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GPM6 - The Global Projection Model with 6 Regions

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Abstract

This is the sixth of a series of papers that are being written as part of a project to estimate a small quarterly Global Projection Model (GPM). The GPM project is designed to improve the toolkit to which economists have access for studying both own-country and cross-country linkages. In this paper, we add three more regions and make a number of other changes to a previously estimated small quarterly projection model of the US, euro area, and Japanese economies. The model is estimated with Bayesian techniques, which provide a very efficient way of imposing restrictions to produce both plausible dynamics and sensible forecasting properties.

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I. INTRODUCTION

The goal of the Global Projection Model (GPM) project is to develop a series of country or regional small macro models incorporating carefully articulated real and financial linkages. The resulting model would allow forecasters to project a coherent world economic outlook.

While it would theoretically be better to use a series of DSGE models as inputs into a global projection model, in practice we are far from being able to integrate such models into a global model at this stage of the development of macro model building. Thus, we decided to aim for an intermediate position between a DSGE model and a purely time series model, in which we use both theory and calibration (in part based on insights from micro-founded DSGE models) and Bayesian estimation as a basis for the individual country and regional models, and also incorporate real and financial cross-country linkages into the multi-country model. These should help the model to replicate behavior in the real world. Furthermore, since each of the small quarterly country projection models on which the global GPM model is based uses only a small number of behavioral equations to characterize the macroeconomic structure of the economy, the model is both easy to use by modelers and comprehensible to policymakers.

Our specification of the GPM model is thus based on economic theory (although not necessarily theory fully developed from micro-foundations) and the estimation involves Bayesian methods based in part on prior judgments with respect to the values of the model parameters and standard deviations of the error terms in the equations. We use a number of criteria for judging what is an acceptable model, perhaps the most important of which is that the model simulations result in sensible impulse response functions. Such an approach, using theory, calibration, and Bayesian estimation, falls between fully micro-founded estimated models and purely time series or VAR models. On the one hand, it avoids one of the problems of many fully-estimated macro econometric models—unrealistic simulation properties because of difficulties in dealing with simultaneity problems. On the other hand, by using economic theory as the basis for the model, the approach should be able to outperform global VAR models in forecasting and enable researchers to undertake policy simulations that cannot be addressed by VAR models.

The GPM model is intended for use by international organizations and country central banks. The advantage to central banks is that it is preferable to use such a model to develop their external forecast rather than any of the current approaches in use. At present, in constructing their economic outlook, most central banks approach the projection of the external environment (which in many cases is a crucial input into their domestic forecast) in one of four ways. First, they may use forecasts for their trading partners that are derived from separate projections made available by financial institutions or purchased from commercial sources. These have the advantage of being based on expert knowledge about the individual economies, but may be globally inconsistent in the sense that the outlook for one country may incorporate assumptions for the outlook for its trading partners that are different from the projections being used for those trading partners. For example, the assumptions about future developments in the Chinese economy from Chinese sources may be inconsistent with the Chinese forecast underlying the Japanese projection taken from Japanese sources. Also, the timing of the country projections from each country's domestic sources may be different from the timing of the projections of other countries, and important developments subsequent to the release of the earliest projections may therefore not be taken into account. Second, they may use forecasts that try to maintain coherence across countries, such as the OECD annual forecast and the IMF semiannual forecast.[1] The disadvantage of these forecasts from the perspective of central banks is that they are typically not issued frequently enough for the central banks' internal forecast needs. Thus, central banks may be forced to choose between using coherent out-of-date external forecasts and less coherent but more up-to-date external forecasts. Third, central banks may build their own models of external economies. This is a very resource intensive approach and beyond the realm of possibility for all but the largest central banks or perhaps for countries with one principal trading partner for which they can build their own model. Fourth, in practice, rather than building their own models of the external sector, central banks could use subjective adjustments of the forecasts from the first and second approaches to address timing problems.

All of the approaches, with the exception of the third, have another important disadvantage in that they do not allow the central bank to carry out alternative projections that address questions that are important to consider in policymaking. For example, what would be the effect on the domestic economy (and therefore on the projected path for the domestic policy instrument) if the US economy or the emerging economies were to grow faster or slower than projected in the base case projection? What would be the effect on the domestic economy if financial conditions in the major industrialized economies were tighter or easier than projected?

As noted, the goal of the global projection model is to allow forecasters to construct a coherent multi-country economic outlook and to use it for policy simulations. Thus, in our approach the projection for aggregate demand in country 1 is the input for spillovers to country 2 from country 1 and vice versa. Equally important, the model facilitates the development of alternative projections based on "what if" questions. It also allows for the construction of confidence intervals around the various forecast outlooks. And the version of GPM to be discussed in this paper covers a very large proportion (about 85 percent) of global GDP. In addition to helping forecasters at central banks (and elsewhere) to utilize internally consistent projections of the major econo-

[1] Both organizations provide quarterly updates but these are not sufficiently detailed to be the basis for the quarterly forecasts of central banks.

mies and regions of the world as inputs into their domestic forecast, GPM6 is expected to assist the country desks at the IMF in their role of providing useful input into the IMF's World Economic Outlook (WEO) projection exercise and thereby improve the multilateral consistency of the WEO projection. As well, the GPM process is expected to help the country desks to engage in more fruitful discussions with their central bank and government counterparts in the course of their interactions with the authorities of the countries for which they are responsible.

This study is the sixth of a series of studies designed to develop a full global projection model. The first study in the series, "A small quarterly projection model of the US economy" (Carabenciov and others, 2008a), set out a closed economy version of the model and applied it to the US economy using Bayesian estimation techniques. It incorporated a financial variable for the US economy, enabling us to see the effects of changes in this variable on US output and inflation. The second in the series, "A small quarterly multi-country projection model" (Carabenciov and others, 2008b), extended the model to an open economy. It set out a small quarterly projection model of the US, euro area, and Japanese economies (henceforward the G3 economies) to illustrate the way that such models can be used to understand past economic developments and to forecast future developments in a multi-country setting. The third paper in the series, "A Small Quarterly Multi-Country Projection Model With Financial-Real Linkages and Oil Prices" (Carabenciov and others, 2008c), added oil prices to the three country model. This permitted us to examine the effects of temporary and permanent shocks to the level and growth rate of oil prices on the three economies.[2] The fourth paper in the series,"Adding Latin America to the Global Projection Model" (Canales-Kriljenko and others, 2009) added the aggregate of the five inflation-targeting Latin American economies (Brazil, Chile, Colombia, Mexico and Peru) to the previously-estimated three country model without oil. The fifth paper in the series, "Adding Indonesia to the Global Projection Model" (Andrle and others, 2009) added a model of the Indonesian economy to the previously-estimated three country model without oil.

The new elements in this, the sixth paper of the series, are as follows. First, having six regions (United States, euro area, Japan, emerging Asia, the five Latin America inflation-targeting countries, and a remaining countries grouping) covering a very large proportion (about 85 percent) of world economic output brings us much closer to a truly global model. Second, there is more emphasis on both real and financial linkages across countries than in the earlier studies. Third, while the previous studies allowed for financial spillovers only from the United States to other countries, this version of the model allows for financial spillovers from the United States, the euro area and Japan. Fourth, in addition to the traditional country demand shock, we focus in this paper on demand shocks that are common across a number of countries or are global in their

[2] Clinton and others (2010) used this model to discuss international deflation risks under alternative macroeconomic policies.

dimension. Fifth, the models in this this study contain medium-term interest rates, which are a function of policy interest rates although without a term premium.[3] Sixth, the model incorporates a specification of the real exchange rate of emerging and developing economies that incorporates the Balassa-Samuelson insight with respect to trend appreciations in the real value of the currencies of these economies relative to those of the G3 economies.

While the emphasis in this paper is on the results of the extended model, a companion "how to" paper is currently being written that will present a guide to central banks in other countries that would like to add a small model of their own economy to GPM6 or subsequent models, a version that will be called GPM+. That paper will show how to add a new country to the basic 6 to 8 region model in a way that is most efficient.

Future work in this project will involve adding other financial variables to enrich real-financial sector linkages, adding a term premium to the medium-term interest rate equations, treating China a separate block, and adding commodity prices.

II. Background to the Model Specification

In recent years, the IMF has developed two main types of macroeconomic models—dynamic stochastic general equilibrium (DSGE) models and small quarterly projection models (QPMs)—that it has used for policy analysis and projections. And multi-country variants of these models have allowed researchers to provide some insights about spillover effects of shocks in one country on economic variables in other countries. The DSGE models are based on theoretical underpinnings and have been found to be very useful in analyzing the effects of structural changes, as well as the effects of longer-term developments such as persistent fiscal deficits and current account deficits.[4] The small QPMs typically use few behavioral equations to characterize the macroeconomic structure of an economy in a way that is both easy to use by modelers and readily comprehensible to policymakers. They focus on the key macroeconomic variables in the economy—typically output, inflation, a policy interest rate (and in some versions a long-term interest rate) along with the exchange rate and sometimes the unemployment rate. By virtue of their relatively simple and readily understandable structure, they are already being used for forecasting and pol-

[3] The medium-term interest rates are based on the expectations theory of the term structure applied to policy interest rates or short-term interest rates. They are latent variables, without any reference to observed medium-term interest rates.

[4] See Botman and others (2007) for a summary of some applications using these models, and Freedman and others (2010) for an example of the use of the IMF's Global Integrated Monetary and Fiscal (GIMF) model in analyzing fiscal issues.

icy analysis purposes in central banks and by country desks in the IMF.[5] In the past, the parameters of such models have typically been calibrated on the basis of the knowledge of country experts of the economic structure of the country being studied and that of similar countries.

The series of earlier papers cited in the introduction and this paper make a number of important extensions to the basic small macro model.

First, in all the papers in the series, Bayesian techniques are used to estimate many of the parameters of the model. Bayesian methods allow researchers to input their priors into the model and then to confront them with the data, in order to determine whether their priors are more or less consistent with the data. Although regime shifts in recent years (most notably, the anchoring of inflation expectations to a formal or informal target in many countries) limit the time series to relatively short periods, the estimation approach taken in these papers will be increasingly useful over time as the lengths of usable time series are extended.

Second, given the importance in recent years and at present of financial-real linkages, we have been experimenting with financial variables that might be helpful in explaining economic developments and in forecasting future movements of the economy. In past studies we used a single financial variable, a US bank lending tightening measure, which contributed importantly to the explanation of movements of the US economy over the sample period and also improved out-of-sample forecasting. In this paper we extend the use of this financial variable to include similar measures in the euro area and Japan.

Third, as noted in the introduction, the earlier studies involved continual expansion of the number of countries in the model. Moreover, the model has been programmed in such a way that researchers will be able to add other countries to the model in a relatively straightforward manner. Such models will give forecasters a new tool to assist them in preparing worldwide forecasts and in carrying out alternative policy simulations in the global context. There is strong demand for such an empirically based multi-country model, both for IMF surveillance work and for helping central bank forecasters to assess the external environment in preparing their projections. While large-scale DSGE models show promise in this regard, we are years away from developing empirically-based multi-country versions of these models. And while global VARs (GVARs) have been developed for forecasting exercises, they are not very useful for policy analysis be-

[5] See Berg, Karam, and Laxton (2006a,b) for a description of the basic model as well as Epstein and others (2006) and Argov and others (2007) for examples of applications and extensions. Currently, Fund staff are using the model to support forecasting and policy analysis and to better structure their dialogue with member countries. A number of inflation-targeting central banks have used similar models as an integral part of their Forecasting and Policy Analysis Systems—see Coats, Laxton and Rose (2003) for a discussion about how such models are used in inflation-targeting countries.

cause they lack the identification restrictions necessary to obtain plausible impulse response functions. They therefore cannot be used for alternative policy scenarios.

Fourth, in this paper, we further extend the model to include more regions. Because of the size and complexity of the GPM6 model with six regions, we use a mixture of calibration and Bayesian estimation to parameterize the model. Generally speaking, we add one additional region at a time to the GPM3 model (to give us three GPM4 models), in each of them treating the coefficients in the G3 regions estimated in GPM3 as given and using a mixture calibration and estimation to derive coefficient estimates for the additional region. We then treat almost all of these coefficient values as given, using Bayesian estimation to generate a small number of estimated coefficients in the six-region GPM6 model. More detail will be given in the section on results later in this paper.

III. The specification of the model

This section of the paper sets out the small model that in a general sense describes the behavior in both the original large G3 economies and the additional emerging economic regions. However, because of a number of differences in specification between the G3 economies and the emerging market economies, we will first set out the behavioral equations for the G3 countries and then discuss the differences in the specification of the same equations for the emerging economies.

The generic open economy model describes the joint determination of output, unemployment, inflation, interest rates and the exchange rate. The model is fundamentally a gap model, in which the gaps of the variables from their equilibrium values play the crucial role in the functioning of the system. A number of definitions and identities are used to complete the model. We present the model specification for a single country labelled i. The specification for other countries will be very similar, although there are some differences across countries that will be clarified in the discussion.

The principal differences in specification between G3 countries and emerging economies are as follows. First, the three G3 economies (US, Euro area, and Japan) have an unemployment sector whereas the three other regions (emerging Asia[6], LA5[7] and the remaining countries grouping[8]) do not for reasons of data availability. Second, there is a trend appreciation of the real ex-

[6] Emerging Asia includes China, India, South Korea, Indonesia, Taiwan, Thailand, Malaysia, Hong Kong S.A.R., Philippines and Singapore, and accounts for 23.4 percent of world GDP in purchasing power parity terms.

[7] LA5 includes Brazil, Chile, Colombia, Mexico and Peru, and accounts for 6.1 percent of world GDP in purchasing power parity terms.

[8] The remaining countries grouping includes Russia, United Kingdom, Canada, Turkey, Australia, Argentina, South Africa, Venezuela, Sweden, Switzerland, Czech Republic, Denmark, Norway, Israel, Bulgaria, New Zealand and

change rate for the emerging economies. Third, there is no bank lending tightening variable for the emerging economies, again for data availability reasons. Fourth, while the G3 economies have succeeded in achieving their steady-state target rate of inflation, some of the emerging economies are still in the process of moving towards their steady-state rate of inflation. Finally, the priors for the coefficient estimates and for the standard deviations of the structural shocks will differ across economies on the basis of expert knowledge of those economies.

A. Data definitions

The benchmark model has 5 observable variables for each G3 economy.[9] These are real GDP, the unemployment rate, CPI inflation, the policy interest rate, and the exchange rate.[10] For the emerging economies, the same variables are used with the exception of the unemployment rate, which as noted is not used at all for reasons of data availability. We use uppercase letters for the variables themselves, a letter with a bar on top as the equilibrium value for the variables, and lowercase letters for the gaps between the variables and their equilibrium values. Thus, for example, we define Y as 100 times the log of real GDP, $\overline{Y}$ as 100 times the log of potential output and y as the output gap in percentage terms ($y = Y - \overline{Y}$). [11] Similarly, we define the unemployment gap, u, as the difference between the equilibrium unemployment rate or NAIRU, $\overline{U}$ and the actual unemployment rate (U). The quarterly rate of inflation at annual rates in per cent (π) is defined as 400 times the first difference of the log of the CPI. In addition, we define the year-on-year measure of inflation ($\pi 4$) as 100 times the difference of the log of the CPI in the current quarter from its value four quarters earlier. The nominal interest rate is I and the real interest rate is R, defined as the difference between the nominal interest rate and the expected rate of inflation for the subsequent quarter. The log of the nominal exchange rate vis-à-vis the US dollar is S and the log of the real exchange rate vis-à-vis the US dollar is Z.

B. Stochastic processes

A major advantage of Bayesian methods is that it is possible to specify and estimate fairly flexible stochastic processes. In addition, unlike classical estimation approaches, it is possible to spec-

Estonia and accounts for 14.8 percent of world GDP in purchasing power parity terms. Although it is approximately balanced between advanced and emerging economies, for simplicity we generally characterize it in the discussion as an emerging economy region.

[9] The data used to define the variables in this paper are presented in appendix 1.

[10] More accurately, each non-U.S. economy has an exchange rate vis-à-vis the U.S. dollar. So if there are N economies in the model, there will be N-1 exchange rates.

[11] Multiplying the Y and $\overline{Y}$ variables by 100 permits the output gap to be measured in percentage points.

ify more stochastic shocks than observable variables, which is usually necessary to prevent the model from making large and systematic forecast errors over long periods of time. For example, an important ingredient in specifying a forecasting model, as we will see in this section, is allowing for permanent changes in the underlying estimates of the equilibrium values for potential output and for the equilibrium unemployment rate.

1. Potential Output

(1) $$\overline{Y}_{i,t} = \overline{Y}_{i,t-1} + g^{\overline{Y}}_{i,t}/4 + \varepsilon^{\overline{Y}}_{i,t}$$

(2) $$g^{\overline{Y}}_{i,t} = \tau_i g^{\overline{Y}ss}_i + (1-\tau_i) g^{\overline{Y}}_{i,t-1} + \varepsilon^{g^{\overline{Y}}}_{i,t}$$

We assume that there can be shocks to both the level and growth rate of potential output. The shocks to the level of potential output can be permanent, while the shocks to the growth rate can result in highly persistent deviations in potential growth from long-run steady-state growth. In equation (1), $\overline{Y}$ is equal to its own lagged value plus the quarterly growth rate ($g^{\overline{Y}}/4$) plus a disturbance term ($\varepsilon^{\overline{Y}}$) that can cause permanent level shifts in potential GDP. As shown in equation (2), in the long run the growth rate of potential GDP, $g^{\overline{Y}}$, is equal to its steady-state rate of growth, $g^{\overline{Y}ss}$. But it can diverge from this steady-state growth following a positive or negative value of the disturbance term ($\varepsilon^{g^{\overline{Y}}}$), and will return to $g^{\overline{Y}ss}$ gradually, with the speed of return based on the value of τ.

2. NAIRU

(3) $$\overline{U}_{i,t} = \overline{U}_{i,t-1} + g^{\overline{U}}_{i,t} + \varepsilon^{\overline{U}}_{i,t}$$

(4) $$g^{\overline{U}}_{i,t} = (1-\alpha_{i,3}) g^{\overline{U}}_{i,t-1} + \varepsilon^{g^{\overline{U}}}_{i,t}$$

A similar set of relationships holds for the equilibrium or NAIRU rate of unemployment. Ū is defined in equation (3) as its own past value plus a growth term $g^{\overline{U}}$ and a disturbance term ($\varepsilon^{\overline{U}}$). And in equation (4), $g^{\overline{U}}$ is a function of its own lagged value and the disturbance term ($\varepsilon^{g^{\overline{U}}}$).

Thus, the NAIRU can be affected by both level shocks and persistent growth shocks, that is by total and partial hysteresis.

3. Equilibrium real interest rate

(5) $$\overline{RR}_{i,t} = \rho_i \overline{RR}_{i,SS} + (1-\rho_i)\overline{RR}_{i,t-1} + \varepsilon^{\overline{RR}}_{i,t}$$

Equation (5) defines $\overline{RR}$, the equilibrium real interest rate, as a function of the steady-state real interest rate, $\overline{RR}_{SS}$. It has the ability to diverge from the steady state in response to a stochastic shock ($\varepsilon^{\overline{RR}}$).

4. Real exchange rate

(6) $$Z_{i,t} = 100 * (S_{i,t} + \log P_{us,t} - \log P_{i,t})$$

Equation (6) defines Z_i, the log of the real exchange rate in country i vis-à-vis the US dollar, as equal to 100 times the log of the nominal exchange rate, S_i (defined as the log of the number of units of local currency in country i vis-à-vis the US dollar), plus the log of the CPI (P_{us}) in the United States, minus the log of the CPI in country i (P_i). An increase in Z_i is thus a real depreciation of currency i vis-à-vis the US dollar.

(7) $$\Delta Z_{i,t} = 100\Delta S_{i,t} - (\pi_{i,t} - \pi_{us,t})/4$$

The change in the log of the real exchange rate is shown in equation (7) as 100 times the change in the log of the nominal exchange rate less the difference between the quarterly inflation rates in country i and the United States. It is therefore approximately equal to the change in percentage terms for small changes.

(8) $$\overline{Z}_{i,t} = \overline{Z}_{i,t-1} + \varepsilon^{\overline{Z}}_{i,t}$$

Equation (8) defines the log of the equilibrium real exchange rate, $\overline{Z}$, as equal to its lagged value plus a disturbance term, $\varepsilon^{\overline{z}}$. As we will see later, in the case of emerging market economies there are adjustments to the real exchange rate variable to take into account its trend rate of appreciation.

C. Behavioral equations for the G3 economies

1. Output Gap

(9)
$$
\begin{aligned}
y_{i,t} = {} & \{\beta_{i,1} y_{i,t-1} + \beta_{i,2} y_{i,t+1} - \beta_{i,3} mrr_{i,t-1}\} \\
& + \{\beta_{i,4} \sum_{j} \omega_{i,j,4} (z_{i,j,t-1} + z_{i,j,t-2} + z_{i,j,t-3} + z_{i,j,t-4})/4 \\
& + (\beta_{i,5} \sum_{j \neq i} \omega_{i,j,5} y_{j,t-1} + \sum_{j} \omega_{i,j,5} \nu_j)\} - \{\eta_{i,t}\} + \varepsilon^{y}_{i,t}
\end{aligned}
$$

In equation (9), the output gap in region i is determined by three sets of variables. All variables in this equation are expressed as gap variables, i.e., as deviations from their equilibrium values. The variables in the first set of braces relate to domestic effects, those in the second set of braces relate to external effects, and the variable in the third set of braces relates to financial-real linkages beyond interest rate and exchange rate effects.

(a) Domestic effects In equation (9), the variables within the first set of braces relate the output gap (y) to its own lead and lagged values, and the lagged value of the gap in the medium-term real interest rate (mrr). This is the typical demand equation for a closed economy in the new Keynesian paradigm. The own-lag term allows for the inertia in the system, and permits shocks to have persistent effects. The lead term allows more complex dynamics and forward-looking elements in aggregate demand. The medium-term real interest rate variable provides the crucial direct domestic link in the transmission mechanism between monetary policy actions and the real economy. It is a function of the current and expected policy interest rates and can be thought of as the real interest rate that affects spending decisions by firms and households.

(b) External effects The variables in the second set of braces in equation (9) relate to open economy influences on the output gap. The first variable captures the effects of real exchange rate gaps, thus incorporating the indirect external link in the transmission mechanism between monetary policy actions and the real economy, while the second variable captures the direct spillovers through trade from the trading partners of country i.

(i) Exchange rate effects The specification of the real exchange rate gap variables (z) is somewhat complex in a multi-country model. Since all the exchange rate variables are defined in terms of the US dollar, the bilateral real exchange rate gaps for all country pairs except those involving the United States should be in relative terms. Consider, for example, the euro area output gap equation. If the euro area exchange rate were overvalued by 5% (that is, its z is minus 5%[12]) and if the yen exchange rate were undervalued by 10% (that is, its z is plus 10%), then the euro is overvalued by 15% vis-à-vis the yen, and the $z_{eu,ja}$ enters the euro area output gap equation as z_{eu} - z_{ja}, or -15%. In contrast, only z_{eu} has to be inserted in the euro area output gap equation as the real exchange rate gap vis-à-vis the US dollar. In the US output gap equation, one can either use the simple z variables and expect $\beta_{us,4}$ to be negative, or, alternatively, use the negatives of the z variables and expect $\beta_{us,4}$ to have the same positive sign as all the other $\beta_{i,4}$ coefficients. For simplicity, we have chosen to do the latter.[13]

The effective real exchange rate gap variable is a weighted average of the real exchange rate gaps of the foreign countries with which economy i trades. In equation (9), the weights on the real exchange rate gap variables ($\omega_{i,j,4}$) are the ratio of the sum of exports and imports of country i with country j to the sum of exports and imports with all the countries in the model because real exchange rate movements result in adjustments of both exports and imports. The weights are calibrated on the basis of international trade data. The particular specification used in the equation is the average of the real exchange rate gap variable over the four quarters between one quarter ago and four quarters ago.

(ii) Foreign demand effects The foreign output gap term is defined as a weighted average of the lagged foreign output gaps. This weighted foreign output gap variable is thus a form of activity variable that allows for the effect of direct trade links among the various economies. Because of the complexity of the $\omega_{i,j,5}$ terms and the change in the specification of these coefficients in this paper from that in previous papers, we will discuss in some detail the specification and interpretation of these spillover linkage terms, focusing in the exposition on the impulse response function that relates the effect on the output gap in country i of a shock to the output gap in country j.

There are many elements that determine spillovers into country i from a demand shock in country j. Some of them can be captured by factual data observations while others require calibration that reflects expert knowledge or emprical estimates from other studies. The simplest way to under-

[12] An increase in the real exchange rate variable is a depreciation in the real value of the domestic currency while a decrease is an appreciation in the real value of the domestic currency.

[13] Another approach would be to code the real exchange rate gap of the United States versus country i in the same way as the other real exchange rate gaps, i.e., as z_{us} - z_i, and then define z_{us} to be equal to zero.

stand the specification of this term in the equation is through a series of identities, which can then be interpreted in economic terms. The final theoretical specification will have the following form (ignoring time lags):

(10)
$$\Delta y_i = \prod_s a_{s,i,j} \Delta y_j$$

That is, the effect of the shock in the output gap in country j on the output gap in country i will be the product of a series of terms, each of which will have some impact on the size of the spillover.

(11)
$$\begin{aligned} \Delta y_i &= \Delta(Y_i/\overline{Y}_i - 1) \\ &= \Delta Y_i/\overline{Y}_i \end{aligned}$$

(12)
$$\begin{aligned} \Delta y_j &= \Delta(Y_j/\overline{Y}_j - 1) \\ &= \Delta Y_j/\overline{Y}_j \end{aligned}$$

Equations (11) and (12) simply link the change in the output gap in the two countries to the ratio of the change in the level of output to potential output.

(13)
$$\Delta Y_i = (\Delta Y_i/\Delta X_{i,j}) * (\Delta X_{i,j}/\Delta M_{j,i}) * (\Delta M_{j,i}/\Delta Y_j) * \Delta Y_j$$

Equation (13) is an identity linking the change in output in country i to that in country j through three factors. (Note that we are now focusing on output and not the output gap.) Reading from right to left (and omitting the middle term for the moment), it goes from (a) the change in output in country j to (b) the increase in imports by country j from country i ($\Delta M_{j,i}$) to (c) the effect of this increase in exports by country i to country j ($\Delta X_{i,j}$) on output in country i to (d) the change in output in country i. The middle term of equation (13) is the ratio of exports by country i to country j to imports by country j from country i. In almost all cases, this ratio would be equal to one and could be ignored but there is one case (which will be discussed later) in which a somewhat different interpretation can be given to this ratio.

(14)
$$\Delta Y_i/\Delta X_{i,j} = (\Delta Y_i/\Delta VA_i) * (\Delta VA_i/\Delta X_{i,j})$$

Equation (14) divides the link between the change in exports from country i to country j and the change in output in country i (the first term in the right-hand side of equation (13)) into two components. The second term on the right-hand side is the effect of exports by country i to country j on value added in country i. This allows us to distinguish between the case where exports from country i are virtually entirely composed of value added in country i (for example, exports by an G3 country that are entirely produced in that country) and the case where country i is an entrepô t-type country in which increases in exports are accompanied by relatively little value added in the country (for example, exports by an emerging economy that use a very high proportion of imported components). The multiplier component in the latter would be much lower than the multiplier component in the former.

The first term on the right-hand side of equation (14) is the internal (Keynesian-type) multiplier in which the effect on output in country i from the export-induced increase in value added in country i would tend to be greater than 1 because the extra income from the increase in value added would lead to increases in consumption and possibly to an increase in investment expenditures as producers of the exportable goods in country i expand their capacity. There would of course be offsetting leakages from the increase in personal disposable income into saving and imports.[14][15]

$$
\begin{aligned}
(15)\,\Delta M_{j,i}/\Delta Y_j &= \Delta M_{j,i}/\Delta M_j * (\Delta M_j/\Delta Y_j) \\
&= [(\Delta M_{j,i}/M_{j,i})/(\Delta M_j/M_j) * (M_{j,i}/M_j)] * [(\Delta M_j/M_j)/(\Delta Y_j/Y_j) * (M_j/Y_j)]
\end{aligned}
$$

Equation (15) divides the link between the increase in output in country j and the increase in imports by country j from country i (the third term on the right-hand side of equation (13)) into two components in the first line and four components in the second line. Focusing on the first line, the second term on the right-hand side is the marginal propensity to import by country j and the first term is the marginal increase in imports by country j from country i in response to the increase in total imports by country j.

Turning to the second line, each of these marginal responses is treated as the product of an average propensity and an elasticity. Framing it this way allows us to use the trade data for the average propensities. Why might the marginal propensities differ from the average propensities (i.e., the elasticities differ from 1)? In the case of the overall import response, there are two reasons

[14] One can think of this term as the equivalent to the multiplier on output from an increase in government expenditures that are directed entirely to domestically-produced goods.

[15] Implicit in the formulation in equation (14) is that there can be a different marginal propensity to import from exports than from personal disposable income.

why the marginal propensity to import can be different from the average propensity to import. The first involves the data. If the data being used for the average propensity to import were not up-to-date and if there were a trend over time in the average propensity to import, then the marginal propensity would be higher or lower than the average propensity. Second, at times of excess demand in country j, any further increase in demand might result in a higher propensity to import than is typically the case because of the difficulty or inability of producers in country j to supply the extra demand in such circumstances.[16] [17] In the case of the increase in imports from country i relative to the overall increase in imports, the reason why the marginal response might be different from the average response is that country i might be gaining or losing share relative to the shares in the possibly out-of-date data from the trade data matrix.[18]

Putting together equations (11) to (15) gives us equation (16).

$$
\begin{aligned}
(16)\quad \Delta y_i &= \Delta Y_i/\overline{Y}_i \\
&= 1/\overline{Y}_i\{(\Delta Y_i/\Delta X_{i,j}) * (\Delta X_{i,j}/\Delta M_{j,i}) * (\Delta M_{j,i}/\Delta Y_j) * \Delta Y_j\} \\
&= 1/\overline{Y}_i\{(\Delta Y_i/\Delta VA_i) * (\Delta VA_i/\Delta X_{i,j})\} * (\Delta X_{i,j}/\Delta M_{j,i}) * \\
&\quad \{[(\Delta M_{j,i}/M_{j,i})/(\Delta M_j/M_j) * (M_{j,i}/M_j)] * [(\Delta M_j/M_j)/(\Delta Y_j/Y_j) * (M_j/Y_j)]\} * \\
&\quad \overline{Y}_j * \Delta y_j \\
&= \{(\Delta Y_i/\Delta VA_i) * (\Delta VA_i/\Delta X_{i,j})\} * (\Delta X_{i,j}/\Delta M_{j,i}) * (\overline{Y}_j/\overline{Y}_i) * \\
&\quad \{[(\Delta M_{j,i}/M_{j,i})/(\Delta M_j/M_j) * (M_{j,i}/M_j)] * [(\Delta M_j/M_j)/(\Delta Y_j/Y_j) * (M_j/Y_j)]\} * \\
&\quad \Delta y_j
\end{aligned}
$$

This leaves the term $(\Delta X_{i,j}/\Delta M_{j,i})$ to be discussed. Normally, this term would be equal to one since imports by country j from country i must be equal to exports by country i to country j. However, if we interpret the terms to the right of $(\Delta X_{i,j}/\Delta M_{j,i})$ as representing the demand for goods and services by country j and those to the left of $(\Delta X_{i,j}/\Delta M_{j,i})$ as reflecting the ability of country i to supply those goods and services, it is possible to think of this term as having a ratio less than one. This would occur in circumstances in which country i is constrained from supplying all the goods demanded by country j because its economy is operating close to or above full

[16] Ideally, calibration would thus depend upon initial conditions in the economy (i.e., whether it is in excess demand or excess supply). In practice, such adjustments would typically not be made to the calibration.
[17] An example of such relationship is the case when the US economy is overheated and a larger share of the increased demand is directed to Canadian producers (rather than domestic suppliers) than is typically the case.
[18] Care must be taken in calibrating this term to ensure that the marginal gains by one region are offset by marginal losses by one or more other regions.

capacity. The value of $(\Delta X_{i,j}/\Delta M_{j,i})$ would then depend on initial conditions in country i and could therefore vary over time.

For purposes of this paper, we have simplified the calibration of the terms in the bottom two lines of equation (16) to incorporate only the first two terms, the fourth term, the sixth term, and the eighth term. That is, we have ignored the possibility of supply constraints on exports in country i, and the possibility that marginal responses differ from average import responses in country j. There may however be circumstances in which one would like to adjust the calibrations to take such factors into account.

The model also allows for spillover effects directly coming from one country to another over and above those coming indirectly from output gaps. This type of effect might also reflect the possibility of common or global shocks with some persistence and is captured by the specification involving ν in equation (9).

(c) Financial-real linkages The variables in the third set of braces in equation (9) relate to financial-real linkages over and above interest rate and exchange rate effects. As has become increasingly apparent in the last few years, such financial real-linkages sometimes play a very important role in economic developments, both domestically and internationally. It is thus useful to introduce financial-real linkages into the GPM model over and above the traditional mechanisms involving the interest rate and the exchange rate. The expression in the third set of braces in equation (9) reflects the effect of the bank lending tightening (BLT) variables in the United States, the Euro area and Japan. While there are many other measures that potentially could capture the effects of financial developments on the real economy, the BLT variables are a useful starting point that allows non–price terms and conditions on bank lending to affect aggregate demand.

For much of the postwar period, downturns in business cycles were precipitated mainly by increases in interest rates initiated by central banks in response to periods of excess demand that gave rise to inflation pressures. Indeed, in some countries actions of the fiscal and monetary authorities were considered to have brought about a stop-go economy, in which policy switched periodically back and forth between an emphasis on unemployment and economic growth, on the one hand, and an emphasis on inflation, on the other. When the economy was weak, policy eased, giving rise to expansionary pressures. When these pressures were sufficiently strong and inflation became the overriding concern, policy was tightened so that the slowing or contraction of the economy would put downward pressure on inflation and prevent it from getting out of hand.

Such policy-induced slowdowns of the economy persisted from the 1950s into the 1990s, with virtually every downturn preceded by inflationary pressures and a resulting tightening of monetary policy. However, this central bank tightening explanation cannot account for the economic slowdown of the early part of the 2000s, or of the recent global economic recession, since inflation pressures and interest rate increases were clearly not the main reason for these downturns. Indeed, financial developments (including asset price movements) both played a precipitating role in the recent crisis and served as a mechanism by which the crisis was propagated across markets and across countries. In the context of such linkages between financial developments and the real economy, the attention of macro model builders has increasingly turned to the ways in which financial developments can affect the real economy. This interest has been aided by the development of theoretical models to describe and explain these linkages, in particular the financial accelerator mechanism.[19]

In our view, the more traditional types of models that allow central bank actions to play a major role in business cycle developments are still needed to explain much of the postwar period. However, the developments over the last decade or so require an extension to those models that have traditionally placed central bank monetary policy actions at the center of the business cycle (and particularly for the downturns). The key factors in these most recent developments (which also played a much smaller role in earlier developments) are the financial developments that have interacted with the real side of the economy in what has come to be called financial-real linkages.[20]

There are many different variants of financial-real linkages. Some refer to developments in financial institutions, while others focus on developments in financial markets. Within the financial institution sector, some relate to the behavior of banks and other financial institutions in dealing with perceptions of the changing risk situation facing their customers or changing attitudes to risk on their own part, while others relate to situations in which banks' capital positions have deteriorated. In the case of financial markets, there have been cases in which liquidity has seized up and prevented potential borrowers from issuing debt, and other cases in which actual or perceived pressures on the balance sheets of lenders and/or borrowers have been the origin of the inability of the financial markets to carry out their normal intermediation functions.

What does this imply for macro modeling? Consider first financial accelerators. As far as financial accelerator models are concerned, there can be an endogenous element in which the business cycle leads to increases and decreases of collateral values and hence to the ability to access funding, and an exogenous element in which exogenous shocks to asset values result in changes in the ability of borrowers to obtain financing. While the former can typically be captured to a considerable extent by interest rate movements, it will be important to try to model the latter. One issue

[19] See, for example, Bernanke and Gertler (1995). Interestingly, the perceived structural change in the way the economy operates has given rise to renewed interest in models of the business cycle from the interwar period in which real factors and financial factors other than central bank actions played a key role. See Laidler (2003).

[20] More detail on the postwar history of financial-real linkages can be found in the first three papers in this series.

that requires careful attention in structural DSGE models is whether financial institutions ration credit on the basis of collateral values (such as maximum loan-to-value ratios) or simply tighten terms and conditions on the loans that they are prepared to extend. A second type of financial-real linkage relates to the capital position of financial institutions (most importantly banks) and how it affects the willingness of financial institutions to extend loans. A third type of linkage relates to whether financial markets are functioning normally or are facing either liquidity difficulties or problems in evaluating risks. The historical episodes in which financial-real linkages played an important role and the economic behavior patterns underlying them raise the question of whether financial-real linkages should be part of the central macro model or should be modeled via satellite models. Should they feed into the forecast in normal circumstances or only in unusual episodes?.

There a number of advantages to using a small model in trying to understand and model the role of the linkages for macro economic behavior.[21] First of all, the insights that have been developed in more complex DSGE and other models can be added to a well-understood macro model to see whether they aid in the explanation of macroeconomic developments and forecasting. Second, different measures can be used to see which type of proxy is most helpful in capturing the linkages. Third, the small size of the model allows for experimentation of various types. For example, should a proxy for financial-real linkages be introduced as simply an extra variable in the model that functions continuously or should it only be allowed to affect behavior when it reaches critical threshold levels of the sort that were seen in the episodes in which financial-real linkages played a central role? Fourth, by allowing for persistence in real and financial shocks and in their effects on the real economy, judgmental near-term forecasts of these shocks can be integrated into the initial conditions of model-based, medium-term projections through the setting of initial conditions. Fifth, multi-country models with financial-real linkages will allow us to see whether cross-border financial effects have played an important role in transmitting the business cycle internationally, and to assess the relative importance of real linkages and financial linkages in transmitting shocks across countries.[22]

As noted, in this paper, we use only one type of financial variable (over and above interest rates and exchange rates), the bank lending tightening variables for the United States, the euro area and Japan. In future papers, we plan to examine the potential role of a variety of financial indicators, including risk spreads and financial conditions measures. And as data become available we can introduce financial variables in the emerging economy regions into the model.

[21] See Lown, Morgan, and Rohatgi (2000), Lown and Morgan (2002), Lown and Morgan (2006), Swiston (2008), Bayoumi and Melander (2008) and Benes and Kumhof (2011) for other attempts to assess the effects of financial-real linkages.

[22] Bayoumi and Swiston (2007) use VARs to try to achieve the same objective.

For the United States, the financial variable BLT_{US} is an unweighted average of the responses to four questions with respect to tightening terms and conditions in the Federal Reserve Board's quarterly Senior Loan Officer Opinion Survey on Bank Lending Practices. More precisely, for each of four questions on bank credit standards on loan applications,[23] net tightening is equal to the sum of the percentage of banks responding "tightened considerably" and "tightened somewhat" less the sum of the percentage of banks responding "eased somewhat" and "eased considerably". These four net tightening variables are each multiplied by 0.25 to give the overall BLT variable. It is worth noting that the net tightening responses from the survey outweigh the net easing responses on average over the sample period, indicating a bias of about 5% in the variable.

For the euro area, the financial variable BLT_{eu} is based on the response to the following question: "Over the past three months, how have your bank's credit standards as applied to the approval of loans or credit lines to enterprises changed?" Net tightening is defined as the difference between the sum of the percentages for "tightened considerably" and "tightened somewhat" and the sum of the percentages for "eased somewhat" and "eased considerably".

For Japan, BLT_{ja} is based on the question with respect to the judgment of the financial institutions' attitude towards lending as perceived by the responding borrowing enterprise at the time of the survey. The choices given are: (1) accommodative. (2) not so severe. (3) severe. It is equal to the value of the diffusion index, which is the difference between accommodative and severe in percentage points.

The way in which bank lending tightening operates to affect aggregate demand in equation (9) is specified by the following set of equations.

$$BLT_{i,t} = \overline{BLT}_{i,t-1} - \kappa_{US} y_{i,t+4} + \varepsilon_{i,t}^{BLT} \tag{17}$$

$$\overline{BLT}_{i,t} = \overline{BLT}_{i,t-1} + \varepsilon_{i,t}^{\overline{BLT}} \tag{18}$$

[23] The questions relate to C&I loans or credit lines to large and middle-market firms, C&I loans or credit lines to small firms, commercial real estate loans, and mortgage loans to purchase homes. Since the second quarter of 2008, the question on mortgage loans to purchase homes has been subdivided into questions on prime mortgages, nontraditional mortgages and subprime mortgages. Responses to these three residential mortgage loan questions have been consolidated for our purposes.

In equation (17), BLT is a function of $\overline{BLT}$, the equilibrium level of BLT_i, which itself is a random walk (equation (18)), and a disturbance term, ε^{BLT}.[24] As shown in equation (17), banks are assumed to tighten or ease their lending practices in part depending on their view of the expected behavior of the economy 4 quarters ahead. That is, if the output gap is assumed to be positive (a strong economy), there will be a tendency to ease lending conditions, while if it is assumed to be negative (a weak economy), there will be a tendency to tighten lending conditions.

In equation (9), in addition to all the other causal variables, the output gap is affected by η, a distributed lag of ε^{BLT}. Thus, if lending conditions are easier than might have been anticipated on the basis of expectations of future economic behavior (positive ε^{BLT}), the effect will be a larger output gap and a stronger economy.

$$
\begin{aligned}
(19) \quad \eta_{i,t} \quad = \quad & \theta_i(0.04\varepsilon^{BLT}_{i.t-1} + 0.08\varepsilon^{BLT}_{i,t-2} + 0.12\varepsilon^{BLT}_{i,t-3} + 0.16\varepsilon^{BLT}_{i,t-4} + 0.20\varepsilon^{BLT}_{i,t-5} + 0.16\varepsilon^{BLT}_{i,t-6} \\
& + 0.12\varepsilon^{BLT}_{i,t-7} + 0.08\varepsilon^{BLT}_{i,t-8} + 0.04\varepsilon^{BLT}_{i,t-9})
\end{aligned}
$$

The values of the coefficients imposed in equation (19) are intended to reflect a pattern in which an increase of ε^{BLT} (a tightening of the bank lending conditions variable) is expected to negatively affect spending by firms and households in a hump-shaped fashion, with an initial buildup and then a gradual rundown of the effects. This specification is used for all three G3 areas.

There are at least two ways of thinking about the way that the ε^{BLT} variable functions in the model, the first as a causal variable and the second as an indicator variable. In the first, this proxy variable for financial tightening can be thought of as capturing the exogenous element in bank lending that has the potential to set in motion a weakening or strengthening economic situation. That is, those responsible for bank lending look forward to economic conditions about a year in the future and tighten or loosen in part on the basis of their expectations. If their actions are typical for the stage of the cycle, the interest rate variable itself may pick up the normal tightening and easing of terms and conditions on bank lending and BLT would play little role in driving future economic developments. If, on the other hand, their actions are greater or less than is typical in light of the expected economic situation, this could have a direct causal effect on the ability of borrowers to access funds and to make expenditures. A second interpretation puts less emphasis on the direct effects on expenditures of the tightening or easing of bank lending conditions. Rather, from this perspective, one can consider the ε^{BLT} variable as reflecting the views of experts on the lending side of the economy with respect to future economic and financial conditions and thereby functioning as a very useful leading indicator of economic developments.

[24]In the earlier papers the disturbance term was entered with a negative sign to simplify the US cross correlations, and the same specification has been maintained for this paper in spite of the absence of cross correlations in this version of the model.

There are a number of issues surrounding this variable. First, in the interpretation that focuses on the exogenous part of this variable, it is assumed that the part of financial-real linkages that propagates other typical shocks to the system is captured by the interest rate. This is not an unreasonable assumption, since the endogenous part of the financial accelerator mechanism intensifies the effects on the economy of other shocks and, in a macro sense, could be thought of as simply increasing the coefficient on the interest rate variable. Second, there could be an asymmetry between tightening and easing shocks to BLT. While financial conditions that are tighter than typical will have the effect of preventing liquidity-constrained households and businesses from achieving their desired expenditures, beyond a certain point the easing of financial conditions may be less powerful in leading to increased spending. That is, once there is sufficient collateral to satisfy lenders of the safety of their loans, a further increase in the value of the collateral may not affect their behavior very much.[25] Third, it is possible that small changes in financial conditions will have relatively minor effects, and only changes beyond a certain critical threshold will have the capacity to bring about economically significant changes. Fourth, given the complexity of the financial-real linkages in the economy, BLT may not be able to capture all of these types of linkages, and other variables (such as risk spreads) may be introduced into the output gap equations in future work to try to pick up some of the other effects.

(d) Error term Finally, in equation (9), as in all the equations in this section, there is a disturbance term, in this case ε^{y}.

2. Inflation

(20) $$\pi_{i,t} = \lambda_{i,1}\pi 4_{i,t+4} + (1-\lambda_{i,1})\pi 4_{i,t-1} + \lambda_{i,2} y_{i,t-1} + \lambda_{i,3}\sum_{j}\omega_{i,j,3}(z_{i,j,t} - z_{i,j,t-4})/4 - \varepsilon^{\pi}_{i,t}$$

Equation (20) is the inflation equation, which links inflation to its past value and its future value, the lagged output gap, the change in the effective real exchange rate gap of the country (to capture exchange rate pass through), and a disturbance term (ε^{π}). [26] The size of λ_1 measures the relative weight of forward-looking elements and backward-looking elements in the inflation process. The backward-looking elements include direct and indirect indexation to past inflation and the proportion of price setters who base their expectations of future inflation on actual past

[25] It could, however, affect borrower behavior.

[26] The disturbance to the inflation equation was entered with a negative sign in the earlier studies in order to facilitate the estimation of the cross correlations and the same specification was retained in this study in spite of the absence of cross correlations.

rates of inflation. The forward-looking element relates to the proportion of price setters who base their expectations on model-consistent estimates of future inflation. The output gap is the crucial variable linking the rate of inflation to the real side of the economy.

The rate of inflation is also influenced by the average quarterly change over the last year in the change in the gap between the effective real exchange rate of country i and its equilibrium value. As in the case of the output gap equation, the treatment of exchange rate movements is somewhat complex. Since the real exchange rates are all based on the US dollar, the change in the bilateral real rate of exchange of currency i relative to currency j (where neither i nor j is the United States) is defined as the change of the real currency i gap relative to the US dollar minus the change of the real currency j gap relative to the US dollar, or $\Delta z_i - \Delta z_j$, with a positive value being a real depreciation of the currency i gap vis-à-vis currency j. Where j is the United States, the relevant variable is Δz_i. The weights on the changes in the bilateral real exchange rate gaps are based on imports of country i from country j because import prices are typically the most important element in the pass through from exchange rate movements to the CPI. The coefficient $\lambda_{i,3}$ is expected to be positive. For the US inflation equation, the change in the real exchange rate gap variables is entered as -Δz_i, with $\lambda_{us,3}$ expected to be positive.

3. Policy Interest Rate

(21) $$I_{i,t} = (1-\gamma_{i,1})\left[\overline{RR}_{i,t} + \pi 4_{i,t+3} + \gamma_{i,2}(\pi 4_{i,t+3} - \pi_i^{tar}) + \gamma_{i,4} y_{i,t}\right] + \gamma_{i,1} I_{i,t-1} + \varepsilon_{i,t}^{I}$$

(22) $$\pi_i^{tar} = \pi_{i,SS}^{tar}$$

Equation (21) is an Inflation-Forecast-Based rule that determines the short-term nominal interest rate for the three G3 regions. It can be interpreted either as the policy rate, as we do in this paper for the all six regions, or as a short-term market interest rate that is closely linked to the policy rate. It is a function of its own lag (a smoothing device for the movement of policy rates) and of the central bank's responses to movements of the output gap and to the deviation of the expected inflation rate from its target. More precisely, the central bank aims at achieving over time a policy rate that is the sum of the equilibrium real interest rate and expected inflation over the four quarters starting the previous quarter, but adjusts this rate in response to deviations of the expected year-on-year rate of inflation three quarters in the future from the inflation target π^{tar} (assumed to be a constant for the G3 economies as shown in equation (22)) and to the current output gap. [27] The equation also includes a disturbance term (ε^I) to allow for central bank interest rate actions that are not exactly equal to those indicated by the causal variables in equation (21).

4. Medium-term Interest Rate

(23)
$$RR_{i,t} = I_{i,t} - \pi_{i,t+1}$$

(24)
$$\overline{RR}_{i,t} = \rho_i \overline{RR}_{i,SS} + (1-\rho_i)\overline{RR}_{i,t-1} + \varepsilon_{i,t}^{\overline{RR}}$$

The real policy rate (RR) is equal to the difference between the nominal policy rate and the expected rate of inflation in the coming quarter (equation (23)) and the equilibrium real policy rate ($\overline{RR}$) is equal to the weighted average of its steady-state value and its lagged value (equation (24), a repeat of equation (5)).

(25)
$$RR4_{i,t} = (RR_{i,t} + RR_{i,t+1} + RR_{i,t+2} + RR_{i,t+3})/4$$

(26)
$$\overline{RR4}_{i,t} = (\overline{RR}_{i,t} + \overline{RR}_{i,t+1} + \overline{RR}_{i,t+2} + \overline{RR}_{i,t+3})/4$$

The four-quarter average real policy rate ($RR4$) is equal to the average of the current real policy rate and its expected value over the next three quarters (equation (25)) and the four-quarter average equilibrium real policy rate ($\overline{RR4}$) is defined in corresponding fashion (equation (26)).

(27)
$$\begin{aligned} MRR_{i,t} &= \xi_{i,1} RR_{i,t} + \xi_{i,4} RR4_{i,t} + \xi_{i,12}((RR4_{i,t} + RR4_{i,t+4} + RR4_{i,t+8})/3) \\ &\quad + \xi_{i,20}((RR4_{i,t} + RR4_{i,t+4} + RR4_{i,t+8} + RR4_{i,t+12} + RR4_{i,t+16})/5) \end{aligned}$$

(28)
$$\begin{aligned} \overline{MRR}_{i,t} &= \xi_{i,1} \overline{RR}_{i,t} + \xi_{i,4} \overline{RR4}_{i,t} + \xi_{i,12}((\overline{RR4}_{i,t} + \overline{RR4}_{i,t+4} + \overline{RR4}_{i,t+8})/3) \\ &\quad + \xi_{i,20}((\overline{RR4}_{i,t} + \overline{RR4}_{i,t+4} + \overline{RR4}_{i,t+8} + \overline{RR4}_{i,t+12} + \overline{RR4}_{i,t+16})/5) \end{aligned}$$

(29)
$$mrr_{i,t} = MRR_{i,t} - \overline{MRR}_{i,t}$$

[27] The use of the rate of inflation three quarters in the future follows Orphanides (2003).

The medium-term real interest rate, *MRR*, is a function of the current real policy rate, the expected average real policy rate over the coming year, the expected average real policy rate over the next three years, and the expected average real policy rate over the next five years (equation (27)). This specification is based on the expectations theory of longer-term interest rates, but allows for the possibility of some market myopia in which greater weight is put on nearer-term interest rates than is indicated by the pure expectations theory.[28] And equation (28) specifies the equilibrium medium-term real interest rate variable in corresponding fashion in terms of the expectations theory applied to the expected equilibrium real interest rates. Equation (29) defines the medium-term real interest rate gap, *mrr*, as the difference between the medium-term real interest rate and its equilibrium value, $\overline{MRR}$. It is the gap variable that enters into the aggregate demand equation.

5. Uncovered Interest Parity

(30) $$(RR_{i,t} - RR_{us,t}) = 4(Z^e_{i,t+1} - Z_{i,t}) + (\overline{RR}_{i,t} - \overline{RR}_{us,t}) + \varepsilon^{RR-RR_{us}}_{i,t}$$

Equation (30) is a version of uncovered interest parity (or UIP), in which the difference between the real interest rate in country i and its counterpart in the United States is equal to the difference between the log of the real exchange rate of currency i relative to the US dollar and its expected value the following quarter (multiplied by 4 to transform the quarterly rate of change to an annual rate of change in order to make it comparable to the interest rate differentials) plus the difference in the equilibrium real interest rates in the two countries. The difference in the equilibrium real interest rates is equivalent to the equilibrium risk premium. Thus, if the real interest rate in country i is greater than that in the United States, this would be a reflection of one of two possibilities or a combination of the two—either the currency i real exchange rate is expected to depreciate over the coming period (Z^e is higher than Z), or the equilibrium real interest rates in the two countries differ because of a risk premium on yields of country i assets denominated in the i currency. There is also a disturbance term, $\varepsilon^{RR-RR_{us}}$, in the equation, which is autocorrelated with a coefficient of 0.8 on its lagged value.

The model differs from Dornbusch's (1976) overshooting model insofar as Z^e is not fully model consistent, being partly a function of the past levels of the real exchange rate.

(31) $$Z^e_{i,t+1} = \phi_i \, Z_{i,t+1} + (1-\phi_i) \, Z_{i,t-1}$$

[28] All the ξs in equation (27) are assumed to be positive.

Equation (31) defines the expected real exchange rate for the next period, Z^e, as a weighted average of the lagged real exchange rate and the 1-period forward model-consistent solution of the real exchange rate. Note that there are i-1 UIP equations in the model, with no such equation necessary in the US block of equations.

6. Unemployment Rate

$$u_{i,t} = \alpha_{i,1}u_{i,t-1} + \alpha_{i,2}y_{i,t} + \varepsilon^{u}_{i,t} \tag{32}$$

For the G3 economies, equation (32) provides a dynamic version of Okun's law where the unemployment gap is a function of its lagged value, the contemporaneous output gap and a disturbance term (ε^u). This last equation does not play an important role in the model but is used to help measure the output gap in real time by exploiting the correlation between changes in the output gap and contemporaneous and future changes in the unemployment gap.

D. Differences in specification of behavioral equations for the emerging economies

1. Output Gap

$$\begin{aligned} y_{i,t} \;=\; & \{\beta_{i,1}y_{i,t-1} + \beta_{i,2}y_{i,t+1} - \beta_{i,3}mrr_{i,t-1}\} \\ & +\{\beta_{i,4}\sum_{j}\omega_{i,j,4}(z_{i,j,t-1} + z_{i,j,t-2} + z_{i,j,t-3} + z_{i,j,t-4})/4 \\ & +(\beta_{i,5}\sum_{j\neq i}\omega_{i,j,5}y_{j,t-1} + \sum_{j}\omega_{i,j,5}\nu_j)\} - \{\theta_i\sum_{j}\omega_{i,j,5}\eta_{j,t}\} + \varepsilon^{y}_{i,t} \end{aligned} \tag{33}$$

Comparing equation (9) with equation (33), the principal difference between the output gap equation in the G3 economies and that in the emerging economies relates to the η term. In the former, it captures the effect on the domestic output gap of the domestic BLT variable. In the latter, it reflects the effect on the domestic output gap in the emerging economies of the BLT variables in the three G3 economies. Thus, in the absence of data on bank lending tightening in the emerging economy regions, it is assumed that the effects of financial tightening can be captured by the behavior of the BLT variables in the G3 economies, each weighted by the spillover coefficient. These are intended to serve as a rough proxy for financial developments in the emerging economy regions.

There are two possible interpretations of this variable. The first is that tightening of lending terms and conditions in the G3 economies would have a direct effect on lending to the emerging economies and therefore on their output gaps. The second is that tightening of lending terms and conditions in the G3 economies is likely to be correlated with similar behavior by banks in the emerging economies, and it is the latter that would affect lending and aggregate demand in emerging economies.

2. Uncovered Interest Parity

$$(RR_{i,t} - RR_{us,t}) = 4(Z^{e}_{i,t+1} - Z_{i,t}) + (\overline{RR}_{i,t} - \overline{RR}_{us,t}) + DOT(\overline{Z}_{i,t}) + \varepsilon^{RR-RR_{us}}_{i,t} \tag{34}$$

Equation (34) is a version of uncovered interest parity for emerging market economies, in which the difference between the real interest rate in country i and its counterpart in the United States is equal to the difference between the log of the real exchange rate of currency i relative to the US dollar and its expected value the following quarter (multiplied by 4 to transform the quarterly rate of change to an annual rate of change in order to make it comparable to the interest rate differentials) plus the difference in the equilibrium real interest rates in the two countries plus an extra term to capture the trend change in the equilibrium real exchange rate, $DOT(\overline{Z}_{i,t})$. There is also a disturbance term, $\varepsilon^{RR-RR_{us}}$, in the equation, which is autocorrelated with a coefficient of 0.8 on its lagged value.

$$Z^{e}_{i,t+1} = \phi_i Z_{i,t+1} + (1-\phi_i)(Z_{i,t-1} + 2\Delta\overline{Z}_{i,t}/4) \tag{35}$$

For emerging market economies, equation (35) defines the expected real exchange rate for the next period, Z^e, as a weighted average of the lagged real exchange rate and the 1-period model-consistent solution of the real exchange rate, with the last term in the equation adjusting the lagged real exchange rate for the trend rate of appreciation in the equilibrium real exchange rate.

$$\overline{Z}_{i,t} = \overline{Z}_{i,t-1} + DOT(\overline{Z}_{i,t})/4 + \varepsilon^{\overline{Z}}_{i,t} \tag{36}$$

$$DOT(\overline{Z}_{i,t}) = \chi_i DOT(\overline{Z}_{i,SS}) + (1-\chi_i)(DOT(\overline{Z}_{i,t-1})) + \varepsilon^{DOT(\overline{Z})}_{i,t} \tag{37}$$

While the equilibrium real exchange rate follows a random walk in the G3 economies, the corresponding variable in the emerging economies involves a gradual response to an adjusting steady-state real exchange rate. (See equation (36) in which $DOT(\overline{Z}_{i,t})$ is implicitly defined and equation (37) in which its time path is specified.)

Note that the trend equilibrium real exchange rate appreciation relative to the US dollar applies only to the emerging economies (equation (34)) but not to the Euro area and Japan (equation (30)). Nonetheless, in terms of the effective or multilateral real exchange rate, there is a trend equilibrium real exchange rate depreciation in each of the G3 regions.

3. Unemployment Rate

For reasons of data availability, the unemployment rate equation is specified only in the models for the G3 countries and not in those for the developing or emerging regions.

IV. Confronting the Model with the Data

A. Bayesian estimation

1. General approach

Bayesian estimation provides a middle ground between classical estimation and the calibration of macro models. The use of classical estimation in a situation of a relatively small sample size (which is almost always the case for time series data) often gives model results that are strange, and are inconsistent with the views of macroeconomists as to the functioning of the economy. This problem is accentuated by the simultaneity challenges to macro models, which are not handled well by simultaneous equation methods in small samples. For example, because an aggregate demand shock can lead to persistent inflationary pressures and to central bank actions to raise interest rates to offset the shock, classically estimated models using time series data will sometimes show an increase in interest rates leading to an increase in inflation. This is particularly problematic when the model is to be used for policy simulations, since it may well indicate the need for an interest rate decline to slow the rate of inflation.

Models with calibrated parameters avoid this problem, but are often criticized as representing no more than the modelers' judgment, which may or may not be consistent with the data. While calibration is typically based on the understanding of experts of the functioning of the economy, the desire to confront the model with the data in a statistical sense has led researchers to use Bayesian estimation techniques to estimate models.

The Bayesian approach has the benefit of putting some weight on the priors of the researchers and some weight on the data over the sample period. By changing the specification of the tightness (e.g., the standard deviation) of the distribution on the priors, the researcher can change the relative weights on the priors and the data in determining the posterior distribution for the parameters. In the limit, a diffuse or noninformative distribution puts more weight on the data while a distribution with a very tight prior distribution (e.g., a small standard deviation) puts more weight on the priors.

There are a number of criteria by which researchers evaluate the success of Bayesian estimated models and decide between models with different weights placed on priors and the data. First, if an estimated model yields coefficients that are close to the priors in spite of allowing considerable weight to be placed on the data, this indicates that the priors are not inconsistent with the data. A second criterion involves seeing whether the impulse response functions (IRFs) from the model estimated with Bayesian techniques are compatible with the views of the researchers (and in the case of models built at central banks with the views of the management of the central bank) with respect to the functioning of the economy in response to shocks. Third, in comparing different variants of a given macro model (for example, one that treats shocks to output as largely demand determined and another that treats shocks as largely supply determined), researchers can use the relative magnitudes of the log data density and root mean squared errors (RMSEs) as indications of which model is more consistent with the data. And, fourth, the plausibility of the variance decomposition of the variables in the model can help to indicate whether the model is sensible. [29]

Bayesian estimated models are likely to have better model properties than classically estimated models, but may sometimes not fit the data as well as simple VAR models, since the sole purpose of the latter is to maximize fit. It is the combination of reasonable fit, appropriate structural results from a theoretical perspective, and the ability to give sensible results for policy simulations that gives estimated Bayesian models their strength. Also, the use of such models along with judgmental inputs for the first two quarters of the forecast period is likely to give better and more sensible forecasting results than most other models. A comparison of Bayesian-estimated GPMs with competitor global models will be presented in one of the future papers in this series.

[29] For example, in a two country model, if the variance decomposition showed that a shock to the output gap equation of the large country had a smaller effect on the output gap of the small country than the reverse, considerable doubt would be thrown on the validity or usefulness of the model results.

2. Calibration and estimation in the GPM6 model

Because of constraints due to the size of the six region model, a mixture of calibration and Bayesian estimation is used in GPM6. By and large, we use the estimated coefficients of the G3 model without oil (Carabenciov, 2008b) for the G3 countries. We then add each of the emerging country regions separately to the G3 model treating the G3 coefficients as given, and estimate some of the coefficients of the additional emerging economy region using Bayesian methods—λ_1, λ_2, β_1, β_2, γ_1, γ_2 and γ_4. The rest of the coefficients for the emerging economy region under consideration are calibrated. That is, the model for the G3 countries and emerging Asia was used to generate some of the coefficients for emerging Asia, the model for G3 and Latin America is used to generate some of the coefficients for Latin America, and finally the model for G3 and the remaining countries region is used to generate some of the coefficients for the remaining countries region. Then, for the version of the model used in this paper, three parameters and all the shocks were estimated for all six regions taken together. The estimated parameters are the coefficient on the spillover activity variable (β_5) and the coefficient on the financial spillover variable (θ) for the emerging economies in the output gap equations and the coefficient on the real exchange rate gap terms (λ_3) in the inflation equation.

B. Results

Tables 1 to 6 set out the estimated and calibrated values for the coefficients in the model and the estimates of the standard deviation of the structural shocks while figures 1 through 22 set out a number of impulse respose functions from model simulations.

1. Estimated and calibrated coefficients

(a) Key coefficients in specified equations Table 1 presents some of the key data measures and coefficients of the model. This table sets out all the estimated and calibrated coefficients in GPM3 (for the G3), GPM4 (for the G3 and one additional region) and GPM6 (for all six regions). The calibrated coefficients are displayed in black, the coefficients estimated in GPM3 and GPM4 are displayed in red, while the coefficients estimated in GPM6 are displayed in green. The top panel shows the estimated steady state values for GDP growth in the G3 and their calibrated counterparts for the other regions ($g^{\overline{Y}ss}$ in equation (2)), the estimated and calibrated values of the equilibrium real interest rate ($\overline{RR}_{SS}$ in equation (5)), and the calibrated values of the inflation target (π^{tar} in equation (22)).

The second panel sets out the adjustment coefficients for potential real output growth relative to its steady-state value (τ in equation (2)), the real interest rate relative to its equilibrium value (ρ in equation (5)) and the change in the equilibrium real exchange rate relative to the steady-state change in its value for emerging economies (χ in equation (36)).

The third panel shows the estimated and calibrated coefficients for the output gap equations ((9), (19) and (33)). The following results are noteworthy. In all regions except the remaining countries group, the coefficient on the lag of the output gap is considerably larger than the coefficient on the lead of the output gap. That is, over the estimation period there was considerable inertia in the real economy. And the coefficient on the lead of the output gap is very small in the euro area and Japan. Monetary policy operates through both channels of the transmission mechanism in all regions. The foreign activity variable is assumed to have the same effect on the domestic output gap across all regions. And the BLT variable in the United States has a stronger effect on its output gap than its counterparts in the euro area and Japan.

The fourth panel shows the estimated coefficients for the inflation equation ((20)). Inflation is less forward looking in the LA6 and RC6 regions than in the other regions. The coefficient on the output gap is estimated to be roughly the same size in the various regions. And the estimated effect of the change in the real exchange rate gap in the euro area, Latin America and Japan is larger than in the other three regions.

The fifth panel shows the estimated coefficients for the policy rate equation ((21)). Here too the coefficients in the G3 economies are on balance of the same order as the coefficients in the non-G3 regions.

The sixth panel shows the estimated coefficients on the forward-looking exchange rate in the expected exchange rate equation that feeds into for the UIP equations ((31) and (35)). These show a relatively large weight on the forward-looking real exchange rate term.

The seventh panel shows the estimated coefficients for the unemployment equation ((32)) in the G3 regions. The long-run response of unemployment to a change in the output gap ranges from about unity in the United States to about half in the euro area and about a quarter in Japan.

And the bottom panel shows the calibrated coefficients on current and expected future real policy interest rates in the formation of medium-term real interest rates, both actual and equilibrium, in equations (27) and (28). These coefficients incorporate some market myopia in which greater weight is put on nearer-term interest rates than indicated by the pure expectations theory.

For the 10 coefficients estimated in GPM6, Table 2 sets out the distribution used in the estimation (gamma), the prior mean, the prior standard deviation, the posterior mode, and the posterior standard deviation. We do not present the corresponding information for the other estimated coefficients because of the sequential form in which these coefficients were estimated.

(b) Trade and spillover coefficients Tables 3 and 4 presents various coefficients related to international trade and spillovers across the regions. By way of information, the top panel also shows the percentage share of world GDP at purchasing power parity weights for the six regions in the model.

The bottom panel of Table 3 sets out the spillover ratios across the regions that play an important role in the output gap equations (the $\omega_{i,j,5}$ variables in equations (9) and (33)). As was discussed earlier towards the end of the subsection "foreign demand effects" in section III C1, the calculation of spillovers in this paper involves the product of five terms in equation (16)–the domestic multiplier; one minus the import component of exports[30]; the relative size of the two regions involved in the spillover calculation; the proportion of imports from a particular region; and the average propensity to import. These terms can be found in table 3. For example, the spillover coefficient from the United States to emerging Asia can be computed as follows: dY/dVA$_{EA}$ (1.30) times dVA/dX$_{EA}$ (.79) times rsize$_{US/EA}$ (2.35) times imp$_{US/EA}$ (.315) times mrat$_{US}$ (.127), in total .097 as shown in spill$_{US/EA}$.

(c) Standard deviation of structural shocks Tables 5 and 6 set out estimation results for the the standard deviation of the structural shocks in the model. They show the distribution used in the estimation (inverted gamma), the prior mean, the prior standard deviation, the posterior mode, and the posterior standard deviation.

2. Root Mean Squared Errors

Table 7 shows the root mean squared errors (RMSE) for a number of key variables for one quarter ahead, four quarters ahead and eight quarters ahead projections. These RMSEs correspond to the sample period from the first quarter of 1999 through the fourth quarter of 2007. The G3 projections are for one quarter output growth rates, four quarter output growth rates, the unemployment rate, four quarter inflation rates, the policy interest rate, and the bank lending tightening variable. For the other regions, there are no projections for the unemployment rate and the bank lending tightening variable.

[30] The values for individual countries are taken from Koopman and others (2010) and later aggregated into the country groups of GPM6.

For the one quarter output growth rate, the near-term forecasts have about the same RMSE in all regions except the euro area, where the RMSE is smaller, and LA6, where it is larger. The RMSEs for the one-quarter-ahead projections for the four quarter output growth rate are considerably smaller than those for the one quarter output growth rate. This result is in line with our expectations since the projections for the four quarter growth rate ending the next quarter contain considerable past information.

Other noteworthy results are the large RMSEs for the four quarter inflation rates for the emerging economy regions relative to those for the G3 and the especially high RMSE for policy interest rate for LA6. The RMSE for BLT for the euro area is much larger than that for the United States, while that forJapan is much smaller.

3. Variance decompositions

Tables 8 and 9 present forecast error variance decompositions over the sample period at different (quarterly) horizons at the posterior mode of the parameter estimates for the main variables and shocks.

First, we examine the shocks that drive the output gap. In the short run, volatility in the output gap across regions is accounted for primarily by domestic demand shocks. In the longer run, especially for advanced economies, potential output growth shocks and either risk premium or financial conditions shocks gain in relevance. For emerging economies, monetary policy shocks plus risk premium and foreign demand shocks are of greater importance in explaining output gap volatility over the long run.

Next, we consider the main shocks that explain the volatility in inflation. In the short to medium run, supply-side shocks account for most of the variation in inflation across the 6 regions. In the long run and for advanced economies, potential growth and risk premium shocks become more important. In contrast, for emerging-market countries monetary policy shocks (including shocks to the inflation target) gain in relevance over the long run. Considering that many emerging-market countries adopted disinflation programs over the sample period, this is expected.

Continuing with policy interest rates, their volatility worldwide is largely driven by supply-side shocks in the short term and by monetary policy shocks (again including shocks to the inflation target) in the long term.

Lastly, real exchange rate volatility is driven almost exclusively by shocks to equilibrium real exchange rates.

4. Impulse response functions

Figures 1 through 22 present a selection of impulse response functions (IRFs) from the GPM6 model simulations. All the shocks are equal to one standard deviation of the disturbance term to the relevant equation over the sample period.

Figure 1 shows the effects of a shock to the output gap in the United States on a number of US variables while figure 2 sets out effects of the same shock on the output gap in all six regions. The results of the standard demand and inflation shocks are very much as expected on the basis of economic theory and earlier empirical work. The increase in aggregate demand in the United States leads to an immediate increase of about 0.6 percent in US output and output remains above control for about two years. The higher output results in a persistent increase relative to control in inflation, the policy interest rate, real short-term interest rates, the medium-term real interest rate gap, an appreciation in the US dollar real exchange rate gap and (for a brief period) an easing in the bank lending tightening variable. While the output increase in the United States leads to increases in output in all the other regions, the size of their increase relative to that in the United States is about 1/10 in the other G3 regions and about 1/5 in the non-G3 regions. As shown by the relatively small increase in the effect on the US output gap of the induced increase in the foreign activity variable (denoted as FACT, for foreign activity, in the third panel on the right-hand side of the odd-numbered figures), the feedback effect on the United States of the increase in the other regions is relatively small, about 0.1 percent at its peak.

Figures 3 and 4 show the results of an equivalent shock to the output gap in emerging Asia. The results are similar qualitatively for the domestic variables in emerging Asia, with somewhat smaller spillover effects on balance to the other regions (with the exception of Japan) than is the case with the shock to the US output gap.

By way of comparison, figures 5 through 8 present the effects of shocks to the output gap in the Euro area, Japan, Latin America and the remaining countries group on aggregate demand in all six regions. These are similar qualitatively to the set of shocks in the United States and emerging Asia, but differ to some extent quantitatively because the spillovers from one region to another do differ somewhat depending on the source of the shock. One noteworthy result is that emerging Asia typically tends to benefit more from spillovers from demand shocks elsewhere than do the other regions.

The rest of the IRFs are shown only for the United States as an example of a shock to a G3 region and for emerging Asia as an example of a shock to a non-G3 region.[31]

[31] The IRFs of shocks to other regions and of other types of shocks are available upon request to the authors.

Figures 9 through 12 show the results of a negative shock to the inflation rate in the United States and emerging Asia, figures 13 through 16 of a shock to the policy rate in the same two regions, figures 17 and 18 of a shock to the BLT variable in the United States, and figures 19 through 22 of a shock to the ν variable in the output gap equations in the United States and emerging Asia.

The negative shocks to inflation (figures 9 through 12) result in reductions in the policy interest rate, a depreciation in the real exchange rate (as a result of a decline in the domestic price level relative to control and a depreciation in the nominal exchange rate in response to the decline in the domestic interest rate), an easing of bank lending tightening (in the case of the shock in the United States). As as a result of this easing in the domestic and international channels of monetary policy, there is an increase in the domestic output gap. Spillovers from the country undergoing the shock to other countries are initially negative as the depreciation in the country undergoing the shock has a larger impact than the direct effect of the increase in its aggregate demand.

An increase in the policy rate (figures 13 through 16) has the typical negative effect on output and inflation, and results in an appreciation of the domestic currency. Spillovers to the other countries are sometimes negative, reflecting the output gap movement in the country whose policy rate has increased and sometimes positive in cases where the exchange rate channel is stronger than the direct output gap effect.

An easing in the US BLT variable (figures 17 and 18) results in a strengthening of the US economy, higher inflation, an increase in the policy rate and an appreciation of the real exchange rate. With a lag that reflects the increase in the US output gap, there are positive spillover effects to all the other regions.

Finally, an increase in the ν variable in the output gap equations (figures 19 through 22) has very similar effects to the increase of the disturbance term in the same equations. There are some small quantitative differences mainly because there is no lag on the effect on other countries from this shock while there is such a lag in the effect of a shock to the disturbance term in the output gap equations.

5. A global demand shock

To illustrate one of the advantages of GPM in quantifying the spillover mechanisms working at the global level, in Figure 23 we present a simulation of a positive global demand shock. In the simulation, each region experiences a perfectly correlated demand shock equal to one standard deviation that lasts for one quarter. The simulation is conducted starting from a position of steady state where none of the economies is subject to the constraints imposed by the zero interest rate floor.

In qualitative terms, as expected, the inflation response triggers a monetary policy tightening that dampens excess demand worldwide. However, relative to the case where only one region experiences such a shock, such as the one presented in Figure 19 for the United States, three aspects are worth mentioning. First, the own positive demand effects on inflation are much stronger because of higher demand globally. Second, the persistence of inflation and thus the degree of tightening are more pronounced in emerging-market countries, particularly in emerging Asia and Latin America, than in the G3 countries, which likely reflects their lower credibility as inflation fighters. Third, as would be expected from a global shock, there is no clear effect on real exchange rate movements, in contrast to the effect of a demand shock in a single country. To illustrate this point, take the case of a demand shock in the United States. as presented in Figure 19. In this case, the excess demand that gives rise to inflation and triggers a monetary tightening, also induces a real exchange rate appreciation, which dampens net exports. On the contrary, when all the regions seek to tighten policy, as in the case presented in Figure 23, the real exchange rate in the United States depreciates.

V. Concluding Remarks

This study is the sixth of a series of studies designed to develop a full global projection model. The new elements in this paper are as follows. First, having six regions (United States, euro area, Japan, emerging Asia, the five Latin America inflation-targeting countries, and a remaining countries grouping) covering a very large proportion (about 85 percent) of world economic output brings us much closer to a truly global model. Because of the size and complexity of the GPM6 model with six regions, we use a mixture of calibration and Bayesian estimation to parameterize the model. Generally speaking, we add one additional region at a time to the GPM3 model (to give us three GPM4 models), in each of them treating the coefficients in the G3 regions estimated in GPM3 as given and using a mixture calibration and estimation to derive coefficient estimates for the additional region. We then treat almost all of these coefficient values as given, using Bayesian estimation to generate a small number of estimated coefficients in the six-region GPM6 model. Second, there is more emphasis on both real and financial linkages across countries than in the earlier studies. Third, while the previous studies allowed for financial spillovers only from the United States to other countries, this version of the model allows for financial spillovers from the United States, the euro area and Japan. Fourth, in addition to the traditional country demand shock, we focus in this paper on demand shocks that are common across a number of countries or are global in their dimension. Fifth, the models in this this study contain medium-term interest rates, which are a function of policy interest rates although without a term premium. Sixth, the model incorporates a specification of the real exchange rate of emerging and developing economies that incorporates the Balassa-Samuelson insight with respect to trend appreciations in the real value of the currencies of these economies relative to those of the G3 economies.

Future work in this project will involve adding other financial variables to enrich real-financial sector linkages, adding a term premium to the medium-term interest rate equations, treating China a separate block, and adding commodity prices.

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APPENDIX 1: GPM6 DATA DEFINITIONS

G3 Countries

United States	
GDP	Gross Domestic Product (SAAR, Bil.Chn.2005.$)
Interest rate	Federal Open Market Committee:
	Fed Funds Target Rate (avg,%)
CPI	Consumer Price Index (SA, 1982-84=100)
Unemployment	Civilian Unemployment Rate (SA, %)
Bank lending	Average of: FRB Sr Officers Survey:
tightening (BLT)	Banks Tightening C&I Loans to Large Firms (%)
	Banks Tightening C&I Loans to Small Firms (%)
	FRB Sr Loan Off Survey:
	Tightening Standards for Commercial Real Estate (%)
	FRB Sr Loan Survey:
	Res Mortgages: Net Share, Banks Tightening (Haver Est,%)
Euro area	
GDP	Gross Domestic Product (SA/WDA, Mil.Chn.2000.Euros)
Interest rate	Euro Area11-16: Main Refinancing Operations: Minimum Bid Rate (avg, %)
CPI	Euro Area16: Monetary Union Index of Consumer Prices (SA, 2005=100)
Unemployment	Euro Area16: Unemployment Rate (SA, %)
BLT	Change in Credit Standards for Business Loans.
	Overall, Past 3Months (% Bal.)
Japan	
GDP	Gross Domestic Product (SAAR, Bil.Chn.2000.Yen)
Interest rate	Overnight Call Rate: Uncollateralized Target Rate (avg, %)
CPI	Consumer Price Index (SA, 2005=100)
Unemployment	Unemployment Rate (SA, %)
BLT	TANKAN: All financial insttutions loan policy: Accomm.-Severe (%)

Emerging Asia Countries

China	
GDP	{Cumulative}: Year-to-Year Percent Change (%)
	(Quarterly series interpolated by RES)
Interest rate	Prime Lending Rate (avg, %)
CPI	Cost of Living Index: Staff and Workers

India	
GDP	Gross Domestic Product at Factor Cost (SA, Bil.1993/94,Rupees)
Interest rate	Repo Rate (EOP, %)
CPI	Industrial Workers (SA, 1982=100)
South Korea	
GDP	Gross Domestic Product (SA, Bil.1995.Won)
Interest rate	Official Bank Base Rate (avg, %)
CPI	All Items (SA, 2000=100)
Indonesia	
GDP	Gross Domestic Product (SA, Bil.1993.Rupiahs)
Interest rate	Bank of Indonesia Target Rate [1-month Discount Rate] (avg, %)
CPI	Total (SA, 1996=100)
Taiwan	
GDP	Gross Domestic Product (SA, Mil.1996.NT$)
Interest rate	Central Bank of China Rediscount Rate (avg, %)
CPI	Total (SA, 2001=100)
Thailand	
GDP	Gross Domestic Product (SA, Mil.1988.Baht)
Interest rate	Policy Target Rate (avg, %)
CPI	All Commodities: Whole Kingdom (SA, 1998=100)
Malaysia	
GDP	Gross Domestic Product (SA, Mil.1987.Ringgit)
Interest Rate	Overnight Policy Rate (avg, %)
CPI	All Groups (SA, 2000=100)

Hong Kong	
GDP	Gross Domestic Product (SA, Mil.2000.HK$)
Interest rate	Discount Window Base Rate (avg, %)
CPI	Composite: All Items (SA, Oct1999-Sep2000=100)
Philippines	
GDP	Gross Domestic Product (SA, Mil.1985.Pesos)
Interest rate	Reverse Repo Rate: Overnight {Borrowing} (avg, %)
CPI	All Items (SA, 1994=100)
Singapore	
GDP	Gross Domestic Product (SA, Mil.1995.S$)
Interest rate	Interbank Overnight Repo Rate (avg, %)
CPI	All Items (NSA, Nov1997-Oct1998=100)

Latin America

Brazil	
GDP	Real Gross Domestic Product: Chained Index (SA, 1990=100) (Converted to level using the WEO quarterly figure)
Interest rate	Brazil Selic Target Rate (Period avg)
CPI	National Consumer Price Index [Extended,IPCA] (SA, Dec1997=100)
Mexico	
GDP	Gross Domestic Product (SAAR, Mil.1993.NewPesos)
Interest rate	Bank of Mexico Official Overnight Rate (Period avg)
CPI	Consumer Price Index (1994=100)
Colombia	
GDP	Gross Domestic Product (SA, Mil.1994.Pesos)
Interest rate	Intervention Rate: Minimum Liquidity Expansion Rate (avg, %)
CPI	Consumer Price Index (NSA, Dec1998=100)
Chile	
GDP	Gross Domestic Product (SA, Mil.1996.Ch$)
Interest rate	Chile Monetary Policy Rate (avg, %)
CPI	Consumer Price Index (Dec1998=100)
Peru	
GDP	Real Gross Domestic Product (SA, Mil.1994.NewSoles)
Interest rate	Peru Central Bank Reference Rate (avg, %)
CPI	Consumer Price Index (SA, Dec2001=100)

Remaining Countries

Russia	
GDP	Gross Domestic Product (SA, Bil.2000.Rubles)
Interest rate	Refinancing Rate (avg, %)
CPI	Consumer Prices: Total (SA, 2000=100)
United Kingdom	
GDP	Gross Domestic Product (SA, Mil.1995.Pounds)
Interest rate	Bank of England Official Bank Rate (avg, %)
CPI	Harmonized Consumer Price Index (SA, 1996=100)
Canada	
GDP	Gross Domestic Product at Market Prices (SAAR, Mil.Chn.1997.C$)
Interest rate	Target Rate (avg, %)
CPI	All Items (SA, 1992=100)

Turkey	
GDP	Gross Domestic Product (SA, Bil.1987.TL)
Interest rate	Turkish Interbank Rates Lira Overnight (avg, %)
CPI	All Items (SA, 1994=100)
Australia	
GDP	Gross Domestic Product (SA, Mil.Chn.1999/2000.A$)
Interest rate	Official Cash Rate (avg, %)
CPI	Consumer Price Index (SA, 1989/90=100)
Argentina	
GDP	Gross Domestic Product (SAAR, Mil.1993.Pesos)
Interest rate	Interbank Offered Rate in Pesos, [1-day] (avg, %)
CPI	Consumer Price Index (SA, 1999=100)
South Africa	
GDP	Gross Domestic Product (SAAR, Mil.1995.Rand)
Interest rate	South Africa Repo (avg, %)
CPI	Consumer Price Index (SA, 2000=100)
Venezuela	
GDP	Gross Domestic Product (SA, Mil.1984.Bolivares)
Interest rate	Commercial Bank 30 Day Deposit Rate (avg, %)
CPI	Consumer Price Index (SA, 1997=100)
Sweden	
GDP	Gross Domestic Product (SA, Mil.Chn.1995.Kronor)
Interest rate	Repo Rate (avg, %)
CPI	Harmonized Consumer Price Index (SA, 1996=100)
Switzerland	
GDP	Gross Domestic Product (SA, Mil.Chn.2000.Francs)
Interest rate	3-month Interbank offered rate (Swiss Franc LIBOR) (avg, %)
CPI	Consumer Price Index (SA, May2000=100)
Czech Republic	
GDP	Gross Domestic Product (SA, Bil.1995.CZK)
Interest rate	Ceska Narodni Banka 2 week limit repo rate (avg, %)
CPI	Consumer Price Index (SA, 2000=100)

Denmark	
GDP	Gross Domestic Product (SA, Mil.1995.Kroner)
Interest rate	National Bank: Lending Rate (avg, %)
CPI	Harmonized Consumer Price Index (SA, 1996=100)
Norway	
GDP	Gross Domestic Product (SA, Mil.2010.Kroner)
Interest rate	Norges Bank: Sight Deposit Rate (avg, %)
CPI	Harmonized Consumer Price Index (SA, 1996=100)
Israel	
GDP	Gross Domestic Product (SA, Mil.Chn.2000.NIS)
Interest rate	Israel Bank Base Rate (avg, %)
CPI	General Index incl. VAT (SA, 2002=100)
Bulgaria	
GDP	Gross Domestic Product (SA, Mil.1995.Leva)
Interest rate	BNB Base Rate (avg, %)
CPI	Consumer Price Index (NSA, 1995=100)
New Zealand	
GDP	Gross Domestic Product (SA, Mil.Chn.1995/96.NZ$)
Interest rate	Official Cash Rate (avg, %)
CPI	All Groups (SA, Q2 1999=100) (Monthly series interpolated by RES)
Estonia	
GDP	Gross Domestic Product (NSA, Mil.2000.Kroons)
Interest rate	Interbank Lending Rate: 3 Months (avg, %)
CPI	Consumer Price Index (NSA, 1997=100)

GPM6 Parameters [1]

		US	Euro Area	Japan	EA6	LA6	RC6
Steady State Values							
	GDP Growth	2.273	2.261	1.444	7.900	4.000	4.000
	Real Interest Rate	1.728	1.984	1.379	2.000	2.000	2.000
	Inflation Target	2.500	1.900	1.000	4.000	3.500	4.500
Adjustment Coefficients							
τ	Potential Output	0.027	0.029	0.037	0.030	0.030	0.030
ρ	Real Interest Rate	0.290	0.467	0.030	0.200	0.200	0.200
χ	Real Exchange Rate				0.050	0.050	0.050
Output Gap							
β_1	Lag	0.569	0.756	0.779	0.471	0.544	0.441
β_2	Lead	0.231	0.044	0.021	0.215	0.178	0.408
β_3	Medium-term interest rate gap	0.187	0.201	0.148	0.200	0.200	0.200
β_4	REER gap	0.051	0.067	0.036	0.171	0.148	0.070
β_5	Foreign Activity	0.891	0.891	0.891	0.891	0.891	0.891
θ	BLT	1.071	0.300	0.300	0.996	0.992	0.996
Headline Inflation							
λ_1	Lead	0.750	0.700	0.750	0.720	0.594	0.545
λ_2	Output gap	0.180	0.222	0.184	0.197	0.228	0.149
λ_3	REER gap	0.100	0.246	0.152	0.081	0.161	0.098
Monetary Policy Rule							
γ_1	Lag	0.711	0.686	0.750	0.667	0.645	0.725
γ_2	Inflation gap	0.910	1.306	1.058	1.114	0.911	0.898
γ_4	Output gap	0.205	0.201	0.169	0.169	0.202	0.162
UIP							
ϕ	Exp Change in Exch Rate		0.834	0.856	0.800	0.800	0.800
Unemployment	Dynamic Okun's Law						
α_1	Lag	0.824	0.717	0.759			
α_2	Output gap	0.182	0.140	0.060			
$(1-\alpha_3)$	Trend coefficient	0.635	0.899	0.779			
Med-Term Interest Rate	Weights						
ξ_1	1 qtr ahead	0.100	0.100	0.100	0.100	0.100	0.100
ξ_4	1 yr ahead	0.350	0.350	0.350	0.350	0.350	0.350
ξ_{12}	3 yrs ahead	0.350	0.350	0.350	0.350	0.350	0.350
ξ_{20}	5 yrs ahead	0.200	0.200	0.200	0.200	0.200	0.200

[1] Estimated parameters are in green. Partially estimated (GPM3 or GPM4) are in red. Calibrated parameters are in black.

Table 1. GPM6 Parameters Table

Estimated Parameters

	Prior distribution	Prior mean	Prior s.d.	Posterior mode	s.d.
β_5	gamma	1.000	0.1000	0.8911	0.0807
$\lambda_{3,US}$	gamma	0.120	0.0500	0.0996	0.0455
$\lambda_{3,EU}$	gamma	0.208	0.0500	0.2462	0.0442
$\lambda_{3,JA}$	gamma	0.180	0.0500	0.1516	0.0460
$\lambda_{3,EA6}$	gamma	0.100	0.0500	0.0812	0.0466
$\lambda_{3,LA6}$	gamma	0.150	0.0500	0.1613	0.0580
$\lambda_{3,RC6}$	gamma	0.100	0.0500	0.0981	0.0564
θ_{EA6}	gamma	1.000	0.1000	0.9964	0.1001
θ_{LA6}	gamma	1.000	0.1000	0.9921	0.0997
θ_{RC6}	gamma	1.000	0.1000	0.9961	0.1001

Table 2. Results from estimation of parameters in GPM6 (sample 1994Q1-2007Q4)

GPM6 Trade and Spillovers Table

		US	Euro Area	Japan	EA6	LA6	RC6
GDP	% share of world GDP, PPP[1]	19.740	14.570	5.816	26.112	6.336	14.746
Value Added	Multiplier	1.5	1.4	1.4	1.3	1.2	1.3
Effect of Exports							
	to US	...	0.88	0.88	0.88	0.88	0.88
	to EU	0.89	...	0.89	0.89	0.89	0.89
	to JA	0.89	0.89	...	0.89	0.89	0.89
	to EA6	0.79	0.79	0.79	...	0.79	0.79
	to LA6	0.69	0.69	0.69	0.69	...	0.69
	to RC6	0.80	0.80	0.80	0.80	0.80	...
Imports	Aggregate (% of GDP)	0.127	0.129	0.111	0.161	0.161	0.182
GPM6 Trade Weights							
	from US	...	0.113	0.149	0.205	0.422	0.207
	from EU	0.154	...	0.106	0.212	0.145	0.489
	from JA	0.084	0.051	...	0.307	0.058	0.049
	from EA6	0.315	0.259	0.532	...	0.243	0.208
	from LA6	0.148	0.048	0.041	0.053	...	0.047
	from RC6	0.299	0.529	0.173	0.222	0.132	...
Rel. Country Size[2]							
	to US	...	0.810	0.350	0.430	0.170	0.610
	to EU	1.230	...	0.430	0.520	0.200	0.750
	to JA	2.830	2.310	...	1.210	0.470	1.730
	to EA6	2.350	1.910	0.830	...	0.390	1.440
	to LA6	6.050	4.920	2.130	2.570	...	3.700
	to RC6	1.640	1.330	0.580	0.700	0.270	...
Spillovers							
	to US	1.000	0.016	0.008	0.019	0.015	0.030
	to EU	0.030	1.000	0.006	0.022	0.006	0.083
	to JA	0.037	0.019	1.000	0.075	0.005	0.019
	to EA6	0.097	0.066	0.050	1.000	0.016	0.056
	to LA6	0.094	0.025	0.008	0.018	1.000	0.026
	to RC6	0.065	0.094	0.012	0.026	0.006	1.000

[1] As of end of 2010.
[2] Calculated as the average from 2003 to 2007 using nominal figures in USD.

Table 3. GPM6 Trade and Spillovers Table

GPM6 Trade and Spillovers Table[2]

		US	Euro Area	Japan	EA6	LA6	RC6
Exports	Aggregate (% of GDP)	0.074	0.124	0.149	0.201	0.165	0.171
GPM6 Trade Weights							
	to US	...	0.202	0.284	0.366	0.687	0.369
	to EU	0.168	...	0.131	0.228	0.111	0.452
	to JA	0.077	0.038	...	0.196	0.029	0.044
	to EA6	0.190	0.133	0.457	...	0.062	0.108
	to LA6	0.178	0.039	0.021	0.031	...	0.027
	to RC6	0.386	0.588	0.106	0.179	0.112	...

Table 4. GPM6 Trade and Spillovers Table[2]

Standard Deviation of Structural Shocks[1]

	Prior distribution	Prior mean	Prior s.d.	Posterior mode	s.d.
$\varepsilon_{EA6}^{DOT(\overline{Z})}$	invg	0.100	0.0010	0.0994	0.0050
$\varepsilon_{EA6}^{\pi^{tar}}$	invg	0.250	0.0500	0.2396	0.0377
$\varepsilon_{EA6}^{g^{\overline{Y}}}$	invg	0.100	Inf	0.3479	0.1023
$\varepsilon_{EA6}^{\overline{Y}}$	invg	0.200	Inf	0.0897	0.0348
$\varepsilon_{EA6}^{\overline{Z}}$	invg	1.000	Inf	1.4596	0.2216
ε_{EA6}^{π}	invg	0.500	Inf	1.0600	0.1349
$\varepsilon_{EA6}^{\overline{RR}}$	invg	0.200	0.0400	0.1840	0.0330
$\varepsilon_{EA6}^{RR-RR_{US}}$	invg	1.000	Inf	0.3975	0.1223
ε_{EA6}^{I}	invg	0.500	0.0500	0.4465	0.0518
ε_{EA6}^{y}	invg	0.700	0.2000	0.4271	0.0578
ε_{EA6}^{ν}	invg	0.500	0.2000	0.2969	0.0536
$\varepsilon_{EU}^{g^{\overline{Y}}}$	invg	0.100	0.0500	0.0771	0.0253
$\varepsilon_{EU}^{\overline{Y}}$	invg	0.200	0.0500	0.1980	0.0435
$\varepsilon_{EU}^{\overline{Z}}$	invg	1.000	Inf	5.9125	1.0141
ε_{EU}^{π}	invg	0.500	Inf	1.2678	0.1630
$\varepsilon_{EU}^{\overline{RR}}$	invg	0.200	0.0400	0.1891	0.0357
$\varepsilon_{EU}^{RR-RR_{US}}$	invg	1.000	Inf	2.6939	0.4511
ε_{EU}^{I}	invg	0.250	Inf	0.2426	0.0403
$\varepsilon_{EU}^{\overline{U}}$	invg	0.100	Inf	0.0346	0.0087
$\varepsilon_{EU}^{g^{\overline{U}}}$	invg	0.100	Inf	0.0315	0.0075
ε_{EU}^{u}	invg	0.200	Inf	0.0506	0.0085
ε_{EU}^{y}	invg	0.700	0.2000	0.4070	0.0537
ε_{EU}^{ν}	invg	0.500	0.2000	0.2826	0.0485
$\varepsilon_{JA}^{g^{\overline{Y}}}$	invg	0.100	0.0500	0.0704	0.0208
$\varepsilon_{JA}^{\overline{Y}}$	invg	0.200	0.0500	0.5572	0.0665
$\varepsilon_{JA}^{\overline{Z}}$	invg	4.000	Inf	4.2367	0.5073
ε_{JA}^{π}	invg	1.000	Inf	0.8742	0.1076
$\varepsilon_{JA}^{\overline{RR}}$	invg	0.100	0.0400	0.1708	0.0653
$\varepsilon_{JA}^{RR-RR_{US}}$	invg	0.500	Inf	0.2361	0.1031
ε_{JA}^{I}	invg	0.250	Inf	0.1585	0.0240
$\varepsilon_{JA}^{\overline{U}}$	invg	0.100	Inf	0.0479	0.0222
$\varepsilon_{JA}^{g^{\overline{U}}}$	invg	0.100	Inf	0.0452	0.0126
ε_{JA}^{u}	invg	0.100	Inf	0.0898	0.0185
ε_{JA}^{y}	invg	0.700	0.2000	0.3696	0.0467
ε_{JA}^{ν}	invg	0.500	0.2000	0.2618	0.0421

Table 5. Results from estimation – standard deviation of structural shocks[1]

Standard Deviation of Structural Shocks[2]

	Prior distribution	Prior mean	Prior s.d.	Posterior mode	s.d.
$\varepsilon_{LA6}^{DOT(\overline{Z})}$	invg	0.100	0.0010	0.0993	0.0050
$\varepsilon_{LA6}^{\pi^{tar}}$	invg	0.250	0.0500	0.7735	0.0888
$\varepsilon_{LA6}^{g^{\overline{Y}}}$	invg	0.100	0.0500	0.2034	0.0322
$\varepsilon_{LA6}^{\overline{Y}}$	invg	0.200	Inf	0.0961	0.0431
$\varepsilon_{LA6}^{\overline{Z}}$	invg	1.000	Inf	3.7339	0.6630
ε_{LA6}^{π}	invg	1.000	Inf	2.0863	0.2790
$\varepsilon_{LA6}^{\overline{RR}}$	invg	0.500	0.0500	0.5051	0.0722
$\varepsilon_{LA6}^{RR-RR_{US}}$	invg	1.000	Inf	1.6575	0.3724
ε_{LA6}^{I}	invg	0.500	0.2000	0.3807	0.1025
ε_{LA6}^{y}	invg	0.700	0.2000	0.4413	0.0625
ε_{LA6}^{ν}	invg	0.500	0.2000	0.3075	0.0582
$\varepsilon_{RC6}^{DOT(\overline{Z})}$	invg	0.100	0.0010	0.0992	0.0050
$\varepsilon_{RC6}^{\pi^{tar}}$	invg	0.250	0.0500	0.4154	0.0687
$\varepsilon_{RC6}^{g^{\overline{Y}}}$	invg	0.100	Inf	0.0485	0.0217
$\varepsilon_{RC6}^{\overline{Y}}$	invg	0.200	Inf	0.0947	0.0408
$\varepsilon_{RC6}^{\overline{Z}}$	invg	1.000	Inf	2.6651	0.4452
ε_{RC6}^{π}	invg	0.500	Inf	1.3712	0.1802
$\varepsilon_{RC6}^{\overline{RR}}$	invg	0.200	0.0400	0.1810	0.0316
$\varepsilon_{RC6}^{RR-RR_{US}}$	invg	1.000	Inf	0.6770	0.5671
ε_{RC6}^{I}	invg	0.500	0.0500	0.4465	0.0523
ε_{RC6}^{y}	invg	0.700	0.2000	0.4856	0.0806
ε_{RC6}^{ν}	invg	0.500	0.2000	0.3253	0.0680
ε_{US}^{π}	invg	0.700	Inf	1.3831	0.1663
$\varepsilon_{US}^{\overline{RR}}$	invg	0.200	Inf	1.1772	0.2128
ε_{US}^{I}	invg	0.700	Inf	0.2538	0.0514
$\varepsilon_{US}^{\overline{U}}$	invg	0.100	Inf	0.0463	0.0187
$\varepsilon_{US}^{g^{\overline{U}}}$	invg	0.100	Inf	0.0430	0.0148
ε_{US}^{u}	invg	0.200	Inf	0.0989	0.0189
ε_{US}^{y}	invg	0.700	0.2000	0.4146	0.0531
ε_{US}^{ν}	invg	0.500	0.2000	0.2892	0.0500

Table 6. Results from estimation – standard deviation of structural shocks[2]

GPM6 - RMSE Table

	1Q Ahead	4Q Ahead	8Q Ahead
GROWTH_US	2.2	2.2	1.6
GROWTH4_US	0.58	1.4	1.2
UNR_US	0.15	0.36	0.69
PIE4_US	0.39	0.77	0.73
RS_US	0.35	1.2	1.8
BLT_US	6.8	12	16
GROWTH_EU	1.8	1.6	1.3
GROWTH4_EU	0.44	1.7	1
UNR_EU	0.078	0.41	0.69
PIE4_EU	0.28	0.73	0.5
RS_EU	0.19	0.69	1.3
BLT_EU	18	26	31
GROWTH_JA	2.6	2.4	2.5
GROWTH4_JA	0.68	1.4	1.4
UNR_JA	0.13	0.31	0.59
PIE4_JA	0.27	0.95	1.3
RS_JA	0.23	1	1.9
BLT_JA	2.3	5.5	5.7
GROWTH_EA6	2.6	2.4	2.4
GROWTH4_EA6	0.66	1.8	1.4
PIE4_EA6	0.5	1.1	1.2
RS_EA6	0.52	0.94	1
GROWTH_LA6	3.5	4.2	3.3
GROWTH4_LA6	0.88	3.6	3.3
PIE4_LA6	0.54	2	2.4
RS_LA6	2	2.8	2.5
GROWTH_RC6	2.4	2.6	2.4
GROWTH4_RC6	1.1	1.6	1.6
PIE4_RC6	0.55	1.7	2.7
RS_RC6	0.45	1.4	2.5

Table 7. Root Mean Squared Errors 1999Q1-2007Q4

Variance Decomposition for Nominal Interest Rate and Real Effective Exchange Rate 1/

	Global Demand Shocks Originating in						Idiosyncratic	Monetary	Financial	Risk	Inflation	Potential
	US	Euro	Japan	EA	LA	RC	Demand Shocks	Policy 2/	Conditions in G3	Premium 3/	Shock	Growth 4/
							Nominal Interest Rate					
t=1												
US	4.8	0.2	0.0	0.1	0.0	0.2	9.9	19.3	1.4	36.2	23.1	4.8
Euro	0.5	7.9	0.1	0.1	0.0	1.4	16.7	17.9	0.4	16.5	36.7	2.0
Japan	0.8	0.5	10.6	0.7	0.0	0.5	22.4	27.8	1.2	3.4	29.8	2.3
EA	1.0	0.6	0.2	3.5	0.0	0.6	9.1	60.1	0.4	3.1	19.4	1.9
LA	0.4	0.1	0.0	0.0	1.7	0.1	3.8	52.7	0.1	7.3	32.8	1.0
RC	0.3	0.5	0.0	0.1	0.0	3.0	6.6	66.2	0.1	1.9	20.5	0.9
t=4												
US	9.6	0.4	0.1	0.1	0.1	0.6	20.0	4.3	4.4	35.5	10.7	14.4
Euro	1.1	17.4	0.1	0.3	0.0	3.3	37.0	3.7	1.4	15.4	16.6	3.7
Japan	1.8	0.9	20.7	1.5	0.0	1.0	43.8	5.5	3.0	5.3	12.4	4.0
EA	4.0	2.5	0.9	8.9	0.1	2.5	28.0	21.5	1.9	10.0	13.0	6.7
LA	1.8	0.4	0.1	0.1	5.1	0.5	13.3	20.8	0.8	22.1	31.7	3.3
RC	1.7	2.4	0.1	0.2	0.0	11.1	26.1	22.4	0.8	6.5	24.9	3.8
t=8												
US	9.1	0.5	0.1	0.2	0.1	0.8	19.4	2.2	8.5	25.1	6.2	27.8
Euro	1.6	19.2	0.2	0.4	0.1	4.0	41.9	2.4	3.2	12.6	9.7	4.9
Japan	2.3	1.2	21.1	1.7	0.1	1.3	46.2	2.6	5.5	6.6	6.6	5.0
EA	4.7	3.1	1.1	6.6	0.1	3.0	27.5	20.0	3.6	12.1	6.9	11.2
LA	2.1	0.6	0.1	0.2	3.5	0.6	11.3	35.2	1.4	23.8	16.2	5.1
RC	2.4	3.2	0.2	0.3	0.1	10.9	28.0	23.2	1.8	7.5	16.1	6.4
t=12												
US	8.3	0.6	0.1	0.2	0.1	0.8	17.9	1.9	10.1	22.0	5.3	32.9
Euro	1.7	18.2	0.2	0.4	0.1	3.9	40.2	2.4	4.4	14.1	8.7	5.8
Japan	2.4	1.3	19.8	1.6	0.1	1.3	44.2	2.2	7.3	8.5	5.4	6.1
EA	4.3	2.9	1.1	5.4	0.1	2.7	24.5	24.0	4.5	11.3	5.7	13.5
LA	1.7	0.5	0.1	0.1	2.5	0.5	8.7	46.9	1.7	20.4	11.2	5.7
RC	2.2	2.9	0.2	0.3	0.0	9.0	23.9	32.7	2.4	6.6	12.2	7.6
							Real Effective Exchange Rate					
t=1												
US	0.6	0.7	0.1	0.1	0.1	0.6	4.1	5.5	1.5	79.4	3.1	4.4
Euro	0.0	0.3	0.0	0.0	0.0	0.0	0.6	0.8	0.1	97.7	0.4	0.1
Japan	0.0	0.1	0.5	0.0	0.0	0.0	1.3	0.6	0.3	96.4	0.3	0.4
EA	0.0	0.0	0.0	0.4	0.0	0.0	0.9	4.9	0.0	92.2	1.4	0.1
LA	0.0	0.0	0.0	0.0	0.3	0.0	0.7	7.4	0.0	89.7	1.8	0.1
RC	0.0	0.1	0.0	0.0	0.0	0.2	0.7	5.0	0.0	92.5	1.3	0.1
t=4												
US	0.8	0.8	0.1	0.2	0.1	0.7	5.1	2.4	1.9	80.0	2.5	5.6
Euro	0.0	0.3	0.0	0.0	0.0	0.0	0.7	0.4	0.1	98.0	0.4	0.1
Japan	0.0	0.1	0.6	0.0	0.0	0.0	1.4	0.3	0.3	96.8	0.2	0.3
EA	0.0	0.0	0.0	0.5	0.0	0.0	1.1	2.0	0.0	95.3	1.0	0.1
LA	0.0	0.0	0.0	0.0	0.4	0.0	0.8	3.2	0.0	93.9	1.5	0.1
RC	0.0	0.1	0.0	0.0	0.0	0.3	1.0	2.6	0.0	94.5	1.3	0.2
t=8												
US	0.5	0.6	0.1	0.1	0.0	0.6	3.9	1.3	1.8	84.1	1.6	5.3
Euro	0.0	0.2	0.0	0.0	0.0	0.0	0.5	0.2	0.1	98.7	0.3	0.1
Japan	0.0	0.0	0.5	0.0	0.0	0.0	1.1	0.1	0.3	97.6	0.1	0.2
EA	0.0	0.0	0.0	0.3	0.0	0.0	0.7	1.0	0.0	97.3	0.6	0.1
LA	0.0	0.0	0.0	0.0	0.3	0.0	0.6	1.7	0.0	96.5	0.9	0.1
RC	0.0	0.0	0.0	0.0	0.0	0.3	0.7	1.4	0.0	96.5	1.0	0.1
t=12												
US	0.4	0.4	0.1	0.1	0.0	0.5	2.9	1.0	1.4	88.1	1.2	4.1
Euro	0.0	0.1	0.0	0.0	0.0	0.0	0.3	0.2	0.1	99.1	0.2	0.1
Japan	0.0	0.0	0.3	0.0	0.0	0.0	0.8	0.1	0.2	98.3	0.1	0.2
EA	0.0	0.0	0.0	0.2	0.0	0.0	0.5	0.7	0.0	98.2	0.4	0.1
LA	0.0	0.0	0.0	0.0	0.2	0.0	0.4	1.2	0.0	97.6	0.6	0.1
RC	0.0	0.0	0.0	0.0	0.0	0.2	0.5	0.9	0.0	97.5	0.7	0.1

1/ Data sample : 1999Q1 to 2010.Q2
2/ Monetary policy shocks include: interest rate and inflation target shocks
3/ Risk premium shocks include real exchange rate,real equilibrium exch. rate, real interest rate and real interest rate differential shocks
4/ Potential growth shocks include: potential growth, and equilibrium unemployment shocks

Table 8. Variance Decomposition[1]

Variance Decomposition for Nominal Interest Rate and Real Effective Exchange Rate 1/

	Global Demand Shocks Originating in						Idiosyncratic	Monetary	Financial	Risk	Inflation	Potential
	US	Euro	Japan	EA	LA	RC	Demand Shocks	Policy 2/	Conditions in G3	Premium 3/	Shock	Growth 4/
							Nominal Interest Rate					
t=1												
US	4.8	0.2	0.0	0.1	0.0	0.2	9.9	19.3	1.4	36.2	23.1	4.8
Euro	0.5	7.9	0.1	0.1	0.0	1.4	16.7	17.9	0.4	16.5	36.7	2.0
Japan	0.8	0.5	10.6	0.7	0.0	0.5	22.4	27.8	1.2	3.4	29.8	2.3
EA	1.0	0.6	0.2	3.5	0.0	0.6	9.1	60.1	0.4	3.1	19.4	1.9
LA	0.4	0.1	0.0	0.0	1.7	0.1	3.8	52.7	0.1	7.3	32.8	1.0
RC	0.3	0.5	0.0	0.1	0.0	3.0	6.6	66.2	0.1	1.9	20.5	0.9
t=4												
US	9.6	0.4	0.1	0.1	0.1	0.6	20.0	4.3	4.4	35.5	10.7	14.4
Euro	1.1	17.4	0.1	0.3	0.0	3.3	37.0	3.7	1.4	15.4	16.6	3.7
Japan	1.8	0.9	20.7	1.5	0.0	1.0	43.8	5.5	3.0	5.3	12.4	4.0
EA	4.0	2.5	0.9	8.9	0.1	2.5	28.0	21.5	1.9	10.0	13.0	6.7
LA	1.8	0.4	0.1	0.1	5.1	0.5	13.3	20.8	0.8	22.1	31.7	3.3
RC	1.7	2.4	0.1	0.2	0.0	11.1	26.1	22.4	0.8	6.5	24.9	3.8
t=8												
US	9.1	0.5	0.1	0.2	0.1	0.8	19.4	2.2	8.5	25.1	6.2	27.8
Euro	1.6	19.2	0.2	0.4	0.1	4.0	41.9	2.4	3.2	12.6	9.7	4.9
Japan	2.3	1.2	21.1	1.7	0.1	1.3	46.2	2.6	5.5	6.6	6.6	5.0
EA	4.7	3.1	1.1	6.6	0.1	3.0	27.5	20.0	3.6	12.1	6.9	11.2
LA	2.1	0.6	0.1	0.2	3.5	0.6	11.3	35.2	1.4	23.8	16.2	5.1
RC	2.4	3.2	0.2	0.3	0.1	10.9	28.0	23.2	1.8	7.5	16.1	6.4
t=12												
US	8.3	0.6	0.1	0.2	0.1	0.8	17.9	1.9	10.1	22.0	5.3	32.9
Euro	1.7	18.2	0.2	0.4	0.1	3.9	40.2	2.4	4.4	14.1	8.7	5.8
Japan	2.4	1.3	19.8	1.6	0.1	1.3	44.2	2.2	7.3	8.5	5.4	6.1
EA	4.3	2.9	1.1	5.4	0.1	2.7	24.5	24.0	4.5	11.3	5.7	13.5
LA	1.7	0.5	0.1	0.1	2.5	0.5	8.7	46.9	1.7	20.4	11.2	5.7
RC	2.2	2.9	0.2	0.3	0.0	9.0	23.9	32.7	2.4	6.6	12.2	7.6
							Real Effective Exchange Rate					
t=1												
US	0.6	0.7	0.1	0.1	0.1	0.6	4.1	5.5	1.5	79.4	3.1	4.4
Euro	0.0	0.3	0.0	0.0	0.0	0.0	0.6	0.8	0.1	97.7	0.4	0.1
Japan	0.0	0.1	0.5	0.0	0.0	0.0	1.3	0.6	0.3	96.4	0.3	0.4
EA	0.0	0.0	0.0	0.4	0.0	0.0	0.9	4.9	0.0	92.2	1.4	0.1
LA	0.0	0.0	0.0	0.0	0.3	0.0	0.7	7.4	0.0	89.7	1.8	0.1
RC	0.0	0.1	0.0	0.0	0.0	0.2	0.7	5.0	0.0	92.5	1.3	0.1
t=4												
US	0.8	0.8	0.1	0.2	0.1	0.7	5.1	2.4	1.9	80.0	2.5	5.6
Euro	0.0	0.3	0.0	0.0	0.0	0.0	0.7	0.4	0.1	98.0	0.4	0.1
Japan	0.0	0.1	0.6	0.0	0.0	0.0	1.4	0.3	0.3	96.8	0.2	0.3
EA	0.0	0.0	0.0	0.5	0.0	0.0	1.1	2.0	0.0	95.3	1.0	0.1
LA	0.0	0.0	0.0	0.0	0.4	0.0	0.8	3.2	0.0	93.9	1.5	0.1
RC	0.0	0.1	0.0	0.0	0.0	0.3	1.0	2.6	0.0	94.5	1.3	0.2
t=8												
US	0.5	0.6	0.1	0.1	0.0	0.6	3.9	1.3	1.8	84.1	1.6	5.3
Euro	0.0	0.2	0.0	0.0	0.0	0.0	0.5	0.2	0.1	98.7	0.3	0.1
Japan	0.0	0.0	0.5	0.0	0.0	0.0	1.1	0.1	0.3	97.6	0.1	0.2
EA	0.0	0.0	0.0	0.3	0.0	0.0	0.7	1.0	0.0	97.3	0.6	0.1
LA	0.0	0.0	0.0	0.0	0.3	0.0	0.6	1.7	0.0	96.5	0.9	0.1
RC	0.0	0.0	0.0	0.0	0.0	0.3	0.7	1.4	0.0	96.5	1.0	0.1
t=12												
US	0.4	0.4	0.1	0.1	0.0	0.5	2.9	1.0	1.4	88.1	1.2	4.1
Euro	0.0	0.1	0.0	0.0	0.0	0.0	0.3	0.2	0.1	99.1	0.2	0.1
Japan	0.0	0.0	0.3	0.0	0.0	0.0	0.8	0.1	0.2	98.3	0.1	0.2
EA	0.0	0.0	0.0	0.2	0.0	0.0	0.5	0.7	0.0	98.2	0.4	0.1
LA	0.0	0.0	0.0	0.0	0.2	0.0	0.4	1.2	0.0	97.6	0.6	0.1
RC	0.0	0.0	0.0	0.0	0.0	0.2	0.5	0.9	0.0	97.5	0.7	0.1

1/ Data sample : 1999Q1 to 2010.Q2
2/ Monetary policy shocks include: interest rate and inflation target shocks
3/ Risk premium shocks include real exchange rate,real equilibrium exch. rate, real interest rate and real interest rate differential shocks
4/ Potential growth shocks include: potential growth, and equilibrium unemployment shocks

Table 9. Variance Decomposition[2]

Figure 1. Shock to ε^{y}_{US}

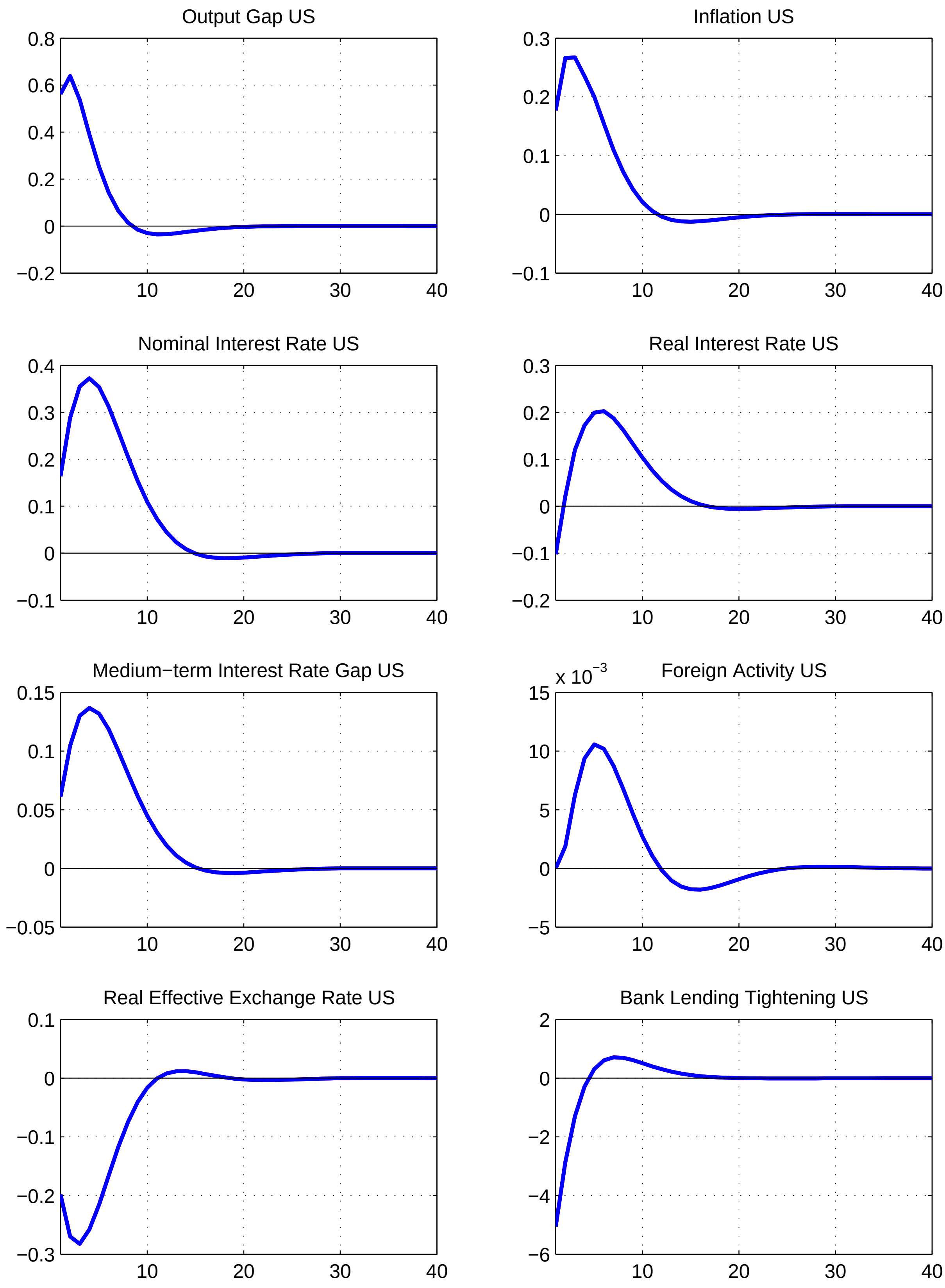

Figure 2. Shock to ε^{y}_{US}

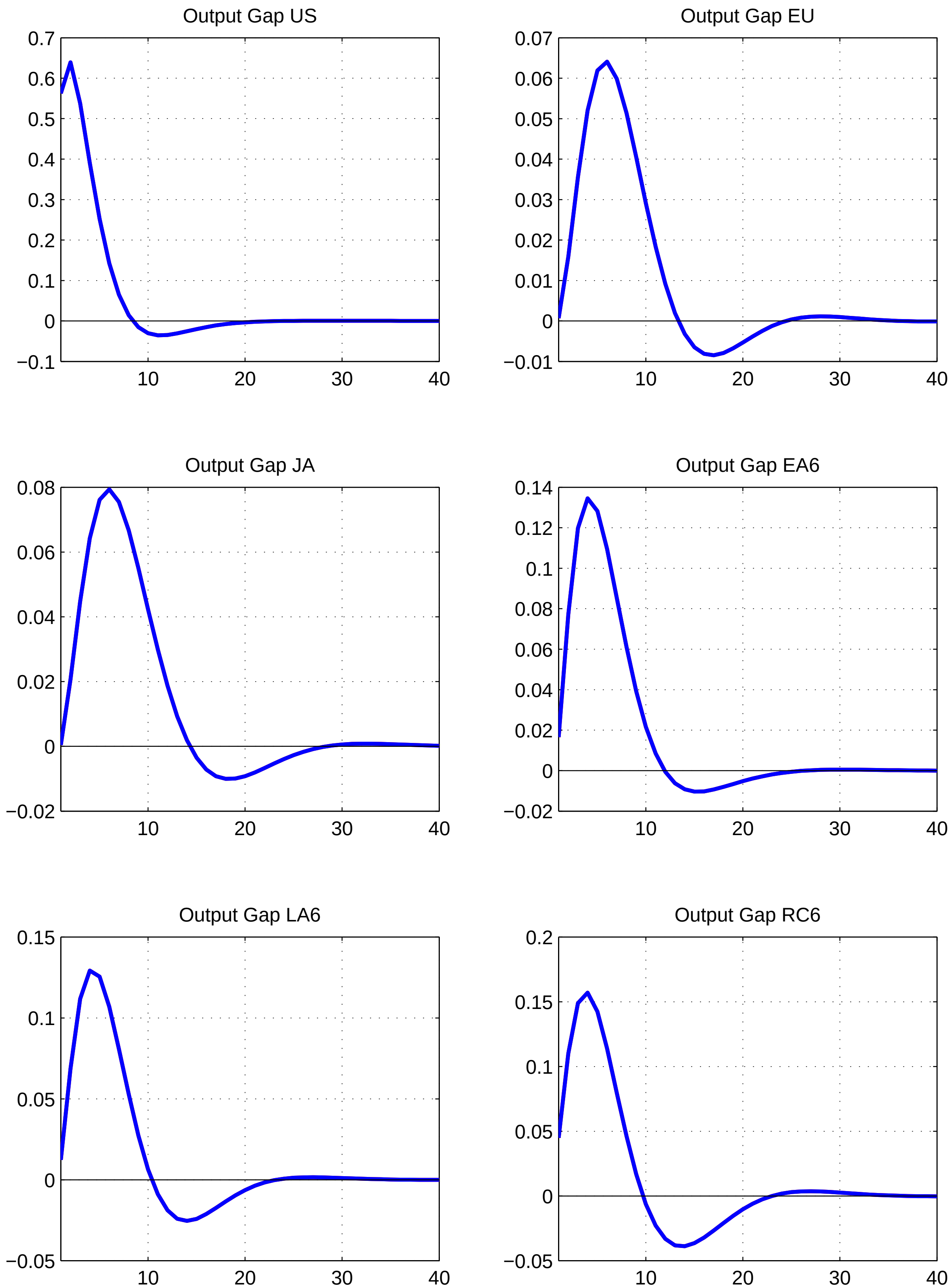

Figure 3. Shock to ε^{y}_{EA6}

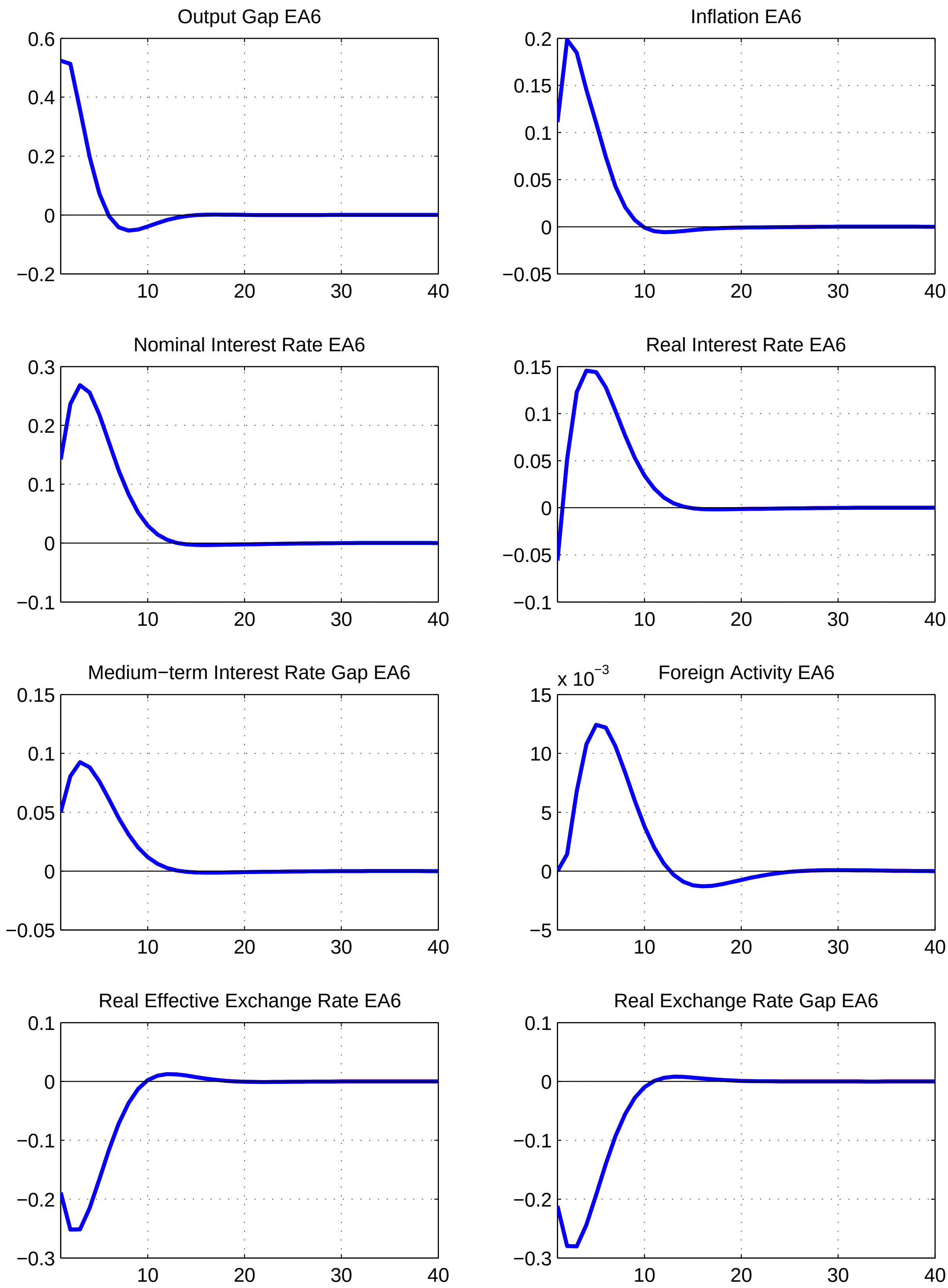

Figure 4. Shock to ε^{y}_{EA6}

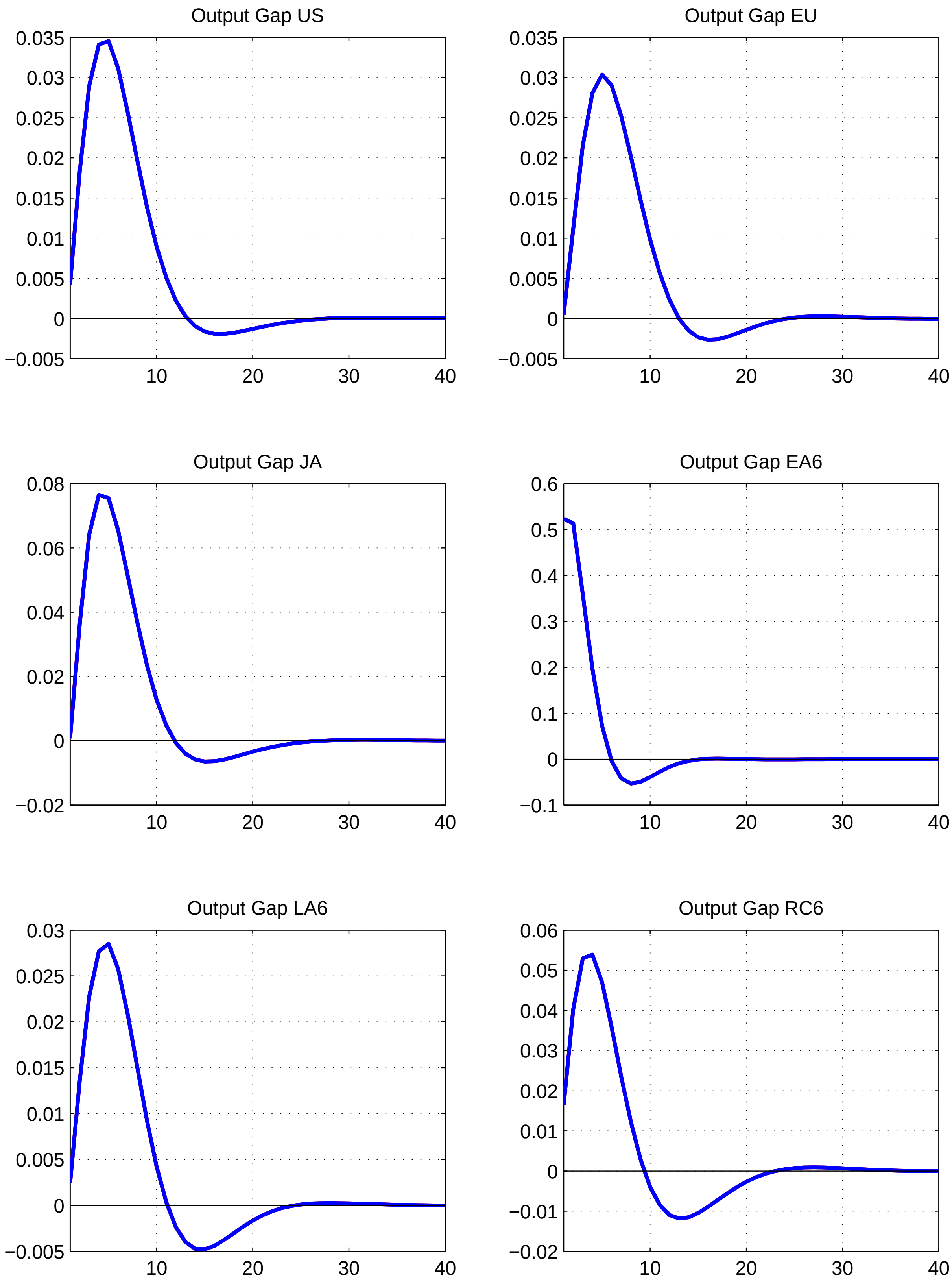

Figure 5. Shock to ε^{y}_{EU}

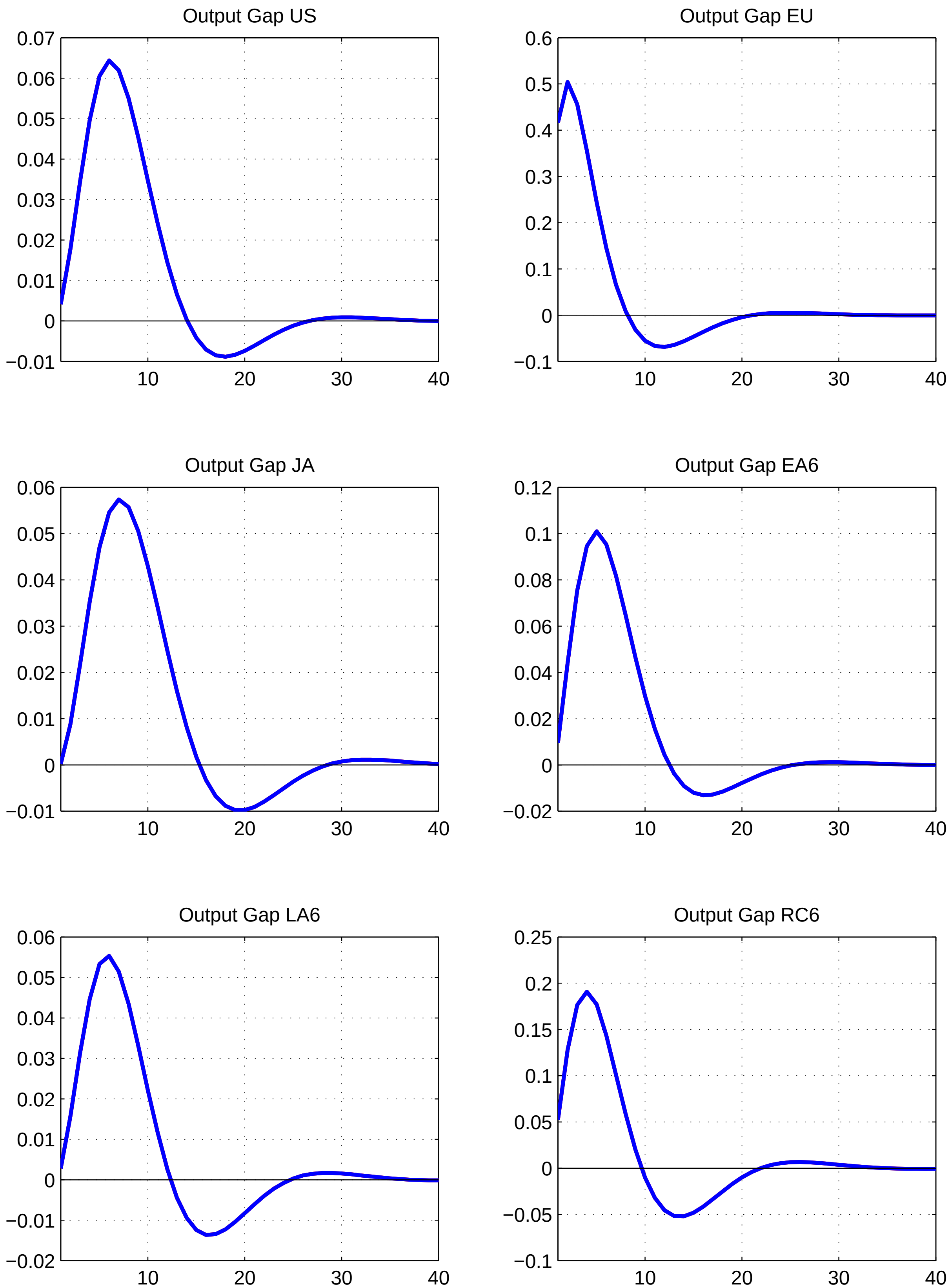

Figure 6. Shock to ε_{JA}^{y}

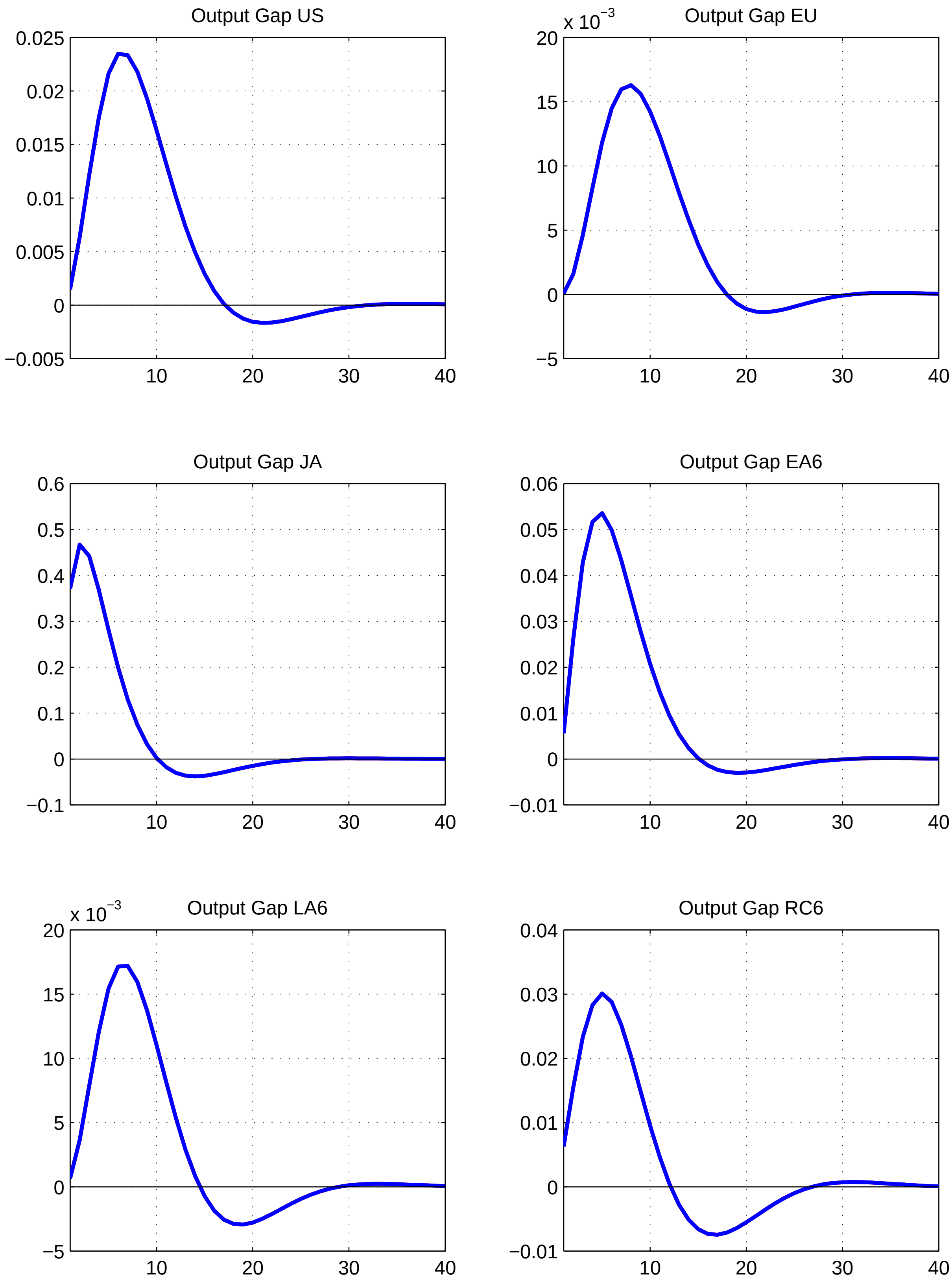

Figure 7. Shock to ε^{y}_{LA6}

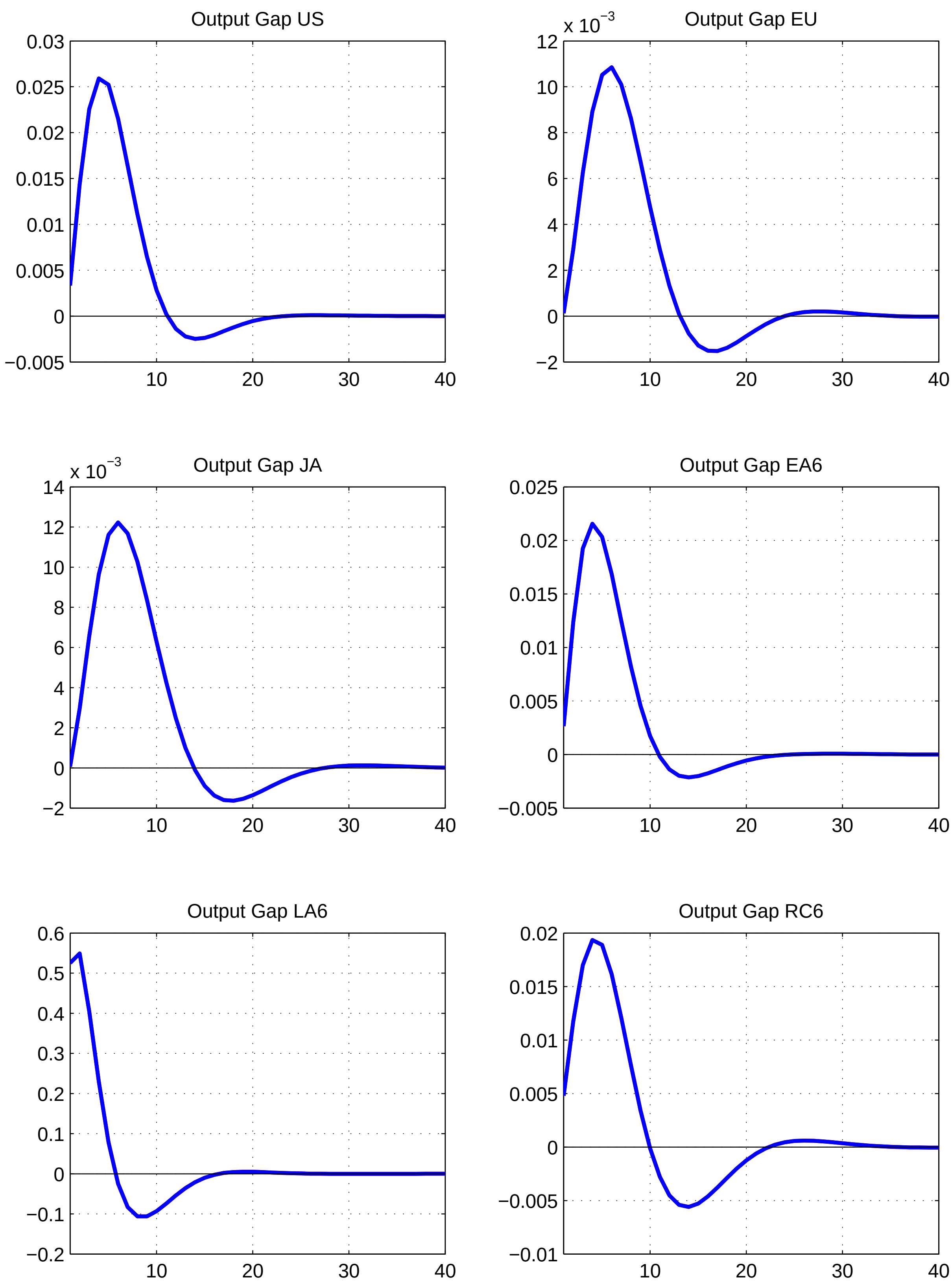

Figure 8. Shock to ε^{y}_{RC6}

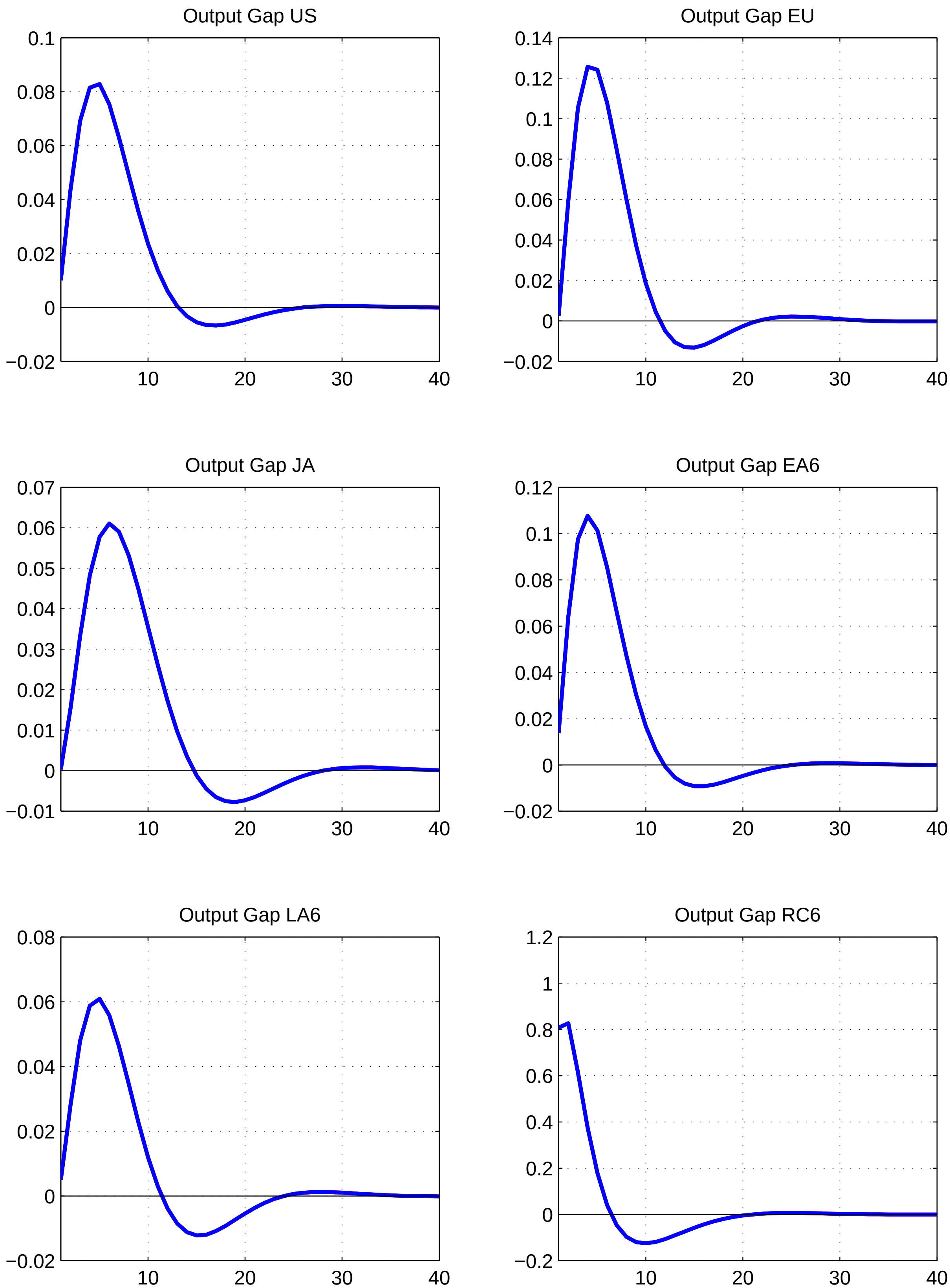

Figure 9. Shock to ε_{US}^{π}

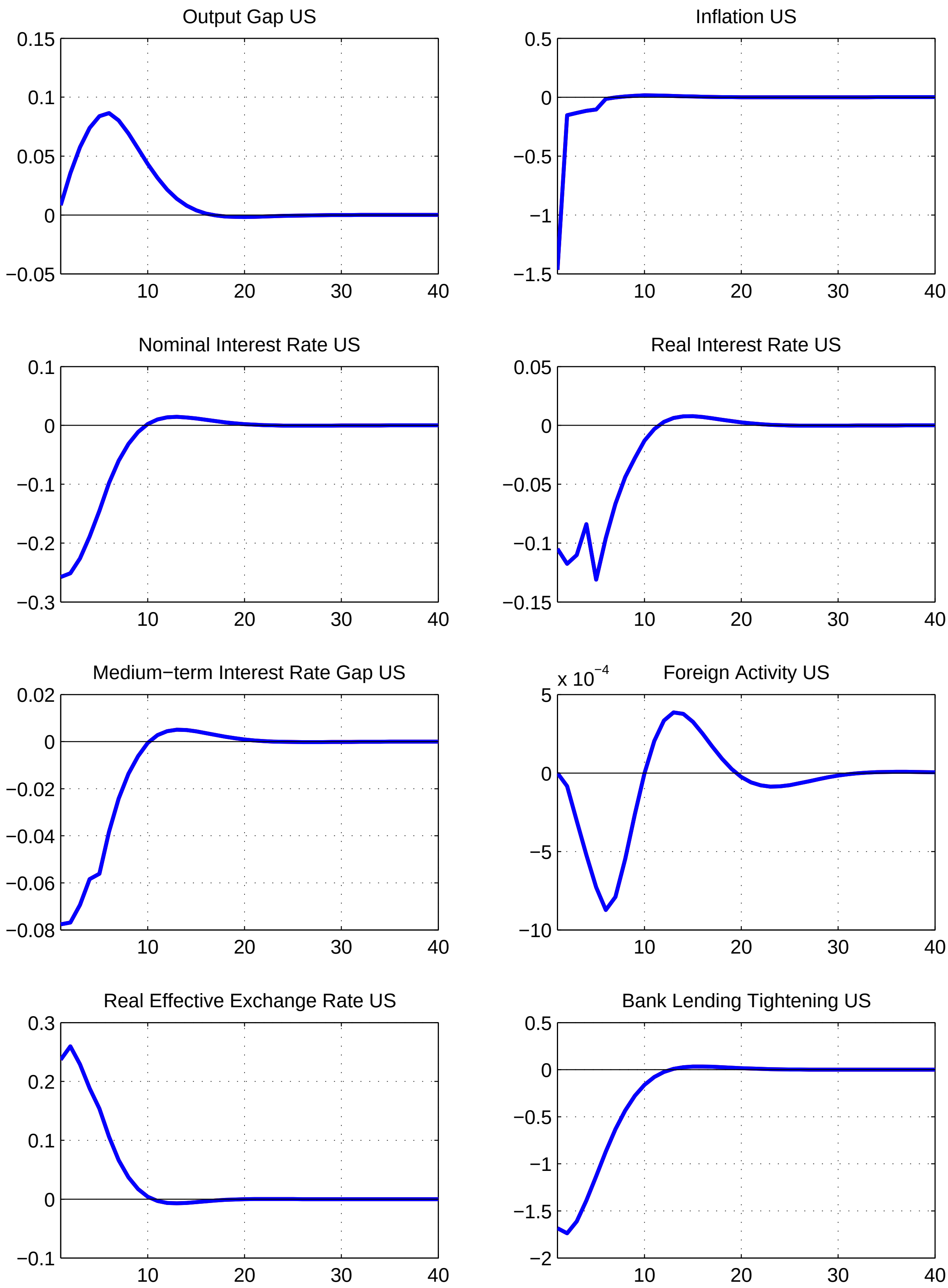

Figure 10. Shock to ε_{US}^{π}

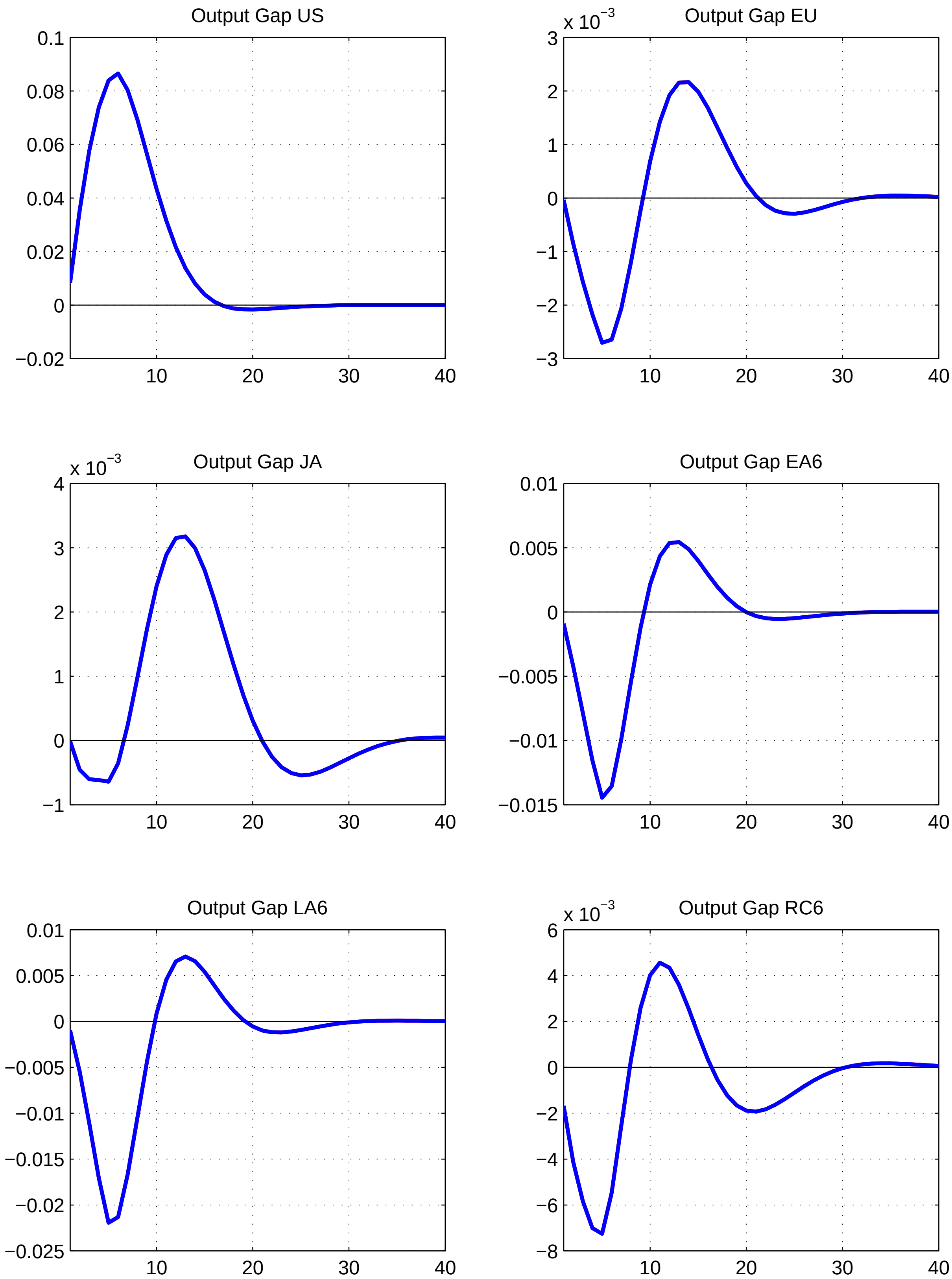

Figure 11. Shock to ε^{π}_{EA6}

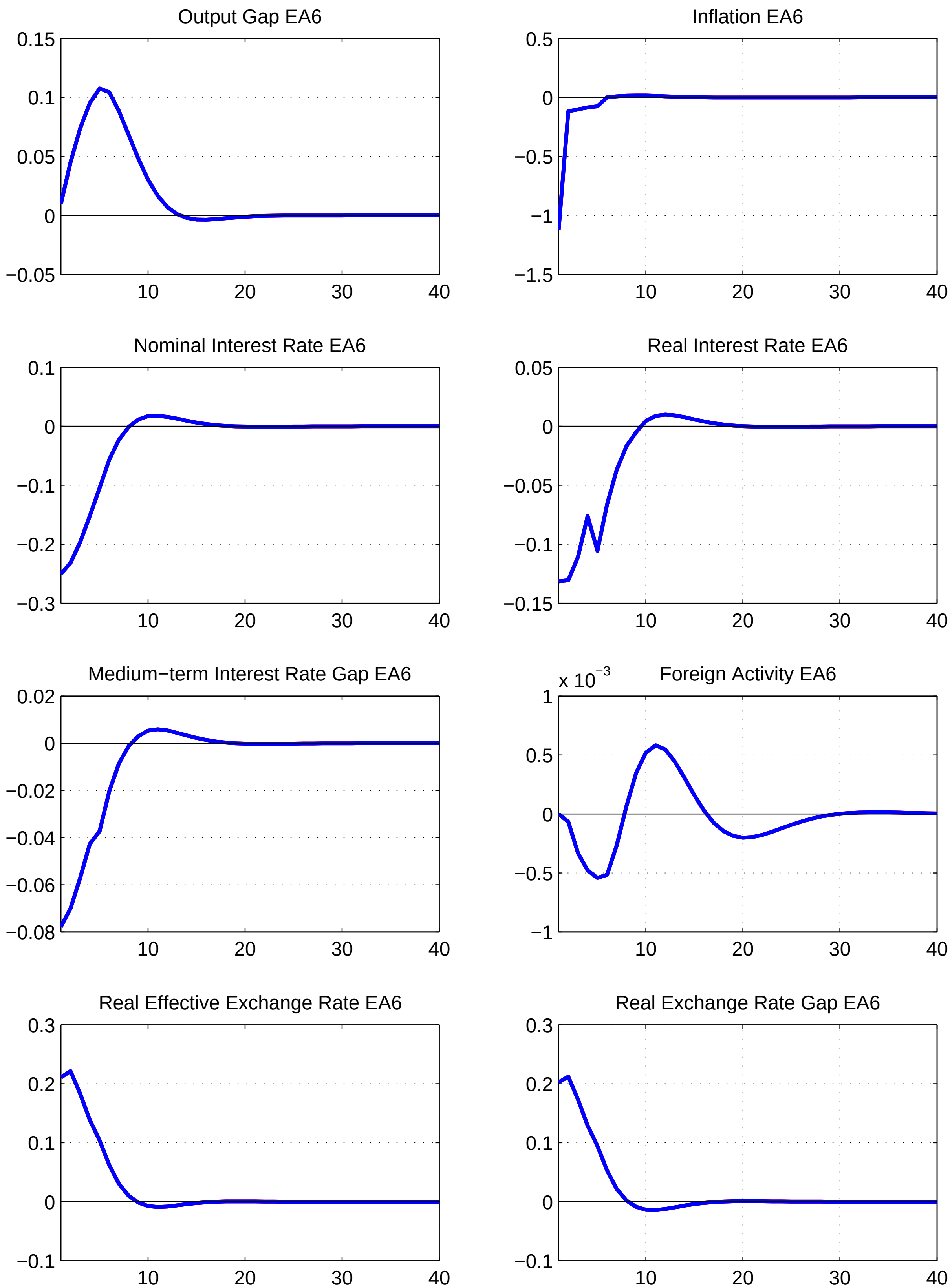

Figure 12. Shock to ε^{π}_{EA6}

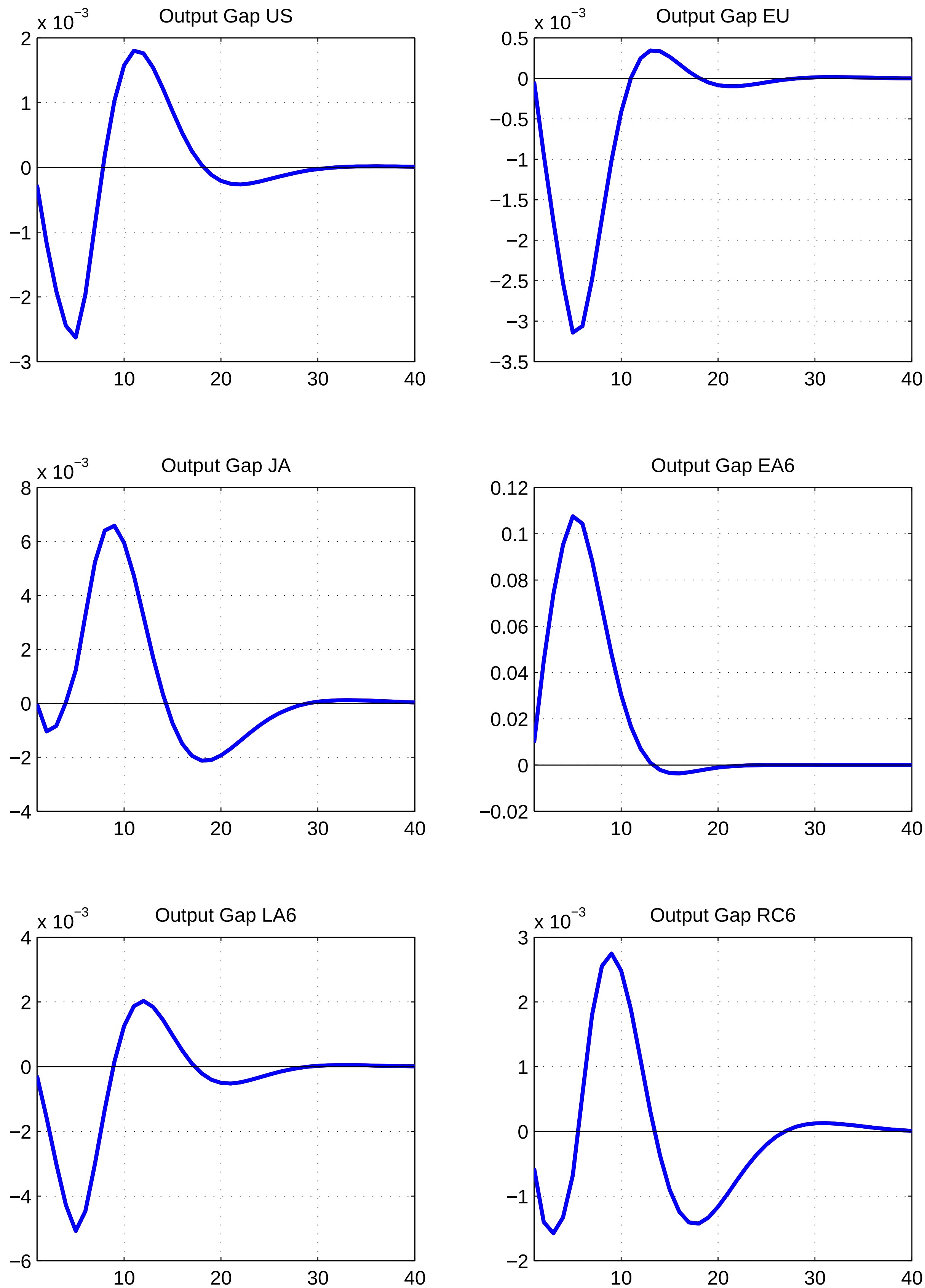

Figure 13. Shock to ε^{I}_{US}

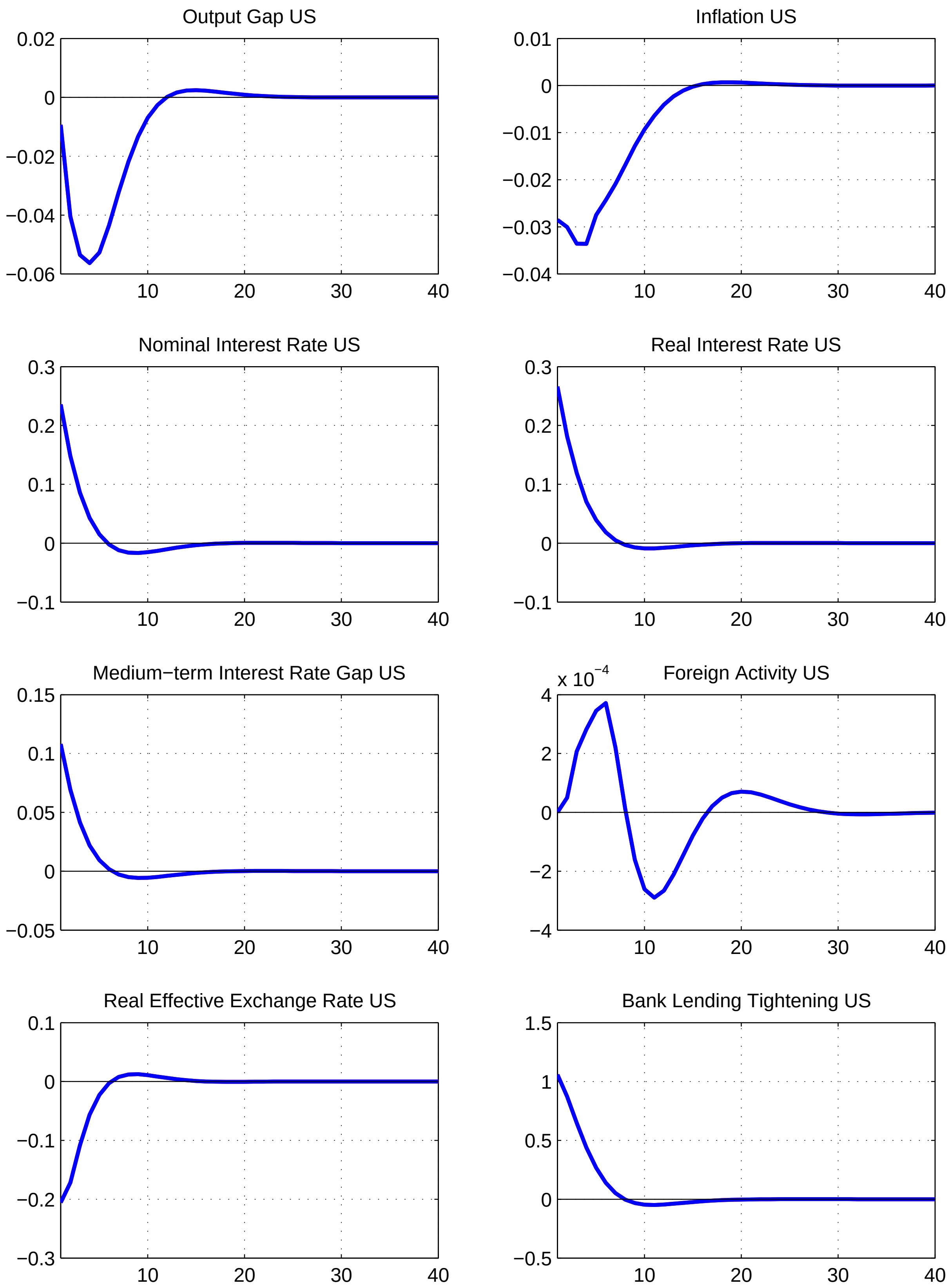

Figure 14. Shock to ε^{I}_{US}

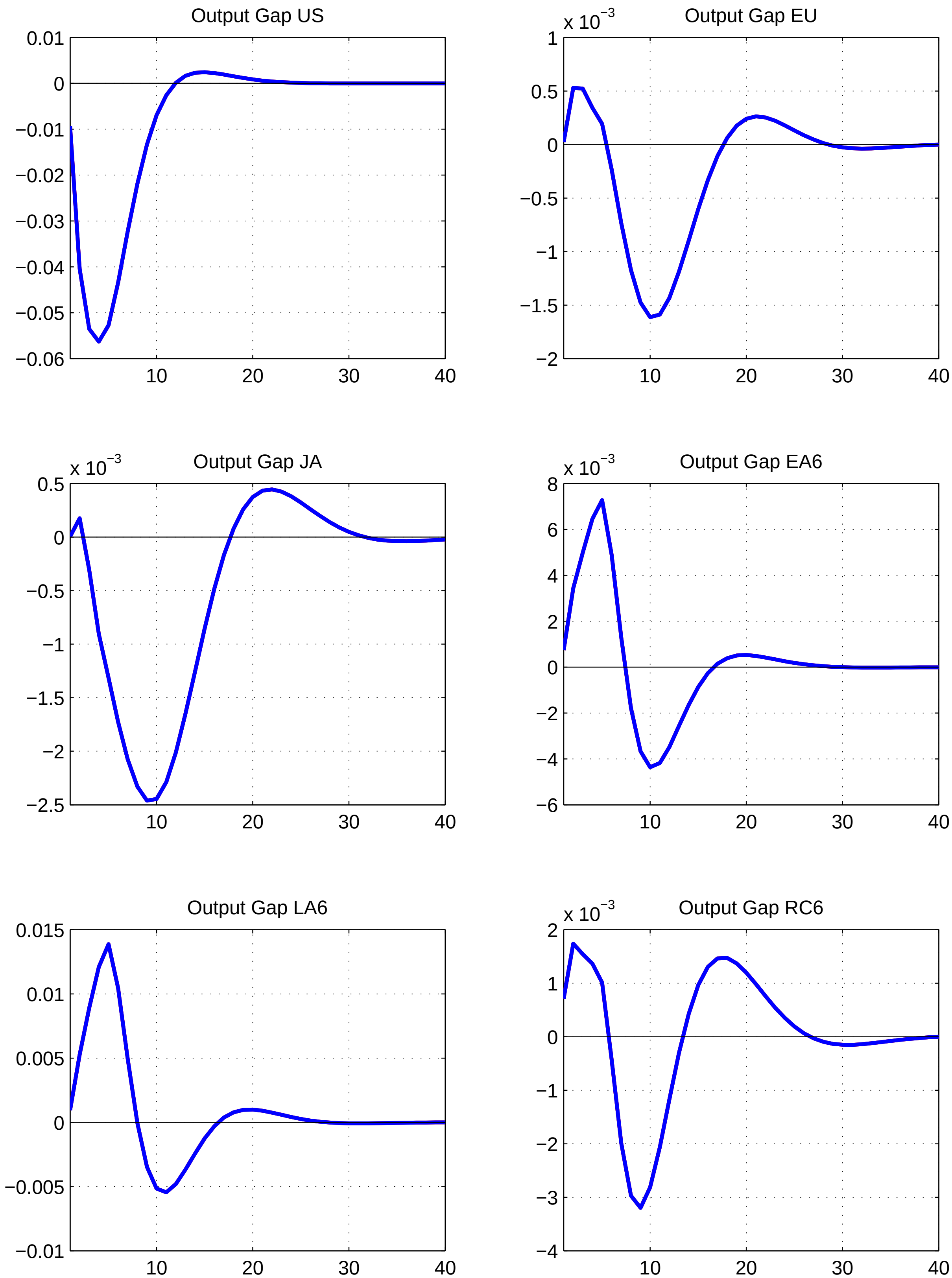

Figure 15. Shock to ε^{I}_{EA6}

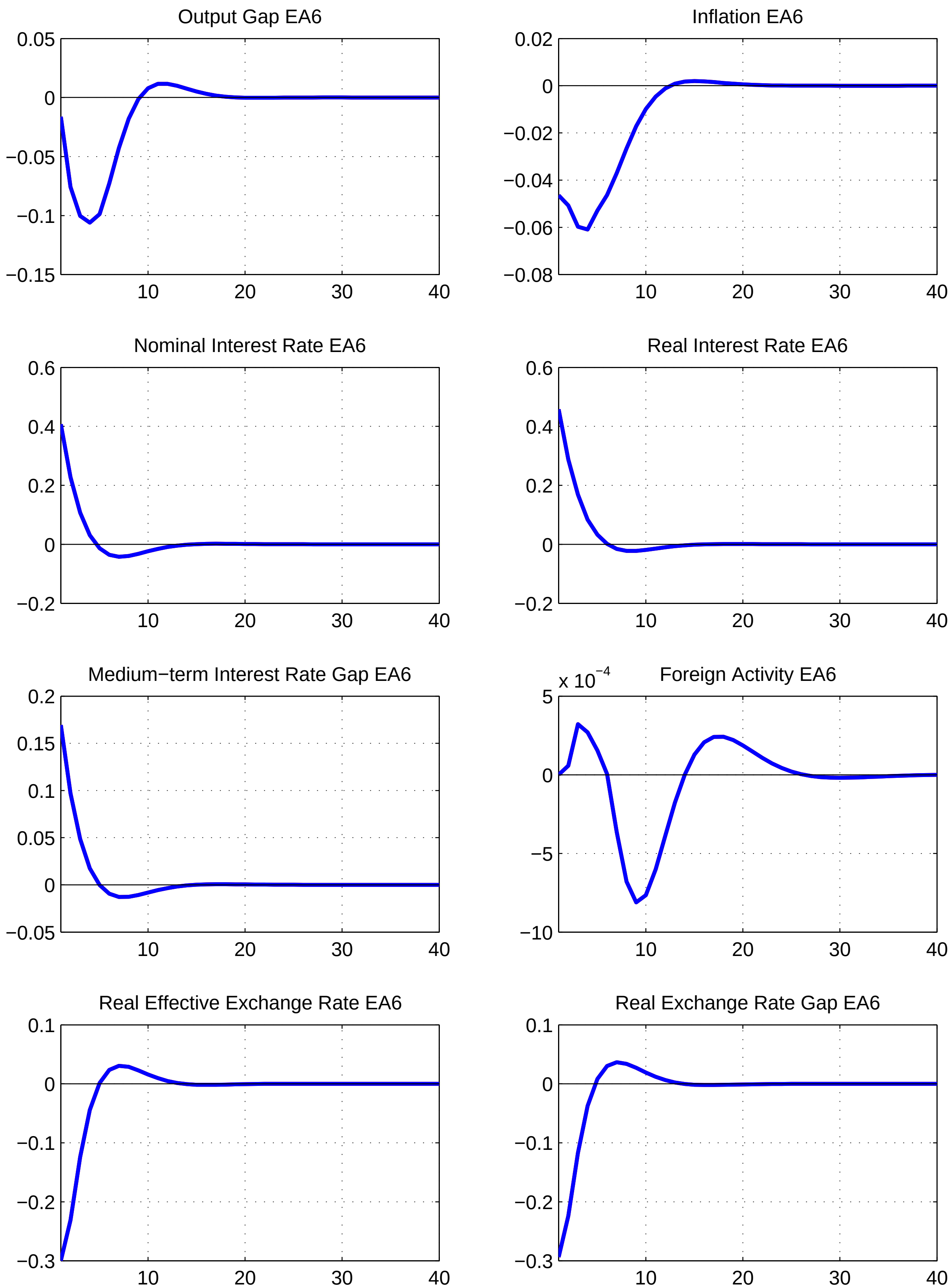

Figure 16. Shock to ε^{I}_{EA6}

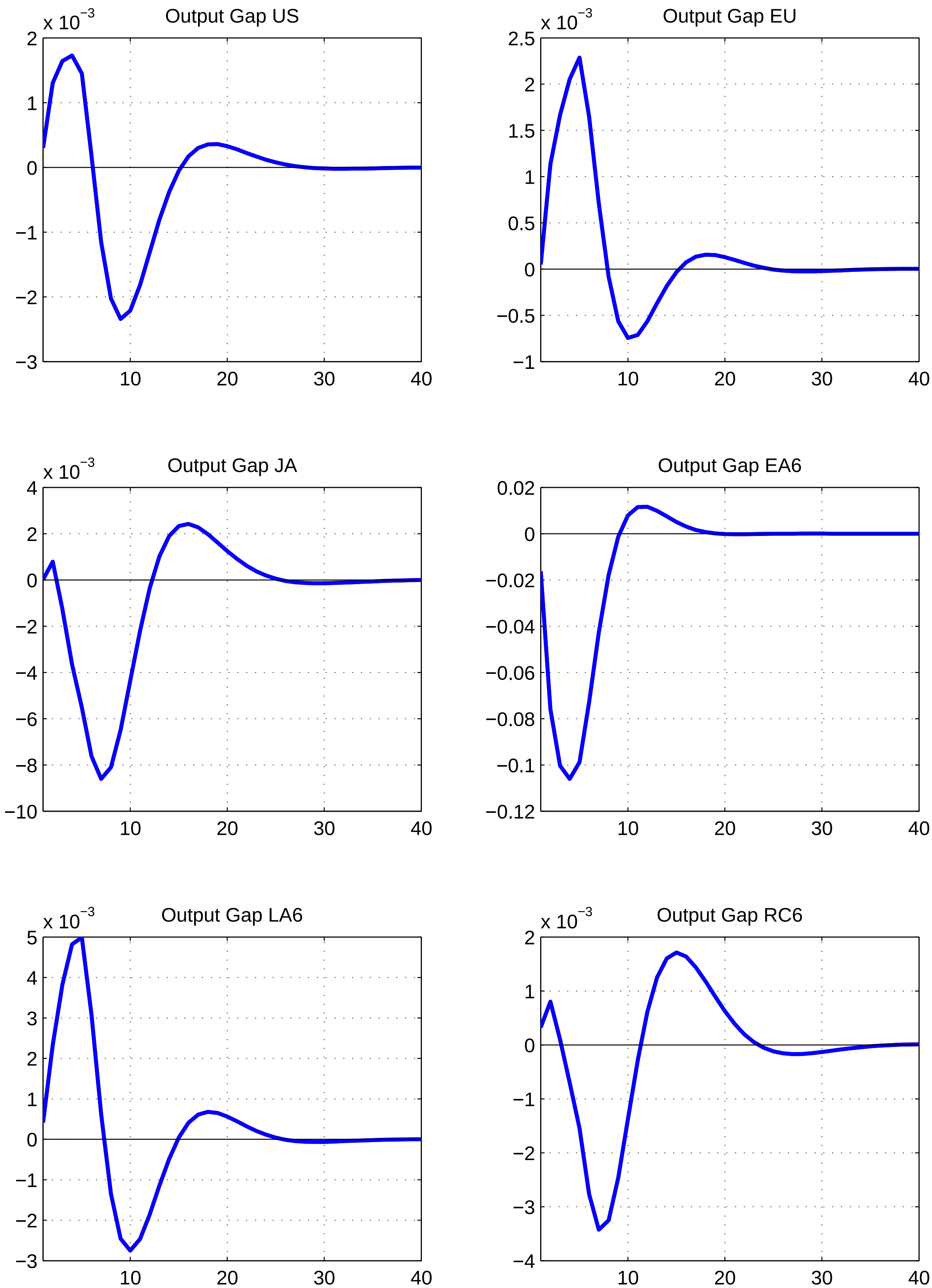

Figure 17. Shock to ε_{US}^{BLT}

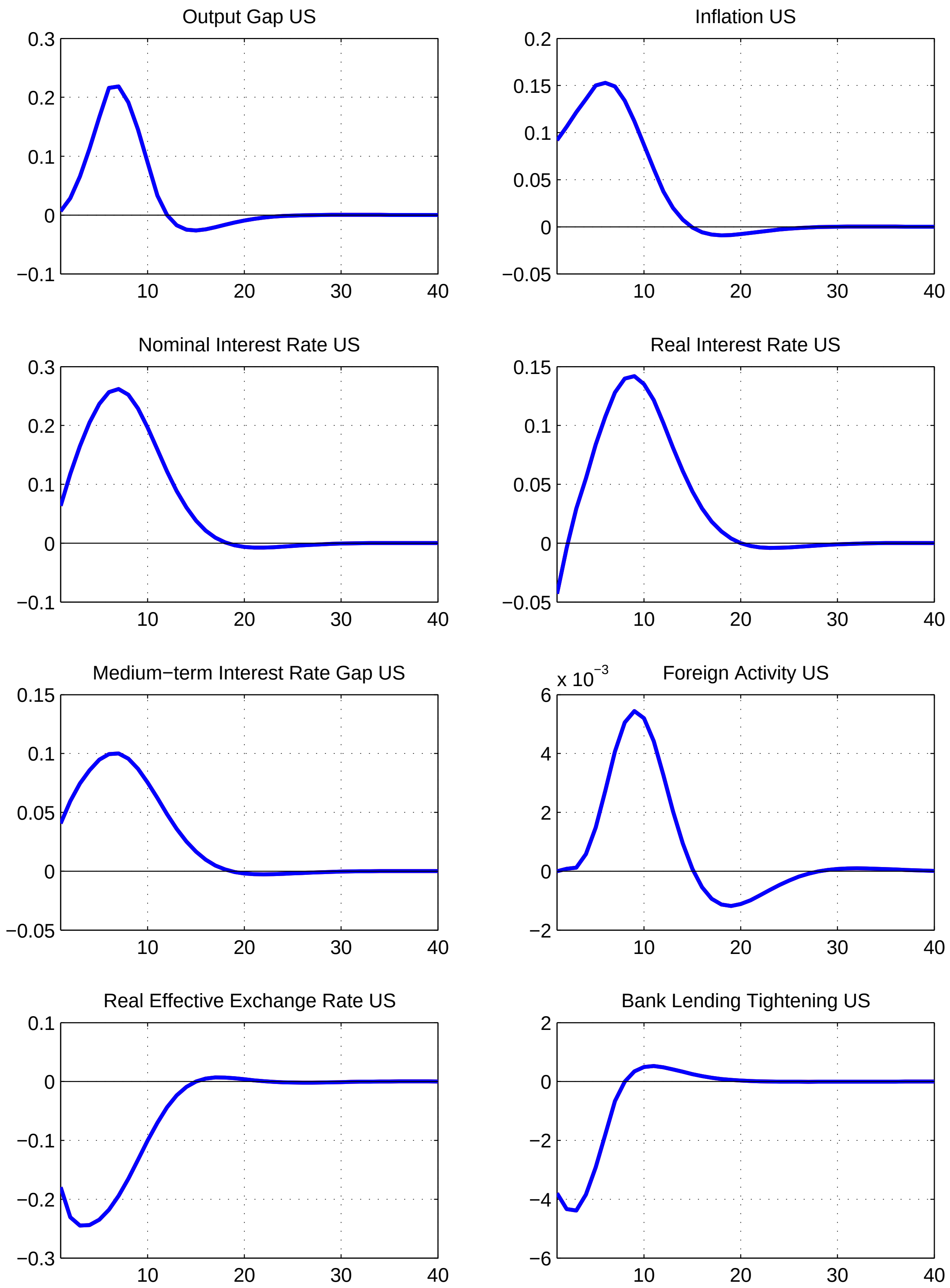

Figure 18. Shock to ε_{US}^{BLT}

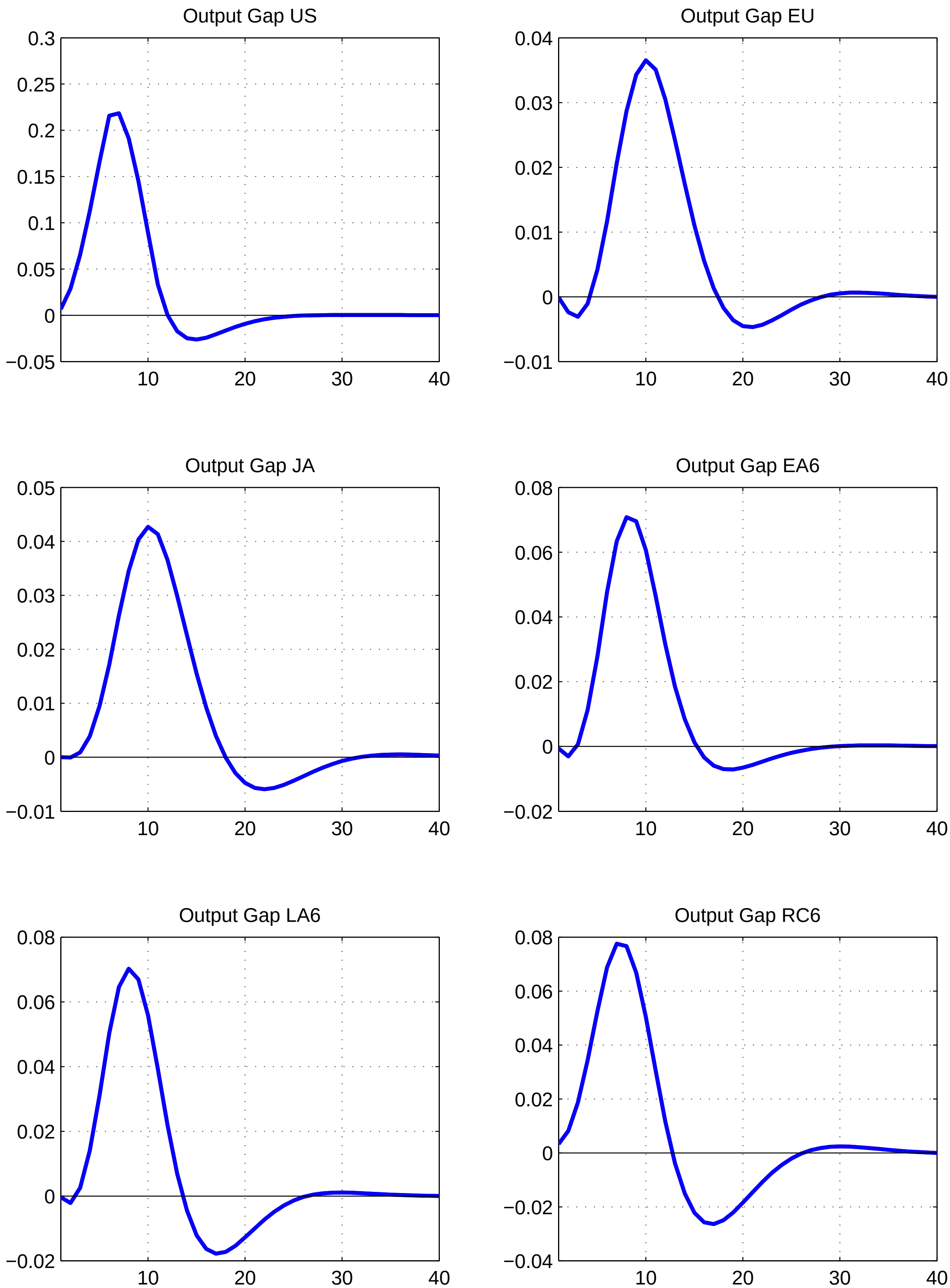

Figure 19. Shock to ε_{US}^{ν}

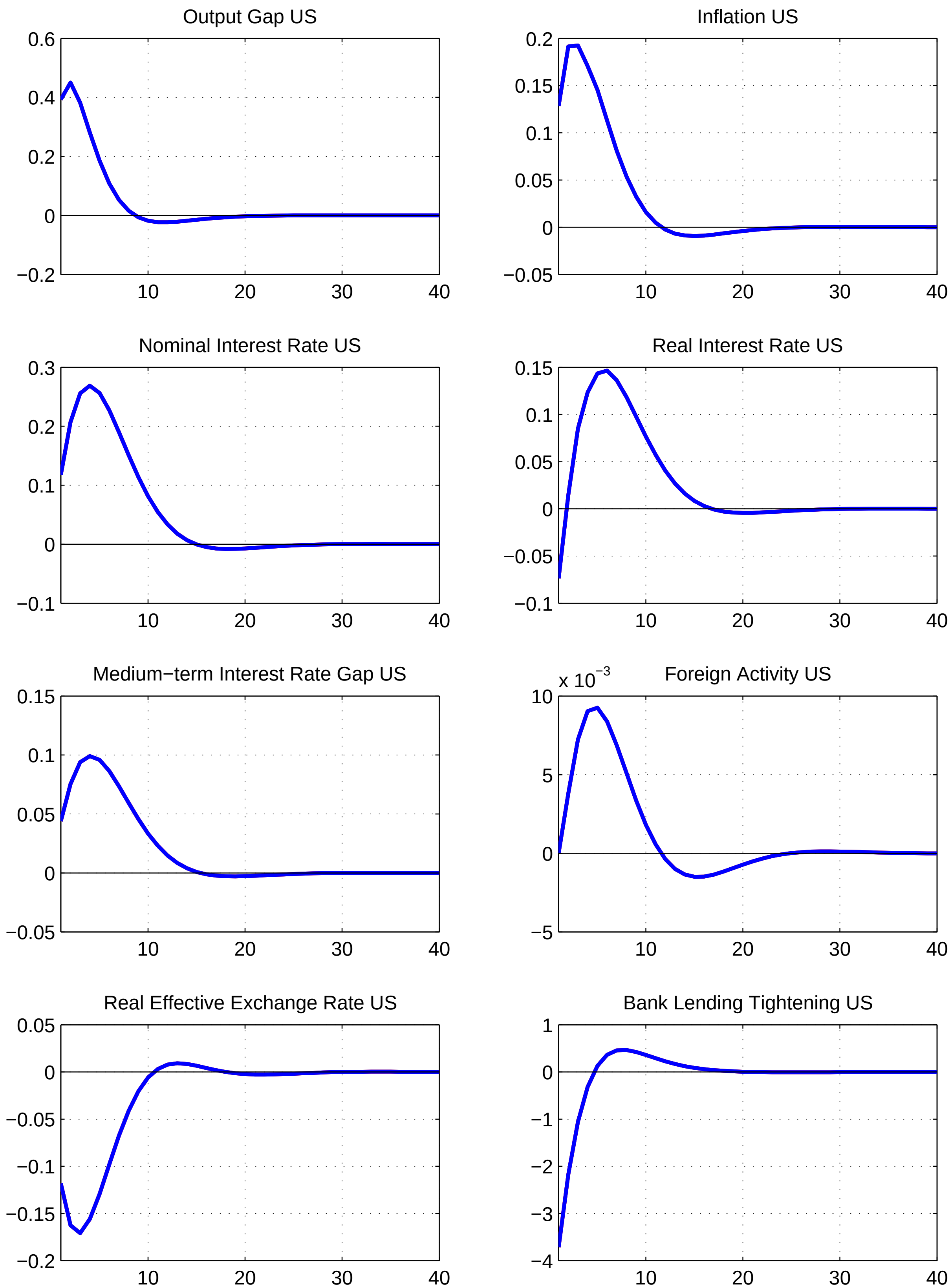

Figure 20. Shock to ε_{US}^{v}

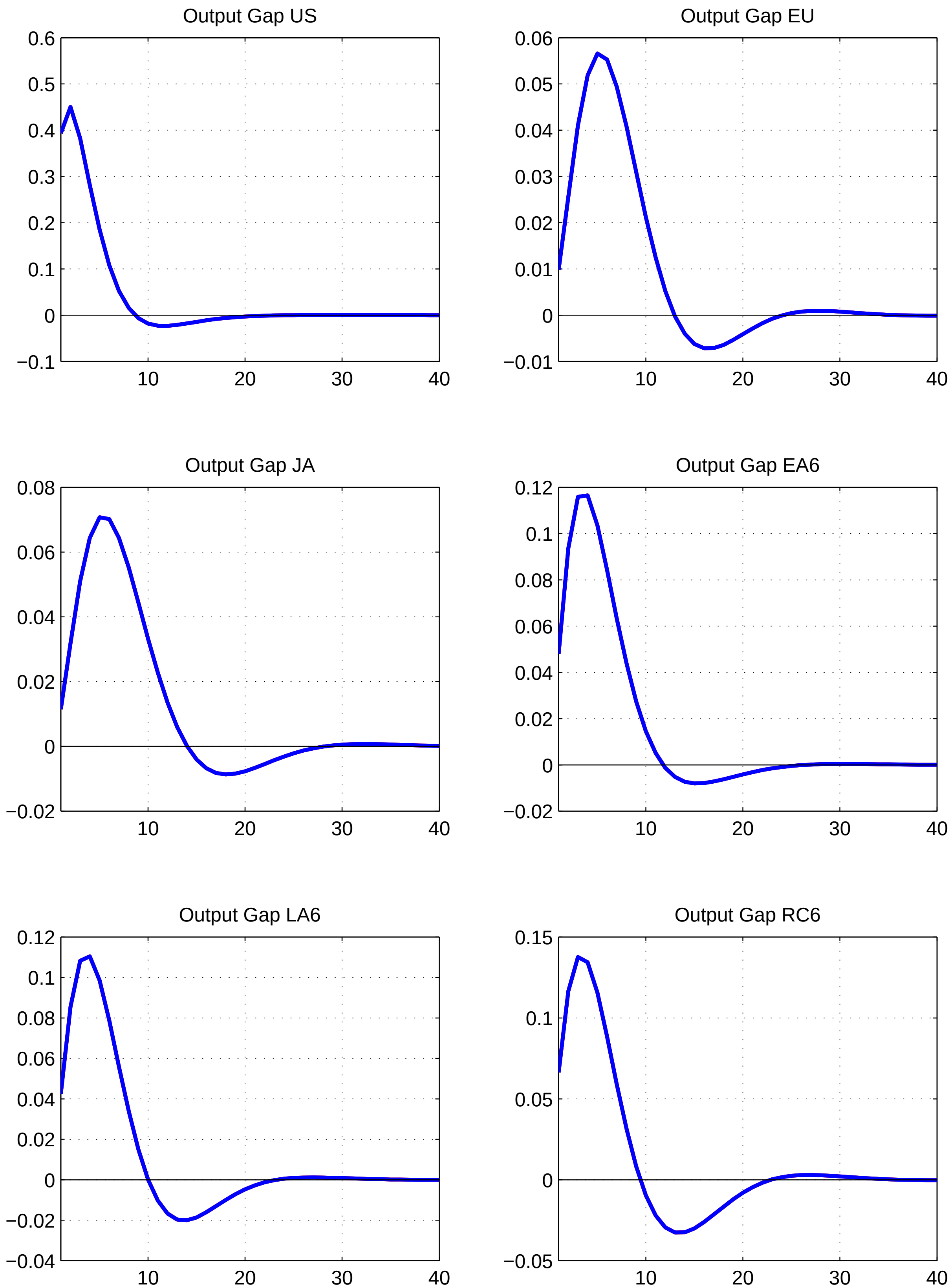

Figure 21. Shock to ε^{v}_{EA6}

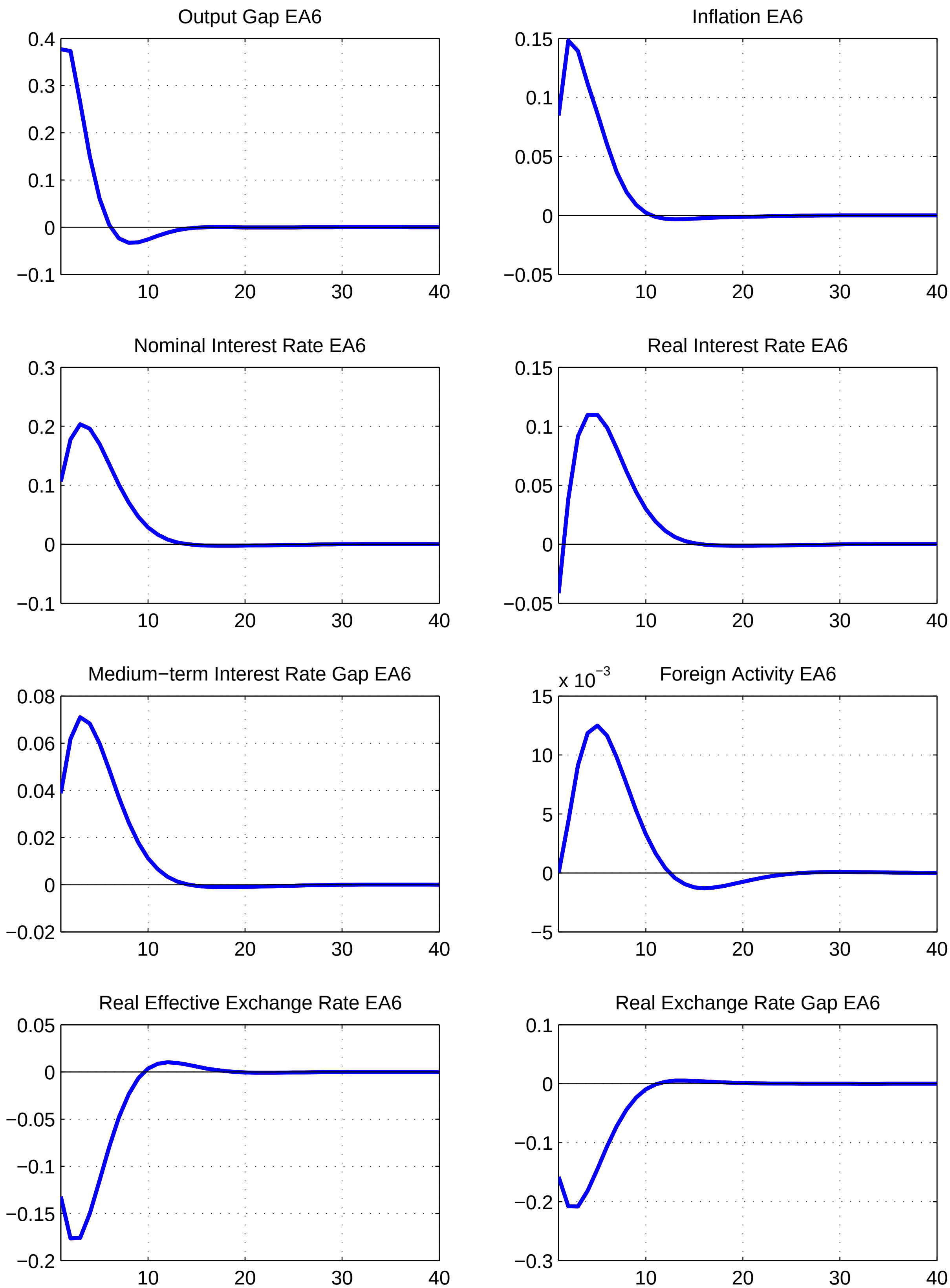

Figure 22. Shock to ε_{EA6}^{v}

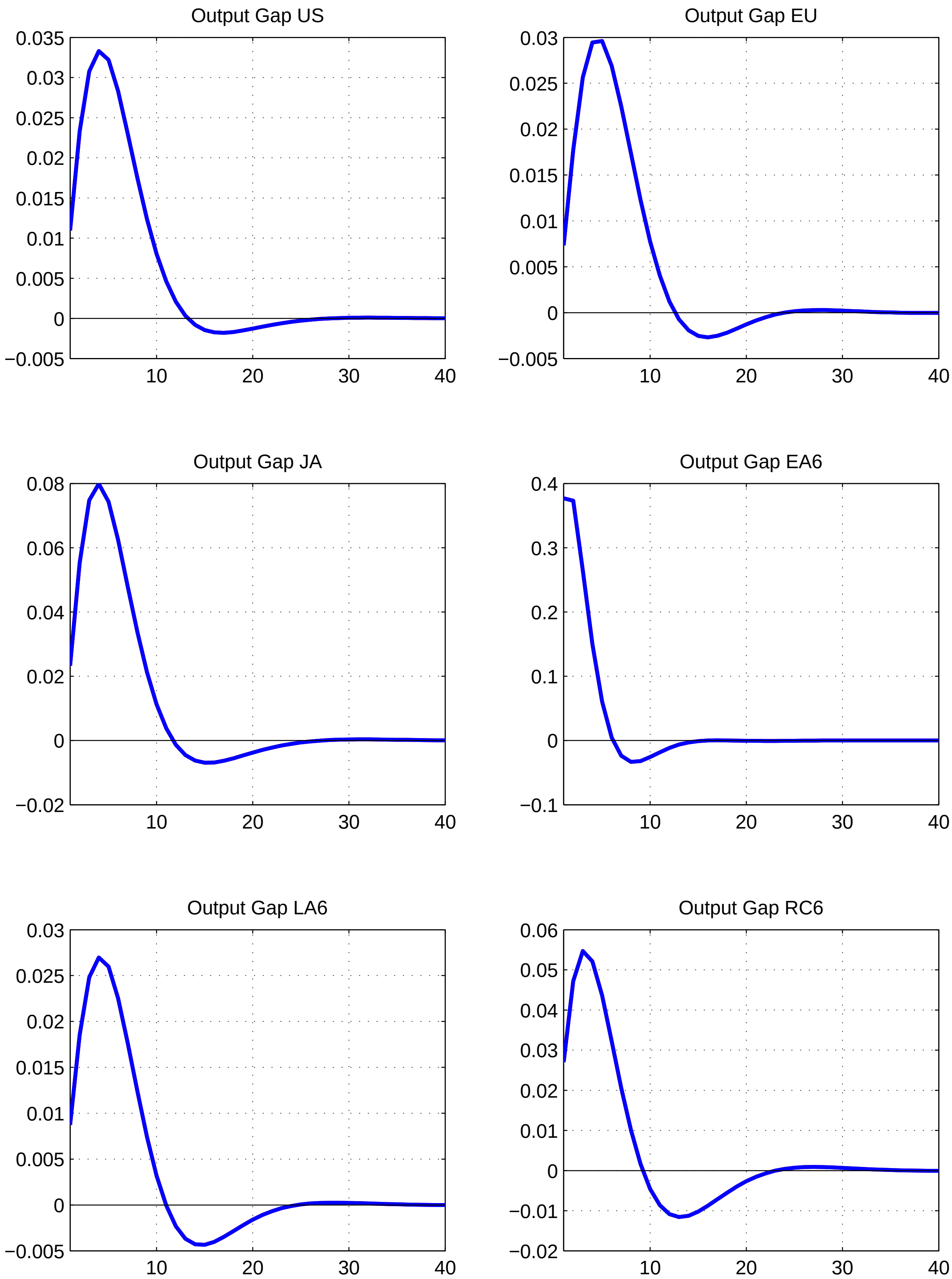

Figure 23. Global Demand Shock

Shock: ε^{ν} = 1 std dev in steady-state