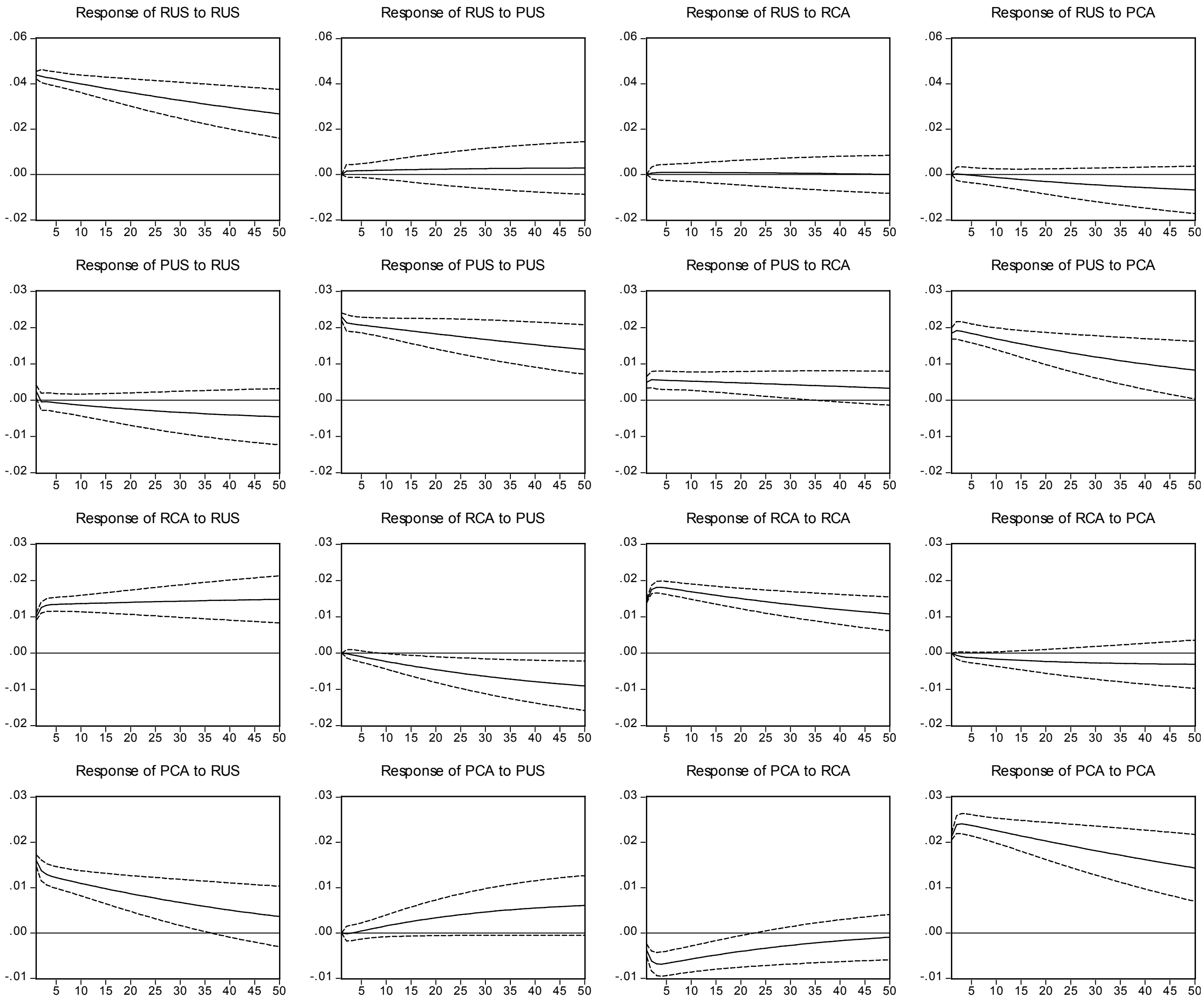
Source: IMF staff calculations.

Figure 10. Impulse-Response Functions for Alternate Ordering, Australia



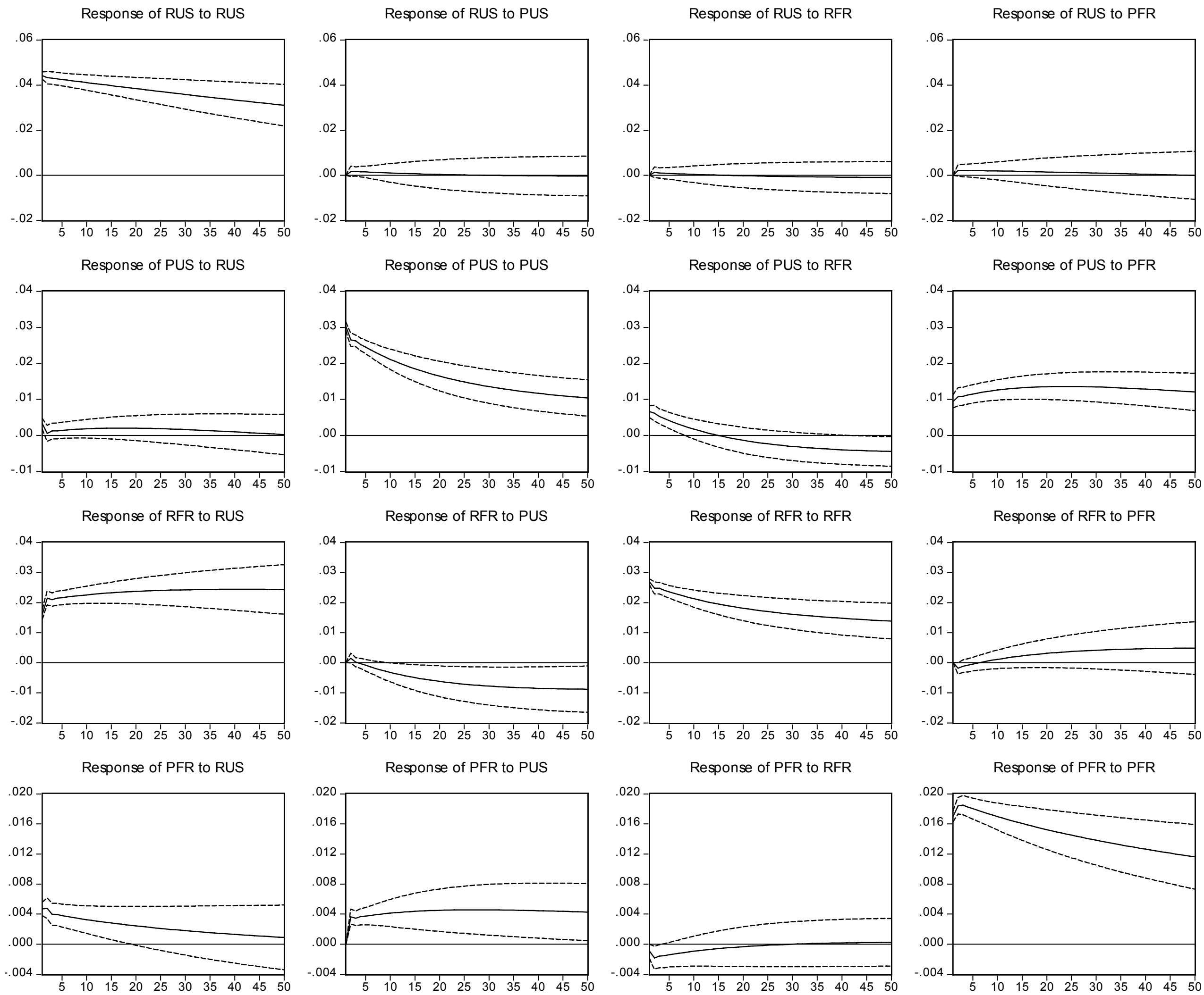
Source: IMF staff calculations.

Figure 11. Impulse-Response Functions for Alternate Ordering, Canada



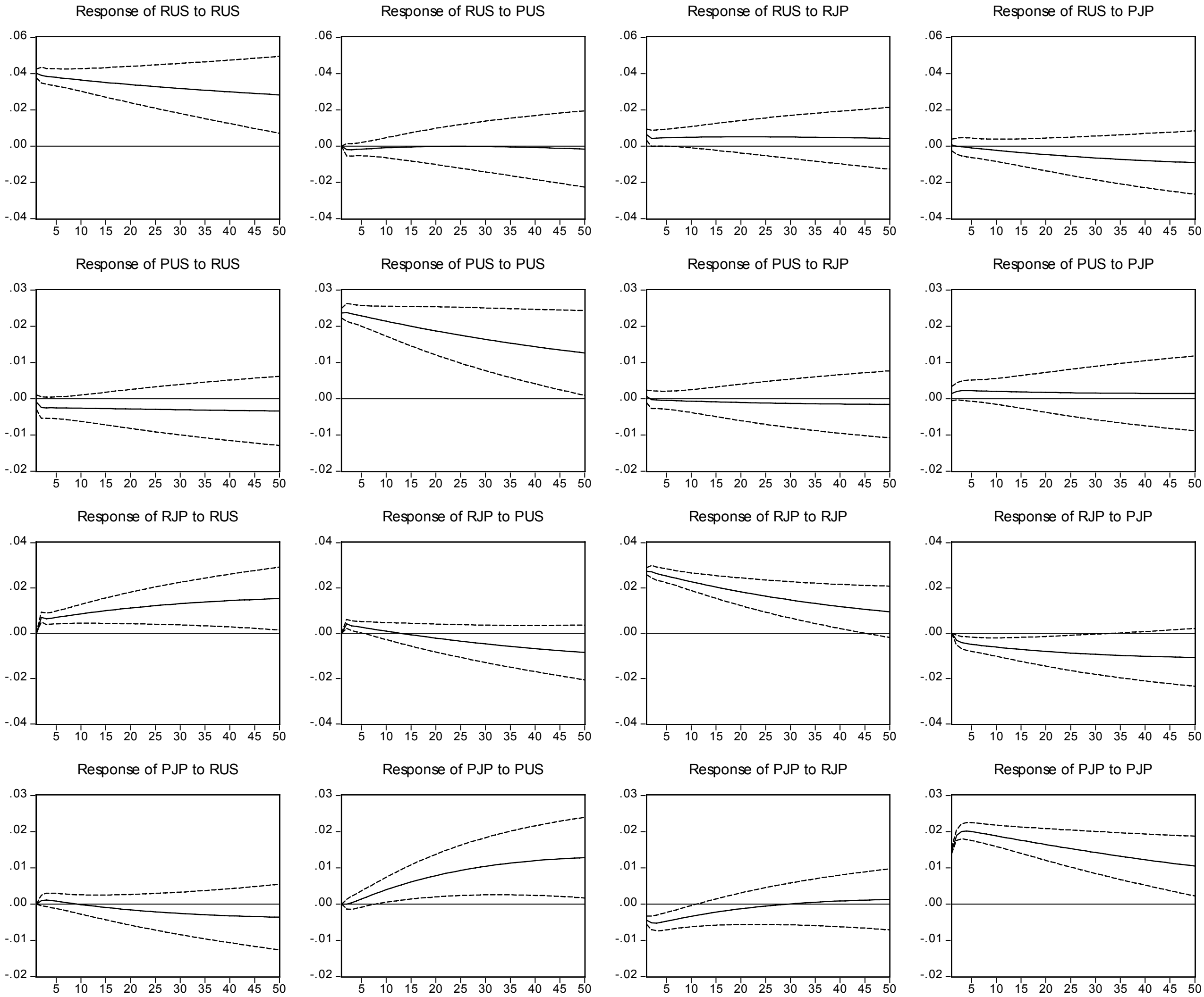
Source: IMF staff calculations.

Figure 12. Impulse-Response Functions for Alternate Ordering, France



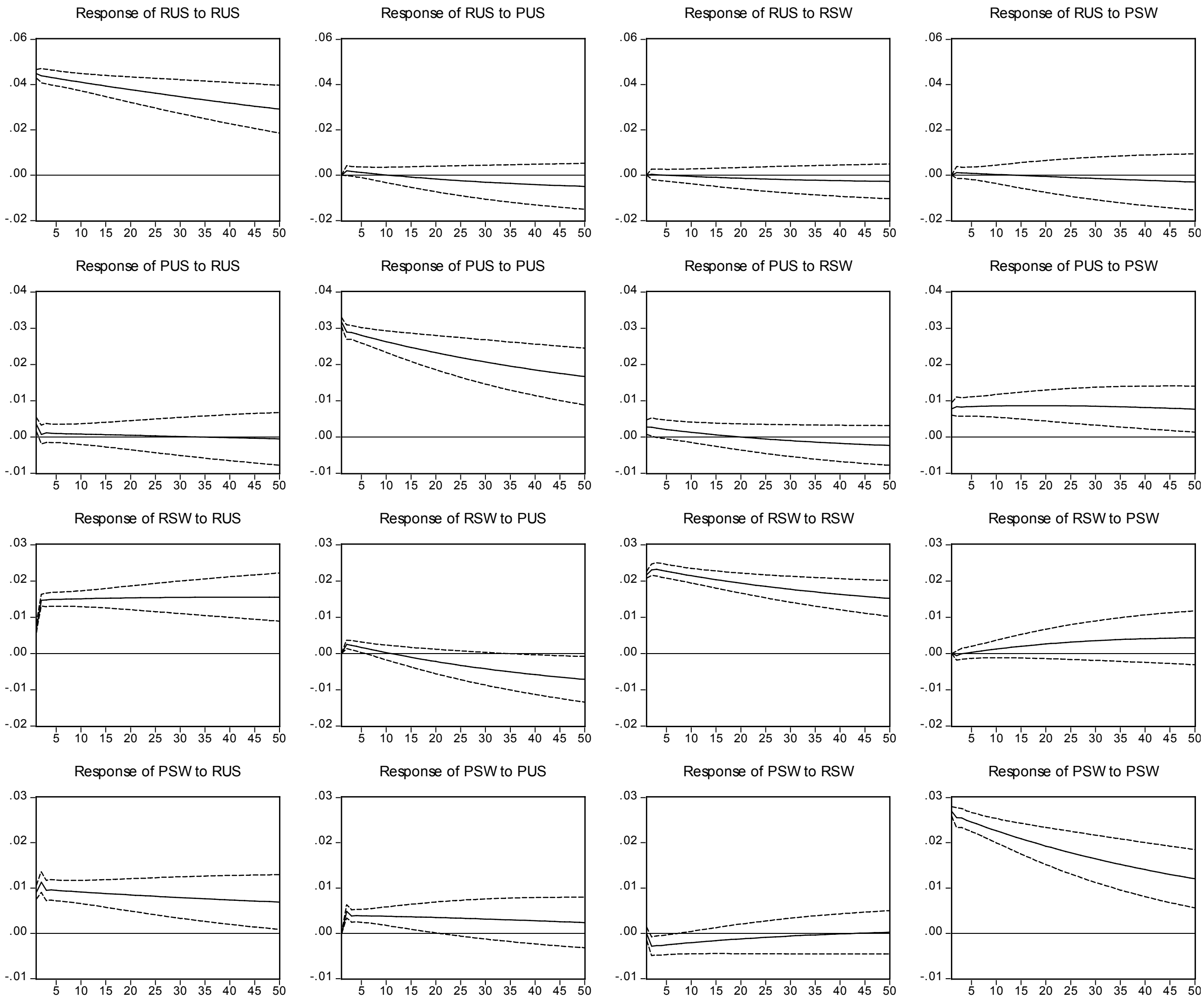
Source: IMF staff calculations.

Figure 13. Impulse-Response Functions for Alternate Ordering, Japan



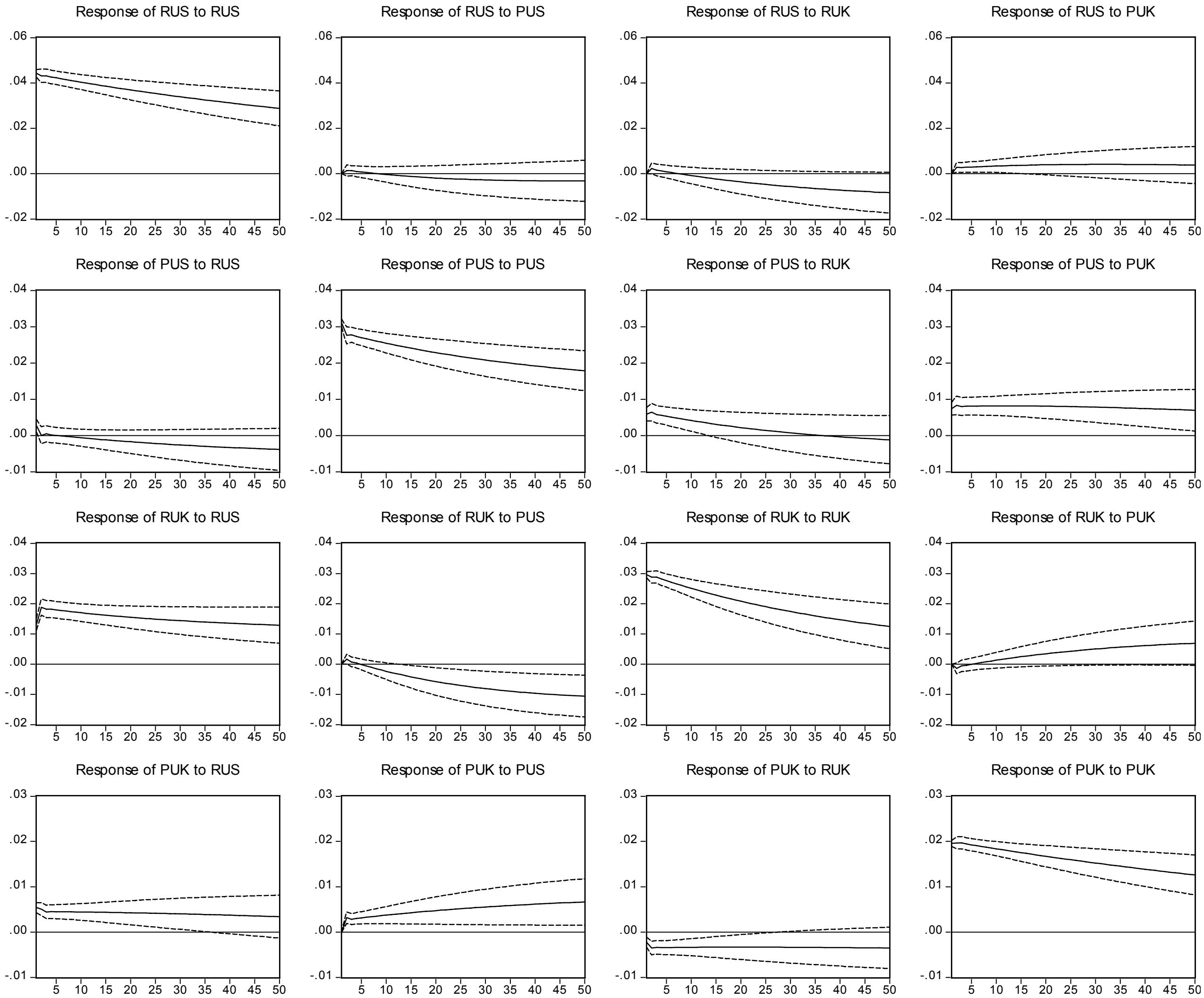
Source: IMF staff calculations.

Figure 14. Impulse-Response Functions for Alternate Ordering, Sweden



Source: IMF staff calculations.

Figure 15. Impulse-Response Functions for Alternate Ordering, United Kingdom



Source: IMF staff calculations.