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Foreign Entanglements: Estimating the Source and Size of Spillovers Across Industrial Countries

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Foreign Entanglements: Estimating the Source and Size of Spillovers Across Industrial Countries

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Abstract

VARs of real growth since 1970 are used to estimate spillovers between the U.S., euro area, Japan, and an aggregate of small industrial countries, which proxies for global shocks. U.S. and global shocks generate significant spillovers, while those from the euro area and Japan are small. This paper also calculates the standard errors of impulse-response functions including uncertainty over the proper Cholesky ordering. Extensions adding real net exports, commodity prices, and financial variables indicate that financial effects dominate spillovers. The results by subperiod underline the importance of the great moderation in U.S. output fluctuations and associated financial stability in lowering output volatility elsewhere.

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I. Introduction

The extent of spillovers across industrial regions remains an area of considerable interest and uncertainty. The importance of common or international factors in national output fluctuations is widely recognized given the long history of substantial international business cycle fluctuations (see, for example, Bordo and Helbling, 2004). Consequently, a large body of literature has sought to measure the contribution of common factors to national business cycle fluctuations. In recent studies, dynamic factor models have been the preferred approach since these models reduce common variations across individual countries to a small number of significant but unrelated factors (see Gerlach, 1988, Gregory, Head, and Raynauld, 1997, Kose, Otrok, and Whiteman, 2003, and Stock and Watson, 2005).

The common factors in such studies, however, are typically difficult to interpret, because basic factor model decompositions are atheoretical and lack a structural identification scheme. The common factor could reflect global shocks, correlated shocks, or spillovers from one country to others.[2] So far, plausible schemes to identify common shocks and spillovers have not yet been developed, so questions such as whether or not U.S. shocks account for a significant share of common output fluctuations remain unanswered.[3]

This paper uses a new approach to solving this identification issue. Focusing on industrial countries, we calculate spillovers across three major regions—the United States, the euro area, and Japan—and an aggregate of small industrial countries including Australia, Canada, Denmark, Norway, New Zealand, Sweden, and Switzerland that, for convenience, we will henceforth call the rest of the world.[4] The rest of the world contains a set of countries that is diverse in terms of both geography and industrial structure, characteristics that are heightened by giving each country an equal weight in the aggregate.

The assumption that the small industrial countries are a reasonable proxy for the rest of the world is crucial to the identification scheme. Given the diversity of the constituent countries, any shock to this aggregate is a strong candidate for a global disturbance. Because the economies involved are also relatively small both individually and in aggregate, they are unlikely to have significant direct effects on the other major regions. Spillovers from the rest

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[2] See, for example, Canova and Dellas (1993). There are other problems as well. For example, if countries respond differently to some common shock, say, for example, because of differences in economic structure, the estimated common factors may or may not capture the effects of these common shocks, depending on the stringency of the restrictions on the dynamic structure of the underlying model.

[3] Stock and Watson (2005) allow for lagged spillovers of country-specific shocks, but this still leaves contemporaneous shocks unidentified.

[4] Industrial countries are used as they are less likely to have structural breaks in their growth path than more dynamic emerging markets, and the data are available over a longer sample. The sensitivity of the results to the country composition of the rest of the world aggregate is left to future research.

of the world to the major industrial countries can thus be regarded as a proxy for the impact of global shocks. Using vector autoregressions (VARs) of growth across the four regions, we can therefore differentiate between the impacts of global, U.S., euro area, and Japanese shocks. U.S. and global shocks generate significant spillovers to other regions of about ⅓ to ½ the size of the initial shock after two years. Spillovers from the euro area and Japan, meanwhile, are smaller and insignificant in most cases. We also introduce a procedure to calculate uncertainty across VAR identification schemes, which allows us to examine the robustness of our results to differing assumptions about the direction of causation between contemporaneous shocks. We find that this specification uncertainty rarely influences the statistical significance of the results.

We also use this identification scheme to identify the major international channels through which shocks are propagated—trade, commodity prices, and financial markets. This is accomplished by extending the VAR to include the contribution of real net exports to growth, the change in real commodity prices, short-term interest rates, bond yields, and the change in real equity prices of the major industrial groups. Financial variables play the largest role in the transmission of global and U.S. shocks, and, consistent with other literature on the dominance of U.S. markets in generating financial spillovers, there is little feedback from other regions to the United States. This method can also be used as a cross-check on the plausibility of the main results. Encouragingly, the estimated aggregate impact of these separate channels corresponds reasonably closely to the direct estimation of impulses.

II. A New Approach to Identifying Vector Autoregressions

In order to identify independent impulse response functions from a VAR, it is first necessary to transform the errors across the individual regressions so that they are orthogonal. Traditionally, this is done using a Cholesky decomposition, which assumes that all of the correlations between errors are assigned to the equation that is earliest in the ordering. For example, in a 3-variable VAR, all of the correlation between the errors in the first equation and the second and third ones is assigned to the first, while any remaining correlation between the errors in the second and third equations is assigned to the second.

Such an approach works well if there is a relatively clear ordering for the Cholesky decomposition. For example, in small monetary VARs containing inflation, output, and interest rates, it appears intuitive to assume that easily-adjustable interest rates respond to shocks in more slow-moving inflation and output, and not the other way around. However, it is much less clear that such a stark assumption about causation is appropriate in a VAR containing growth across countries. Accordingly, while results for some individual Cholesky orderings are reported, the empirical results focus on an average of impulse responses across a range of “plausible” Cholesky orderings.

This procedure has a strong Bayesian flavor. The weights assigned to the various orderings can be seen as placing priors on the relative importance of spillovers going from variable A to B as opposed to those from B to A. These priors are then updated using the estimated variance-covariance matrix of equation errors. Note, however, that this updating depends only on the parameters of the variance-covariance matrix, not on the full probability distribution, which is used in traditional Bayesian methods.[5] The underlying approach is easily illustrated using a two variable VAR. Consider the matrix A that transforms the estimated errors e from such a VAR into orthogonalized errors ε. Mathematically, $\varepsilon = A\, e$. For the two possible Cholesky decompositions, the matrix A is:

$$A = \begin{pmatrix} 1 & -\frac{\sigma_{12}}{\sigma_{11}} \\ 0 & 1 \end{pmatrix} or \begin{pmatrix} 1 & 0 \\ -\frac{\sigma_{12}}{\sigma_{22}} & 1 \end{pmatrix} \tag{1}$$

where σ_{ij} is the relevant entry in the estimated variance-covariance matrix of the equation errors (for example, σ_{11} is the variance of the error on the first variable in the first equation). The zeros in the lower left of the first matrix and the upper right of the second indicate that in each of these decompositions contemporaneous feedback between the two variables flows in only in one direction.

By putting weight on both decompositions, however, our procedure allows such feedback to go in both directions. More specifically, the procedure assigns a (user-defined) weight of α to the first Cholesky decomposition and $(1-\alpha)$ to the second. The matrix that decomposes the equation errors into their orthogonalized versions is now:

$$A = \begin{pmatrix} 1 & -\alpha \frac{\sigma_{12}}{\sigma_{11}} \\ -(1-\alpha)\frac{\sigma_{12}}{\sigma_{22}} & 1 \end{pmatrix} \tag{2}$$

One way of interpreting the weight α is that it defines the prior on the relative importance of contemporaneous spillovers between the two error terms. Note, however, that this prior is modified by the estimated parameters of the variance-covariance matrix of errors $(\sigma_{11}, \sigma_{12}, and\, \sigma_{22})$. Mathematically,

$$\frac{a_{12}}{a_{21}} = \frac{\alpha}{(1-\alpha)} \frac{\sigma_{22}}{\sigma_{11}} \tag{3}$$

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[5] For approaches that use Bayesian techniques to update forecasts across models see Sala-i-Martin, Doppelhofer, and Miller (2004) and Leamer (1978). See Wright (2003) for a discussion and application of Leamer's Bayesian model averaging technique.

where a_{ij} is the relevant entry of the matrix A. The relative importance assigned to each possible direction of causation depends on both the prior (α) and on the ratio of the variance of the error on the first equation (σ_{11}) and the second one (σ_{22}). Therefore, the estimated magnitude of spillovers depends on both the prior and estimated variances and covariances of the errors in the VAR (which are not affected by the ordering of the variables). This updating of the priors by the estimated coefficients turns out to be important in interpreting the results, as discussed further below.

The intuition of this example can be generalized to the n-variable case, with the complication that adding variables to the VAR makes it more difficult to define the errors on each equation (the *e*'s). In particular, account has to be taken of correlations with errors of variables ordered earlier in the VAR. But, once this has been done, the rest of the logic of this two-variable case holds.

In addition, it is possible to calculate how uncertainty over the correct Cholesky ordering adds to the variance around the impulse response functions, over and above the usual variance associated with uncertainty about the underlying parameters of the VAR. Sticking with the 2-variable example, let $\bar{x}_t$ represent the average impulse response for period *t* across the two decompositions (so that $\bar{x}_t = \alpha\bar{x}_{1t} + (1-\alpha)\bar{x}_{2t}$). The variance of the impulse response function can be written:

$$\begin{aligned} E(x_{ijt} - \bar{x}_t)^2 &= \alpha^2 E(x_{1jt} - \bar{x}_{1t})^2 + 2\alpha(1-\alpha)E(x_{1jt} - \bar{x}_{1t})(x_{2jt} - \bar{x}_{2t}) + (1-\alpha)^2 E(x_{2jt} - \bar{x}_{2t})^2 \\ &\quad + \alpha^2 E(\bar{x}_{1t} - \bar{x}_t)^2 + (1-\alpha)^2 E(\bar{x}_{2t} - \bar{x}_t)^2 \end{aligned} \tag{4}$$

where subscript *i* indicates the different orderings (1 and 2) and subscript *j* represents the volatility about the impulse responses generated by uncertainty over the coefficients estimates (recall that the coefficient estimates are independent of the choice of ordering).

The first line of equation (4) reflects the familiar uncertainty associated with each individual identification scheme coming from the fact that the coefficients of the VAR are estimated with error. Given that the individual identification schemes differ only in their assumptions about the ordering of the variables, the errors across individual orderings are likely to be highly correlated. Accordingly, we assume that the correlation across different orderings is unity. Given this assumption, the first line can be approximated by taking the weighted average of the variances of each of the decompositions. The second line reflects the uncertainty due to variation in the response across orderings and is simply the variance of the response across these decompositions.

Hence, the uncertainty associated with identification can be approximated by simply adding the average variance of the impulse responses across identification schemes to the average variance associated with parameter uncertainty. Given our assumption of a perfect correlation of errors associated with parameter uncertainty across ordering, this is an upper limit for the true value of this variance. This argument can again be generalized to the n-variable case.

III. How large are spillovers?

Data on quarterly growth (measured as the difference in the logarithm of real GDP) for our four industrial regions were collected from 1970 to 2006. The official euro area data extend back to 1991, and earlier data were spliced back to 1970 using the estimates in Fagan, Henry, and Mestre (2005). For the smaller industrial countries, equal weights were used to aggregate real GDP across countries, as their shocks proxy for global events which should have similar effects on all countries regardless of size.

Regressions were run on the full sample and its first and second halves, with the split between the two subsamples being set at the first quarter of 1988. This break was chosen to differentiate the relatively turbulent 1970s and 1980s, with large oil shocks and rampant inflation, from the period after inflation had been controlled, which also includes the great moderation in real output variability that became apparent in the late 1990s.

The basic VARs contain growth for each of our four regions. Growth was used rather than the level of real GDP as it implies that output follows a stochastic trend with drift. Given the possibility that the underlying rate of growth of some areas may have changed over time, using a stochastic trend appears a more reasonable assumption for modeling underlying potential than using levels of real GDP and a fixed time trend. Four lags were used in the VAR, as, in addition to being a logical value for quarterly data, this was the length suggested by standard tests.[6]

A major focus of the empirical analysis is examining the robustness of the results to alternative orderings of the contemporaneous correlations across shocks in the VAR. Table 1 reports the correlation of these shocks for the full sample period and the two subperiods. For the full sample, there are two large correlations in the residuals of the order of 0.4 to 0.5–those between the unexpected shocks to growth in the United States and the rest of the world, and between the euro area and the rest of the world. Furthermore, this pattern is also seen across both subperiods, suggesting that it is a structural feature, not an artifact of the chosen sample. Hence, using the rest of the world as a proxy for global shocks has reduced, but not eliminated, the correlation of these shocks with those from the United States and euro area.

Table 2 reports the variance-covariance matrix for the three samples, which gives a sense of the relative size of disturbances across regions. The shocks to the United States and Japan are significantly larger than those for the euro area and rest of the world. As a result,

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[6] Both the final prediction error and Schwarz information criterion suggest 4 lags, while the Aikaike information criterion finds one lag to be sufficient.

the covariance between shocks to growth in the United States and the rest of the world are significantly larger than those between the euro area and the rest of the world even though the correlations are similar. In addition, it means that the updating of the priors associated with the U.S.-rest of the world covariance reduces the weight on the former and increases it on the latter. Both of these observations will be important in interpreting the results. In addition, consistent with the onset of the great moderation, all of the equation variances (on the main diagonal) decline in the second period. The fall has been largest in the United States (whose variance declines by a factor of five) and smallest in Japan (whose variance falls by only around one-quarter).[7]

This paper does not take a strong view on the appropriate ordering in the VAR. Rather, results are averaged across several plausible orderings, in order to allow for the possibility of spillovers in either direction between countries. This is also consistent with the evidence that averaging across a range of models tends to produce better forecasts than a single model.[8] This is augmented by discussing results from two "extreme" ordering that help illustrate the range of potential results. Using US, EA, JP, and ROW to represent the United States, euro area, Japan, and the rest of the world, respectively, the simple average across the following eight Cholesky decompositions is reported (in order of independence from other regions):

US, EA, JP, ROW;	ROW, US, EA, JP
US, JP, EA, ROW;	ROW, US, JP, EA;
US, EA, ROW, JP;	ROW, EA, JP, US;
US, JP, ROW, EA;	ROW, JP, EA, US.

The four orderings on the left place U.S. shocks ahead of those of other countries, implying that the U.S. economy is the most important driver of global fluctuations. In two of these the rest of the world is placed last, consistent with the view that it simply reflects the disturbances of a set of small countries with no contemporaneous impact on the major industrial regions. In the other two cases, the rest of the world is placed second-to-last, so there are some contemporaneous spillovers to the euro area or Japan. In the other four decompositions on the right, the rest of the world is ordered first as it is assumed to be a proxy for global shocks. In two cases the United States is placed second, consistent with the view that the United States remains a key component of contemporaneous spillovers, while in the other two cases the United States is placed last, and hence all contemporaneous shocks

[7] The source of the great moderation—smaller underlying shocks or better policies—remains a subject of much debate. See Stock and Watson (2003) and Juillard and others (2006). The disproportionate fall in U.S. volatility is robust to modest changes in the sample period.

[8] Stock and Watson (2004) find simple averages across models work surprisingly well compared to other, more sophisticated and time-varying, aggregation techniques.

are assumed to emanate from other areas. This is allows for two-way causation between the United States and the other two major industrial regions.

As discussed above, the choice of orderings can be seen as defining "priors" on the relative importance of contemporaneous spillovers from one area to another. The United States is placed before the rest of the world in four cases out of eight, and behind them in the other four cases, implying an even prior on the direction of causation. As we order the euro area and Japan interchangeably, there is also an even prior on this relationship. Similar calculations yield a prior of three-quarters that the contemporaneous correlation between the United States and the euro area/Japan emanates from the United States, while for the rest of the world and the same two regions the equivalent prior is five-eighths.

Two "extreme" orderings are also examined in some detail, namely ROW, US, EA, JP and US, EA, JP, ROW. The first assumes that all contemporaneous correlation between shocks to the rest of the world and those of other regions are global shocks that spill over onto the main industrial regions. The second assigns the contemporaneous correlation between shocks to the United States, assuming that the rest of the world represents small countries that create no contemporaneous spillovers to the other regions (as discussed above, the prior in our averaging procedure puts an even chance on these two interpretations). Finally, we also briefly consider responses from the ordering EU, JP, ROW, US and its reverse. The first ordering allows us to examine the sensitivity of the results to placing the euro area and Japan before the other two regions in the decomposition. Comparing these results with the reverse ordering allows us to examine the relative importance of the euro area and Japan versus the United States in explaining global shocks.

A. Results For Full Sample

The impulse response functions (IRFs) showing the impact on the level of real GDP over eight quarters averaged across eight Cholesky decompositions are shown in Figure 1. The first column reports the impact of a shock to U.S. real GDP first on itself, then on the euro area, Japan, and finally on the rest of the world. The second, third and fourth columns reports IRFs for shocks to the euro area, Japan, and rest of the world in the same order. Each graph reports the response ± two standard error bands that only account for coefficient uncertainty, and an additional set of bands incorporating the specification uncertainty discussed above.

The main uncertainty created in the specification is to the estimated spillovers from the rest of the world. With the exception of the response of the United States to the rest of the world and (to a lesser degree) the euro area to the rest of the world, the two calculations produce similar qualitative results. This can be seen by comparing the IRFs for the average with the two extreme decompositions for the rest of the world, reported in Figure 2 (full IRFs for the "extreme" specifications with standard errors are reported in Appendix Figures A1 and A2). The fact that the uncertainty is mainly reflected in spillovers from the rest of the world to the United States (and euro area), rather than vice versa, reflects the larger variance of U.S. shocks compared to shocks to the rest of the world. The extreme ordering with the rest of the world first also results in smaller contemporaneous spillovers from the United States to other regions.

Turning to results for individual regions, spillovers from the United States to other regions are of economic and statistical significance. A typical shock to the level of US GDP is ¾ percent initially and rises over time to around 1¼ percent after 2 years. The initial impact elsewhere is small, but gradually rises to about ½ percent in the euro area, Japan, and rest of the world real GDP. Hence, after two years somewhere around 40 percent of any U.S. shock spills over to the other regions. All of these responses are significant except that of Japan. This may well reflect the high level of volatility of Japanese growth numbers, which are generally believed to contain significant amount of noise.[9]

By contrast, a shock to euro area real GDP has a negligible impact on other regions. Domestic shocks of the order of ½ percent of GDP have small positive effects on the other regions in the short run that are significant only in the case of the rest of the world (which could reflect the number of smaller European countries included in this group). In addition, all of these effects are negligible and insignificant after two years. Spillovers from Japan, are only significant to the euro area, where their size is similar to those from the United States. However, as discussed below, this result is not robust across subperiods or confirmed by summing the impact of each of the main sources of spillovers.

Spillovers from the rest of the world are the most sensitive to the Cholesky ordering. The last column of Figure 1 shows that the average shock to the rest of the world is some ½ percent of real GDP, with spillovers to other regions statistically insignificant in all cases. However as can be seen in Figure 2, if the rest of the world is placed first—and hence the correlation between its shock and fluctuations in other regions reflects global disturbances—the estimated spillovers approximately double, and are statistically significant for the euro area, and, for the first few quarters, the United States. The impact stays relatively constant over time, rather than building in the way U.S. spillovers do, consistent with the interpretation of the spillovers to other regions as global shocks. By contrast, when the rest of the world is last in the VAR all spillovers are negligible. Spillovers from the rest of the world thus depend crucially on whether their output fluctuations can be assumed to accurately reflect global shocks.

The results of an ordering placing the euro area and Japan before the rest of the world and the United States last are reported in Figure 3 (with standard error bands).Results from the reverse ordering and from our average across plausible orderings are presented to aid comparison. Placing the euro area and Japan first in the ordering does not affect the statistical

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[9] See IMF (2000), pages 18-19.

significance of spillovers from the United States to the euro area and the rest of the world. While the short-term impact of shocks to euro area output exceeds that of U.S. shocks, longer-term responses remain small and insignificant. Meanwhile, the results for Japan remain remarkably stable across the specifications. Unsurprisingly, spillovers from the rest of the world to the United States depend almost exclusively on the ordering between these two regions. More striking is the finding that the long-term response of the euro area to the rest of the world is similar across the three orderings reported in Figure 3, in contrast to the divergence shown in Figure 2. This implies that the assumed ordering between the United States and rest of the world is as important as that between the euro area and the rest of the world for determining the size of this spillover.

Within the estimation procedure executed in this paper, global shocks have significant spillovers elsewhere (except possibly Japan), with their size depending crucially on the chosen prior—particularly as regards the link between shocks to the United States and the rest of the world. When the rest of the world is ordered first in the VAR, the global shock increases output in the small industrial countries, euro area, and United States by ¼-¾ percent, with the impact being somewhat greater for the more open countries that comprise the rest of the world than for the other less open regions. These effects fall approximately proportionately with the weight given to this prior.

B. Results for Subsamples

The results from estimating the baseline "average" VAR over the periods 1970–1987 and 1988–2006 are reported in Figure 4 (Appendix Figures A3 and A4 report IRFs and standard errors). As will be discussed further below, three underlying themes are apparent—namely the relative decline in the average size (and hence variability) of U.S. shocks at home and associated spillovers, the fall in the importance of spillovers from Japan to other regions, and the larger role played by spillovers from the rest of the world.

Focusing initially on results for the United States, the first column of Figure 4 shows that all of the IRFs from U.S. shocks approximately halve between the first and second samples. Put differently, the great moderation in U.S. macroeconomic volatility halves the volatility and hence average size of U.S. disturbances. As the impact of a given shock to U.S. real GDP on other regions remains relatively similar, spillovers fall equivalently.

The results for the other three regions are very different. There is no evidence that the magnitude of domestic shocks in the other three regions have moderated. Indeed, particularly given the U.S. results and uncertainties involved in estimation (almost a quarter of the degrees of freedom are used to estimate the parameters), the similarity of domestic responses across subsamples is quite striking. There do, however, appear to be some changes in the spillovers from these shocks. The effect of Japanese real GDP shocks on other regions has declined—consistent with the observation that the intense economic difficulties experienced by Japan after the bursting of the real estate bubble in the late 1980s had relatively limited impact elsewhere. By contrast, the impact of shock from the rest of the world on other regions has risen, consistent with the view that rising globalization may have made the world more sensitive to global events. Anticipating the results of the next section, both of these trends are consistent with financial markets being the main conduit for spillovers. Japan's financial links with other countries were limited by the banking problems associated with the bursting of the bubble, while increasing financial globalization has provided a more effective conduit for global financial shocks. Lastly, the decline in the estimated impact of Japan on the euro area between the two periods is offset by a rise in estimated spillovers the other way, an instability that suggests these links may not be structural.

The main implication of these results is that the great moderation in U.S. output volatility is the driving force behind the moderation in output uncertainty elsewhere. Since domestic shocks in the other three regions have remained similar over time, and smaller spillovers from Japan have been largely offset by larger spillovers from the rest of the world, the main factor behind lower global volatility appears to be the fall in U.S. instability and corresponding reduction in spillovers to the rest of the world. Variance decompositions, which relate the share of variability in each region's output accounted for by fluctuations in the other regions, illustrate this. Table 3, reports the variance decomposition after 8 quarters and shows that U.S. shocks fall in relative importance in all cases while the importance of the euro area increases. Similarly, Japanese shocks generally decline in importance and shocks from the rest of the world become more important.

IV. WHAT ARE THE SOURCES OF SPILLOVERS?

The next issue we examine is the relative importance of the three main potential connections between regions—trade, commodity prices, and financial conditions. It should be recognized from the outset that these links are less likely to fully describe domestic disturbances, which are also driven by additional "domestic" effects such as consumer and business confidence.

The analysis was accomplished by augmenting the VAR in the following ways. For *trade*, the contribution of net exports to growth for the United States, euro area, and Japan are added as the first variables in the VAR (the variables for the rest of the world are excluded as these countries are assumed to be too small to have a direct impact on the larger regions). In this augmented VAR, any spillovers that are associated with net trade should be identified with shocks to net trade rather than GDP. For the change in *real oil and nonoil commodity prices* (calculated using the U.S. GDP deflator), the current value and first four lags of each series were also included, but as exogenous variables rather than as additional equations in the VAR. For the change in *real equity prices,* and the level of *nominal government bond yields* for each region, a similar procedure was used except that, as these variables approximate random walks, only the contemporaneous value and first lag were added as exogenous variables (real equity prices were calculated by dividing the relevant series by the region's GDP deflator). The same approach to that for bond yields was taken for the level of nominal short-term interest rates.

In our main results, each variable is added separately to the basic VAR with GDP growth. This keeps the VARs smaller, which is particularly important for the two subperiods, where the degrees of freedom are limited.[10] This procedure amounts to assuming that each channel is independent of the others, and hence can be treated separately. The difference between the response of GDP excluding and including these variables was used to calculate the spillover from this particular source. For example, the difference between responses of euro area growth to U.S. growth for the base case and for the augmented VAR with net exports equals the impact of net exports spillovers between these two regions. As the sources of spillovers are quantified using this separate methodology, the sum is not constrained to mirror the estimates of aggregate spillovers coming from the base VAR. Thus, this "independent" approach to identifying the sources of spillovers provides an alternative estimate on the size of overall spillovers, which can be compared to the main results. In addition, we report results from a VAR in which all of the variables are included, thereby assuming that the channels are interlinked.

The relative importance of these five variables for our average of eight orderings is reported in Figure 5 (Results for the two extreme orderings for the full sample are reported in Appendix Figures A5 and A6, while results for the average procedure over the two subsamples are reported in Figures A7 and A8). While, as expected, the specification does not do a particularly good job at identifying the sources of fluctuations within each region, the fit is better for spillovers across regions, especially in cases where the response itself is statistically significant.

The results for each type of variable can be summarized as follows:

- **Trade**. The impact of direct trade links is small even with 4 lags included in the specification (this result basically holds even if the VAR lags are extended to 8). It plausibly reflects the fact that international trade accounts for only a fraction of activity among the main economic regions in the world, and hence that the impact of trade shocks is inevitably relatively minor.[11].

- **Commodity prices**. The impact of commodity prices on real GDP is generally limited, with the direction depending on the structure of trade of the region. Because the rest of the world has sizable commodity exports, a rise in activity, which will tend to raise global commodity prices, has a positive impact on real GDP. By contrast, Japan is a significant

[10] For example, the trade VAR uses up over one-third of the degrees of freedom in the subsamples.

[11] Such a result would not, presumably, hold for immediate neighbors. For example, one would expect U.S. trade to matter for Canada. This represents an area for further study.

commodity importer, so the effects of higher growth in other regions on commodity prices are negative for economic activity. Responses for the United States and euro area, where commodity trade balances fall somewhere between these two extremes, are mixed, but are always negative for the global shock. This makes sense as these global commodity price shocks are likely dominated by oil prices.

- **Financial variables**. The largest estimated contributions to spillovers almost universally come from financial variables. These effects are largest and generally positive for U.S. spillovers and for the rest of the world. By contrast, the impact of financial market shocks on euro area and Japanese spillovers are less consistent, and are often negative. This implies that financial markets are the main conduits for both U.S. and global shocks but financial shocks from other regions are not as important. This is consistent with the large body of work finding that U.S. financial disturbances appear to affect other regions with little or no feedback in the other direction (see Faust and others, 2007, Ehrmann and Fratzscher, 2005, and Bayoumi and Swiston, 2007). Within these financial variables, short-term interest rates tend to be the most important single factor, but bond yields and equity prices also matter. Hence, while monetary policy is an important driver of spillovers, so are financial conditions more generally. Furthermore, as can be seen in Figure A9, the results from adding all three financial variables into the VAR at the same time are similar to including them separately, suggesting that the effects of the three financial variables are relatively orthogonal to each other and hence these channels of financial spillovers can be thought of as distinct. This presumably reflects the fact that short-term interest rates, bond yields, and equity prices respond in different ways to underlying shocks.

Figure 6 compares the IRFs estimated for the average specification with the responses implied by summing the impact of the individual potential sources of spillovers, as well as those implied from a VAR where all variables are added simultaneously. The results confirm that summing the individual sources of shocks provides only a limited explanation for domestic shocks. Turning to spillovers, however, the correspondence between the two approaches is generally close. Indeed, the main exceptions are the response of euro area real GDP to Japanese shocks, supporting the supposition that this link is not robust, and the response of U.S. output to euro area shocks, where the sum of individual components implies an implausibly large negative effect. In addition, the results from the VAR that includes all of the channels simultaneously appears less capable of mimicking the initial IRFs, particularly as regards U.S. spillovers, suggesting that the various channels of spillovers can be regarded as relatively independent of each other.

Finally, Figure 7 reports the decomposition across sources of spillovers from the rest of the world to other regions for the two extreme identification schemes. If one of these decompositions fit significantly better than the others, this might be regarded as evidence supporting a particular implicit prior on the importance of global shocks. Unfortunately, no clear pattern is evident. Spillovers to the United States are not well explained by the individual channels when the rest of the world is taken as a proxy for the global shock, but those for the euro area and Japan fit relatively well. Overall, this procedure does little to resolve the question of whether this identification scheme accurately measures global shocks.

V. CONCLUSIONS

This paper has examined both the sources and size of spillovers across major industrial country regions. Particular attention has been given to identifying the uncertainties involved in distinguishing between spillovers emanating from the United States and from global sources, by using disturbances to an aggregate of seven smaller industrial countries as a proxy for global shocks.

The results suggest the following:

- *The United States creates the largest spillovers to other regions*. Regardless of the identifying assumptions used, the United States generates statistically significant spillovers to the euro area and the rest of the world. The effect on foreign output is about ⅓ to ½ the size of the shock to U.S. GDP.

- *There also appear to be significant spillovers from global shocks* (identified as those coming from smaller industrial countries). However, their size is uncertain, and depends on priors, particularly on the causal relationship between shocks simultaneously felt in the United States and smaller industrial countries. The euro area and Japan generally have limited effects on other parts of the world.

- *Smaller U.S. domestic shocks appear to be central to the global moderation in output fluctuations between the 1970s/1980s and the 1990s/2000s*. While U.S. domestic shocks fell notably, the magnitude of domestic shocks elsewhere has remained stable.

- *The main source of spillovers is global financial conditions*. Both short-term interest rates and financial conditions more generally (bond yields and equity prices) matter for transferring activity across regions. By contrast, trade and commodity prices are less potent factors in this process. These channels also seem relatively independent of each other.

Taken together, these results imply that the reduction in global financial volatility as a result of a more stable U.S. environment was crucial for lower global output volatility. It is supportive of the view that more stable U.S. monetary policy was crucial for stabilizing real and financial uncertainty at the center of the system, allowing all countries to enjoy a less volatile environment. This more stable environment may well have been conducive to better domestic policies elsewhere, but the size of domestic shocks does not appear to have fallen over time in these regions, as it has in the United States.

These results also suggest that the analysis of global spillovers should focus more on financial linkages. Significant effort has been put into documenting and calculating the impact of trade shocks, with less work on the macroeconomic consequences of financial conditions. However, large macroeconomic models that capture trade linkages better than financial ones have consistently failed to find large spillovers across major global regions. This has led many to conclude that global economic fluctuations reflect common shocks rather than spillovers between countries, but this paper casts considerable doubt on that explanation. Even if there are large global shocks (an issue that remains uncertain) there are also significant spillovers from U.S. shocks. These are transmitted through financial markets, suggesting that documenting the macroeconomic effects of these linkages is an important future task. Finally, a possible extension of the approach in this paper is to examine spillovers from the major industrial countries or regions onto other economies. This can be done by adding growth of another region last in the VAR, and is left for future endeavor.

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Table 1. Correlations of VAR Residuals

Full sample: 1970Q1 to 2006Q2

	United States	Euro area	Japan	Rest of world
United States	1.00	0.22	0.17	0.42
Euro area	0.22	1.00	0.16	0.48
Japan	0.17	0.16	1.00	0.04
Rest of world	0.42	0.48	0.04	1.00

First half of sample: 1970Q1 to 1987Q4

	United States	Euro area	Japan	Rest of world
United States	1.00	0.27	0.36	0.43
Europe	0.27	1.00	0.14	0.50
Japan	0.36	0.14	1.00	0.20
Rest of world	0.43	0.50	0.20	1.00

Second half of sample: 1988Q1 to 2006Q2

	United States	Euro area	Japan	Rest of world
United States	1.00	0.09	-0.13	0.32
Euro area	0.09	1.00	0.24	0.52
Japan	-0.13	0.24	1.00	-0.15
Rest of world	0.32	0.52	-0.15	1.00

Source: IMF staff calculations.

Table 2. Variance-Covariance of VAR Residuals

Full sample: 1970Q1 to 2006Q2

	United States	Euro area	Japan	Rest of world
United States	0.60	0.09	0.12	0.16
Euro area	0.09	0.24	0.07	0.12
Japan	0.12	0.07	0.84	0.02
Rest of world	0.16	0.12	0.02	0.24

First half of sample: 1970Q1 to 1987Q4

	United States	Euro area	Japan	Rest of world
United States	1.03	0.14	0.30	0.26
Europe	0.14	0.33	0.09	0.17
Japan	0.30	0.09	0.90	0.10
Rest of world	0.26	0.17	0.10	0.36

Second half of sample: 1988Q1 to 2006Q2

	United States	Euro area	Japan	Rest of world
United States	0.20	0.01	-0.05	0.05
Euro area	0.01	0.14	0.07	0.07
Japan	-0.05	0.07	0.71	-0.05
Rest of world	0.05	0.07	-0.05	0.13

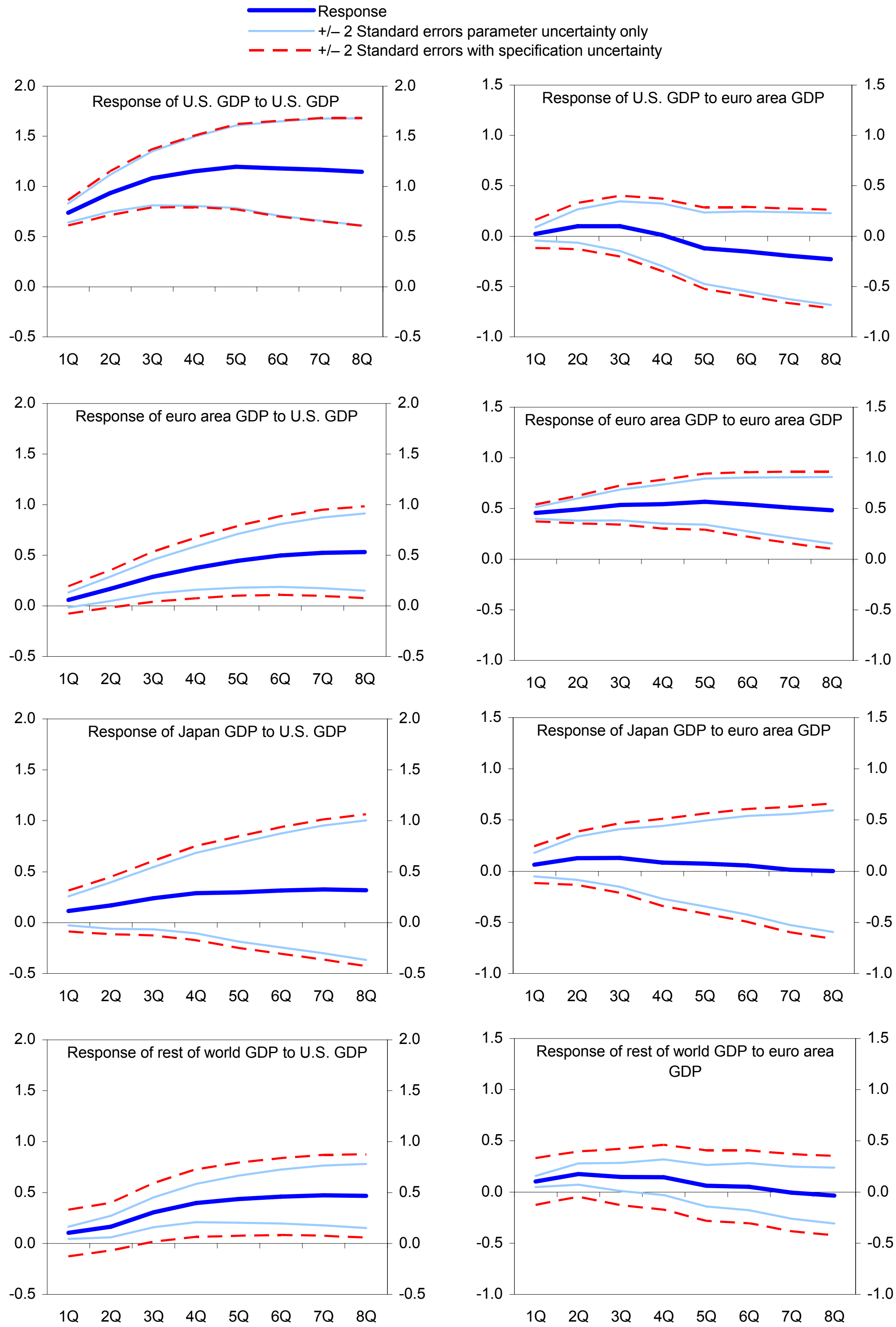
Source: IMF staff calculations.

Table 3. Variance Decompositions of Real GDP

Forecast variable	Share explained by	Share explained after eight quarters: Full sample	1970–1987	1988–2006
United States	United States	83.3	75.1	71.9
	Euro area	5.4	6.7	8.0
	Japan	3.5	8.7	6.8
	Rest of world	7.7	9.5	13.4
Euro area	United States	13.8	14.1	6.8
	Euro area	60.7	49.8	66.4
	Japan	15.2	27.6	6.8
	Rest of world	10.3	8.6	20.0
Japan	United States	2.9	10.8	9.1
	Euro area	1.7	2.7	6.9
	Japan	94.5	83.7	78.0
	Rest of world	0.8	2.7	5.9
Rest of world	United States	17.6	19.8	8.3
	Euro area	12.4	11.2	24.1
	Japan	1.7	4.6	9.4
	Rest of world	68.2	64.4	58.1

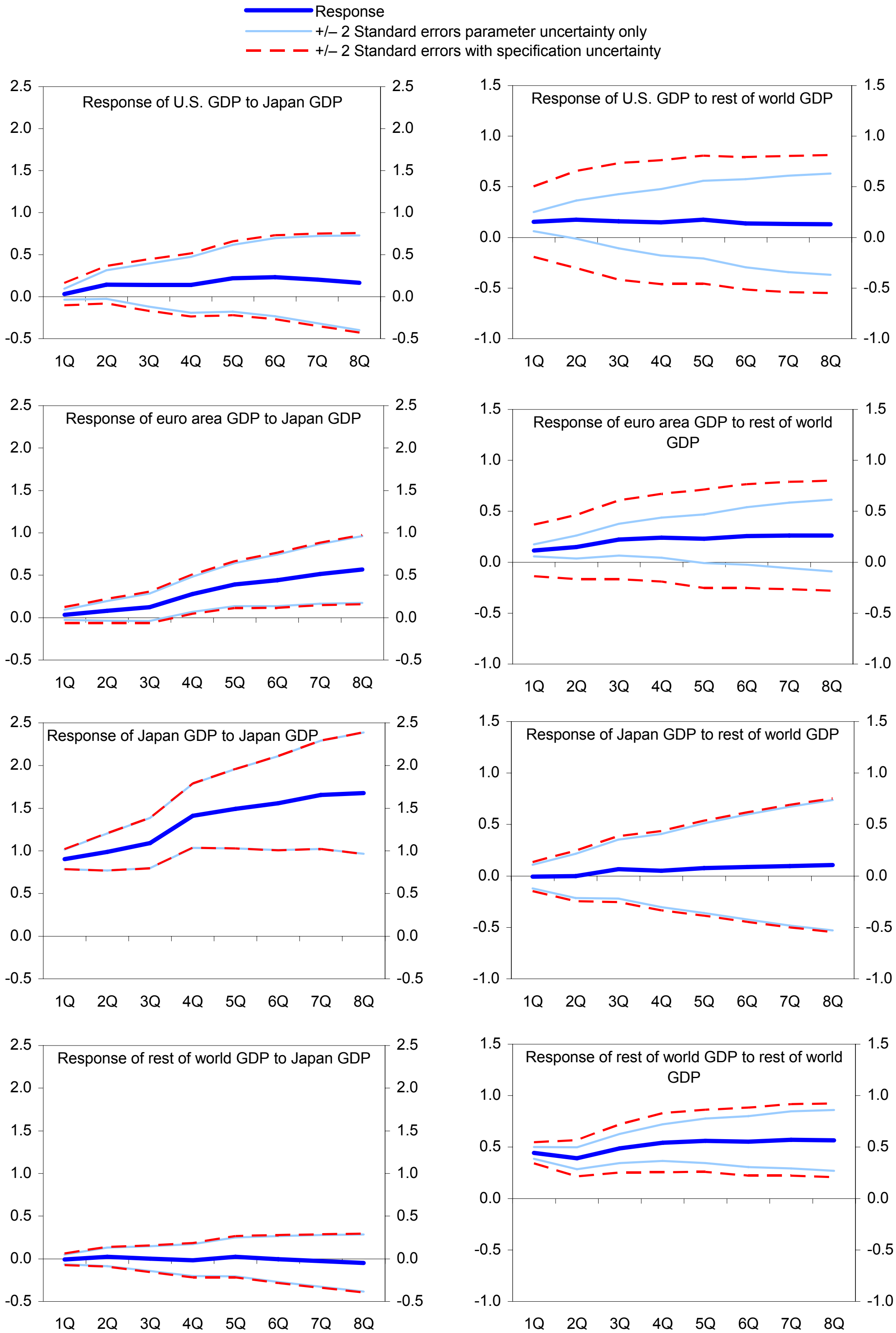
Source: IMF staff calculations.

Figure 1. Responses to Shocks to GDP Across Eight VARs



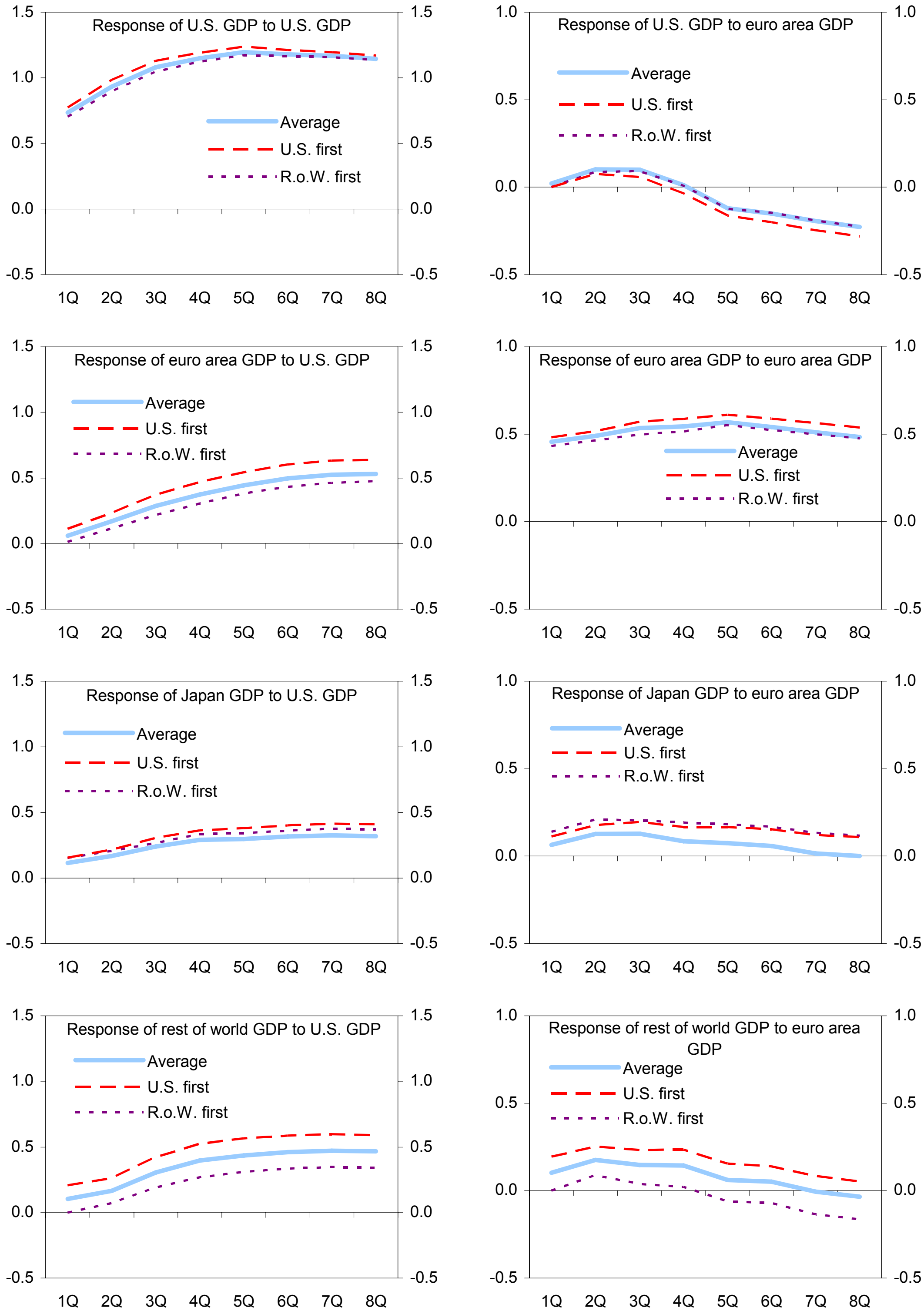
Source: IMF staff calculations.

Figure 1 (continued). Responses to Shocks to GDP Across Eight VARs



Source: IMF staff calculations.

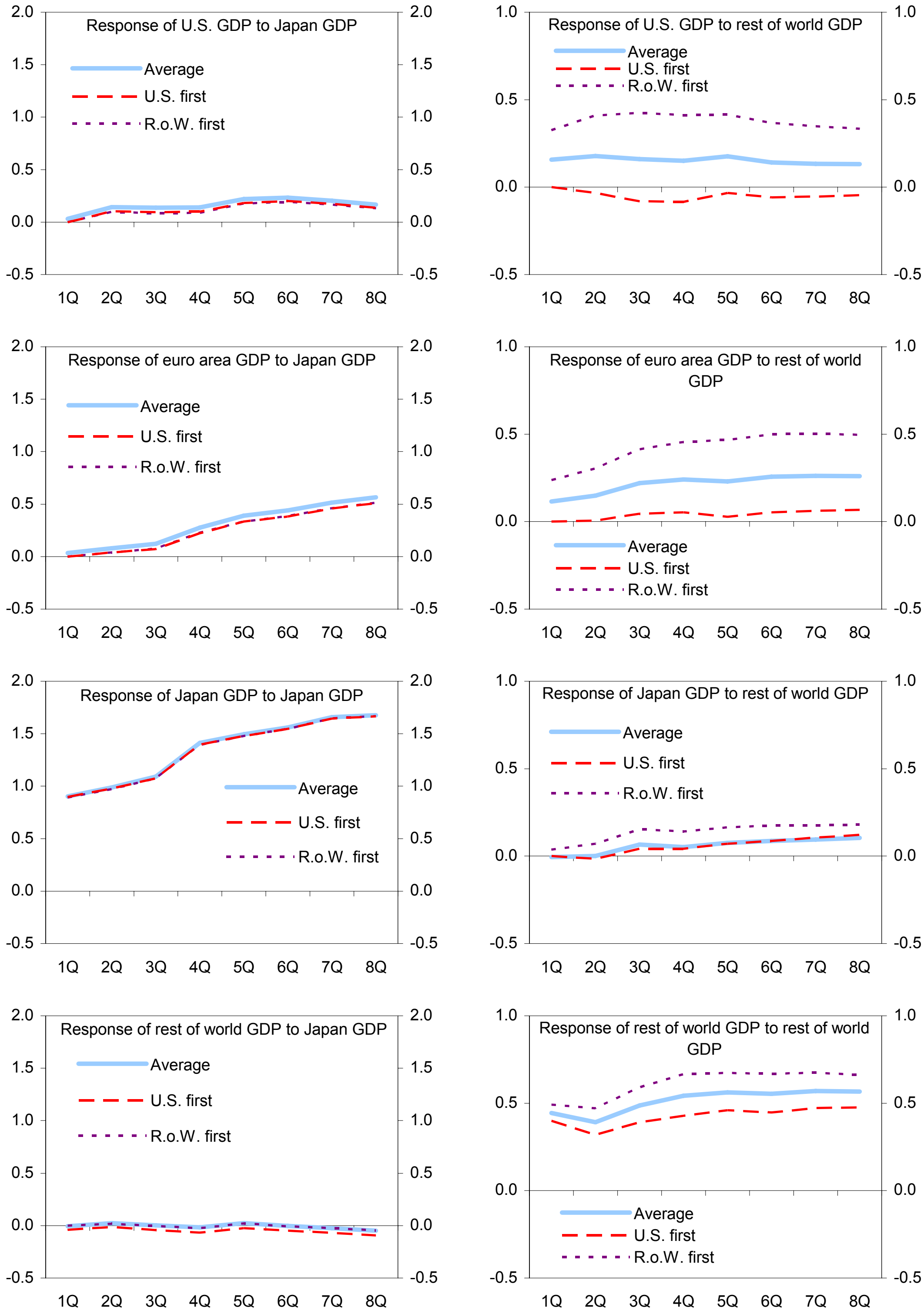
Figure 2. Responses Across Specifications
Responses to U.S. and euro area GDP



Source: IMF staff calculations.

Figure 2 (continued). Responses Across Specifications

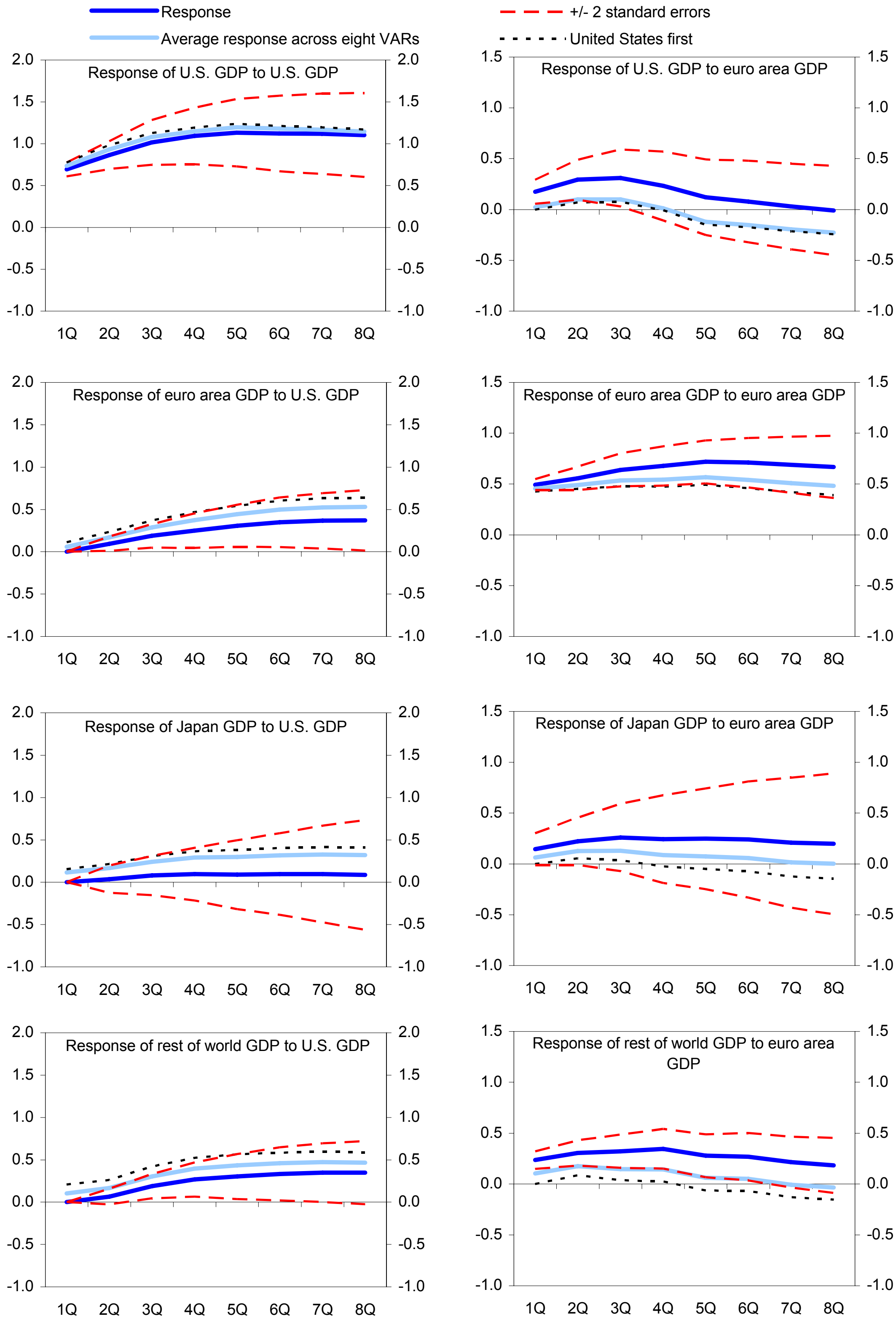
Responses to Japan and rest of world GDP



Source: IMF staff calculations.

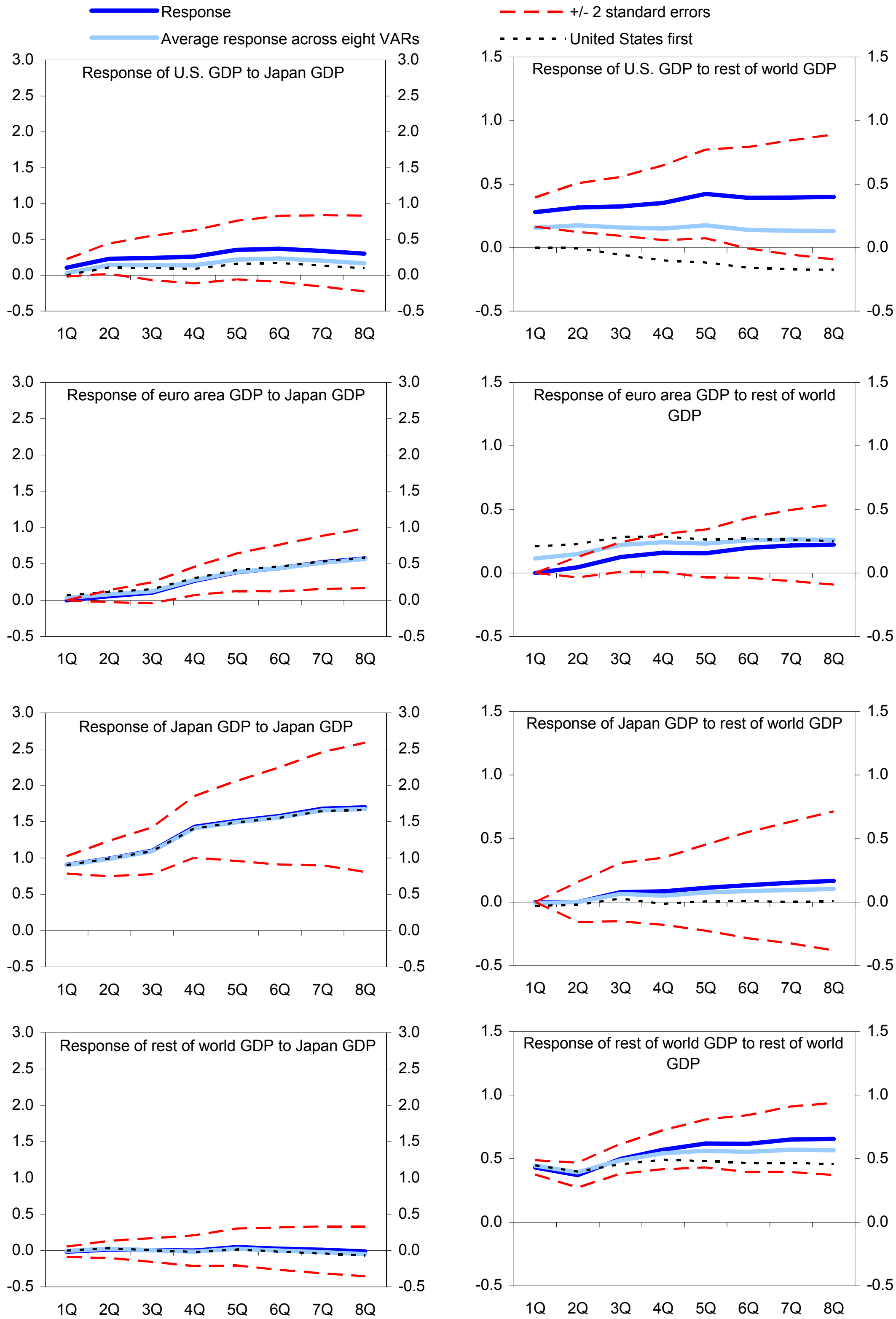
Figure 3. Response to Shocks to GDP with Euro Area First

VAR Ordering: Euro area, Japan, rest of world, United States



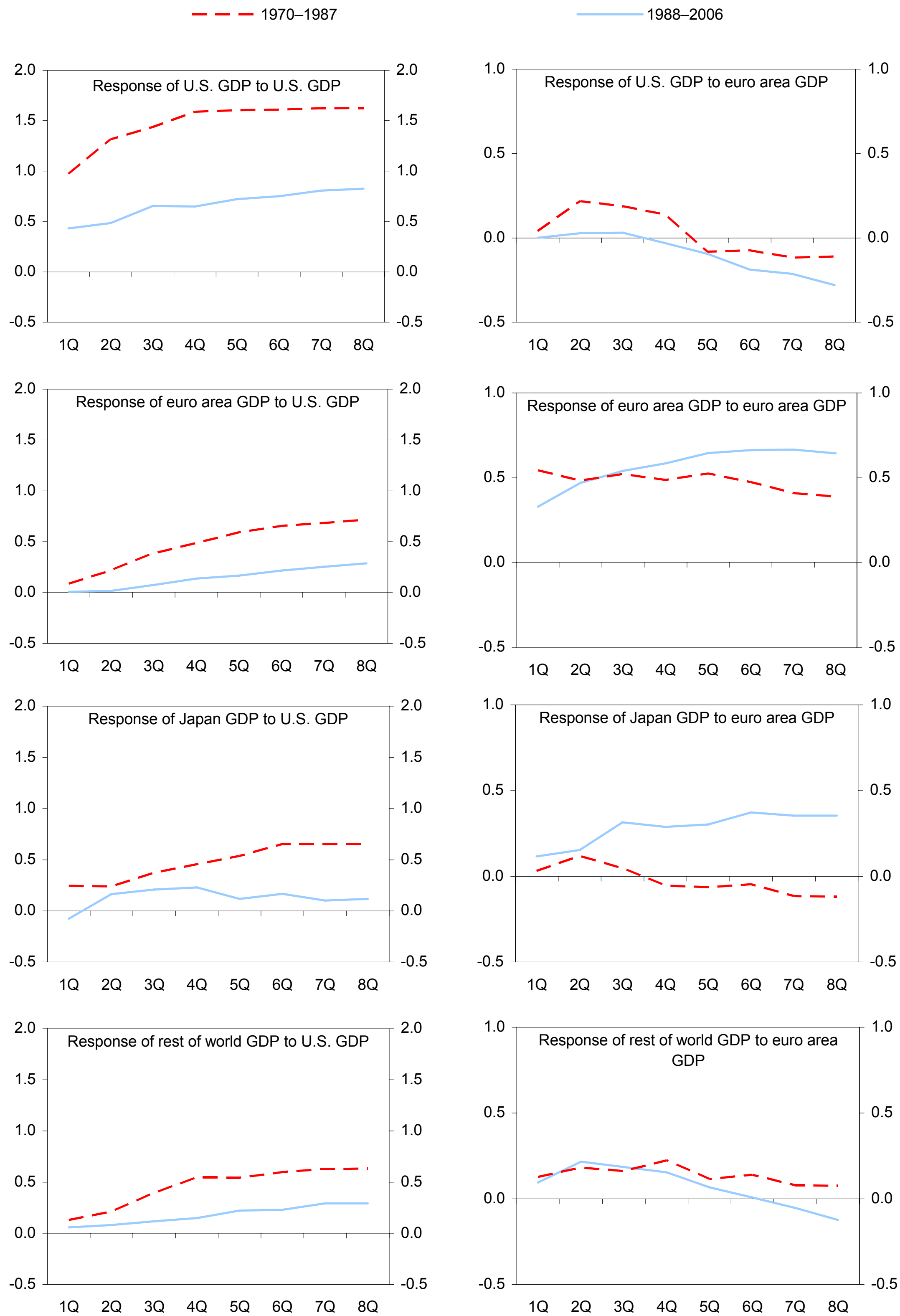
Source: IMF staff calculations.

Figure 3 (continued). Response to Shocks to GDP with Euro Area First
VAR Ordering: Euro area, Japan, rest of world, United States



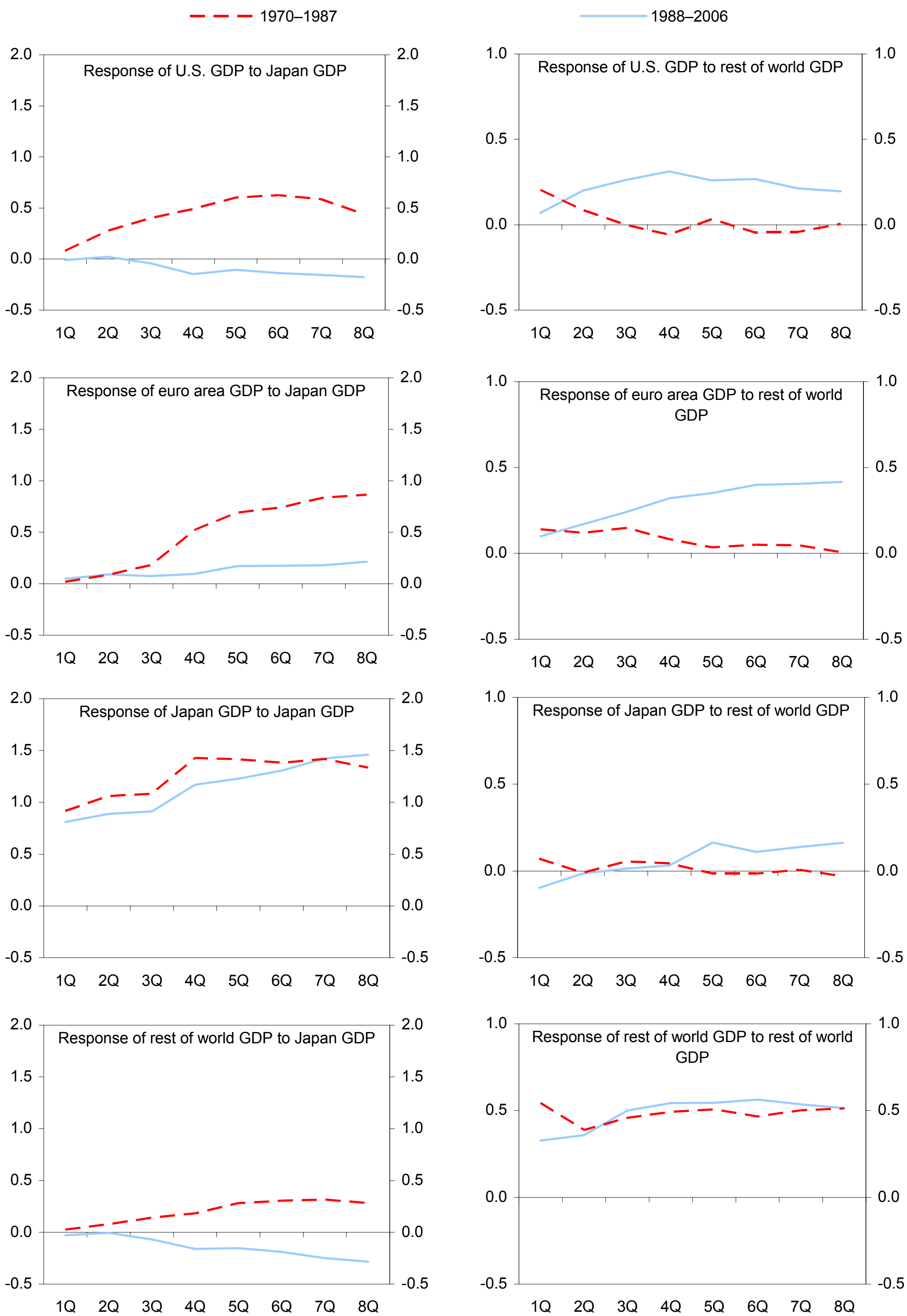
Source: IMF staff calculations.

Figure 4. Responses to Shocks to GDP Across Eight VARs by Subsample



Source: IMF staff calculations.

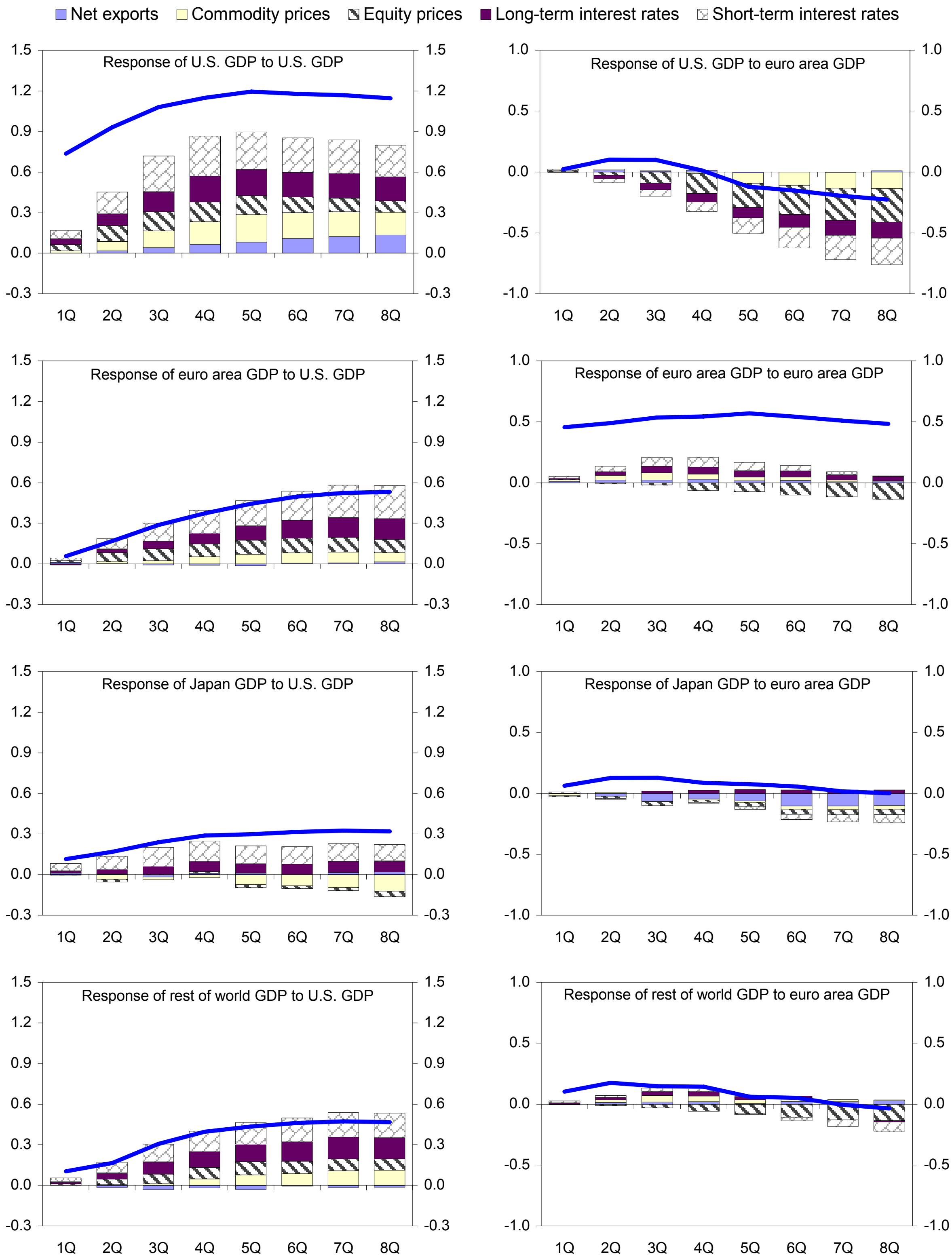
Figure 4 (continued). Responses to Shocks to GDP Across Eight VARs by Subsample



Source: IMF staff calculations.

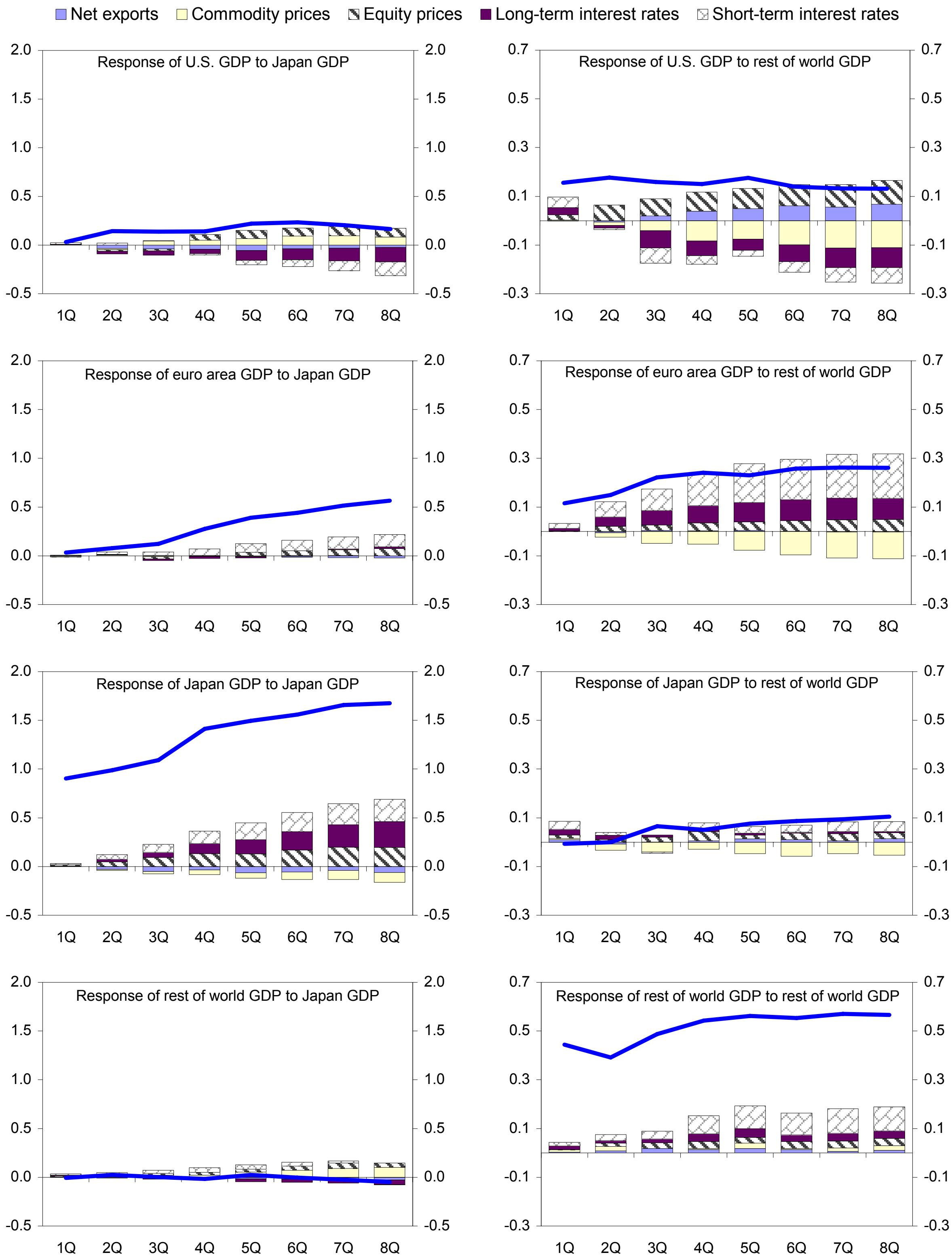
Figure 5. Decomposition of Responses to GDP Shocks

Responses to U.S. and euro area GDP



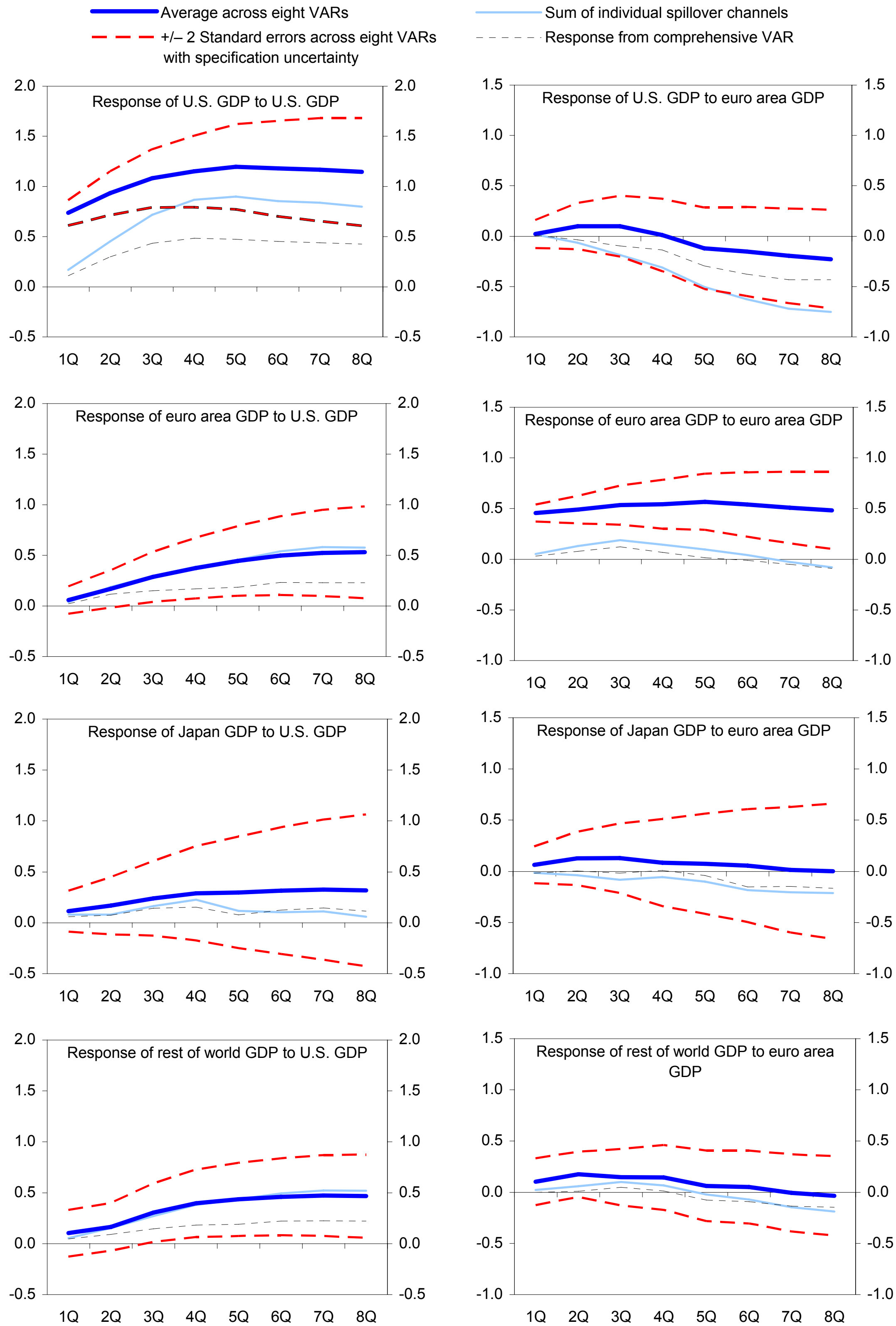
Source: IMF staff calculations.

Figure 5 (continued). Decomposition of Responses to GDP Shocks
Responses to Japan and rest of world GDP



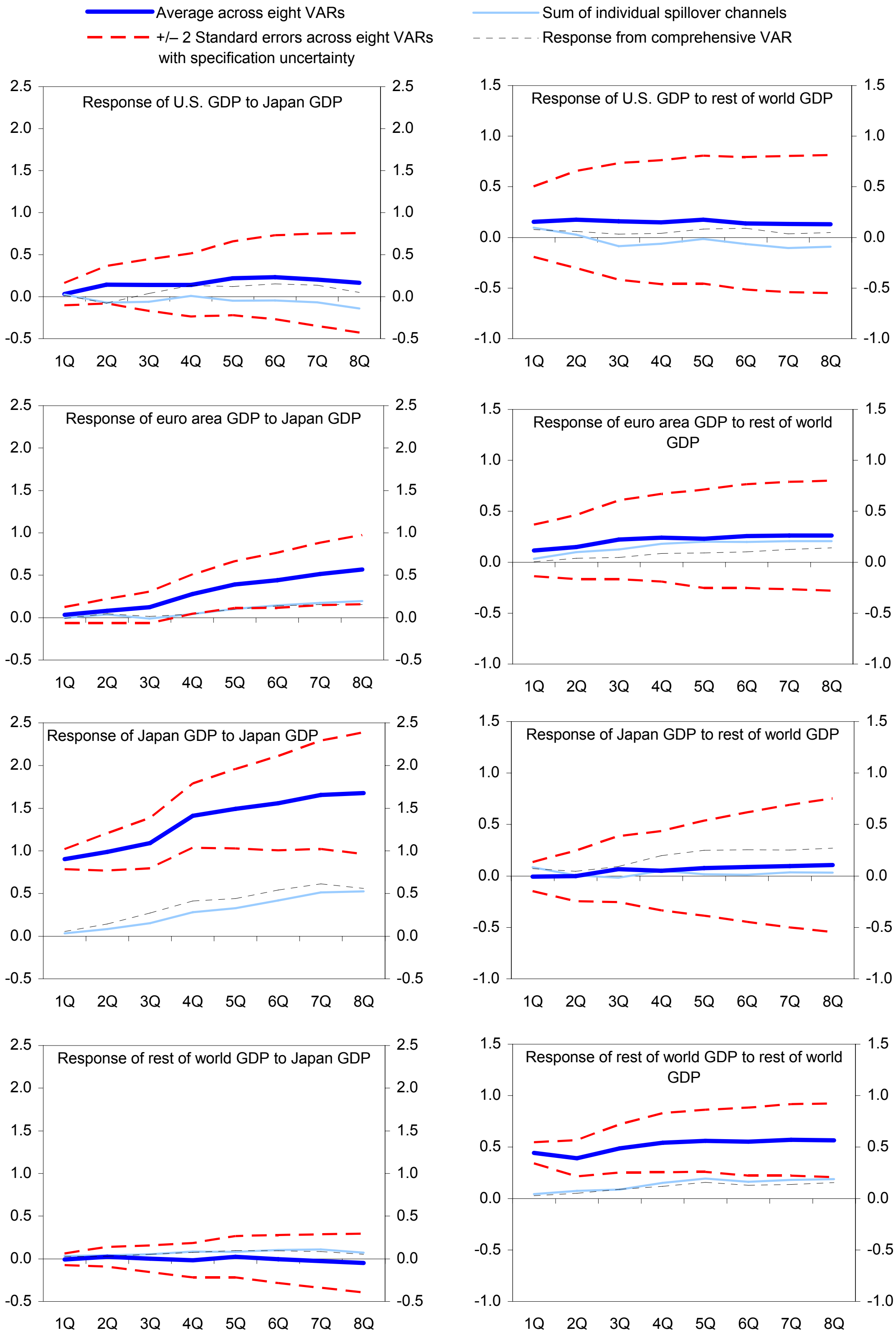
Source: IMF staff calculations.

Figure 6. Responses by Identification Method



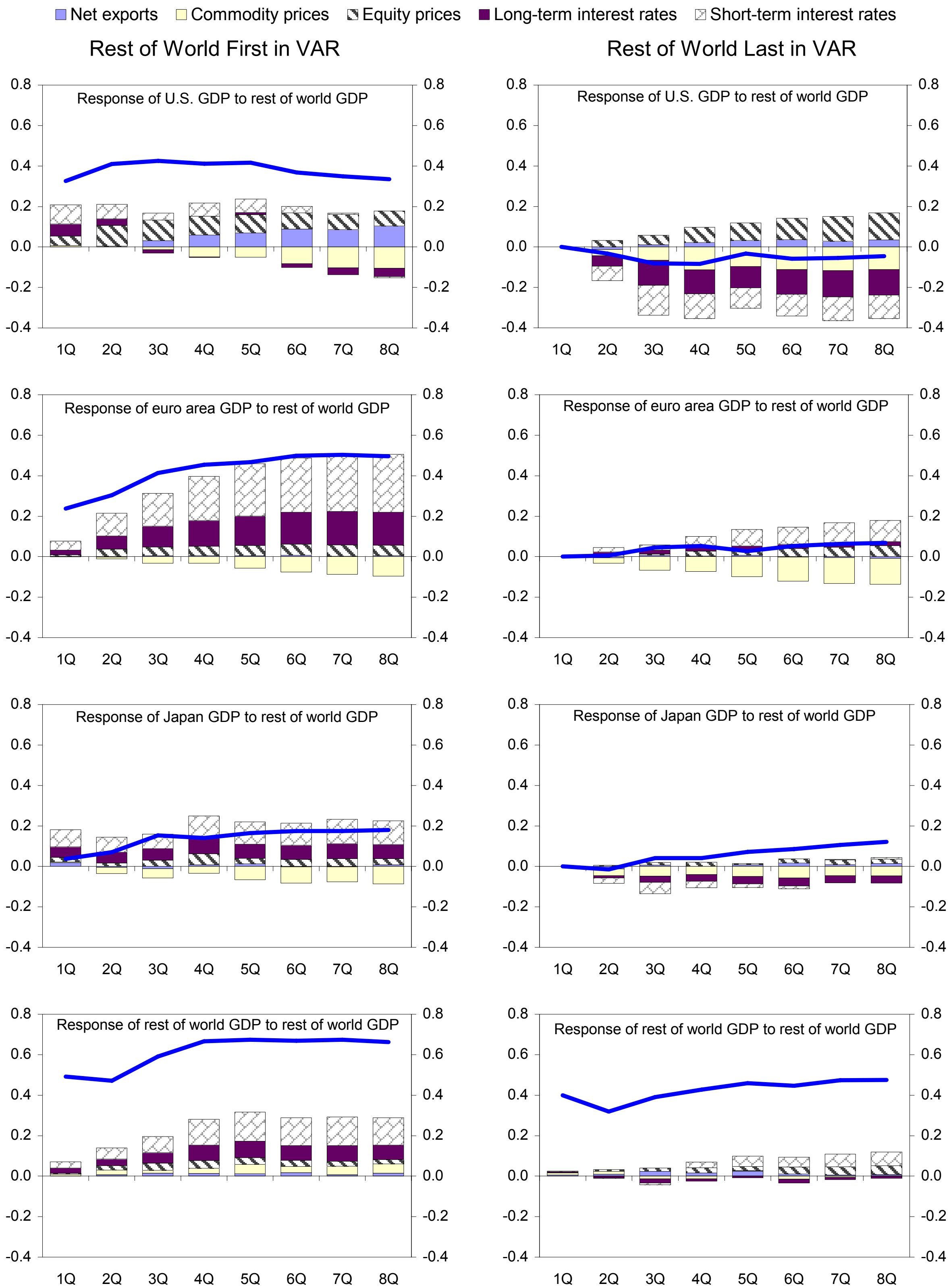
Source: IMF staff calculations.

Figure 6 (continued). Responses by Identification Method



Source: IMF staff calculations.

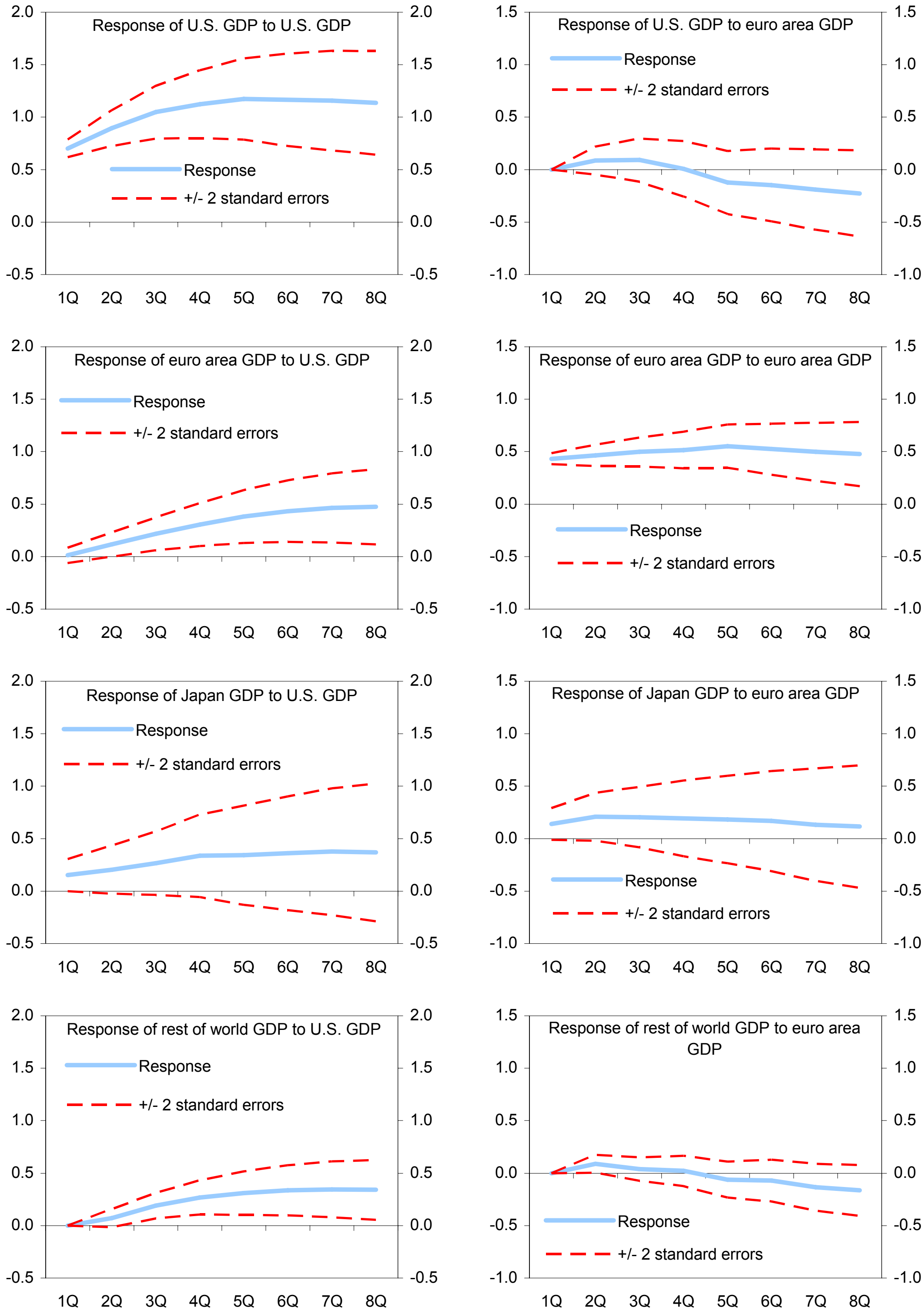
Figure 7. Decomposition of Responses to Rest of World GDP Shocks



Source: IMF staff calculations.

Figure A1. Response to Shocks to GDP

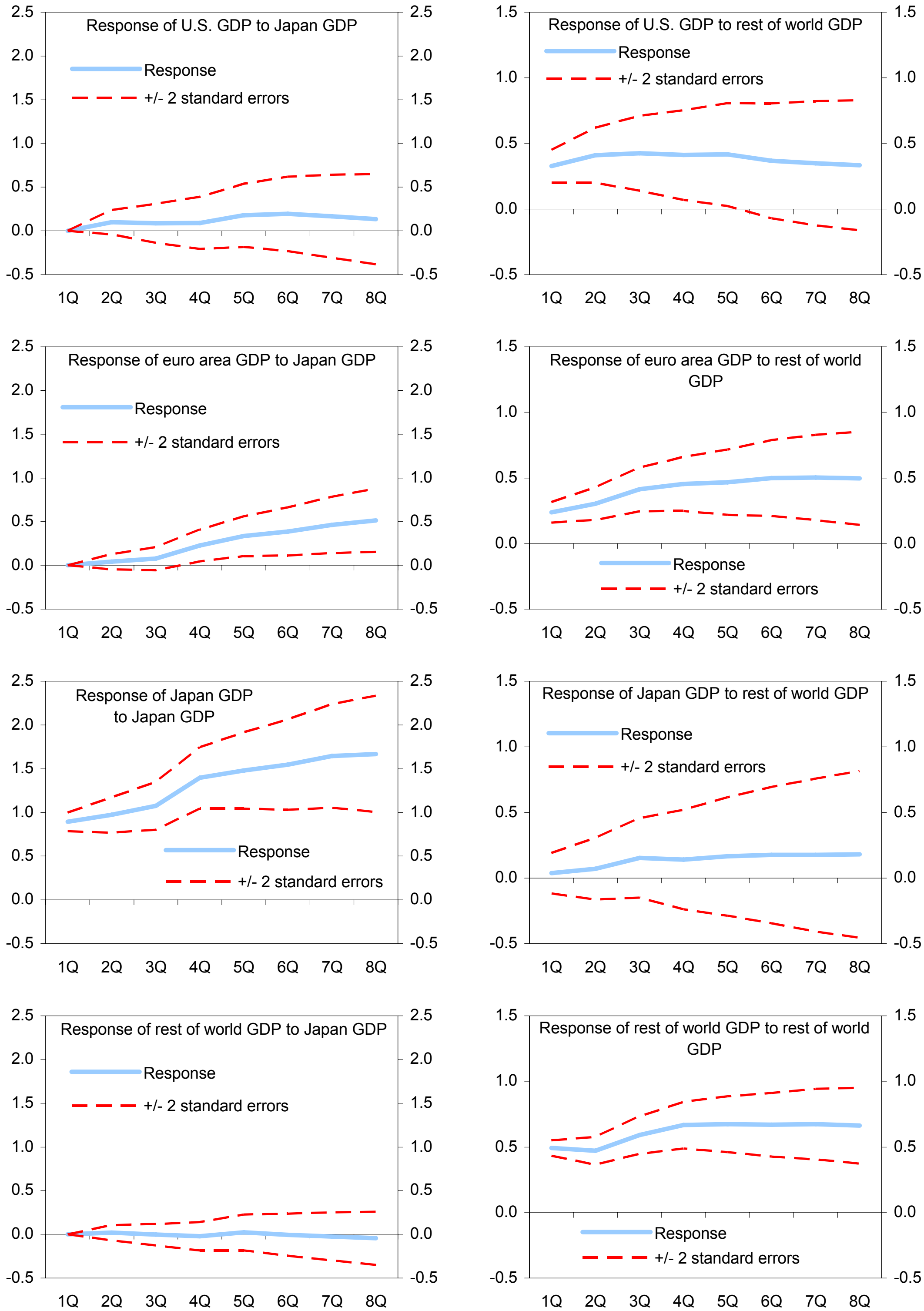
VAR Ordering: Rest of world, United States, euro area, Japan



Source: IMF staff calculations.

Figure A1 (continued). Response to Shocks to GDP

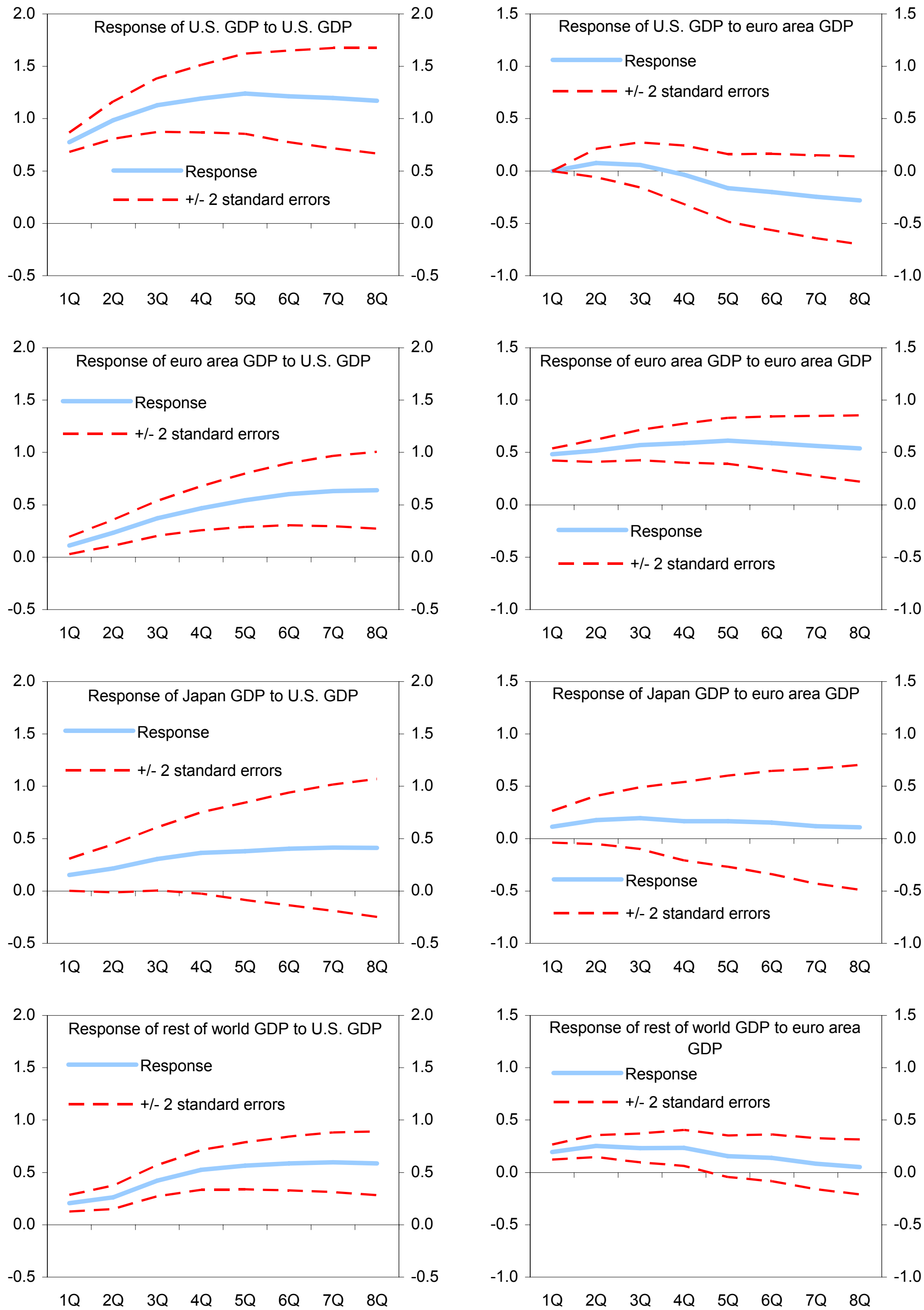
VAR Ordering: Rest of world, United States, euro area, Japan



Source: IMF staff calculations.

Figure A2. Response to Shocks to GDP

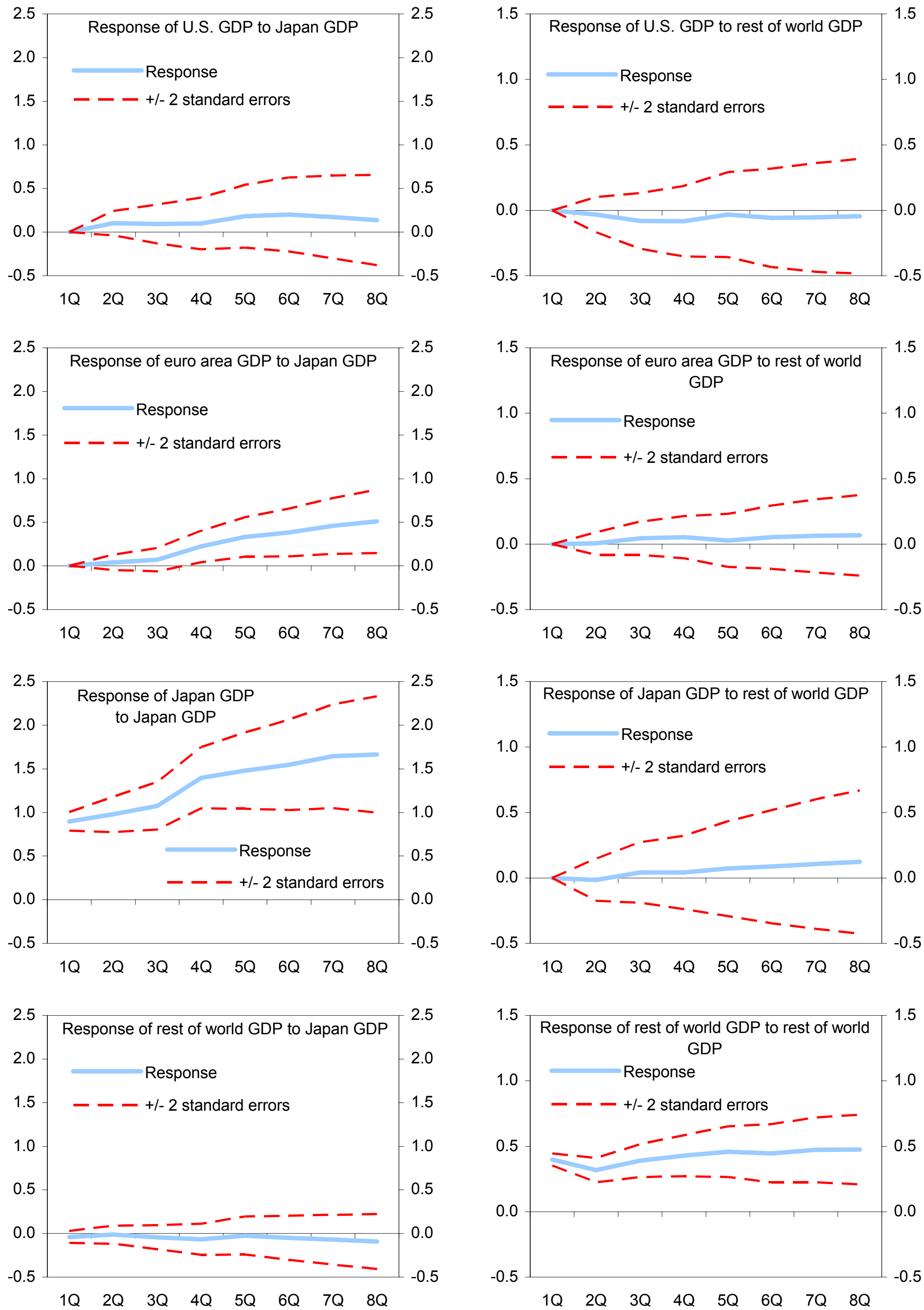
VAR Ordering: United States, euro area, Japan, rest of world



Source: IMF staff calculations.

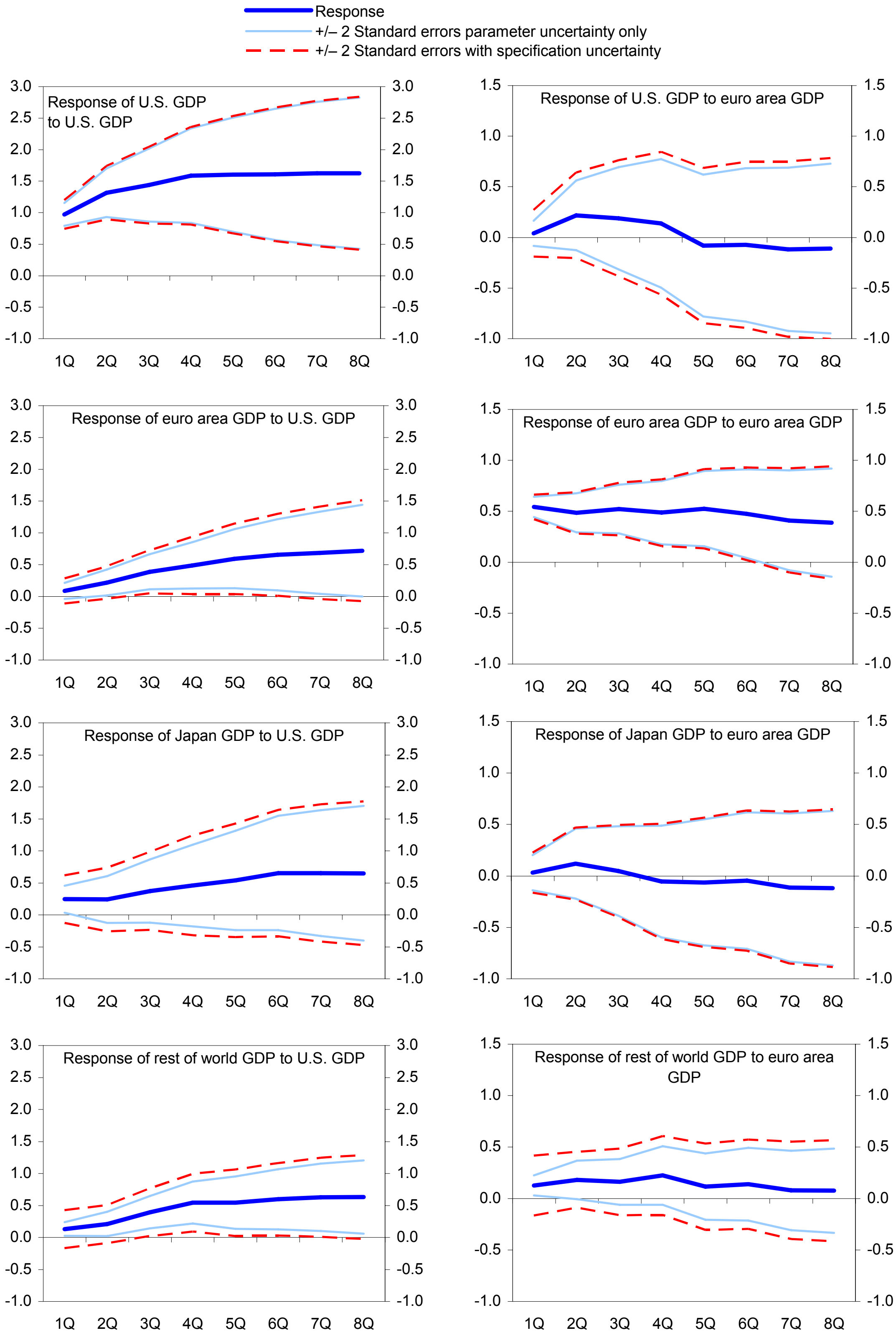
Figure A2 (continued). Response to Shocks to GDP

VAR Ordering: United States, euro area, Japan, rest of world



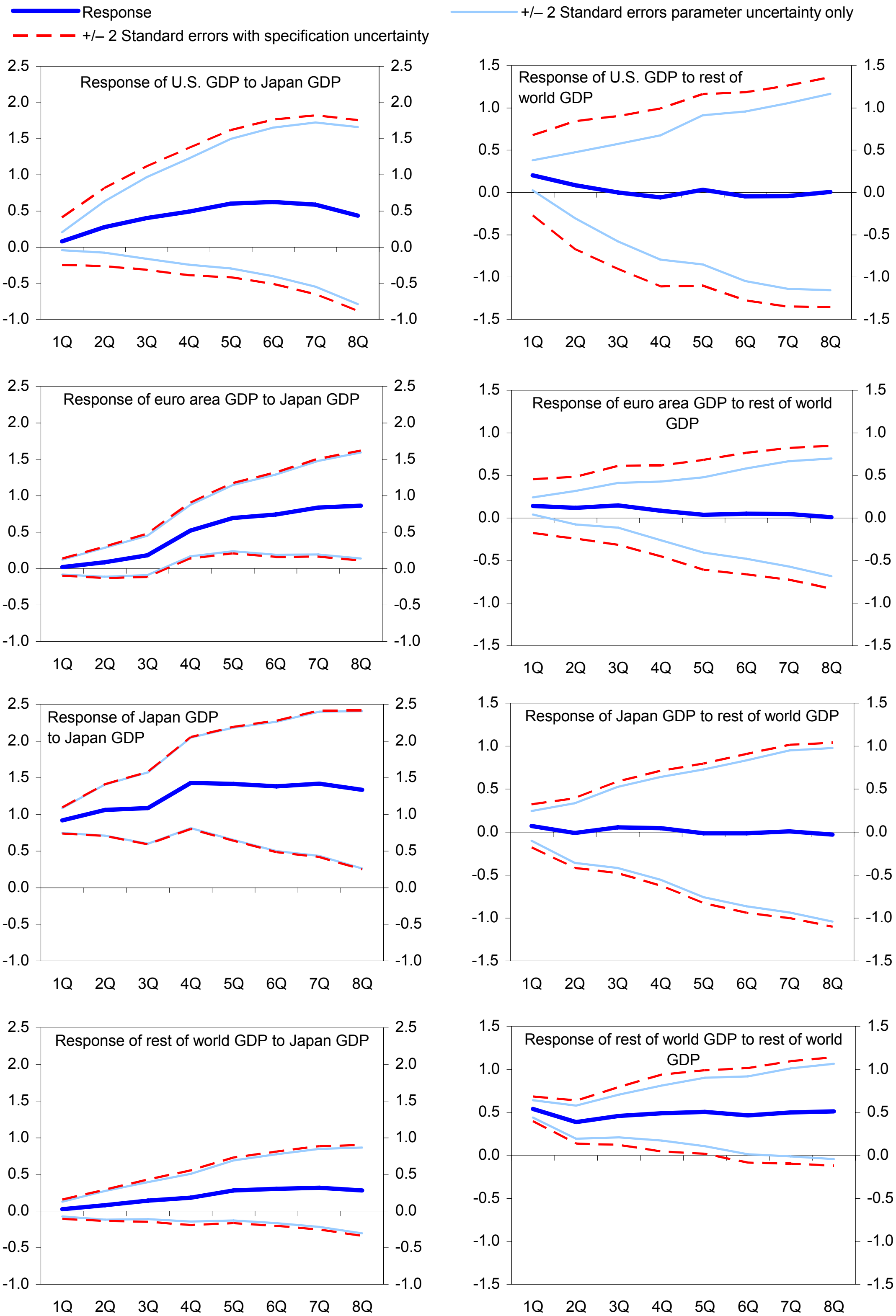
Source: IMF staff calculations.

Figure A3. Responses to Shocks to GDP Across Eight VARs, 1970–1987



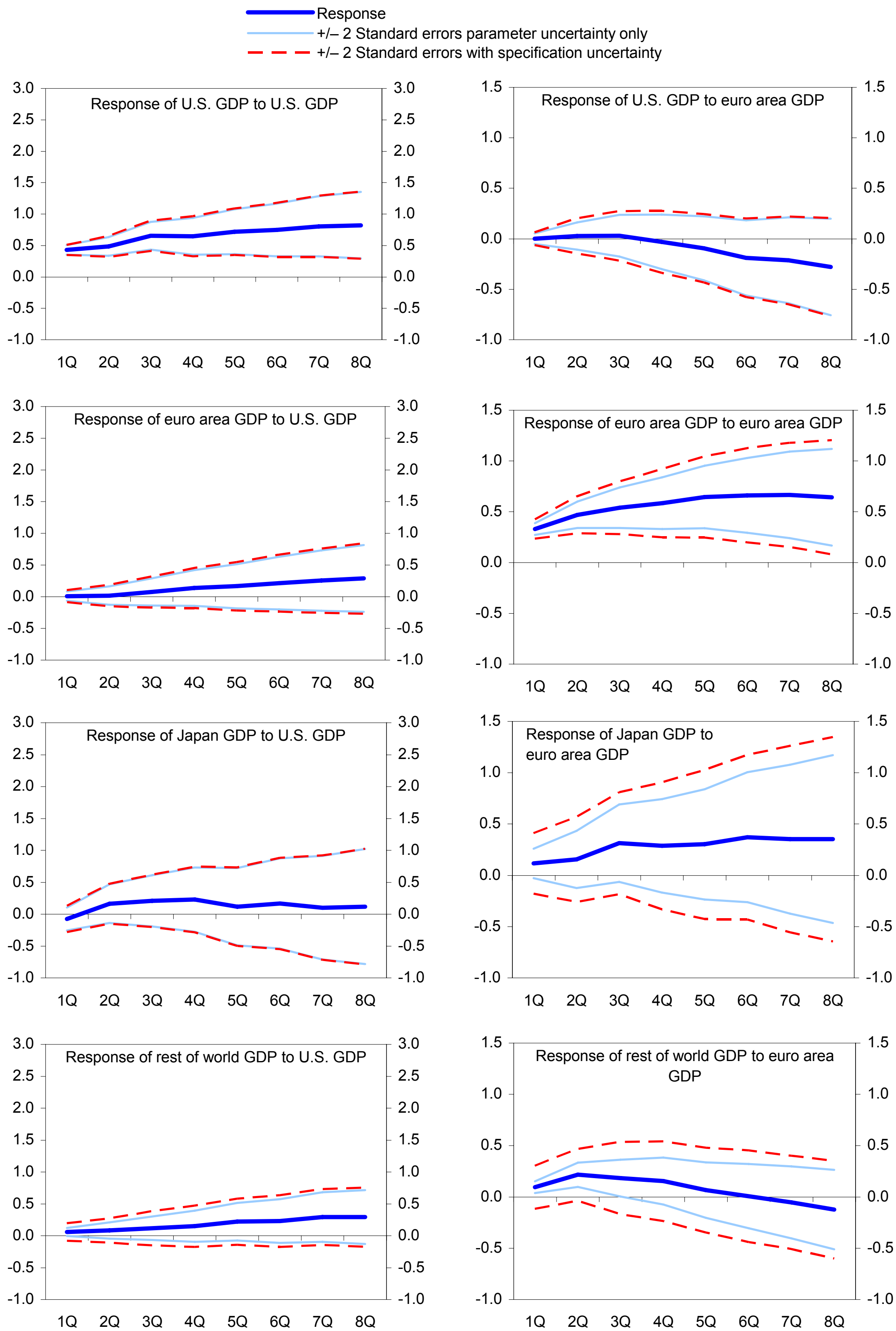
Source: IMF staff calculations.

Figure A3 (continued). Responses to Shocks to GDP Across Eight VARs, 1970–1987



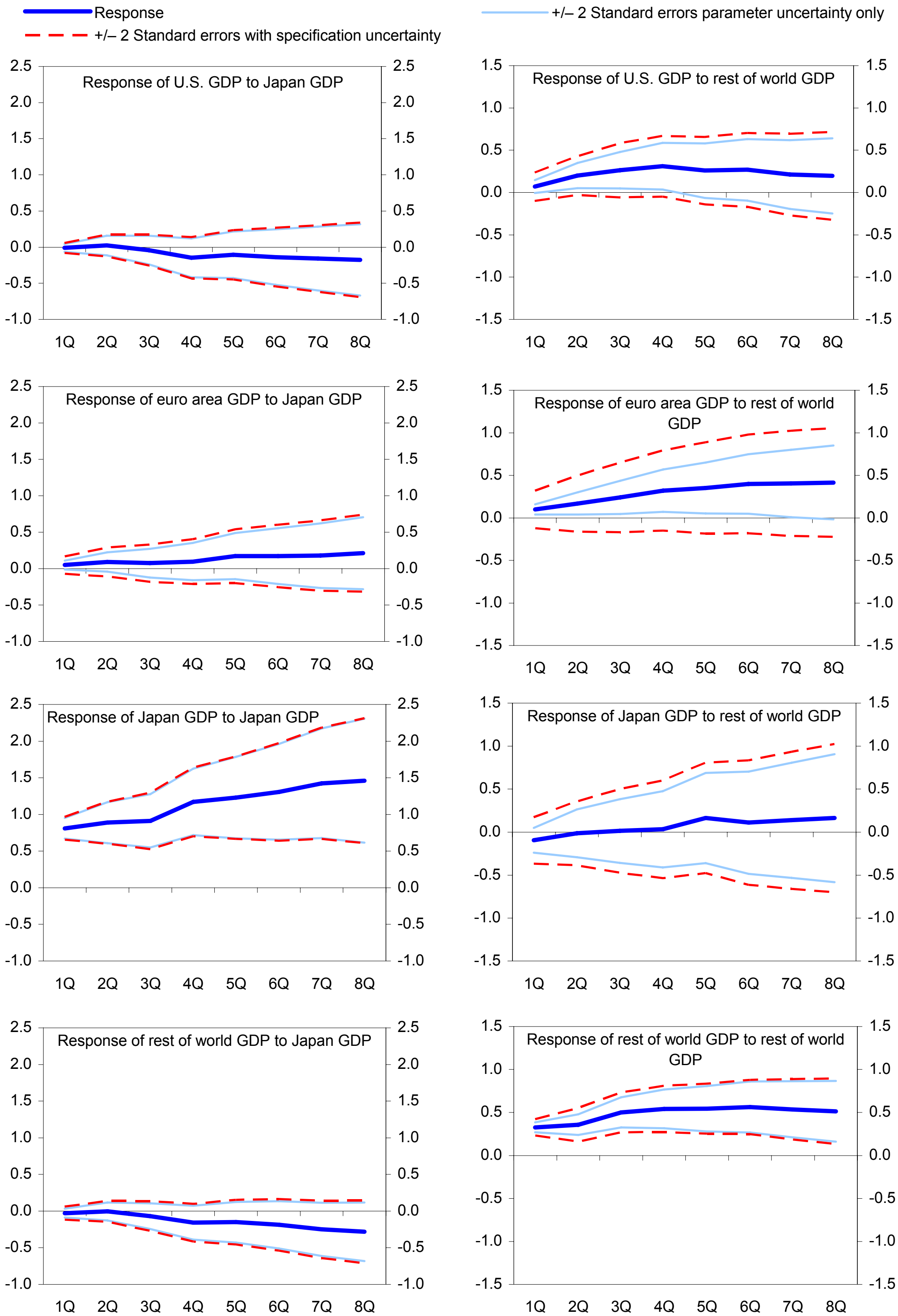
Source: IMF staff calculations.

Figure A4. Responses to Shocks to GDP Across Eight VARs, 1988–2006



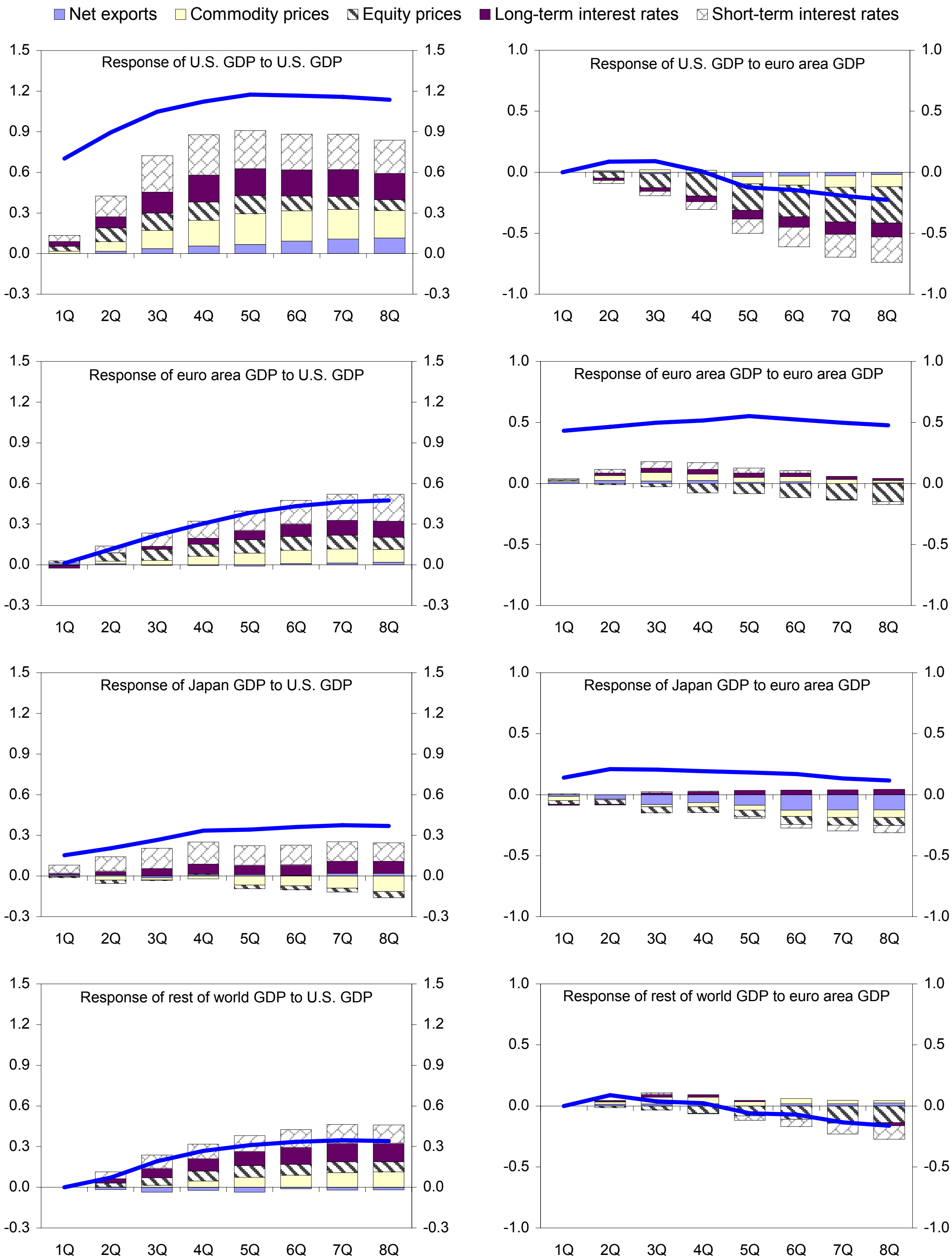
Source: IMF staff calculations.

Figure A4 (continued). Responses to Shocks to GDP Across Eight VARs, 1988–2006



Source: IMF staff calculations.

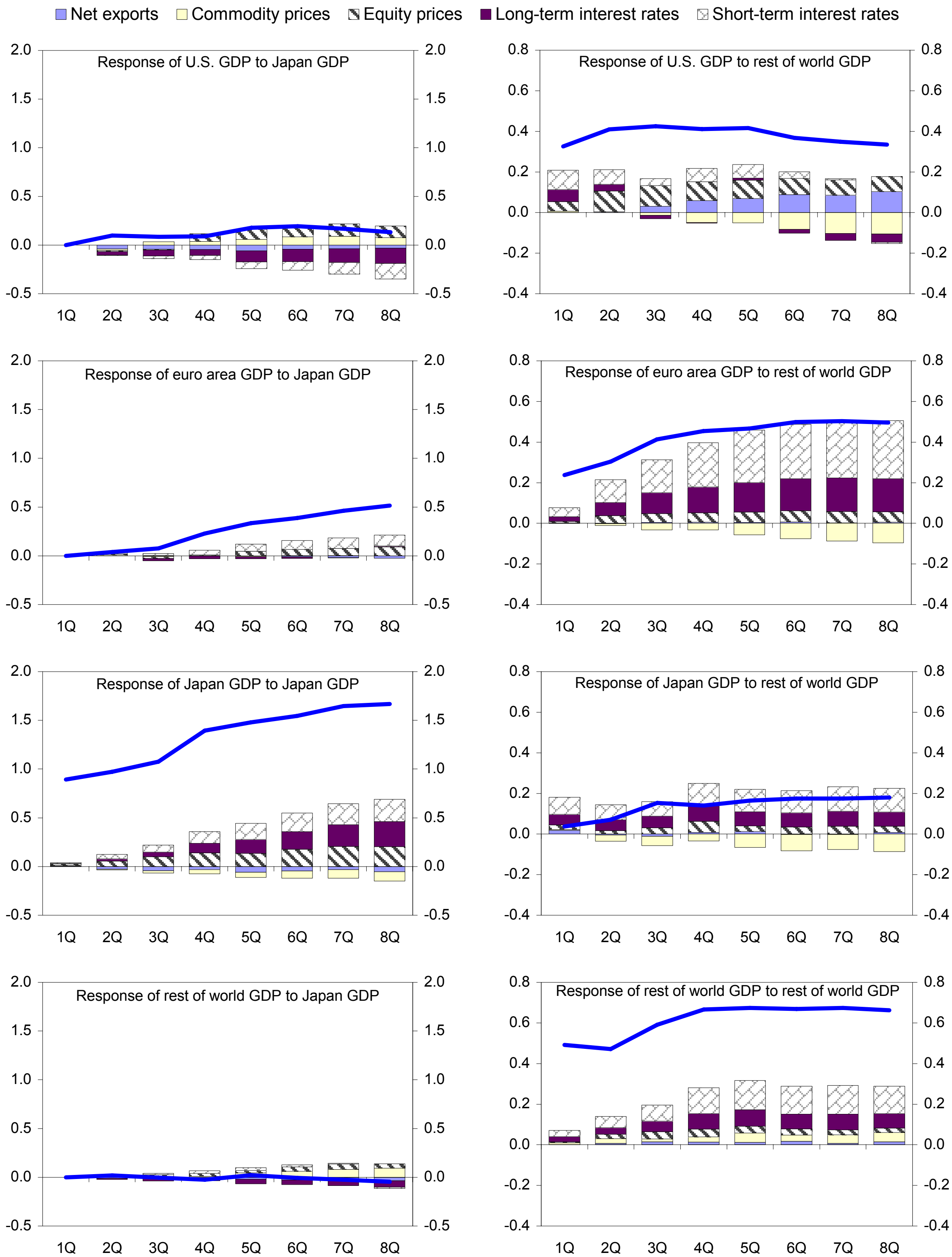
Figure A5. Decomposition of Responses to GDP Shocks
VAR Ordering: Rest of World, United States, euro area, Japan



Source: IMF staff calculations.

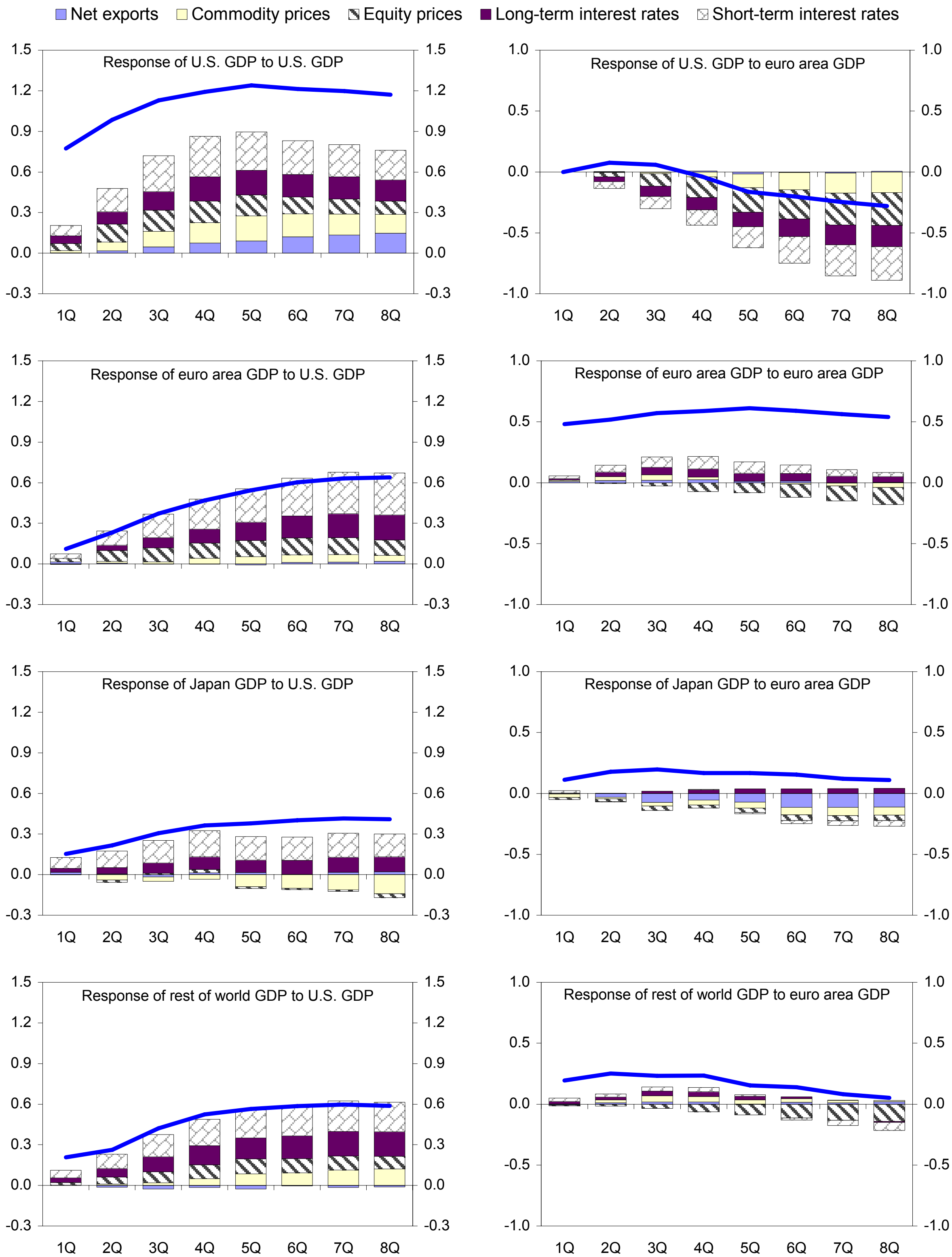
Figure A5 (continued). Decomposition of Responses to GDP Shocks

VAR Ordering: Rest of World, United States, euro area, Japan



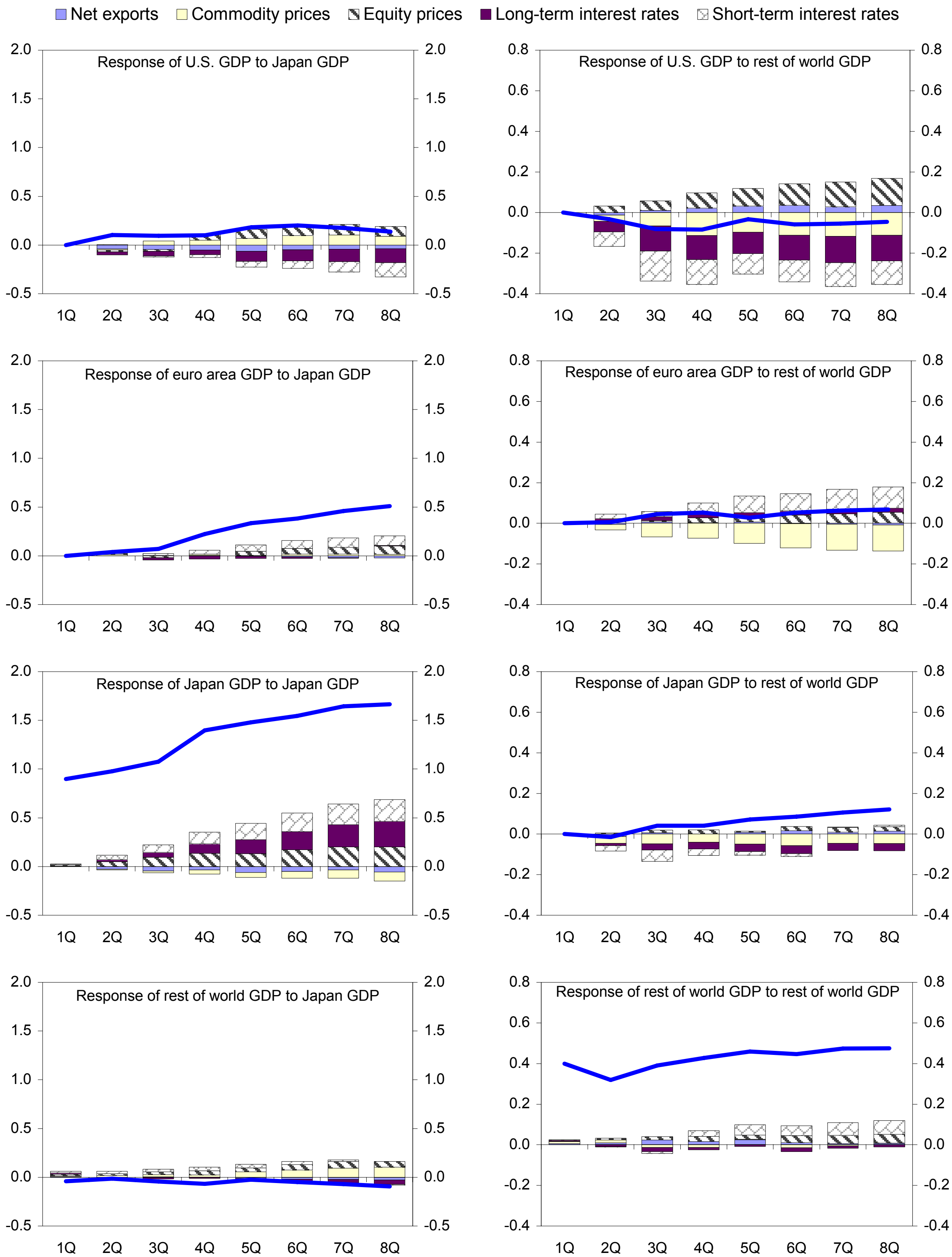
Source: IMF staff calculations.

Figure A6. Decomposition of Responses to GDP Shocks
VAR Ordering: United States, euro area, Japan, rest of World



Source: IMF staff calculations.

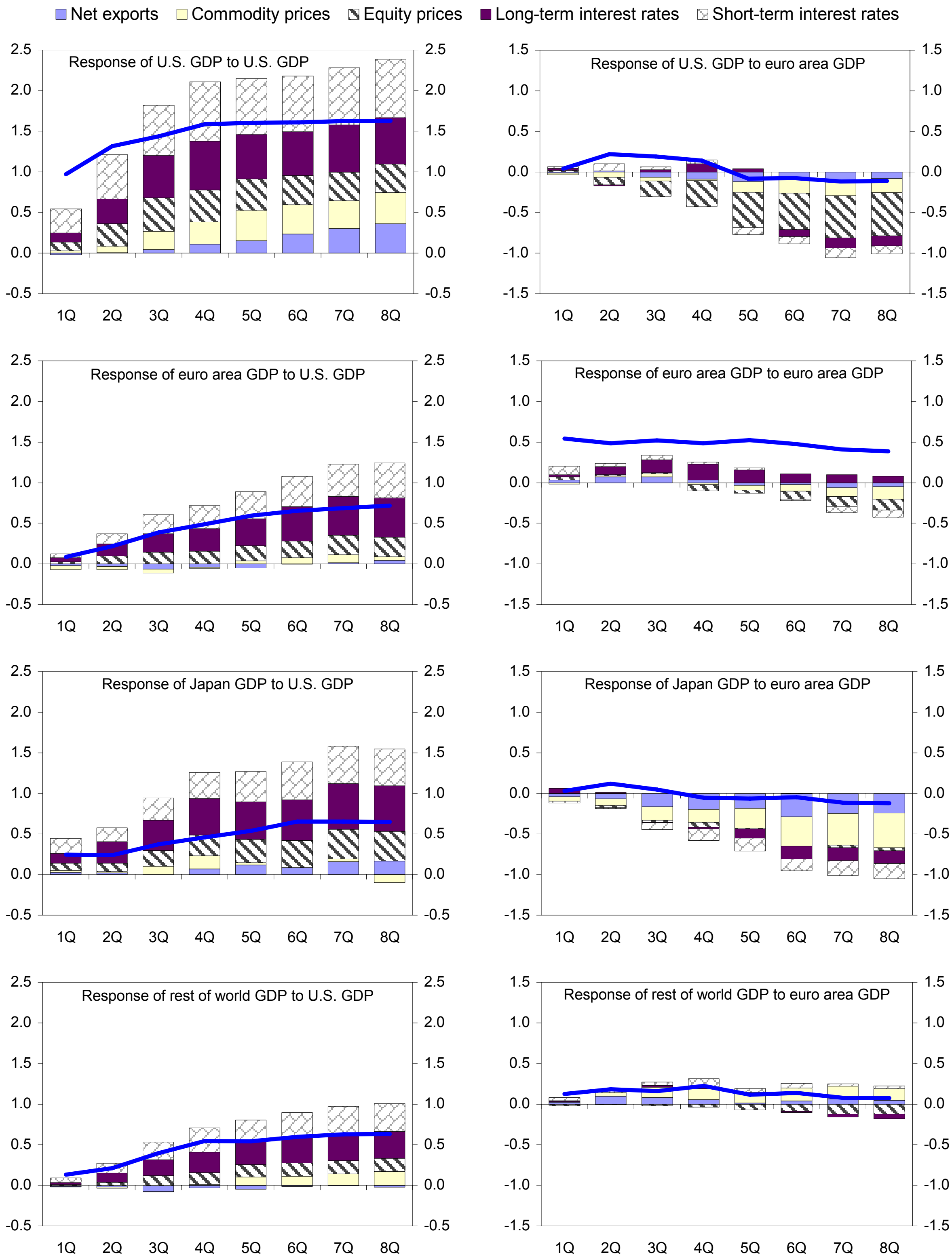
Figure A6 (continued). Decomposition of Responses to GDP Shocks
VAR Ordering: United States, euro area, Japan, rest of World



Source: IMF staff calculations.

Figure A7. Decomposition of Responses to GDP Shocks, 1970–1987

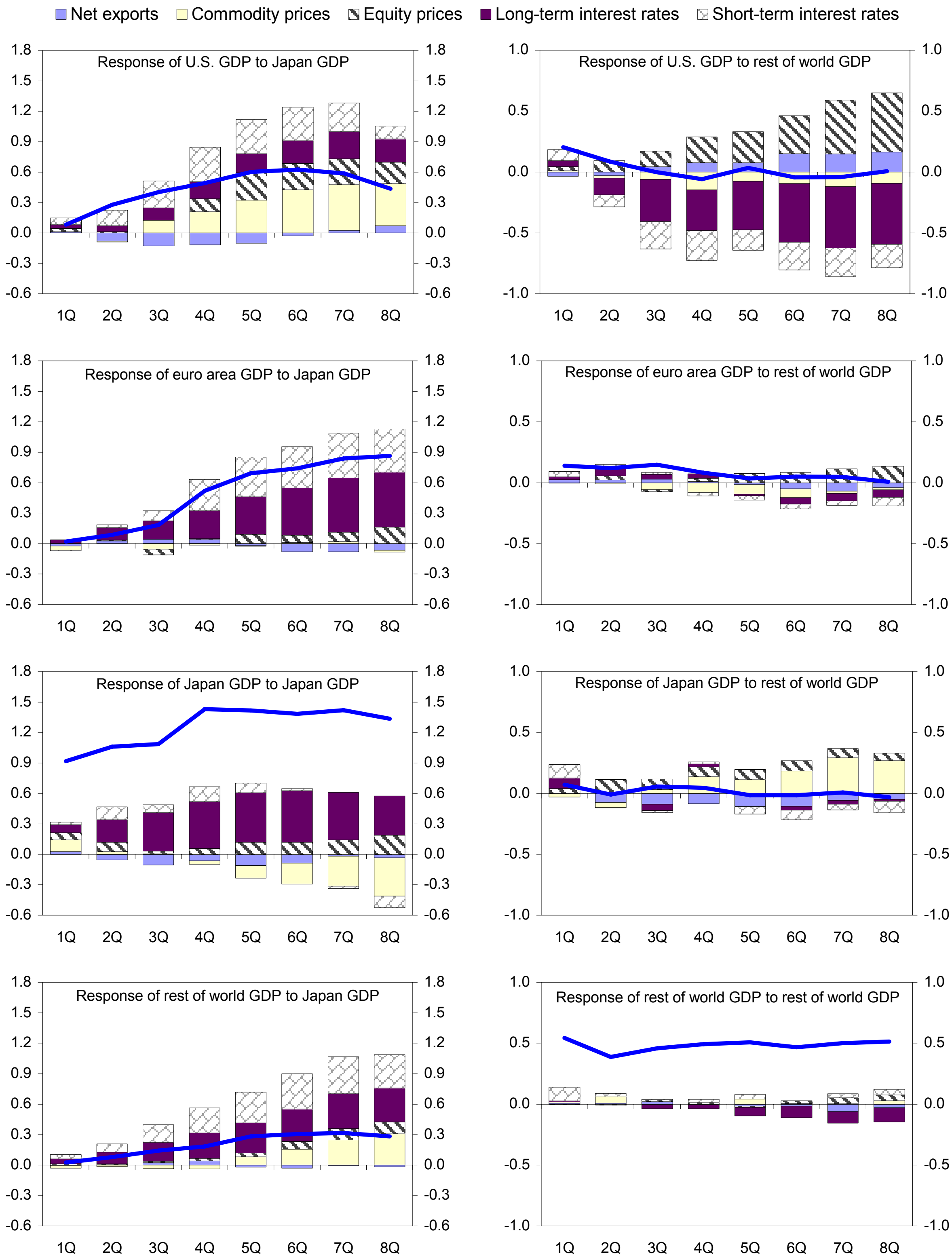
Responses to U.S. and euro area GDP



Source: IMF staff calculations.

Figure A7 (continued). Decomposition of Responses to GDP Shocks, 1970–1987

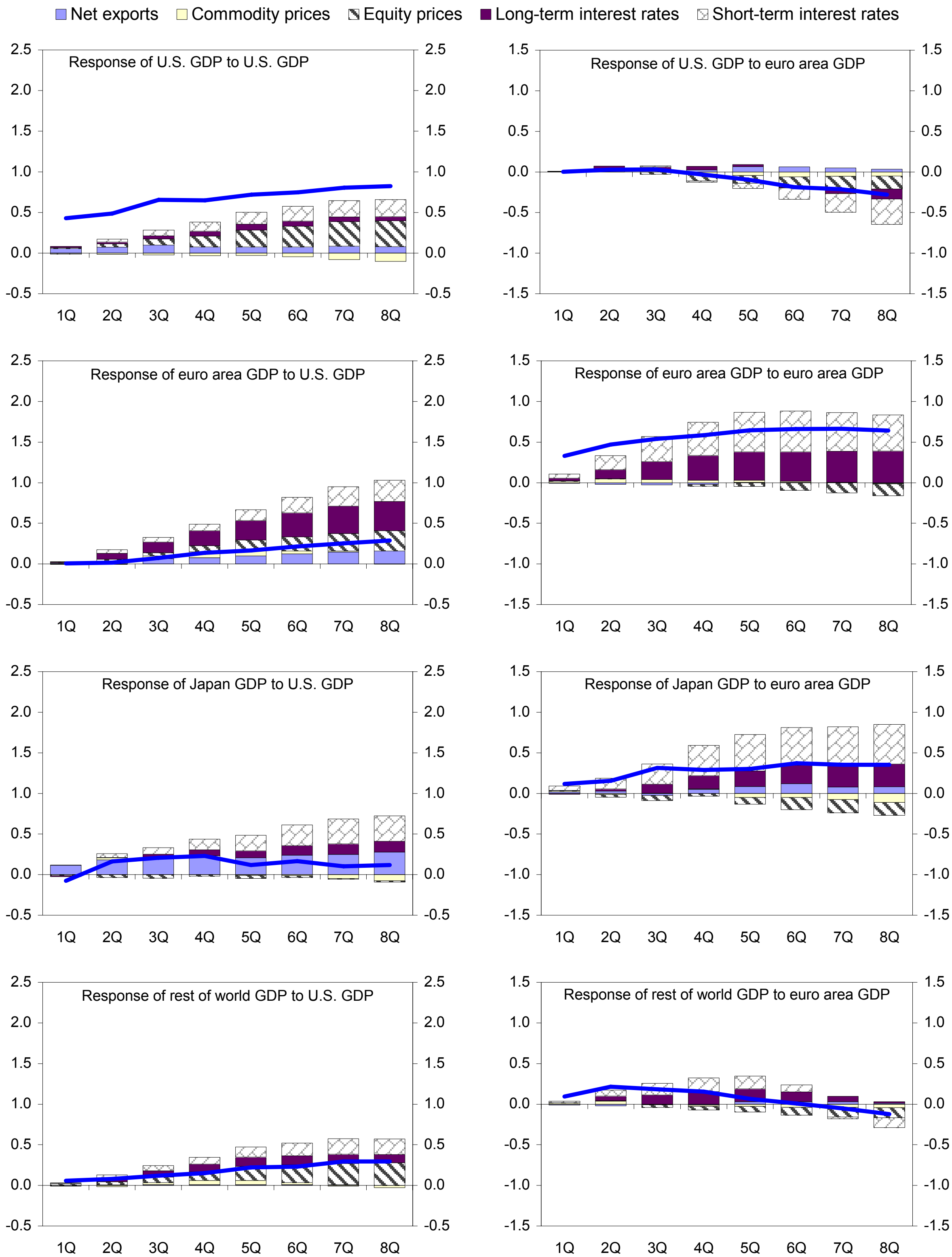
Responses to Japan and rest of world GDP



Source: IMF staff calculations.

Figure A8. Decomposition of Responses to GDP Shocks, 1988–2006

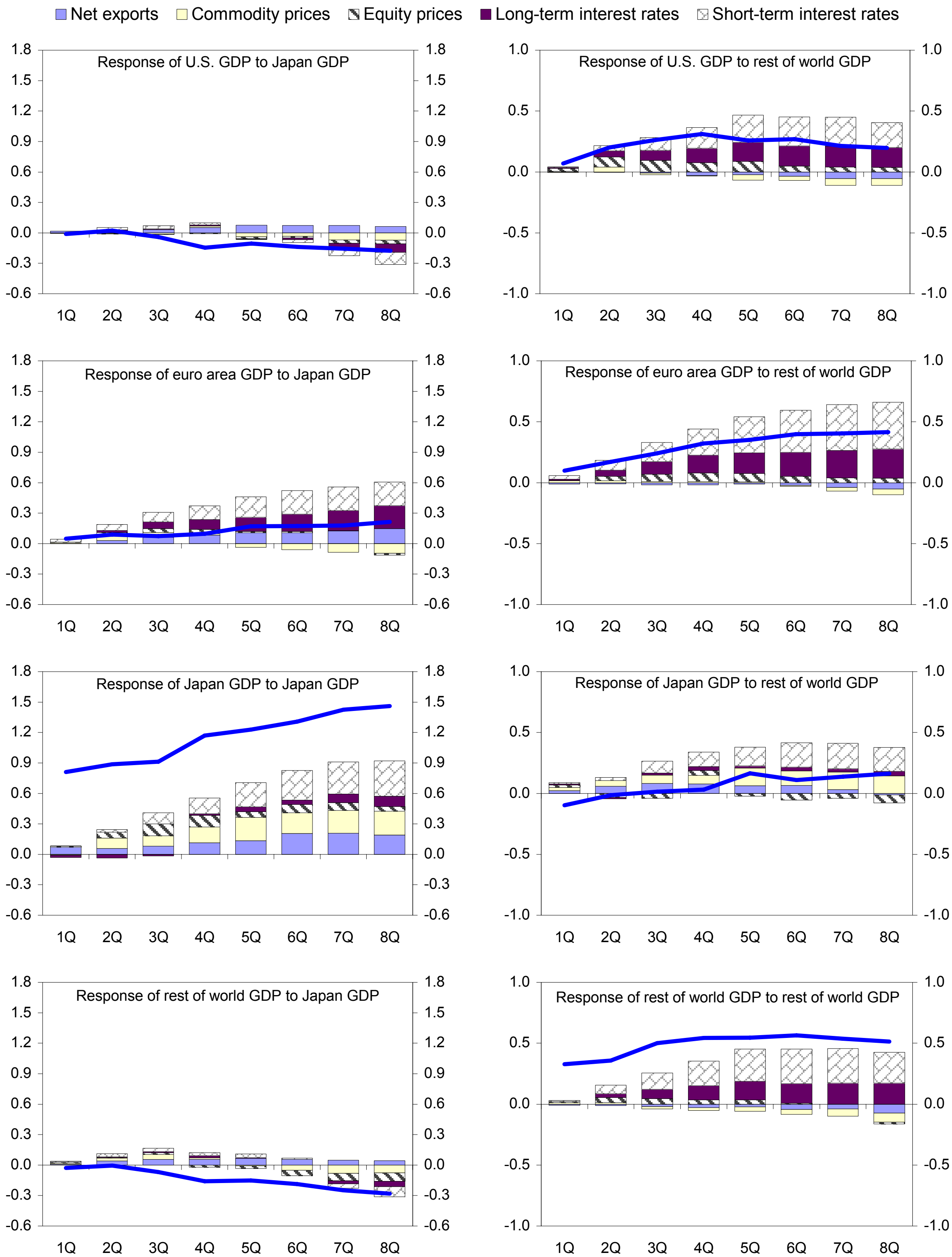
Responses to U.S. and euro area GDP



Source: IMF staff calculations.

Figure A8 (continued). Decomposition of Responses to GDP Shocks, 1988–2006

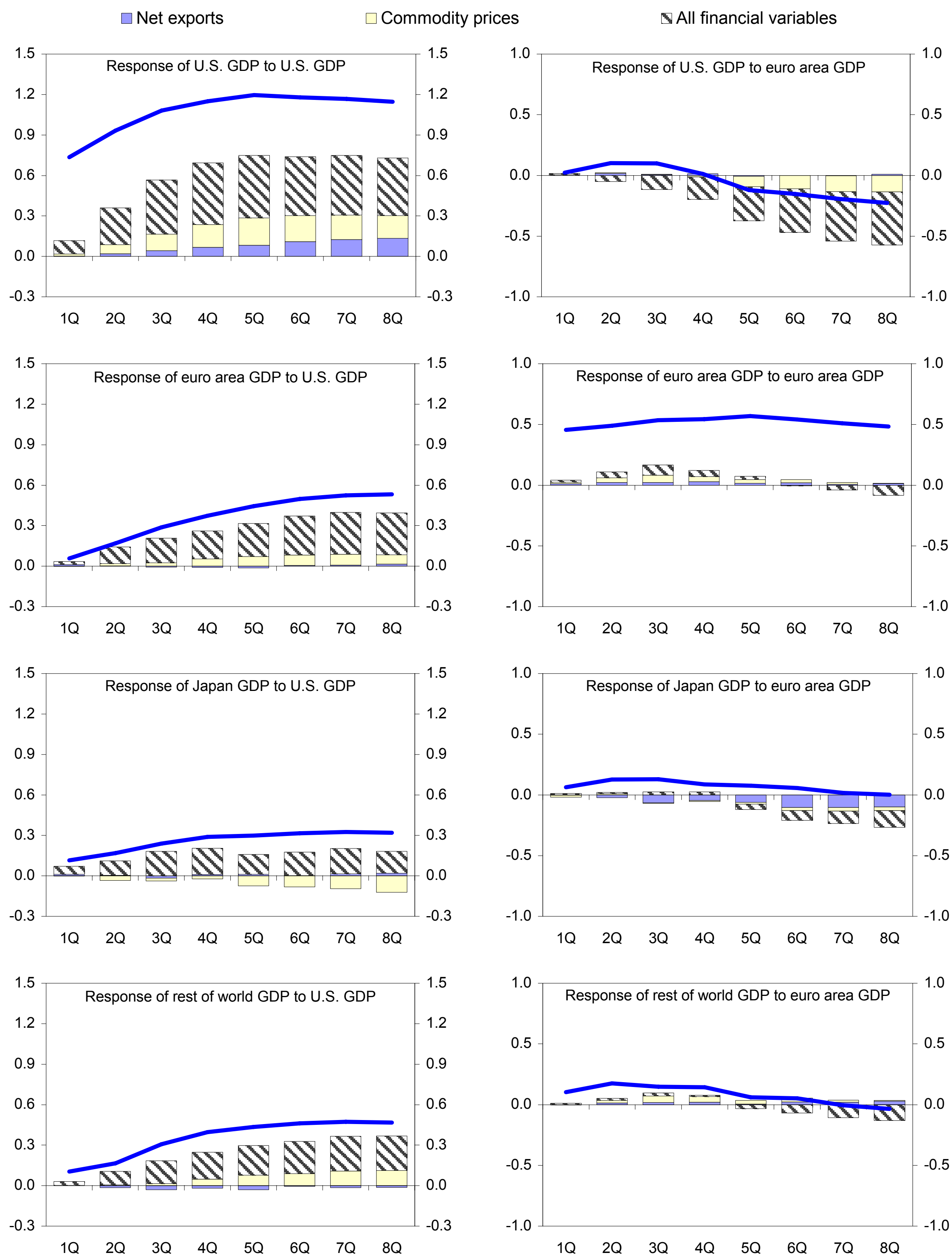
Responses to Japan and rest of world GDP



Source: IMF staff calculations.

Figure A9. Decomposition with Financial Variables Included Jointly

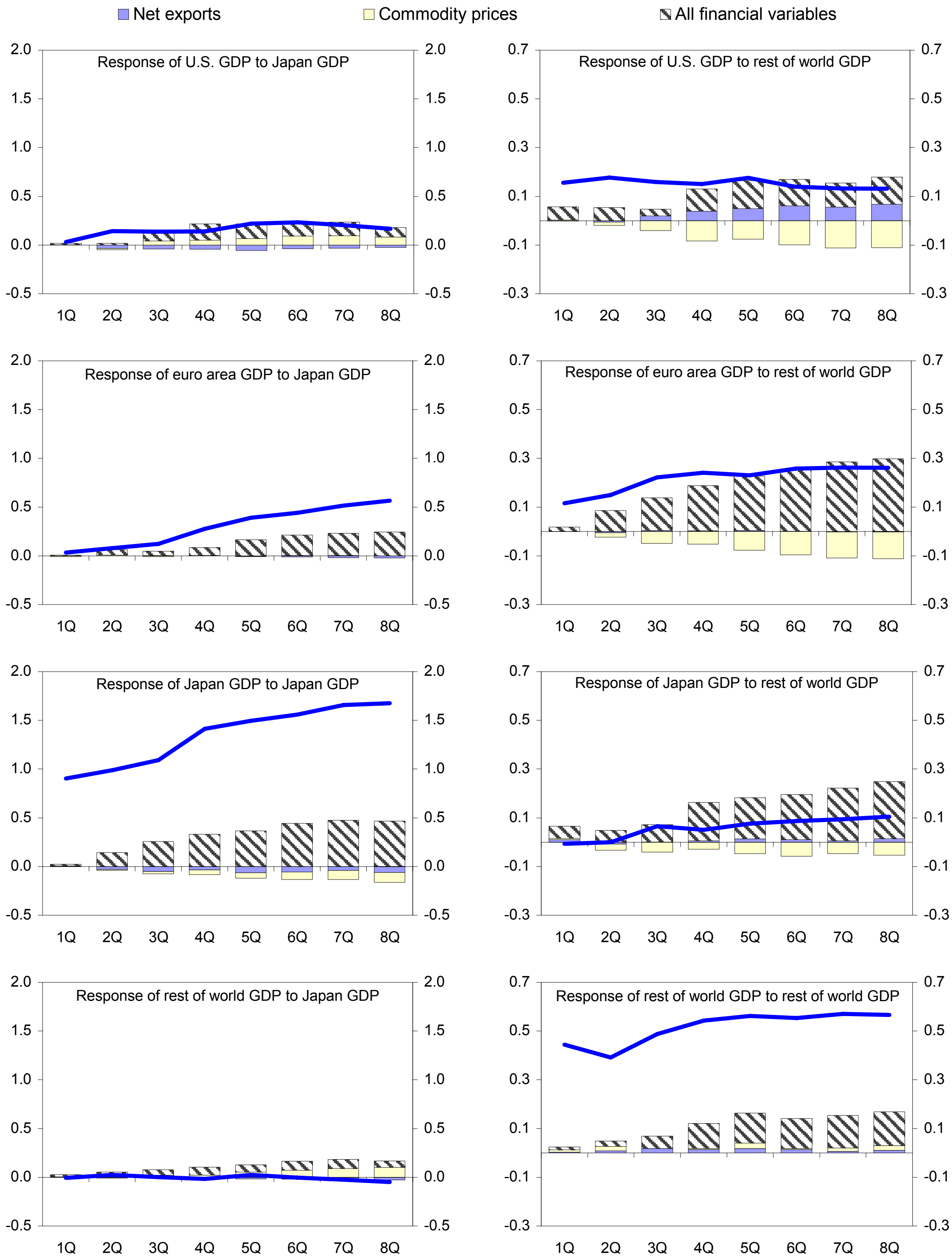
Responses to U.S. and euro area GDP



Source: IMF staff calculations.

Figure A9 (continued). Decomposition with Financial Variables Included Jointly

Responses to Japan and rest of world GDP



Source: IMF staff calculations.