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Introducing the Bank of Canada's Projection Model for the Global Economy

by Jeannine Bailliu, Patrick Blagrave, and James Rossiter

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Abstract

To complement its existing set of tools to analyze and forecast developments in the global economy, the Bank of Canada recently developed a version of the Global Projection Model (GPM) jointly with staff at the International Monetary Fund. The GPM is a highly stylized quarterly projection model for the global economy based on work by Carabenciov et al. (2008). The GPM is specifically designed to meet the need for a better tool to conduct the global projection. The model's main strength is that it provides an internally consistent projection for the global economy, wherein a shock to any individual block of the model is transmitted to the other economies through several channels. Moreover, it enables staff to better account for changes in view from projection to projection and to analyze the general-equilibrium impact on the global economy of a number of key shocks.

JEL classification: C68, E27, E37, F01
Bank classification: Economic models; International topics; Business fluctuations and cycles

Résumé

Afin de compléter les outils dont elle dispose pour analyser et prévoir l'évolution de l'économie mondiale, la Banque du Canada a conçu récemment avec le Fonds monétaire international un nouveau modèle de projection mondial. Ce modèle très stylisé de prévision trimestrielle s'inspire du travail de Carabenciov et autres (2008). Il vise plus précisément à affiner les projections internationales. Son principal atout réside dans la cohérence interne des prévisions obtenues pour l'économie mondiale, car les chocs modélisés dans chaque bloc se transmettent aux autres économies par plusieurs canaux. En outre, le modèle permet aux économistes de mieux tenir compte des changements de points de vue d'une projection à l'autre et d'étudier l'incidence de quelques chocs déterminants sur l'économie mondiale en contexte d'équilibre général.

Classification JEL : C68, E27, E37, F01
Classification de la Banque : Modèles économiques; Questions internationales; Cycles et fluctuations économiques

1. Introduction

The Bank of Canada has a long history of developing and using macroeconomic models for projection and policy analysis. In the early 1990s, it developed a projection model for the Canadian economy, the Quarterly Projection Model (QPM).[1] More recently, the Bank replaced QPM with its Terms-of-Trade Economic Model (ToTEM), which is considered to be state of the art among central bank models.[2]

Given that Canada is an open economy, forecasts of external economic activity have always been an important input for the projection of the Canadian economy. Until quite recently, the Bank had focused its efforts on modelling the external environment on the U.S. economy. Indeed, over the past five years, the Bank has used its Model of the U.S. Economy (MUSE, a macroeconometric model – see Gosselin and Lalonde, 2005) to analyze and forecast the U.S. economy. However, as the global financial crisis has made abundantly clear, economic shocks are increasingly globally synchronized, thus motivating a global consideration of the economic outlook.[3]

A set of individual country forecasts constructed outside of a global model lacks internal consistency, in that a shock to any one of these economies need not be transmitted back to the outlook for the other economies. Properly capturing the spillover effects from one economy to another through trade and exchange rate channels is vital when constructing the outlook for individual economies. Thus, in order to ensure the internal consistency of the Bank of Canada staff projection, we have developed a version of the Global Projection Model (GPM) jointly with staff at the IMF.

The GPM is a highly stylized quarterly projection model for the global economy based on work by Carabenciov et al. (2008). It consists of the following five regions: the United States, the euro area, Japan, China, and a rest-of-world (RoW) block that is included to

[1] QPM was considered to be state of the art at the time in terms of macroeconomic modelling for projection and policy analysis. It was the Bank's main model for Canadian economic projections and policy analysis throughout the 1990s.

[2] For more details on ToTEM, see Murchison and Rennison (2006).

[3] To examine issues in a global context, the Bank of Canada developed its version of the Global Economy Model (GEM), BoC-GEM, in collaboration with researchers at the International Monetary Fund (IMF) and the Federal Reserve Bank of New York – see Lalonde and Muir (2007) for more details on the BoC-GEM. Like ToTEM, the GEM is a dynamic stochastic general-equilibrium (DSGE) model with a fully optimizing framework based on microfoundations. Bank staff have used the BoC-GEM to analyze various issues and to model how those issues could affect Canada either directly or indirectly (for more on how the BoC-GEM is used at the Bank of Canada, see Lalonde and Muir, 2009). One of the shortcomings of the BoC-GEM is that it cannot be used for forecasting purposes.

render the model globally complete. Specifically designed to meet the need for a better tool to help organize the global projection, the GPM is a small-scale model designed to produce sensible impulse-response functions for a small set of key shocks and to forecast relatively well out-of-sample. Although it is reduced-form in nature, the model structure is based on the theory underlying larger-scale structural DSGE models; the model is estimated using state-of-the-art Bayesian econometric techniques. The small scale of the model enhances our ability to interpret shocks, and facilitates the model's use for policy purposes.

In developing our global forecast at the Bank of Canada, the original U.S. block of the model, as estimated by Carabenciov et al. (2008), has been replaced with the Bank's MUSE.[4] This change is motivated by the need for a greater level of detail for our United States projection than is the case for other economies. Given the importance of economic ties between the United States and Canada, Bank staff conduct a detailed projection featuring a sector-by-sector outlook for the U.S. economy. Thus, all analysis of the U.S. economy that is conducted in this report relies on the properties of MUSE (Gosselin and Lalonde, 2005).

Staff started using the GPM to develop the global forecast earlier this year and it has proved to be a very useful organizing framework for building up the global projection. It facilitates the production of an internally consistent forecast for the global economy and for the key foreign economies that we follow. Moreover, it enables staff to better account for changes in view from projection to projection. And it makes it possible to identify the role of various domestic shocks in driving the outlook for each of the other economies in our model.

This report is organized as follows. In section 2, we provide a detailed description of the model structure. In section 3, we describe the estimation methodology and the results. In section 4, we use historical decompositions to examine how the model performs over history. In section 5, we investigate the model properties by examining impulse-response functions for a selection of the key shocks. In section 6, we examine some applications of our version of the GPM, and in section 7 we offer some conclusions.

2. Model Structure

The GPM is a relatively small model that is intended to capture the main elements of richer models with microfoundations. It blends New Keynesian elements – namely, an emphasis on nominal and real rigidities and a central role for aggregate demand in output determination –

[4]This process required considerable effort, and was greatly simplified thanks to work done by René Lalonde.

with the real business cycle tradition methods of DSGE modelling with rational expectations. The GPM integrates a series of country models into a single unified global model where the key features of the macroeconomic structure of each economy are characterized using a small number of behavioural equations. The equations for each block of the GPM not only capture domestic factors, but also include linkages to the other blocks of the model. In addition, exogenous stochastic processes for the unobservable variables are specified.

This section focuses on the equations used for the G-3 economies (i.e., the United States, the euro area, and Japan) as described in Carabenciov et al. (2008). This model for the G-3 economies was extended by Bailliu et al. (2010) to include China. In doing so, important modifications were made to the structure of the benchmark country model, designed for a typical advanced economy, in order to capture better the key structural characteristics of the Chinese economy. The equations used for the China block, some of which are also used for the RoW block, are provided in Appendix A.

2.1 General structure

The GPM is divided into five aggregate regions, covering close to 90 per cent of global GDP (see Appendix C). This extensive global coverage is accomplished by including a RoW block in GPM, in addition to the G-3 and Chinese economies. Doing so allows us to eliminate a large source of uncertainty and introduces near-consistency in variables such as exchange rates across all countries. The RoW block consists of 28 of the 40 largest countries other than the G-4 economies, and accounts for roughly 35 per cent of global output. This block includes a fairly heterogeneous set of countries including India, the United Kingdom, Russia, Brazil, Mexico, and South Korea.[5]

An important and unique feature of the Bank of Canada's version of the GPM is that the U.S. block of the GPM has been replaced with the Bank's MUSE for projection purposes (estimation of the GPM is performed using the original U.S. block as specified in Carabenciov et al. 2008). In doing so, the Bank retains its ability to conduct detailed forecasts of the U.S. economy using a more sophisticated model, while allowing for simultaneous endogenous responses in other countries in a globally consistent environment. MUSE replaces the core behavioural equations of its counterpart block in the GPM, and those endogenous variables necessary for other countries in the GPM are fed directly (and simultaneously) from MUSE into the GPM, and vice versa.

[5]While the benefit of including this RoW block is evident, it also comes at a small cost: its heterogeneity makes it challenging to interpret some of the key equations, such as the monetary policy reaction function.

2.2 Behavioural equations

There are four behavioural equations at the core of each country model. The first behavioural equation is an aggregate demand, or IS, curve that relates the level of real activity to expected future and past real activity, the real interest rate, the real exchange rate, and the level of real activity in each country's trading partners. All variables are expressed as deviations from their equilibrium values so that the aggregate demand equation relates the output gap to its determinants as follows:

$$\begin{aligned} y_{i,t} &= \beta_{i,1} y_{i,t-1} + \beta_{i,2} y_{i,t+1} - \beta_{i,3}(R_{i,t-1} - \overline{R}_{i,t-1}) \\ &+ \beta_{i,4} \sum_j w_{i,j,4}(Z_{i,j,t-1} - \overline{Z}_{i,j,t-1}) + \beta_{i,5} \sum_j w_{i,j,5} y_{j,t-1} + \varepsilon^y_{i,t}, \end{aligned} \tag{1}$$

where y is the output gap, R is the real interest rate, $\overline{R}$ is the equilibrium real interest rate, $Z_{i,j}$ is the bilateral real exchange rate of country i relative to that of country j (such that an increase in $Z_{i,j}$ represents a real depreciation of the currency of country i relative to the currency of country j), $\overline{Z}_{i,j}$ is the equilibrium bilateral real exchange rate, and ε^y is a disturbance term.[6] The foreign output-gap term is defined as a weighted average of the foreign output gaps where the weights ($w_{i,j,5}$) used are the ratios of the exports of country i to country j to its total exports to all the countries in the model.

The lead term captures the forward-looking elements in aggregate demand that arise in a framework where forward-looking households optimize their consumption. Thus, expectations of the future performance of the economy are assumed to influence current aggregate demand because of the forward-looking nature of decisions made by individual households and firms. The own-lag term allows for inertia in the system and permits shocks to have persistent effects. As discussed in Clarida, Gali, and Gertler (1999), the primary justification for allowing some form of lagged dependence in the IS curve is empirical, although it may be possible to explain its presence by appealing to some form of adjustment costs. The real interest rate term provides the crucial link between monetary policy actions and the real economy. Given the sluggish adjustment of prices, by varying the nominal interest rate the central bank is able to influence the real interest rate gap, and hence aggregate demand. And the foreign activity variable and the real exchange rate term allow for critical links between the domestic economy and the other economies in the model.

[6] The weights used to construct the effective real exchange rate term ($w_{i,j,4}$) are the ratios of the sum of the exports and imports of country i with country j to the sum of its exports and imports with all the countries in the model.

The second equation is an inflation equation, or Phillips curve, which links inflation to its past and future values, the lagged output gap, the effective exchange rate gap, and oil-price inflation. The inflation equation is thus assumed to take the following form:

$$\begin{aligned} \pi_{i,t} &= \lambda_{i,1}\pi 4_{i,t+4} + (1-\lambda_{i,1})\pi 4_{i,t-1} + \lambda_{i,2} y_{i,t-1} + \lambda_{i,3}\sum_j w_{i,j,3}\Delta Z_{i,j,t} \\ &+ \nu_{i,1}\pi_{i,t}^{RPOIL} + \nu_{i,2}\pi_{i,t-1}^{RPOIL} - \varepsilon_{i,t}^{\pi}, \end{aligned} \tag{2}$$

where π is the quarterly rate of inflation (at annual rates), $\pi 4$ is the average annual inflation rate, y is the output gap, $Z_{i,j}$ is the bilateral real exchange rate of country i relative to that of country j, $\overline{Z}_{i,j}$ is the equilibrium bilateral real exchange rate, π^{RPOIL} is the rate of inflation of real oil prices (denominated in the domestic currency), and ε^{π} is a disturbance term. The weights ($w_{i,j,3}$) used to construct the effective exchange rate term are the ratios of the imports of country i from country j to its total imports from all the countries in the model.

This inflation equation is in the spirit of the New Keynesian Phillips curve (NKPC), which evolves from the optimal price-setting behaviour of forward-looking firms in an environment of imperfect competition and price stickiness (i.e., it is assumed that firms set prices on a staggered basis). Equation (2) thus emphasizes the forward-looking process for inflation. And, as discussed in Gali and Gertler (1999), lagged inflation can also influence inflation dynamics in the NKPC framework if it is assumed that a fraction of firms set prices using a backward-looking rule of thumb. Inflation is also a function of the output gap, which in the NKPC set-up would be a proxy for marginal cost.[7]

The third equation is the monetary policy reaction function, where the short-term nominal interest rate is determined as a function of its own lag and of the central bank's policy responses to movements of the output gap and deviations of the expected inflation rate from its target. This Taylor-type rule takes the following form:

$$\begin{aligned} I_{i,t} &= (1-\gamma_{i,1})[\overline{R}_{i,t} + \pi 4_{i,t+3} + \gamma_{i,2}(\pi 4_{i,t+3} - \pi_i^{tar}) \\ &+ \gamma_{i,4} y_{i,t}] + \gamma_{i,1} I_{i,t-1} + \varepsilon_{i,t}^{I}, \end{aligned} \tag{3}$$

where I is the short-term nominal interest rate, $\overline{R}$ is the equilibrium real interest rate, $\pi 4$ is

[7]Since it is assumed in the NKPC framework that firms adjust their prices in response to expected movements in marginal cost.

the average annual inflation rate, π^{tar} is the inflation target, y is the output gap, and ε^I is a disturbance term.

More precisely, this reaction function assumes that the central bank aims at achieving a measure of the equilibrium nominal interest rate over the longer run, but adjusts its rate in response to deviations of the expected inflation rate from target, and to the current output gap. This specification for the monetary policy rule assumes that the central bank smooths interest rates, adjusting them gradually to the desired value. This behaviour is widely observed in practice and has been shown by Woodford (2003) to be a desirable outcome in a model of optimizing private sector behaviour, because it can help to steer private sector expectations of future policy. For the Chinese economy, there are important departures from the structure of the monetary policy reaction function outlined here for the G-3 economies; changes to this equation that address the Chinese economy are provided in Appendix A.

In the fourth equation, the bilateral real exchange rate (versus the U.S. dollar) is modelled using the following version of uncovered interest rate parity (UIP):

$$4(Z^e_{i,t+1} - Z_{i,t}) = (R_{i,t} - R_{us,t}) - (\overline{R}_{i,t} - \overline{R}_{us,t}) + \varepsilon^{Z-Z^e}_{i,t}, \tag{4}$$

where the expected real exchange rate is assumed to evolve as follows:

$$Z^e_{i,t+1} = \phi_i Z_{i,t+1} + (1 - \phi_i) Z_{i,t-1}. \tag{5}$$

Equation (4) therefore states that the difference between the real exchange rate and its expected value is a function of the real interest rate differential and the equilibrium real interest rate differential between the two countries. Thus, any deviation in the real interest rates across the two countries should result in either an expected change in the exchange rate or a deviation in the equilibrium real interest rates in the two countries. Any other movement in the exchange rate is captured by the residual in the equation (which can be thought of as a temporary shock to the risk premium). As shown in Equation (5), in this "hybrid" version of UIP, the expected real exchange rate is not fully model-consistent, but also depends, in part, on past values of the real exchange rate.

In the Bank of Canada's version of the GPM, the real bilateral exchange rates are related to the U.S. real effective exchange rate, which is anchored in MUSE by a long-run assumption on the stock of U.S. net foreign assets. Because the U.S. real effective exchange rate is determined in MUSE exogenously to the GPM, the RoW real bilateral exchange rate is determined as a residual, so that all exchange rates are consistent.

2.3 Stochastic processes

As part of the model structure, exogenous stochastic processes that govern the path of the unobservable variables are also specified. More specifically, exogenous stochastic processes for potential output, the equilibrium real interest rate, the equilibrium real exchange rate, and the equilibrium level of the real oil price are specified. We first present two equations that describe the process for potential output. The first equation relates the level of potential output to its own lagged value, its quarterly growth rate, and the rate of inflation in real oil prices as follows:

$$\overline{Y}_{i,t} = \overline{Y}_{i,t-1} + g^{\overline{Y}}_{i,t}/4 - \sigma_i(\sum_{j=0}^{3} \pi^{RPOIL}_{i,t-j}) + \varepsilon^{\overline{Y}}_{i,t}, \tag{6}$$

where $\overline{Y}$ is the log level of potential output, $g^{\overline{Y}}/4$ is the quarterly growth rate of potential, and π^{RPOIL} is the rate of inflation of real oil prices (denominated in the domestic currency). Equation (6) also includes a disturbance term that can cause permanent shifts in the level of potential output. The relationship between potential output and oil prices is such that higher inflation in real oil prices is expected to result in a permanent decline in the level of potential output.

The second equation relates the growth rate of potential to its steady-state growth rate as follows:

$$g^{\overline{Y}}_{i,t} = \tau_i g^{\overline{Y}ss}_i + (1 - \tau_i) g^{\overline{Y}}_{i,t-1} + \varepsilon^{g^{\overline{Y}}}_{i,t}. \tag{7}$$

Therefore, the growth rate of potential can diverge from its steady-state growth rate following a disturbance, and it is assumed that it will return to steady state gradually, with a speed of return based on (1-τ). It is thus assumed that there can be shocks to both the level and the growth rate of potential output, but that shocks to the level of potential output can be permanent, whereas the shocks to the growth rate can result in highly persistent deviations in potential growth from the long-run steady-state growth rate.

Equation (8) defines the equilibrium real interest rate as a function of the steady-state real interest rate level:

$$\overline{R}_{i,t} = \rho_i \overline{R}_i^{ss} + (1 - \rho_i)\overline{R}_{i,t-1} + \varepsilon_{i,t}^{\overline{R}}. \tag{8}$$

The above specification allows for persistent deviations in the equilibrium real interest rate from its steady-state value in response to a stochastic shock.

Next, we turn to the process depicting the evolution of the equilibrium exchange rate, which is assumed to follow a random walk as follows:[8][9]

$$\overline{Z}_{i,t} = \overline{Z}_{i,t-1} + \varepsilon_{i,t}^{\overline{z}}. \tag{9}$$

Finally, the following block of three equations determines the level and the rate of change of real oil prices denominated in the currencies of the various countries in the model. In Equation (10), the log of the equilibrium real price of oil in U.S.-dollar terms is defined as its own lagged value plus its growth rate and a disturbance term that reflects shocks to the log level of real oil prices in U.S.-dollar terms:

$$\overline{RPOIL}_{US,t} = \overline{RPOIL}_{US,t-1} + g_{US,t}^{\overline{RPOIL}} + \varepsilon_{US,t}^{\overline{RPOIL}}. \tag{10}$$

The growth rate in the equilibrium level of real oil prices is equal to lagged growth plus a disturbance term that reflects shocks to the growth rate as follows:

$$g_{US,t}^{\overline{RPOIL}} = (1 - \rho_{g,US}) g_{US,t-1}^{\overline{RPOIL}} + \varepsilon_{US,t}^{g^{\overline{RPOIL}}}. \tag{11}$$

Equation (12) defines the gap between the level of the real oil price and its equilibrium value as a function of its own lagged value and a disturbance term:

$$rpoil_{US,t} = \rho_{rpoil,us} rpoil_{US,t-1} + \varepsilon_{US,t}^{rpoil}. \tag{12}$$

Like the U.S. block, the estimation stage of the oil block in the GPM uses the core model as in Carabenciov et al. (2008), while the forecasting portion of the GPM utilizes tools currently in place at the Bank of Canada. Thus, when using the GPM for projection at the

[8]The structure of this equation differs for the Chinese economy; see Appendix A.

[9]The real exchange rate is related to the equilibrium real exchange rate through the IS curve equation (1). The gap between the real exchange rate and its equilibrium value is closed only gradually, insofar as this gap gives rise to an output gap, which is then addressed by the policy reaction function in the model.

Bank of Canada, the long-run equilibrium price of oil is pinned down outside of the model, and the dynamic profile for oil prices is taken as exogenous by the GPM.[10]

2.4 Cross-correlation of disturbances

Two types of cross-correlation of error terms are specified in the model. The first is a cross-correlation between shocks to the output gap and inflation equations. This is intended to capture the notion that a positive supply shock to the level of potential output would be expected to put downward pressure on costs and prices. The second is a cross-correlation between shocks to the output gap and potential output growth. This is intended to capture the fact that aggregate demand should increase even before potential output starts to rise in response to a persistent positive shock to potential output growth, because of the associated increase in expected permanent income (i.e., households and businesses will increase spending immediately in response to the shock, thus creating a positive output gap).

3. Estimation Methodology and Results

3.1 Methodology

The GPM is estimated using a Bayesian approach similar to the methodology used in Carabenciov et al. (2008). The key difference is that we employ a 3-step estimation procedure. The first step of this approach involves estimating the model for the G-3 economies as in Carabenciov et al. (2008), using data over the period 1994Q1–2008Q3.[11] Next, we impose the posterior estimates from this first stage on the parameters for the G-3 economies and then estimate the China block of our model, allowing only the parameters of the Chinese economy to be estimated. We adopt this approach because of the technical difficulties involved in simultaneously estimating all of the parameters in the 4-country model. Moreover, we do not believe that the data for the Chinese economy would be informative in estimating the structural parameters for the G-3 economies.[12] Once estimates have been obtained for the China block of the model, we apply the same procedure to obtain parameter estimates for

[10] Future work will focus on endogenizing the oil profile in the model.

[11] When estimating the parameters for the Japan, euro area, China, and RoW blocks of our model, we make use of a simplified block for the United States, as in Carabenciov et al. (2008). However, as mentioned in section 2, when conducting the forecast with the GPM, we replace this simplified U.S. block with the Bank of Canada's MUSE.

[12] It could be argued that, in recent years, the Chinese economy has had a large enough global presence to have influenced the parameter estimates of the G-3 economies. However, as mentioned above, for technical reasons we opt to proceed with estimation as described, which we do not feel materially alters our parameter estimates for the G-3 block.

the RoW block.[13] For each stage of the estimation (G-3, China, and RoW), all parameters for that block are estimated simultaneously.

For each of the economies in our model, we use the following data series in our estimation: real GDP, a short-term interest rate, consumer prices, and bilateral exchange rates. In addition, for the G-3 economies we use data on the unemployment rate, and for the United States we use a measure of bank lending tightness that is based on data from the Federal Reserve Board's quarterly *Senior Loan Officer Opinion Survey on Bank Lending Practices*.[14] We also use data on world oil prices. Appendix B provides more details on the sources of the data and on the variable definitions.

In the second stage of our estimation, we use data for the Chinese economy over the period from 2000Q1 to 2008Q3. We use a shorter sample period for China because we do not believe that data prior to the year 2000 would be informative in estimating the key relationships in our model, given the significant structural changes that the Chinese economy underwent in the 1990s. Data limitations also played a role in the selection of our sample period. While we acknowledge that structural change has continued to take place in China since 2000, most notably with China's accession to the World Trade Organization, we feel that further reducing the sample period would cause us to omit important information on the structure of the Chinese economy contained in the data.

For the third stage of our estimation, our sample period is even shorter, running from 2003Q1 to 2008Q3. Since the RoW block of the model includes many developing countries, our sample period was limited, because the inflation and interest rate data prior to 2003Q1 for some countries were very volatile. Specifically, we wanted to exclude periods of hyperinflation when estimating this block of the model.

Our estimation methodology allows us to jointly estimate the model's behavioural parameters and the stochastic processes that govern the low-frequency movements in the data, and to do so without pre-filtering the data so that we don't lose important information contained in the trends. Using Bayesian methods, we are able to incorporate the information from our priors, appropriately weighted, with the information contained in our data set. This approach is particularly useful when estimating a global model that includes China and other developing economies; the use of priors can help deal with the problems associated with esti-

[13]Specifically, we freeze the posterior estimates for the G-3 economies, as well as those for China, and then estimate the parameters of the RoW block.

[14]We opt not to use unemployment data in our estimation of the China and RoW blocks, since such data are not likely to be very informative or reliable in these economies.

mating a model over a short sample period where some parameters may be weakly identified by the data. For example, in the case of China, the data may not be very informative for certain parameters, because of important changes made to the exchange rate and monetary policy regimes over the sample period. Our estimation framework also enables us to better capture heterogeneity across countries, because both the priors and sample periods used in the estimation can vary across countries.

3.2 Estimation results: the selection of priors

In Appendix D, we provide the priors for each of the blocks in our model. The priors for the G-3 economies are based on those used in Carabenciov et al. (2008). We use the priors that we set for the China and RoW blocks as a starting point, and make adjustments where needed to capture the key aspects of these two economies that we would expect to be different.

3.2.1 G-3 economies

For the G-3 economies, there are only a few instances in which priors for the key behavioural equations differ across economies. In the case of the output-gap equation, the priors for the parameters concerning external linkages (β_4 and β_5) differ in each economy according to the degree of trade openness. For example, since the euro area is the most open of the three (in terms of its exports-to-GDP ratio), our prior is that fluctuations in external demand and movements in the real exchange rate will have a greater impact on output here than elsewhere in the G-3 region. All other priors for this equation are identical across the G-3 economies.

Turning to the inflation equation, the key difference among the G-3 economies once again pertains to trade openness. Indeed, λ_3, the prior on the parameter relating exchange rate fluctuations to domestic inflation, varies with the degree of trade openness.

While all of the prior means are set to be equivalent in the monetary policy reaction functions of the G-3 economies, in some cases the standard errors around these priors differ slightly across the different economies. The standard deviation for γ_1 is slightly higher in Japan, since we are less certain about the degree of interest rate smoothing embodied in Japanese monetary policy. We also assign a slightly higher standard deviation to our prior on γ_2 in the United States, since we are less certain about the weight assigned to inflation control in the U.S. monetary policy reaction function.

In addition to these differences in G-3 priors, there are a few other differences that are of lesser importance. First, the prior on α_2 is lower in Japan than elsewhere, since we feel that measured unemployment in Japan responds less to movements in the output gap than is the case elsewhere. Also, the steady-state growth rates for each of the G-3 economies are somewhat different, according to our assessment of future prospects for demographics and productivity growth. Finally, the priors on ρ differ across all economies (albeit very slightly), according to our assessment of the degree of inflexibility of the equilibrium real interest rate process.

Having covered the selection of priors for the G-3 blocks of the model, we next discuss our priors for the China and RoW blocks.

3.2.2 China

Generally speaking, our priors in the China block are similar to those in the G-3 economies. The only parameter whose prior we modify in the Chinese IS curve is β_5, which captures the degree of openness of the economy. We increase the prior on β_5 to reflect the fact that the Chinese economy is more open than that of the United States, the euro area, and Japan. As such, we would expect foreign demand shocks to have a larger impact on the Chinese economy than on the G-3 economies, all else equal.

As discussed in Bailliu et al. (2010), we have made one important modification to the interest rate rule for China, in that we include an exchange rate term to account for the fact that the authorities put significant weight on smoothing the exchange rate when setting monetary policy. In our view, the current Chinese exchange rate regime is best described as somewhat of a crawling peg, rather than a purely fixed regime. Indeed, over the past several years the Chinese renminbi (RMB) experienced sustained appreciation, both in nominal and real terms, vs. the U.S. dollar (see Figure E1).

The exchange rate term that we include in this equation measures deviations of the rate of appreciation of the bilateral exchange rate of the Chinese RMB (relative to the U.S. dollar) from its targeted value; γ_5 is the coefficient that captures the importance the authorities accord to this term when setting policy rates.[15] We assign a slightly lower prior to γ_5 than we do to the parameter concerning deviations of inflation from target.[16] This seems reasonable given that authorities are unlikely to have to put a very large weight on stabilizing

[15]This coefficient is assumed to follow a gamma distribution, since values for γ_5 should be non-negative, but need not have a constrained positive domain.

[16]Our prior for the weight the authorities put on deviations of inflation from target is 0.3 (i.e., $(1-\gamma_1)\gamma_5$), whereas the prior for γ_5 is 0.2.

the exchange rate when setting policy rates, since tight and extensive capital controls were in place over the sample period in China. Importantly, the existence of these capital controls has limited the spillover of U.S. monetary policy to the Chinese economy; extensive capital controls have given Chinese authorities some independence in conducting monetary policy, in spite of the peg (or, since 2005, crawling peg) to the U.S. exchange rate (Goodfriend and Prasad, 2006).

There are two other differences between the monetary policy reaction function in China and that used for the more advanced economies. First, the prior on γ_2 (the weight on deviations of expected inflation from target) is set lower in China because it is assumed that Chinese policy-makers are less concerned with inflation movements than their counterparts in the United States, the euro area, and Japan. Second, we calibrate γ_1, the coefficient on the lagged interest rate, because we believe that the data are not very informative in determining the value of this parameter. Policy interest rates in China did not move much over the early part of the sample (i.e., from 2000 to 2005), most likely because the authorities were concerned about the fragility of the banking sector. We believe that the (uncalibrated) posterior estimate for this parameter overestimates the degree of interest rate smoothing that will be embodied in Chinese monetary policy going forward.[17]

One final coefficient that is worthy of mention is ψ, the coefficient on the catch-up term in the Chinese equilibrium real exchange rate equation. This term is included in order to proxy for a sort of Balassa-Samuelson type of effect (see Bailliu et al. 2010). We set a prior of 0.12 for this coefficient, with a tight standard deviation of 0.01. To assist with the interpretation of this parameter, consider a potential growth rate of 9 per cent (quarter-over-quarter, at annualized rates) in China. This growth rate differs from our assumed steady-state growth rate of 5 per cent for China. Thus, with Chinese potential growth at 9 per cent in this example, we would expect the Chinese RMB to appreciate against the U.S. dollar by roughly 0.5 per cent per quarter (in real terms), ceteris paribus. This appreciation would continue until the Chinese economy had converged to its steady-state growth rate.

In Appendix D, we report the same information for the standard deviations of the structural shocks as we did for our coefficient estimates.[18] Concerning the shock terms for the

[17] Admittedly, Chinese authorities' use of sterilization bonds, alongside administrative measures such as loan quotas and capital controls, makes modelling the behaviour of Chinese monetary policy quite challenging. The approach taken in this model is meant to produce reasonable model properties while replicating some key features of Chinese data. We are currently in the process of extending the Chinese monetary policy block of the model to include a role for credit growth; this work is documented in Bailliu et al. (2010).

[18] Shock terms are assumed to follow an inverted gamma distribution, which guarantees a positive variance.

China block of the model, only two of our priors differ from those for the advanced economies in a material way. First, the prior mean on the standard deviation of the real equilibrium interest rate variable is higher for China than it is for elsewhere, since we view the neutral interest rate in China as being less stable than in a typical advanced economy. Second, the prior on the potential growth rate shock term is higher in China, since we model the growth process in China in recent years as being characterized by persistent positive shocks to the growth rate of potential output.

3.2.3 Rest of world

The selection of priors for the RoW block is challenging, since this block comprises many economies that differ in their stage of development, monetary policy regime, and so forth. As such, in the absence of any strong beliefs about what the priors for this block should look like, for the most part we adopt those set out for the G-3 economies. The departures from the G-3 priors are discussed below.

As was the case for our China block, the only prior that we change in the IS curve equation for the RoW block is β_5, the coefficient that captures spillovers to domestic output through the trade channel. We set this prior lower than for China, but slightly higher than for the remaining G-3 economies, since the RoW block of economies is more open than a typical G-3 economy, but less open than China.

The priors for the monetary policy reaction function in the RoW block are similar to those for the China block, with the notable exception that the RoW reaction function is not modelled as placing any weight on exchange rate fluctuations. The prior on γ_2 is lower than for a G-3 economy, since many economies in this block are not strict inflation-targeters.

3.3 Estimation results: posterior estimates

3.3.1 G-3 economies

The posterior estimates for the G-3 block of the model are taken from Carabenciov et al. (2008). The parameter estimates are broadly in line with the priors discussed in the previous section; however, a few differences among estimates for the G-3 economies are worthy of mention.

Beginning with the IS curve equation, the posterior estimate for β_3 in Japan is somewhat lower than in the euro area or the United States. This indicates that the interest rate is less effective in influencing movements in the output gap in this economy. Given that rates have been largely static over the sample period, it comes as little surprise that the model does not identify an important role for this variable in determining output in the economy.

Pursuant to this point, the posterior estimate for γ_1 in Japan is a great deal higher than is the case elsewhere. The explanation for the high estimate of smoothing in the policy reaction function is, once again, the stasis of policy rates in Japan over the sample period. Another interesting difference in the parameter estimates for the monetary policy reaction functions among G-3 economies is seen in the estimates of γ_2 and γ_4 in the U.S. block of the GPM; in the U.S. policy reaction function, less emphasis is placed on achieving an inflation target, while relatively more emphasis is placed on closing the output gap. This is consistent with the U.S. Federal Reserve not following a strict inflation-targeting regime, but instead choosing to place some emphasis on output stability.

Finally, the posterior estimate for the equilibrium real interest rate in Japan ($\overline{rr}_{ja}$) is substantially lower than elsewhere.

3.3.2 China

Even though the priors on several of the parameters in the Chinese IS curve are the same as those for the advanced economies, there are important differences between the posterior parameter estimates for both β_2 and β_3. Indeed, the posterior estimate for β_2, the coefficient on the lead of the output gap, is substantially lower in China. This suggests that agents are much less forward looking in China than in a more advanced economy, perhaps because financial markets are not as developed and thus agents are less able to smooth consumption over time. This could also be a result of the need for precautionary savings by Chinese households. The posterior estimate on the real interest rate gap, β_3, is also lower, suggesting that monetary policy actions do not influence the output gap as much in China as in advanced economies. This is not surprising given that, as discussed earlier, the Chinese authorities used several different monetary policy instruments over the sample period. In addition, one would not expect monetary policy to be as effective in influencing the domestic output gap in China because the authorities put some weight on limiting exchange rate movements when setting policy rates.

Turning to the parameters in Equation (2), the Phillips curve, the only parameter whose posterior estimate is significantly different for China, is λ_1, the coefficient on the lead of inflation. Indeed, λ_1 is smaller, suggesting that inflation expectations are less well anchored in China. This result is not surprising given the evolving nature of the monetary policy framework in China.

The posterior estimate for γ_5, at around 0.1, suggests that policy rates in China respond somewhat less to changes in the exchange rate than we would have anticipated, perhaps because capital controls were particularly effective over the sample period and/or because other monetary policy instruments were also used to stabilize the exchange rate. Also worthy of note is the fact that the posterior estimate for γ_2 is a good deal lower than the prior, thus providing support for the view that policy-makers assign less importance to inflation control when setting policy than is the case in the G-3 economies.

3.3.3 Rest of world

The posterior estimates for the IS curve equation in the RoW block are somewhat similar to those for China.

In the Phillips curve equation, the estimates of both λ_1 and λ_2 are on the low end of the spectrum, indicating that the inflation process in the RoW block is not as forward looking as elsewhere, and that fluctuations in the output gap have less of an impact on inflation here than elsewhere.

Finally, it is worth noting that the estimates for υ_1 and υ_2 are higher in the RoW block than elsewhere. This suggests that oil-price fluctuations play a more important role in shaping output. The fact that the RoW block includes several key OPEC economies may serve to explain this result.

4. Historical Decompositions

In order to provide insight into the model's interpretation of historical data, we present historical decompositions of each of the behavioural equations in our model.[19] In addition, these decompositions give information about the goodness of fit of each of the behavioural equations in our model, and tell us which variables are key drivers of these equations. This

[19]Historical decompositions are constructed by multiplying the estimated parameters from a given equation by the corresponding data point for a given period. As an example, consider the inflation equation in the euro area: to determine the impact of the (lagged) output gap on inflation at time t, we simply compute $\lambda_2 * Y_{EU,t-1}$. Thus, the historical decomposition breaks down the model's fitted value for each behavioural equation into its component parts.

is particularly useful information when using the GPM in a forecasting environment.

4.1 Euro area

Beginning with the output-gap equation, the top portion of Figure E2 shows that the model's fitted value corresponds quite closely with the calculated output gap.[20] The bottom portion of this same figure shows the components that drive movements in the euro area output gap. Clearly, there is an important role for lagged values of the output gap in this equation. Since we are dealing with a highly stylized model, and one in which we do not include multiple leads and lags of the explanatory variables, the information from the previous period's output gap is best viewed as capturing all of the information from the lags of the other explanatory variables, as well. For this reason, small persistent changes to any of the other explanatory variables can give rise to important movements in the output gap over time, through the persistence in the lag term. The two most important explanatory variables for this equation are the real interest rate gap (that is, the stance of monetary policy) and the real exchange rate gap. Examining Figure E2, we see that the former of these variables played an important role in the 2004 to 2007 period. Stimulative policy pulled the economy from a position of moderate excess supply in mid-2004 to one of mild excess demand by early 2006.

Proceeding to the decomposition of the interest rate equation shown in Figure E3, we see that the fit of this equation is quite good over the sample period. Examining the components that drive this equation, once again we see that the smoothing term is extremely important. Recall that, in the decomposition of the euro area output gap, we saw an important role for stimulative interest rates in returning the economy to balance in the 2004 to 2006 period. Now, in the decomposition of the interest rate equation, we see that interest rate reductions over this period were motivated by an inflation rate that was below target, and by the negative output gap. Once again, we emphasize that small persistent contributions by each of these variables can have a large impact on the dynamics of the output gap, operating through the smoothing term.

Turning to the historical decomposition of the inflation equation shown in Figure E4, it is evident that this equation fits much less well than the two previous equations for the euro area. This does not come as a surprise, since the inflation process is highly volatile and can be very difficult to capture with a simple reduced-form equation. [21] Indeed, Smets and Wouters

[20]Note that we use the term calculated output gap, since this is an unobservable variable that is computed by the model using a Kalman filter, based on all of the information available.

[21]Also, we model the quarterly process for inflation, which is a good deal more volatile than the year-over-

(2003), in their model of the euro area, identify an important role for inflation shocks in determining the dynamics of the inflation process. Concerning the drivers of inflation, Figure E4 identifies important roles for each of the components of the Phillips curve equation: namely, changes in the real effective exchange rate (weighted by trade from neighbouring economies), the output gap, and oil-price fluctuations.

4.2 Japan

Examining the same set of historical decompositions of the Japanese economy, it is evident that our equations do not fit as well as they did in the euro area. Of course, data over the sample period in Japan make estimation of our model very challenging.[22] The top portion of Figure E5 depicts the calculated and fitted values for the output gap in Japan. According to the model, the Japanese economy has endured a situation of mild excess supply for the vast majority of the past ten years. Looking at the bottom portion of this figure, the two chief drivers of output in Japan appear to be the real effective exchange rate gap (trade weighted by imports) and the real interest rate gap. Considering the real effective exchange rate gap, the overvaluation predicted by the model is largely driven by the model's estimate of the degree of undervaluation of the Chinese RMB. Moreover, we see that monetary policy has been adding stimulus for much of the sample period. However, in an environment where policy rates are constrained by the effective lower bound, this stimulus is unable to pull the economy out of its slump.

Next, we examine the behaviour of the Japanese monetary policy equation in Figure E6.[23] It is clear from the bottom portion of this figure that policy rates were kept low for much of the past decade in response to an inflation rate that was below target. Also, the decision to begin raising policy rates in mid-2006 can be attributed to a desire to return the policy rate to its neutral level. Of course, this occurred alongside a mild increase in domestic inflation, and an output gap that was slightly positive.

Figure E7 shows the historical decomposition of the inflation equation in Japan. The primary drivers of this process over the past decade or so have been fluctuations in real oil prices and movements in the real effective exchange rate. However, it is also clear that the

year or the average annual inflation rate.

[22]Volatile GDP data, interest rates stuck at or near zero, and an extended bout of deflation are the key issues.

[23]In estimating this equation, interest rates were not constrained by the zero lower bound for policy. However, when conducting a forecasting exercise with this model, we do have the option of switching on a zero lower bound constraint.

importance of each component of the inflation equation in Japan varies over time.

4.3 China

Figure E8 provides the historical decomposition of the Chinese output gap. The top portion of the figure shows that our model estimates that China was in a position of moderate excess demand from early 2006 through the end of the sample. This excess demand was driven by stimulative monetary policy, real effective exchange rate undervaluation, and strong demand from Chinese trading partners.

Turning to the decomposition of the interest rate equation, the upper part of Figure E9 shows that this equation does not fit the data particularly well over the sample period. Since Chinese officials typically make use of multiple instruments when conducting monetary policy (Laurens and Maino, 2007), the People's Bank of China's base lending rate will not generally reflect the true stance of monetary policy in the Chinese economy. Our model predicts that the policy interest rate will respond more aggressively to shocks in the economy than is true empirically, since the model does not include any of the other instruments utilized by Chinese officials.[24] Not surprisingly, the bottom portion of Figure E9 underscores an important role for interest rate smoothing. Two other factors that are important contributors to the determination of the interest rate are deviations of inflation from the target and movements in the exchange rate. With respect to the latter factor, we can see that interest rates were held slightly lower than would otherwise have been the case through 2007 and into 2008 in order to guard against stronger appreciation of the Chinese renminbi. From the viewpoint of the model, this decision contributed to the overheating of the Chinese economy depicted in Figure E8.

The inflation equation in China does not fit the data very well over the sample period. The bottom portion of Figure E10 depicts an important role for the lead and lag terms in the inflation equation. This indicates that large shocks are needed to explain the behaviour of inflation over the sample period. However, this is actually an encouraging result, since both periods of elevated inflation in China in our sample period (2004, and mid-2007 to mid-2008) were primarily driven by food price inflation, stemming from supply shocks. We would not expect the model to be able to explain inflation arising from these shocks. The other components of the inflation equation (the output gap, oil prices, and exchange rate fluctuations) appear to have played a limited role over the sample period in shaping the

[24] Work is currently under way to extend the monetary policy reaction function in the China block of the model to include a role for an additional instrument: a credit growth target.

inflation process.

4.4 Rest of world

The historical decomposition of the output gap in the RoW block is shown in Figure E11. This process is driven by a host of different factors, chief among them being the real interest rate gap. The mild run-up in excess demand that occurred towards the end of the sample period stemmed from somewhat stimulative monetary policy, from the viewpoint of the model. We would argue that, in a block that comprises such diverse economies, with no coordinated policy framework, monetary policy is unlikely to be able to precisely address fluctuations in the economy of the block as a whole. This sort of policy imprecision would explain why policy is adding stimulus for the block as a whole at a time when it should actually be removing stimulus, according to the model.

Further evidence on the imprecision of policy in this block is given in Figure E12. In this figure, we see that policy is very smooth in the RoW block. For the block as a whole, policy is slow to respond to shocks, and, indeed, the bottom portion of the graph tends to indicate that the only shocks that are given any consideration at all are inflation shocks. Towards the end of the sample period, policy does tighten somewhat in the RoW block, partly in response to elevated inflation.

Concerning inflation, Figure E13 makes it clear that we have a difficult time explaining this process in the RoW block. Indeed, we are only able to identify a small role for changes in the real effective exchange rate and the output gap in determining inflation. Instead, lead and lag terms dominate as the drivers of RoW block inflation.

5. Model Properties

In this section, we investigate the properties of the GPM by subjecting it to a number of shocks and examining the model's reaction using impulse-response functions. We choose several typical shocks to major macroeconomic variables to demonstrate the model's features, both within the countries experiencing the shocks and between the different blocks of the GPM. The shocks cover five major macroeconomic variables: four of them are linked to specific blocks of the GPM, and one of them is global. Unless otherwise noted, shocks are presented as deviations from steady state (in per cent), due to a temporary 1 per cent shock to the variable in question.

5.1 A shock to U.S. inflation

In this scenario, we impose a temporary positive 1 per cent shock to core inflation in the United States.[25] Figure E14 shows the percentage deviation relative to control of major macroeconomic variables in the five blocks of the GPM.

The shock to inflation results in higher U.S. interest rates, which leads to an appreciation of the U.S. real effective exchange rate of about 0.4 per cent. U.S. output is restrained by the higher prices and subsequent increases in interest rates, leading to an increase in excess supply of about 0.3 per cent. The U.S. core inflation shock has some important implications for the non-U.S. economies.

The shock to U.S. inflation propagates to other countries, primarily via exchange rates. Generally speaking, real bilateral exchange rates in the non-U.S. blocks of the GPM depreciate vis-à-vis the U.S. dollar. This occurs because U.S. interest rates increase by relatively more, in order to offset the inflationary shock there. Inflation in the euro area and China spikes temporarily as the real bilateral exchange rates depreciate, before decreasing slightly on a shock-minus-control basis as the exchange rate shock dissipates. The real bilateral exchange rate in Japan also appreciates. The response of output in most countries is fairly cyclical in the near term. At first, the initial exchange rate depreciations are stimulative for growth, but, as they unwind, excess supply opens up. Coupled with this is an opening up of excess supply in the United States, which pulls output down in the other blocks through the foreign activity channel. Monetary policy in the euro area, Japan, and China thus reacts by lowering interest rates.

5.2 A shock to Chinese aggregate demand

Next, we shock output in China temporarily by 1 per cent (Figure E15). Inflation in China responds to the excess demand pressure by temporarily rising by 0.3 per cent. Monetary policy thus reacts by increasing interest rates by 0.6 percentage points. However, with the higher interest rates, China's relative real interest rate differential increases, causing the Chinese real exchange rate to appreciate by 1.7 per cent.

Globally, the response to the output shock in China is fairly muted, with the operative transmission channels being exchange rates and foreign activity. However, Japan reacts more than other countries, since the composition of Japan's major trading partners, which feeds

[25] Inflation in MUSE is defined using the core personal consumption expenditure (PCE) deflator.

the weights in its foreign activity variable, places a higher weight on China than, say, the United States. Thus, Japan is affected through both exchange rate and output channels.

Output in Japan increases by 0.06 per cent, inflation by 0.04 per cent, and the nominal interest rate by 5 basis points. The real bilateral exchange rate in Japan also appreciates, moving somewhat in sync with the Chinese exchange rate, since interest rates in Japan rise by more than those in the United States.

Other major economies respond very little to the Chinese output shock, with output, inflation, and interest rates moving only a few basis points. The important movements occur in the exchange rates, but even still, the responses remain lower than 0.25 percentage points. Of note, the euro area real exchange rate appreciates slightly, while that of the RoW block depreciates. The U.S. real effective exchange rate remains fairly constant, cycling near zero.

5.3 A shock to the euro area interest rate

Next, in Figure E16, we shock the nominal short-term interest rate in the euro area by 100 basis points for one period.

Globally, the effects of the shock are minimal. There are some small exchange rate movements in the RoW block, but these have little effect on the other macroeconomic variables.

In the euro area, however, there are important effects. Output immediately falls by 0.3 percentage points, and inflation drops over the course of the following two years by 0.2 percentage points. Interestingly, the 1 percentage point shock to the nominal interest rate residual does not result in a full per cent shock in the rate. This is due to the forward-looking nature of the model: policy simultaneously reacts to its own shock by easing interest rates in order to accommodate the forthcoming excess supply. The real exchange rate in the euro area immediately appreciates by 0.4 percentage points with the interest rate shock, but depreciates thereafter as the real interest rate differential reverses.

5.4 A shock to Japanese potential output growth

Turning next to potential output, Figure E17 shows a 1-period shock of minus 1 per cent to the growth rate of Japanese potential output.[26] Due to the autoregressive nature of potential output growth in the GPM, this shock results in a permanent negative shock to the level of

[26]For example, this can be thought of as a 1-period shock to productivity.

Japanese potential output of about 3.5 per cent. Output in Japan responds fairly quickly to the shock to potential output, however, with excess supply opening up only 0.1 percentage points in the first quarter and closing quickly thereafter. This is sufficient to cause a slight fall in inflation and nominal interest rates, and a temporary depreciation of the real bilateral exchange rate.

Other countries react fairly mildly to the shock to Japanese potential output growth, with inflation and nominal interest rates generally declining and real exchange rates appreciating vis-à-vis the U.S. dollar. The shocks, however, are fairly minimal, largely owing to the rapid response of actual output to the shock to potential output in Japan, which keeps the effect on the output gap to a minimum. Since foreign activity measures are trade-weighted sums of foreign output gaps, the small shock to Japan's output gap results in little change for other countries. Also, the depreciation of the Japanese yen is fairly minimal in this scenario, at less than 6 basis points, and so exchange rates around the world do not move to a large extent in the scenario.

5.5 A shock to the real U.S.-dollar oil price

Finally, we subject the model to a permanent 10 per cent shock to the U.S.-dollar real oil price (Figure E18). The shock occurs gradually over the course of four quarters. There is a permanent negative effect on potential output in the euro area, Japan, China, and the RoW block, reducing the level of output in the long run by between 0.04 and 0.08 per cent. The oil-price shock also pushes output down, with excess supply opening up in all countries. The combination of excess supply and higher oil prices puts offsetting pressure on inflation, resulting in a fairly muted response. In the euro area, total inflation rises just over 0.1 percentage points, while inflation in Japan and China increases by slightly less. The RoW block experiences the largest increase in inflation, at about 0.4 percentage points. Nominal policy rates rise in line with the shocks to inflation, despite some negative pressure from the excess supply.

6. Applications

In this section, we examine two applications of the GPM that are of policy relevance. The first is a positive shock to the U.S. savings rate, caused by a decline in wealth. The second is a coordinated increase in fiscal stimulus across the G-3 economies.

6.1 An increase in the U.S. savings rate

In Figure E19, we examine a scenario in which a negative wealth shock forces U.S. consumers to increase their savings rate.[27] In this example, U.S. consumers increase their savings rate by 0.8 percentage points. To achieve this increase, consumption falls immediately by 0.8 per cent, and output by about 0.4 per cent. The shock to output reflects some positive responses from other components of demand, which see the future 1 percentage point decrease in the nominal federal funds rate and react accordingly. In the near term, the real effective U.S. exchange rate also falls by close to 1 per cent, but returns towards equilibrium after about five years. The shock to U.S. demand, interest rates, and the exchange rate has important implications for other countries in the GPM, in part because the U.S. real effective exchange rate initially depreciates by about 0.9 per cent.

The shock to the U.S. savings rate has important global effects. In general, the effects of the shock on the U.S. economy cause real bilateral exchange rates elsewhere to appreciate, leading to lower inflation in those countries and thus lower policy rates. Due to the large role played by the United States in global activity, the decline in U.S. output causes foreign activity measures in most countries to fall, putting negative pressure on output.

More specifically, the euro area real bilateral exchange rate absorbs some of the effective U.S.-dollar depreciation, as it appreciates by over 3 per cent in the near term. Furthermore, the euro area's foreign demand also falls. As a result, output in the euro area drops by about 0.3 per cent. Policy-makers in the euro area respond by cutting interest rates by about 35 basis points, and inflation falls temporarily by about 0.45 per cent.

Japan absorbs the shock to U.S. savings in a similar manner. The real exchange rate, as in the euro area, appreciates by a relatively large amount, increasing by almost 3.5 per cent. Reflecting the appreciation of the yen and weaker foreign demand, Japanese output falls by about one quarter of a per cent, inflation falls only very briefly, and nominal rates fall by less than 20 basis points, but take longer to return to equilibrium than in the euro area.

The situation is somewhat different in China. Relative to the other blocks in the GPM, the Chinese real exchange rate bears the largest proportion of the U.S. depreciation, appreciating by over 4 per cent. The combination of the exchange rate shock and its deflationary consequences causes Chinese policy-makers to react aggressively, dropping the nominal in-

[27] The shock is conducted by increasing the rate of time preference on future disposable income in the human wealth equation of MUSE, which causes a drop in human wealth.

terest rate by 1.6 per cent.

The response in the RoW block is fairly muted. Nominal interest rates decline by about 40 basis points at their peak, and there is a fairly volatile persistent depreciation in the real exchange rate that peaks in the medium term at about 0.8 per cent. As mentioned earlier, since the exchange rate in the RoW block is constructed as a residual in the model, this appreciation is the necessary counterpart to the U.S. depreciation, alongside the strong appreciations witnessed in the other blocks of the model.

6.2 A coordinated G-3 increase in fiscal stimulus

This exercise mimics the sizable increases in fiscal stimulus spending announced by governments around the world in late 2008 and early 2009, focusing on the role of the G-3 economies in the GPM. For the euro area and Japan, assumptions are made ex ante to map the fiscal stimulus into aggregate demand in each country. Since the U.S. model is highly detailed, the fiscal stimulus enters directly as shocks to government transfers and taxes.

Before going into the details, some important caveats need to be highlighted. First, the shocks imposed here are only crude mappings of stimulus packages announced in the G-3 countries; for the purpose of this exercise, we ignore stimulus announced elsewhere (such as in China and countries in the RoW block), as well as support coming from market stabilization policies. Second, in this exercise, interest rates are initially at their steady-state equilibrium. In an effective lower bound environment such as in 2009, fiscal stimulus has a greater impact on the economy, since monetary policy does not react to crowd out the increased demand, so this exercise would understate that scenario.

Finally, since the GPM does not distinguish between demand for domestic and foreign goods, the results may overstate the effects of fiscal stimulus. This is because, generally, governments are more likely to consume domestic goods and services than imports. For example, an increase in Japanese fiscal stimulus would be treated no differently in the model than an aggregate demand shock, despite the possible differences in the composition of demand.

The results of the shock are shown in Figure E20. The simultaneous implementation of the fiscal stimulus has important consequences globally. While implemented in only three of the five GPM blocks, it provides a significant boost to GDP in all countries of the GPM, as foreign activity measures rise sharply. The resulting upward pressure on inflation leads to increases in global nominal interest rates. However, since the United States increases rates by the least amount, there are widespread real bilateral exchange rate appreciations vis-à-vis the U.S. dollar.

The shock to U.S. output peaks at about 1.4 per cent, core inflation growth increases by about 0.55 percentage points, and the nominal federal funds rate rises by about 1.7 per cent. The real effective U.S. dollar appreciates by nearly 1.4 per cent in the near term.

Output in the euro area increases by about 1 per cent, and inflation reacts accordingly, rising by 0.7 per cent. Nominal interest rates respond to the positive demand and inflation shocks by rising 1.5 percentage points. The coordinated fiscal stimulus causes output in Japan to rise by nearly 1.6 per cent, and inflation increases by just over 1 per cent. Nominal interest rates respond by increasing over 1.6 percentage points to counteract the demand pressures. As a result, the real bilateral exchange rate appreciates by just over 2 per cent.

China and the RoW block respond similarly to the G-3 fiscal stimulus, with output in both regions increasing as a result of the higher foreign activity. Inflation rises as well, and interest rates increase slightly to counteract inflationary pressures. The shocks in these blocks are significantly smaller than in the G-3 economies, with Chinese output being only 0.4 per cent higher and RoW output 0.3 per cent higher. The RoW real exchange rate depreciates by about 2 per cent, and China's by about 3 per cent.

The fiscal stimulus shocks were propagated through both the foreign activity variables (output gaps) and exchange rates, which move in a globally consistent fashion. The results highlight two key features of the GPM: international linkages and consistency. Spillovers from demand shocks, such as fiscal stimulus, have effects not only domestically but also in other countries. The increase in output in China and the RoW block – despite the absence of stimulus – demonstrates this fact.

7. Conclusion

To complement its existing set of tools to analyze and forecast developments in the global economy, the Bank of Canada recently developed its version of the GPM jointly with staff at the IMF. This highly stylized quarterly projection model is specifically designed to meet the need for a better tool to help organize the global projection. Indeed, it facilitates the production of an internally consistent forecast for the global economy and for the key foreign economies that we follow. Moreover, the GPM makes it possible to analyze the impact on the global economy of a limited number of key shocks in an internally consistent manner.

It is important to bear in mind that the GPM has limitations. Constructed to be highly stylized, the GPM is able to provide analysis for only a limited number of shocks. However, as shown in section 6 of this report, the model can still be used to examine such issues as a globally coordinated fiscal stimulus by mapping the scenario into the output gaps of each of the different blocks. The model is best seen as a complement to the Bank of Canada's other global model, BoC-GEM (Lalonde and Muir, 2007), which can provide more in-depth scenario analysis but is unable to generate projections.

The version of the Bank of Canada's projection model for the global economy described in this report should be viewed as our first step towards building a global forecasting model. Work on extending the Chinese monetary policy reaction function to include a role for credit growth is currently under way, and is discussed in Bailliu et al. (2010). In the future, we will be extending the model to include a disaggregated outlook for domestic demand and net exports, as well as an endogenously determined profile for the price of oil in the model.

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Appendix A: Equations for the China Block

Key Behavioural Equations

Output-gap equation:

$$y_{ch,t} = \beta_{ch,1}y_{ch,t-1} + \beta_{ch,2}y_{ch,t+1} - \beta_{ch,3}(R_{ch,t-1} - \overline{R}_{ch,t-1}) + \beta_{ch,4}\sum_j w_{ch,j,4}(Z_{ch,j,t-1} - \overline{Z}_{ch,j,t-1})$$
$$+\beta_{ch,5}\sum_j w_{ch,j,5}y_{j,t-1} + \varepsilon^{y}_{ch,t}$$

Inflation equation:

$$\pi_{ch,t} = \lambda_{ch,1}\pi 4_{ch,t+4} + (1-\lambda_{ch,1})\pi 4_{ch,t-1} + \lambda_{ch,2}y_{ch,t-1}\lambda_{ch,3}\sum_j w_{ch,j,3}\Delta(Z_{ch,j,t} - \overline{Z}_{ch,j,t})$$
$$+\nu_{ch,1}\pi^{RPOIL}_{ch,t} + \nu_{ch,2}\pi^{RPOIL}_{ch,t-1} - \varepsilon^{\pi}_{ch,t}$$

Monetary reaction function equation:

$$I_{ch,t} = (1-\gamma_{ch,1})[\overline{R}_{ch,t} + \pi 4_{ch,t+3} + \gamma_{ch,2}(\pi 4_{ch,t+3} - \pi^{tar}_{ch}) + \gamma_{ch,4}y_{ch,t}]$$
$$+\gamma_{ch,5}(\Delta S_{ch,t} - \Delta S^{tar}_{ch,t}) + \gamma_{ch,1}I_{ch,t-1} + \varepsilon^{I}_{ch,t}$$

Exchange rate equations:

$$4(Z^{e}_{ch,t+1} - Z_{i,t}) - \Delta\overline{Z}_{ch,t+1} = (R_{ch,t} - R_{us,t}) - (\overline{R}_{ch,t} - \overline{R}_{us,t}) + \varepsilon^{Z-Z^{e}}_{ch,t}$$

$$Z^{e}_{ch,t+1} = \phi_{ch}Z_{ch,t+1} + (1-\phi_{ch})(Z_{ch,t-1} + 0.5\Delta\overline{Z}_{ch,t})$$

Potential output process:

$$\overline{Y}_{ch,t} = \overline{Y}_{ch,t-1} + g^{\overline{Y}}_{ch,t}/4 - \sigma_{ch}(\sum_{j=0}^{3} \pi^{RPOIL}_{ch,t-j}) + \varepsilon^{\overline{Y}}_{ch,t}$$

$$g^{\overline{Y}}_{ch,t} = \tau_{ch} g^{\overline{Y}ss}_{ch} + (1 - \tau_{ch}) g^{\overline{Y}}_{ch,t-1} + \varepsilon^{g^{\overline{Y}}}_{ch,t}$$

Equilibrium real interest rate process:

$$\overline{R}_{ch,t} = \rho_{ch} \overline{R}^{ss}_{i} + (1 - \rho_{ch}) \overline{R}_{ch,t-1} + \varepsilon^{\overline{R}}_{ch,t}$$

Equilibrium real exchange rate process:

$$\Delta\overline{Z}_{ch,t} = \omega_{ch} \Delta\overline{Z}_{ch,t-1} - \psi(g^{\overline{Y}}_{ch,t} - g^{\overline{Y}ss}_{ch}) + \varepsilon^{\overline{z}}_{ch,t}$$

Appendix B: Data Definitions

United States

GDP U.S.	Gross domestic product (SAAR, Bil.Chn.2000.Dollars)
Interest rates	Federal Open Market Committee: Fed funds target rate (per cent) (period average)
CPI U.S.	Consumer price index (SA, 1982–84=100)
Unemployment	Civilian unemployment rate (SA, per cent)
Bank lending tightening (BLT)	
	Average of (all expressed in per cent):
	FRB Sr Officers Survey: Banks Tightening C.I. Loans to Large Firms
	FRB Sr Officers Survey: Banks Tightening C.I. Loans to Small Firms
	FRB Sr Loan Off Survey: Tightening Standards for Comm. Real Estate
	FRB Sr Loan Survey: Res. Mortgage: Net Share, Banks Tightening

Euro area

GDP Euro Area 15	Gross domestic product (SA/WDA, Mil.Chn.00.Euros)
Interest rates	Euro Area 11-15: 3-Months EURIBOR Rate (AVG, per cent)
CPI Euro Area 15	Monetary Union index of consumer prices (SA, 2005=100)
Unemployment	Euro Area15: Unemployment rate (SA, per cent)
Exchange rates	Period averages; increase is depreciation

Japan

GDP Japan	Gross domestic product (SAAR, Bil.Chn.2000.Yen)

Interest rates	Japan: Call rate: Uncollateralized 3-month (EOP, per cent)
CPI Japan	Consumer price index (SA, 2005=100)
Unemployment	Japan: Unemployment rate (SA, per cent)
Exchange rates	Period averages; increase is depreciation

China

GDP China	Real quarterly GDP (SAAR, Bil. of Chinese renminbi, Base year=2000)
Interest rates	People's Bank of China 1-year base lending rate (per cent) (period average).
CPI China	Consumer price index (SA, 1994=100)
Exchange rate	Period averages; increase is depreciation

Rest of World

All RoW series are constructed by taking the weighted average of member country data. Member country data are taken from several sources, including: BIS Data Bank; IMF International Financial Statistics; IHS Global Insight; OECD Main Economic Indicators Member countries are: Argentina; Australia; Brazil; Canada; Chile; Czech Republic; Denmark; Hong Kong SAR; Hungary; India; Indonesia; South Korea; Malaysia; Mexico; Norway; Peru; Philippines; Poland; Russia; Singapore; South Africa; Sweden; Switzerland; Taiwan; Thailand; Turkey; Ukraine; United Kingdom.

Oil Price

Oil price Crude oil (petroleum), simple average of three spot prices; Dated Brent, West Texas Intermediate, and the Dubai Fateh, U.S.-dollar per barrel (period average)

Real Effective

Exchange rates	Weighted averages of the bilateral exchange rates. Weights are based on bilateral trade data from the International Monetary Fund (2006). The rates in the inflation equations are defined with import weights, while the rates in the output-gap equations use total trade (imports + exports) weights.
Foreign output gaps	Weighted averages of the foreign output gaps. Weights are based on bilateral trade data (exports) from the International Monetary Fund (2006).

Appendix C: Share of Global GDP, per country/region

	Share of Global GDP (2007 PPP Weights)
United States	21%
Euro area	16%
Japan	11%
China	7%
Rest of world	35%
Total	90%

Appendix D: Results of Posterior Maximization (Euro Area)

	Prior			Posterior	
	Mean	**S.D.**	**Distribution**	**Mode**	**S.D.**
IS curve					
$\beta_{eu,1}$	0.750	0.1000	Gamma	0.9361	0.0707
$\beta_{eu,2}$	0.100	0.0500	Beta	0.1670	0.0675
$\beta_{eu,3}$	0.200	0.0500	Gamma	0.2113	0.0453
$\beta_{eu,4}$	0.104	0.0400	Gamma	0.0517	0.0205
$\beta_{eu,5}$	0.052	0.0100	Gamma	0.0528	0.0102
Phillips curve					
$\lambda_{eu,1}$	0.500	0.1000	Beta	0.6851	0.0676
$\lambda_{eu,2}$	0.250	0.0500	Gamma	0.2134	0.0402
$\lambda_{eu,3}$	0.208	0.0500	Gamma	0.0965	0.0216
Monetary policy reaction function					
$\gamma_{eu,1}$	0.500	0.0500	Beta	0.6972	0.0362
$\gamma_{eu,2}$	1.500	0.2000	Gamma	1.2521	0.1611
$\gamma_{eu,4}$	0.200	0.0500	Gamma	0.1982	0.0503
Stochastic processes					
$\alpha_{eu,1}$	0.750	0.1000	Beta	0.7118	0.0720
$\alpha_{eu,2}$	0.300	0.1000	Gamma	0.1312	0.0269
$\alpha_{eu,3}$	0.500	0.2000	Beta	0.1049	0.0462
$g_{eu}^{\overline{Y}ss}$	2.000	0.0500	Normal	2.0055	0.0499
ϕ_{eu}	0.500	0.2000	Beta	0.8302	0.0675
ρ_{eu}	0.500	0.1000	Beta	0.4682	0.1180
$\overline{rr}_{eu}$	2.000	0.3000	Normal	1.9539	0.1837
τ_{eu}	0.050	0.0300	Beta	0.0226	0.0151
σ_{eu}	0.003	0.0010	Gamma	0.0016	0.0006
$\upsilon_{eu,1}$	0.003	0.0010	Gamma	0.0035	0.0011
$\upsilon_{eu,2}$	0.003	0.0010	Gamma	0.0022	0.0007

	Prior			Posterior	
	Mean	**S.D.**	**Distribution**	**Mode**	**S.D.**
$\varepsilon_{eu}^{g^{\overline{Y}}}$	0.100	0.0500	Inverted gamma	0.1261	0.0422
$\varepsilon_{eu}^{\overline{Y}}$	0.200	0.0500	Inverted gamma	0.1923	0.0375
$\varepsilon_{eu}^{\overline{Z}}$	1.000	Inf	Inverted gamma	4.3598	0.5762
ε_{eu}^{π}	0.500	Inf	Inverted gamma	0.9800	0.1130
$\varepsilon_{eu}^{\overline{R}}$	0.200	0.0400	Inverted gamma	0.1896	0.0361
$\varepsilon^{R_{eu}-R_{us}}$	1.000	Inf	Inverted gamma	0.4614	0.1890
ε_{eu}^{rs}	0.250	Inf	Inverted gamma	0.2585	0.0334
$\varepsilon_{eu}^{\overline{U}}$	0.100	Inf	Inverted gamma	0.0301	0.0064
$\varepsilon_{eu}^{g^{\overline{U}}}$	0.100	Inf	Inverted gamma	0.0410	0.0074
ε_{eu}^{u}	0.200	Inf	Inverted gamma	0.0428	0.0060
ε_{y}^{u}	0.300	0.0500	Inverted gamma	0.2535	0.0321

Results of Posterior Maximization (Japan)

	Prior			Posterior	
	Mean	**S.D.**	**Distribution**	**Mode**	**S.D.**
IS curve					
$\beta_{ja,1}$	0.750	0.1000	Gamma	0.6035	0.0666
$\beta_{ja,2}$	0.100	0.0500	Beta	0.0528	0.0322
$\beta_{ja,3}$	0.200	0.0500	Gamma	0.1313	0.0352
$\beta_{ja,4}$	0.090	0.0400	Gamma	0.0447	0.0232
$\beta_{ja,5}$	0.045	0.0100	Gamma	0.0429	0.0097
Phillips curve					
$\lambda_{ja,1}$	0.500	0.1000	Beta	0.6450	0.0638
$\lambda_{ja,2}$	0.250	0.0500	Gamma	0.1674	0.0385
$\lambda_{ja,3}$	0.180	0.0500	Gamma	0.0834	0.0225
Monetary policy reaction function					
$\gamma_{ja,1}$	0.500	0.2500	Beta	0.9944	0.0075
$\gamma_{ja,2}$	1.500	0.2000	Gamma	1.1349	0.1516
$\gamma_{ja,4}$	0.200	0.0500	Gamma	0.1666	0.0436
Stochastic processes					
$\alpha_{ja,1}$	0.750	0.1000	Beta	0.7439	0.0979
$\alpha_{ja,2}$	0.100	0.0500	Gamma	0.0628	0.0248
$\alpha_{ja,3}$	0.500	0.2000	Beta	0.1768	0.0904
$g_{ja}^{\overline{Y}ss}$	1.700	0.0500	Normal	1.6945	0.0497
ϕ_{ja}	0.500	0.2000	Beta	0.8260	0.0626
ρ_{ja}	0.500	0.1000	Beta	0.4964	0.1077
$\overline{rr}_{ja}$	2.000	0.3000	Normal	0.6731	0.2144
τ_{ja}	0.050	0.0300	Beta	0.0331	0.0222
σ_{ja}	0.002	0.0010	Gamma	0.0010	0.0006
$\upsilon_{ja,1}$	0.003	0.0010	Gamma	0.0018	0.0008
$\upsilon_{ja,2}$	0.003	0.0010	Gamma	0.0024	0.0010

	Prior			Posterior	
	Mean	**S.D.**	**Distribution**	**Mode**	**S.D.**
$\varepsilon_{ja}^{g^{\overline{Y}}}$	0.100	0.0500	Inverted gamma	0.0804	0.0294
$\varepsilon_{ja}^{\overline{Y}}$	0.200	0.0500	Inverted gamma	0.4365	0.0940
$\varepsilon_{ja}^{\overline{Z}}$	4.000	Inf	Inverted gamma	6.1233	0.9146
ε_{ja}^{π}	1.000	Inf	Inverted gamma	1.4022	0.1518
$\varepsilon_{ja}^{\overline{R}}$	0.100	0.0400	Inverted gamma	0.0794	0.0231
$\varepsilon^{R_{ja}-R_{us}}$	0.500	Inf	Inverted gamma	0.2303	0.0940
ε_{ja}^{rs}	0.250	Inf	Inverted gamma	0.2598	0.0330
$\varepsilon_{ja}^{\overline{U}}$	0.100	Inf	Inverted gamma	0.0508	0.0266
$\varepsilon_{ja}^{g^{\overline{U}}}$	0.100	Inf	Inverted gamma	0.0427	0.0123
ε_{ja}^{u}	0.100	Inf	Inverted gamma	0.0754	0.0183
ε_{y}^{u}	0.500	0.1000	Inverted gamma	0.4491	0.0682

Results of Posterior Maximization (China)

	Prior			Posterior	
	Mean	S.D.	Distribution	Mode	S.D.
IS curve					
$\beta_{ch,1}$	0.750	0.0500	Beta	0.6615	0.0543
$\beta_{ch,2}$	0.150	0.1000	Beta	0.0179	0.0199
$\beta_{ch,3}$	0.250	0.0500	Gamma	0.1603	0.0327
$\beta_{ch,4}$	0.050	0.0100	Gamma	0.0281	0.0064
$\beta_{ch,5}$	0.400	0.0500	Gamma	0.4210	0.0494
Phillips curve					
$\lambda_{ch,1}$	0.500	0.0500	Beta	0.5184	0.0360
$\lambda_{ch,2}$	0.250	0.0500	Gamma	0.1504	0.0334
$\lambda_{ch,3}$	0.120	0.0500	Gamma	0.2022	0.0649
Monetary policy reaction function					
$\gamma_{ch,1}$	0.700				
$\gamma_{ch,2}$	1.200	0.3000	Gamma	0.8831	0.1994
$\gamma_{ch,4}$	0.200	0.0500	Gamma	0.1869	0.0481
$\gamma_{ch,5}$	0.200	0.1000	Gamma	0.1164	0.0214
Stochastic processes					
$g_{ch}^{\overline{Y}ss}$	5.000	0.2000	Normal	5.1192	0.1993
$\overline{R}_{ch}^{ss}$	3.900	0.2000	Normal	4.1081	0.1808
ρ_{ch}	0.900	0.0100	Beta	0.9010	0.0100
τ_{ch}	0.030	0.0050	Beta	0.0247	0.0042
ϕ_{ch}	0.500	0.2000	Beta	0.7843	0.0347
κ_{ch}	0.050	0.0050	Beta	0.0490	0.0050
ψ_{ch}	0.120	0.0100	Gamma	0.1182	0.0099
ω_{ch}	0.900	0.0200	Beta	0.8762	0.0215
$\upsilon_{ch,1}$	0.002	0.0010	Gamma	0.0023	0.0013
$\upsilon_{ch,2}$	0.002	0.0010	Gamma	0.0019	0.0011
σ_{ch}	0.002	0.0010	Gamma	0.0014	0.0008

	Prior			**Posterior**	
	Mean	**S.D.**	**Distribution**	**Mode**	**S.D.**
$\varepsilon_{ch}^{g^{\overline{Y}}}$	0.250	0.0300	Inverted gamma	0.2960	0.0429
$\varepsilon_{ch}^{\overline{Y}}$	0.200	0.0500	Inverted gamma	0.1769	0.0376
$\varepsilon_{ch}^{\overline{z}}$	1.500	0.2000	Inverted gamma	2.3824	0.2985
ε_{ch}^{π}	1.000	Inf	Inverted gamma	2.4983	0.3358
$\varepsilon_{ch}^{\overline{R}}$	0.500	0.0500	Inverted gamma	0.5097	0.0767
$\varepsilon_{ch}^{Z-Z^e}$	1.000	Inf	Inverted gamma	0.4306	0.1548
ε_{ch}^{I}	0.500	Inf	Inverted gamma	0.1224	0.0201
ε_{ch}^{y}	0.300	Inf	Inverted gamma	0.5595	0.0830
ε_{ch}^{LS}	0.500	Inf	Inverted gamma	0.2464	0.1104

Results of Posterior Maximization (Rest of World)

	Prior			Posterior	
	Mean	S.D.	Distribution	Mode	S.D.
IS curve					
$\beta_{rw,1}$	0.750	0.0500	Beta	0.6619	0.0499
$\beta_{rw,2}$	0.100	0.0500	Beta	0.0435	0.0263
$\beta_{rw,3}$	0.200	0.0500	Gamma	0.1040	0.0290
$\beta_{rw,4}$	0.030	0.0100	Gamma	0.0117	0.0042
$\beta_{rw,5}$	0.100	0.0250	Gamma	0.1120	0.0287
Phillips curve					
$\lambda_{rw,1}$	0.500	0.1000	Beta	0.5317	0.0408
$\lambda_{rw,2}$	0.200	0.0500	Gamma	0.1201	0.0342
$\lambda_{rw,3}$	0.100	0.0100	Gamma	0.1061	0.0106
Monetary policy reaction function					
$\gamma_{rw,1}$	0.900	0.0200	Beta	0.9035	0.0190
$\gamma_{rw,2}$	1.200	0.3000	Gamma	1.7113	0.3085
$\gamma_{rw,4}$	0.200	0.0500	Gamma	0.1825	0.0471
Stochastic processes					
$g_{rw}^{\overline{Y}ss}$	4.000	0.4000	Normal	4.7295	0.3959
$\overline{R}_{rw}^{ss}$	2.000	0.2000	Normal	2.2808	0.1893
ρ_{rw}	0.900	0.0100	Beta	0.9009	0.0100
τ_{rw}	0.030	0.0050	Beta	0.0271	0.0047
ϕ_{rw}	0.850	0.1000	Beta	0.9173	0.0730
ω_{rw}	0.900	0.0200	Beta	0.9294	0.0181
$\upsilon_{rw,1}$	0.002	0.0010	Gamma	0.0058	0.0023
$\upsilon_{rw,2}$	0.002	0.0010	Gamma	0.0082	0.0024
σ_{rw}	0.002	0.0010	Gamma	0.0017	0.0009

	Prior			Posterior	
	Mean	**S.D.**	**Distribution**	**Mode**	**S.D.**
$\varepsilon_{rw}^{g^{\overline{Y}}}$	0.110	0.0300	Inverted gamma	0.1249	0.0343
$\varepsilon_{rw}^{\overline{Y}}$	0.160	0.0500	Inverted gamma	0.1470	0.0437
$\varepsilon_{rw}^{\overline{z}}$	1.000	Inf	Inverted gamma	2.0539	0.6048
ε_{rw}^{π}	1.000	Inf	Inverted gamma	0.8010	0.1448
$\varepsilon_{rw}^{\overline{R}}$	0.200	0.0500	Inverted gamma	0.1765	0.0373
$\varepsilon_{rw}^{Z-Z^e}$	0.500	Inf	Inverted gamma	0.2306	0.0944
ε_{rw}^{I}	0.300	Inf	Inverted gamma	0.4018	0.0910
ε_{rw}^{y}	0.300	Inf	Inverted gamma	0.3033	0.0585

Appendix E: Figures

Figure E1: Chinese Exchange Rate

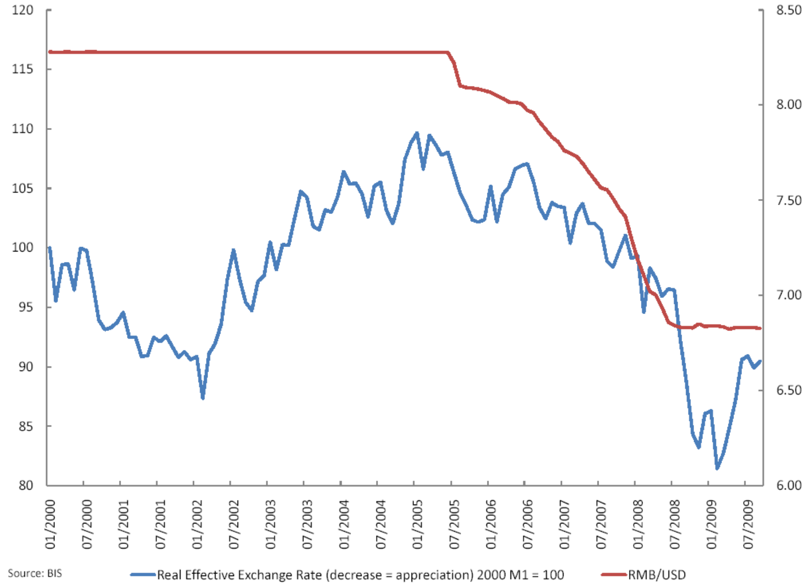


Figure E2: Euro Area Historical Decomposition of the Output Gap

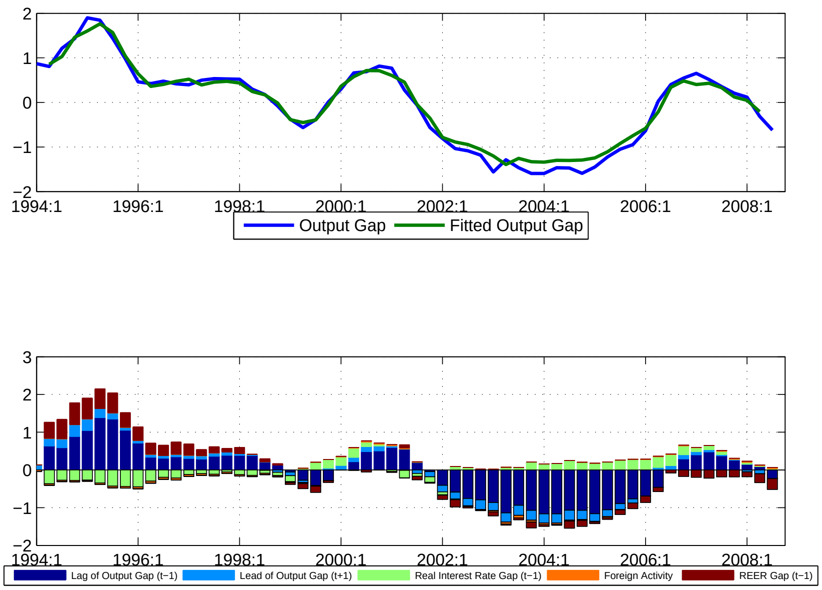


Figure E3: Euro Area Historical Decomposition of the Interest Rate

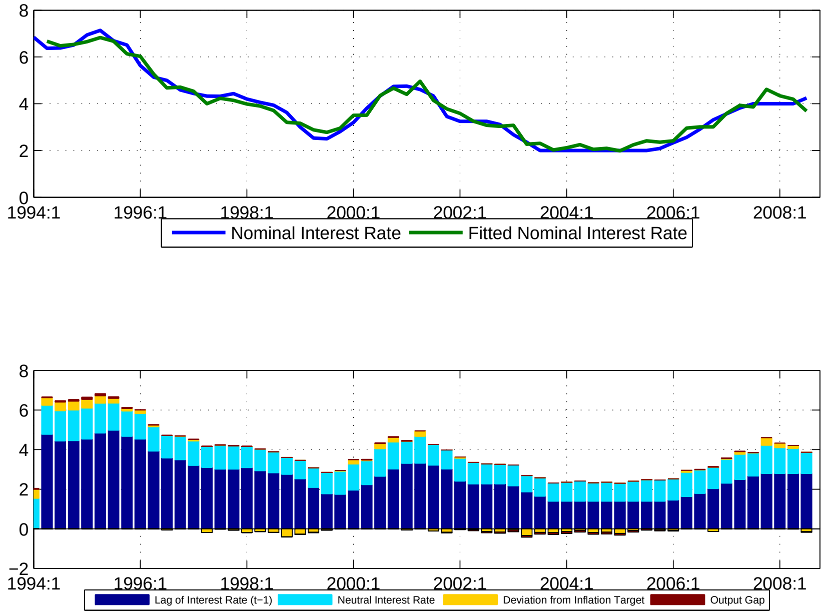


Figure E4: Euro Area Historical Decomposition of the Inflation Process

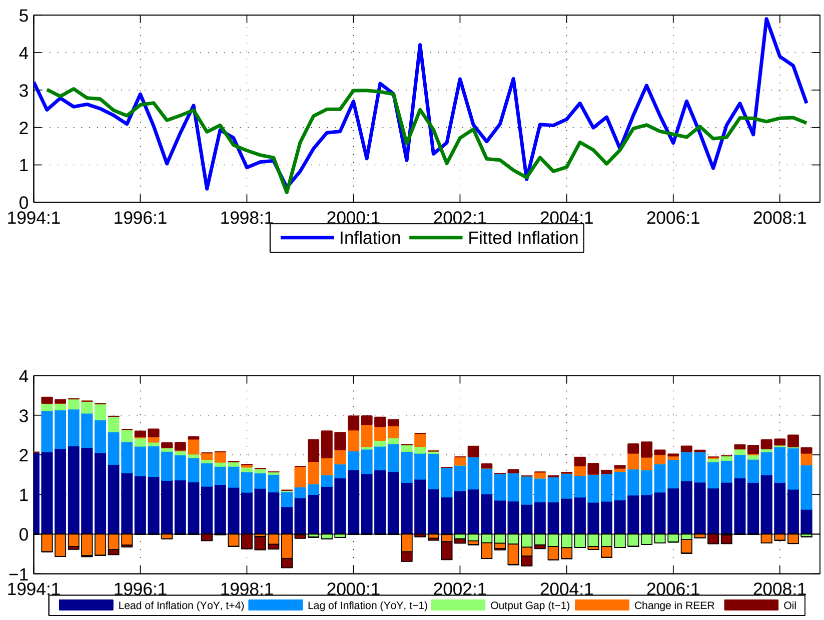


Figure E5: Japanese Historical Decomposition of the Output Gap

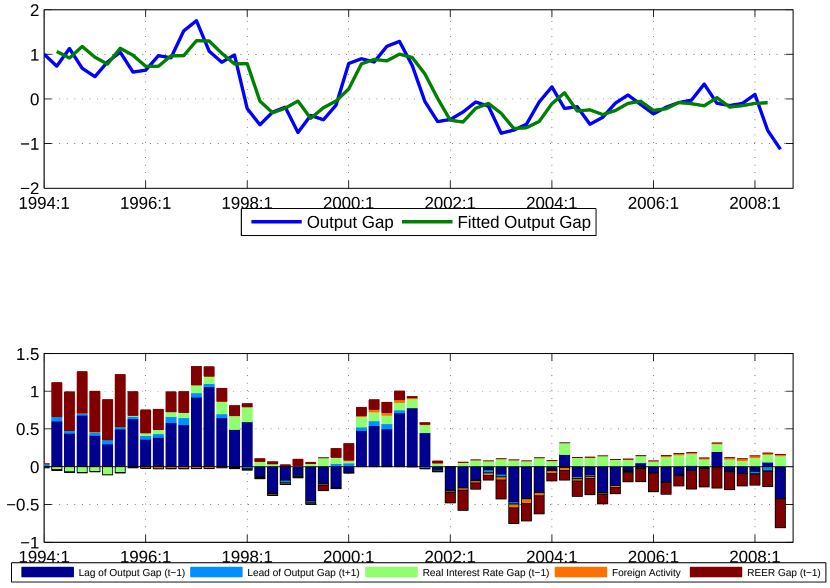


Figure E6: Japanese Historical Decomposition of the Interest Rate

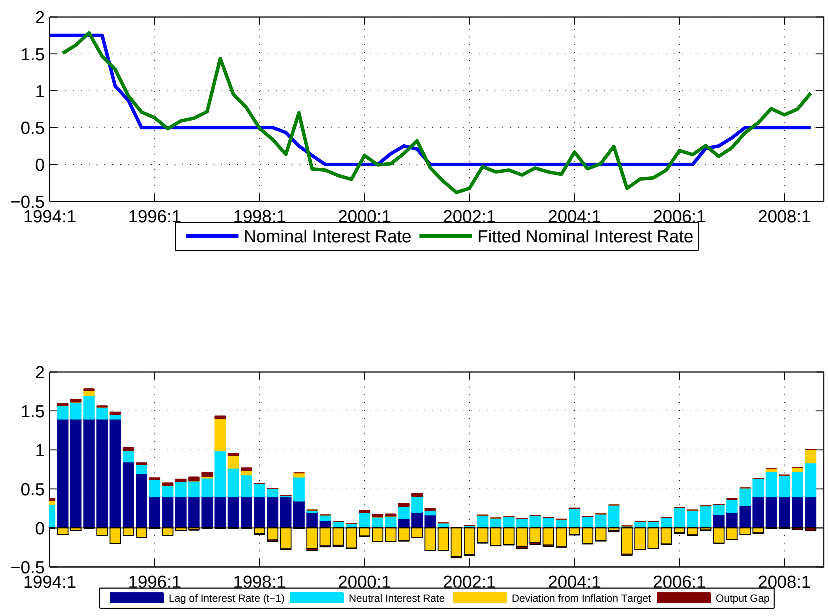


Figure E7: Japanese Historical Decomposition of the Inflation Process

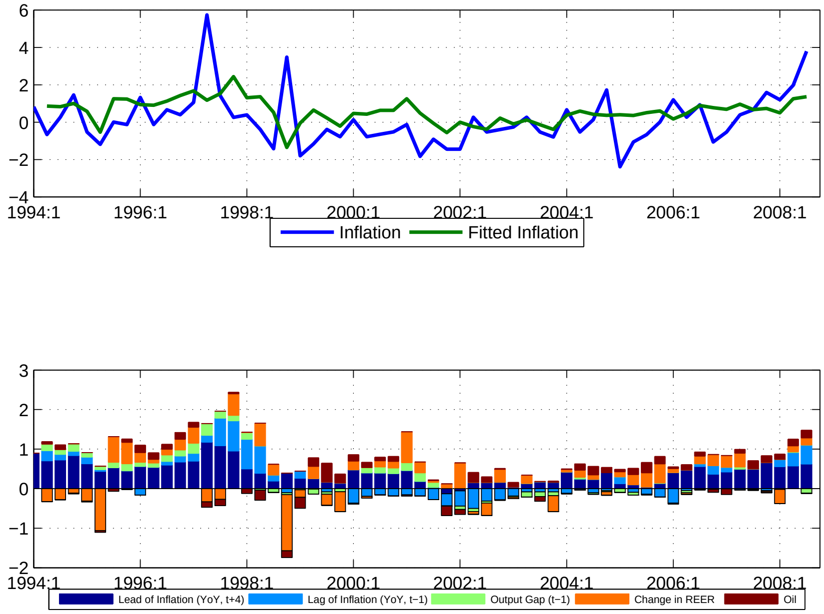


Figure E8: Chinese Historical Decomposition of the Output Gap

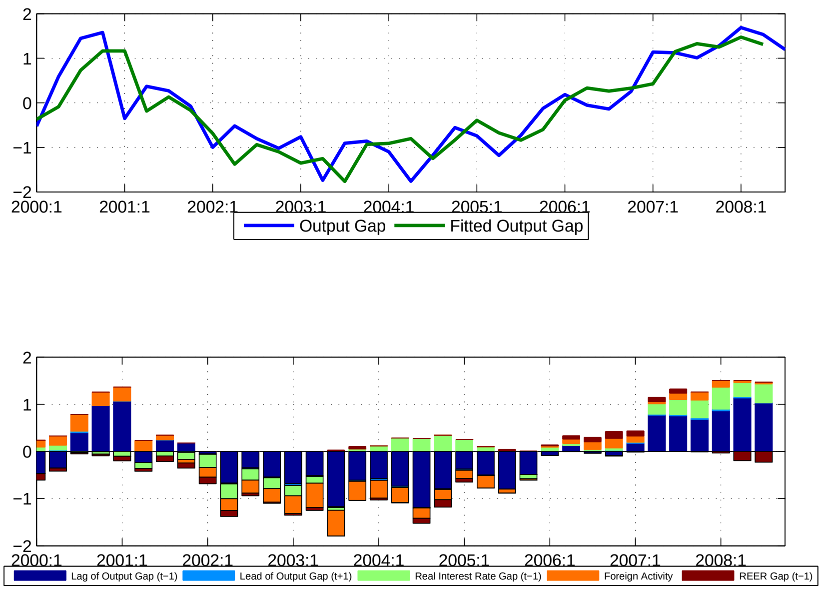
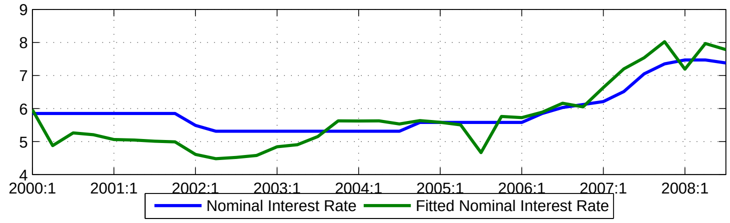


Figure E9: Chinese Historical Decomposition of the Interest Rate



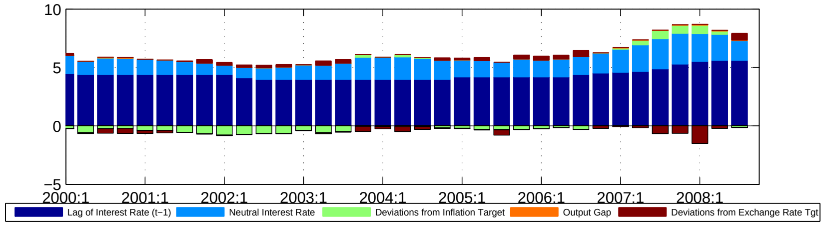
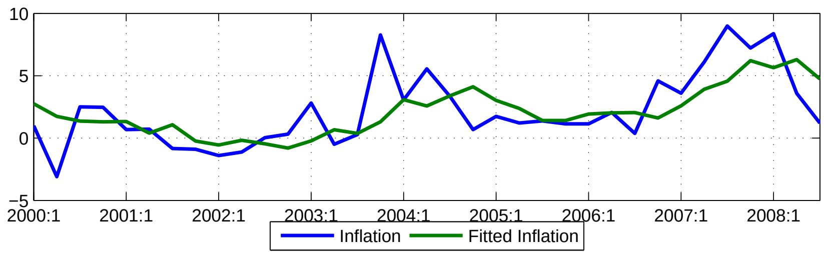


Figure E10: Chinese Historical Decomposition of the Inflation Process



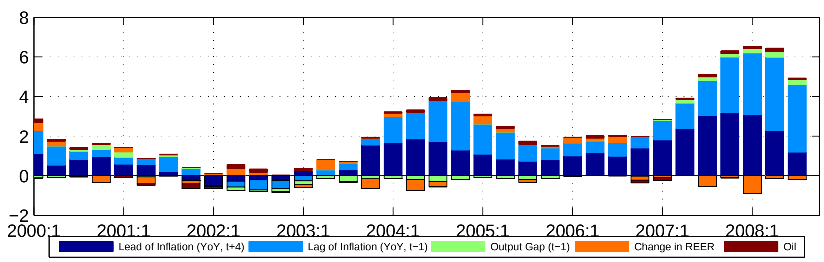


Figure E11: Rest of World Historical Decomposition of the Output Gap

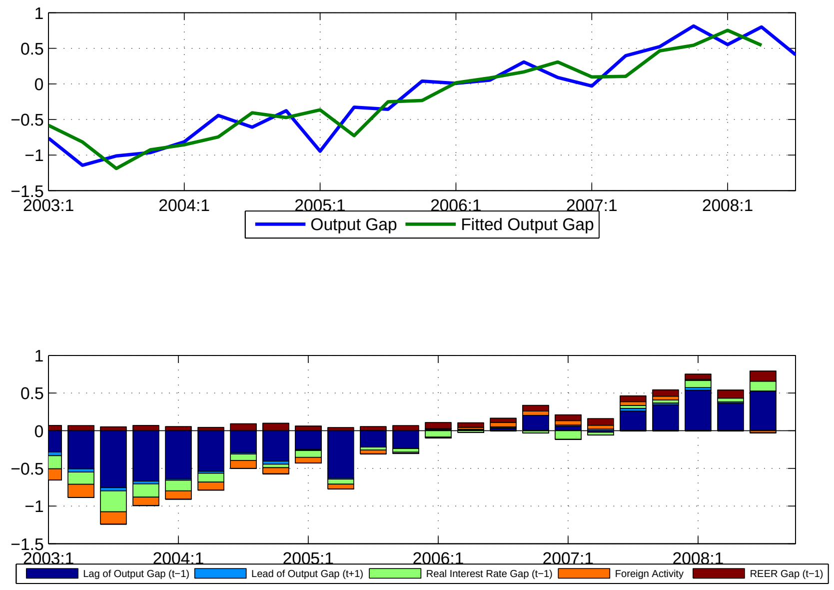


Figure E12: Rest of World Historical Decomposition of the Interest Rate

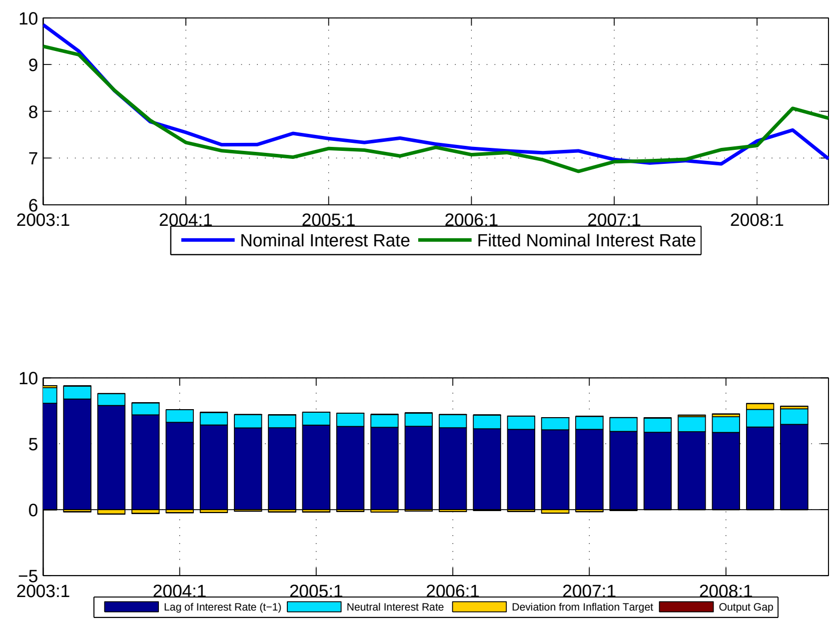
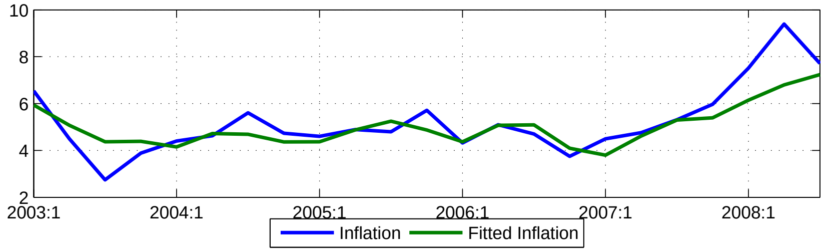


Figure E13: Rest of World Historical Decomposition of the Inflation Process



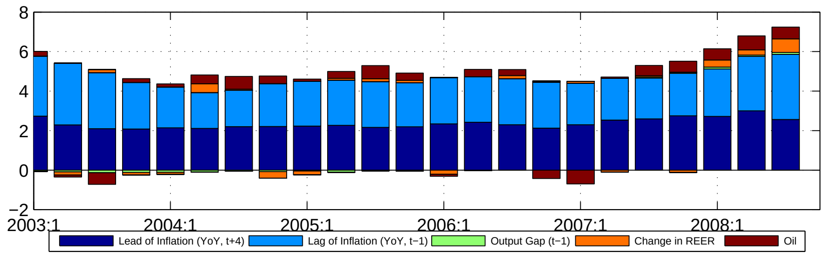
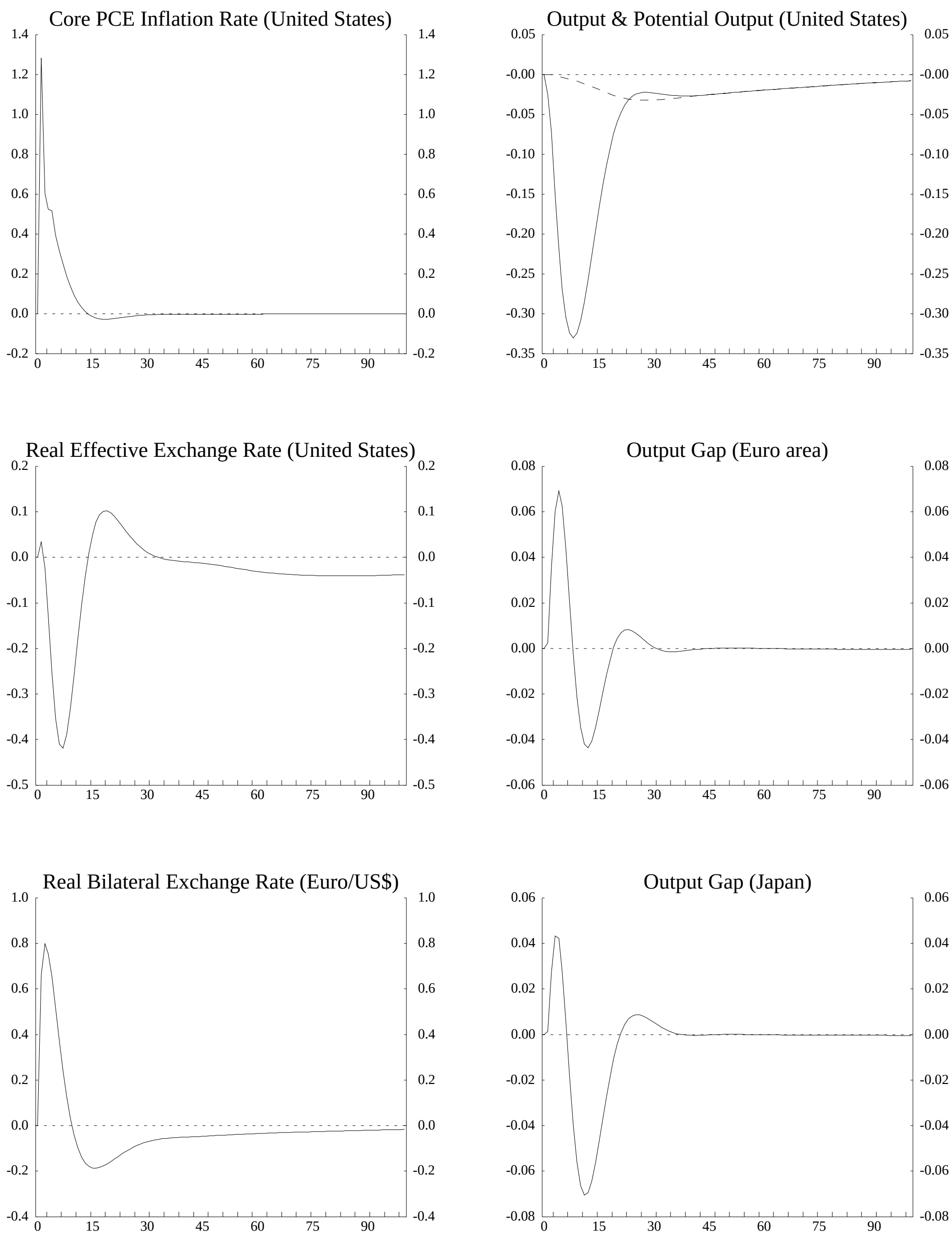


Figure E14:

U.S. Core Inflation Shock



U.S. Core Inflation Shock (Continued)

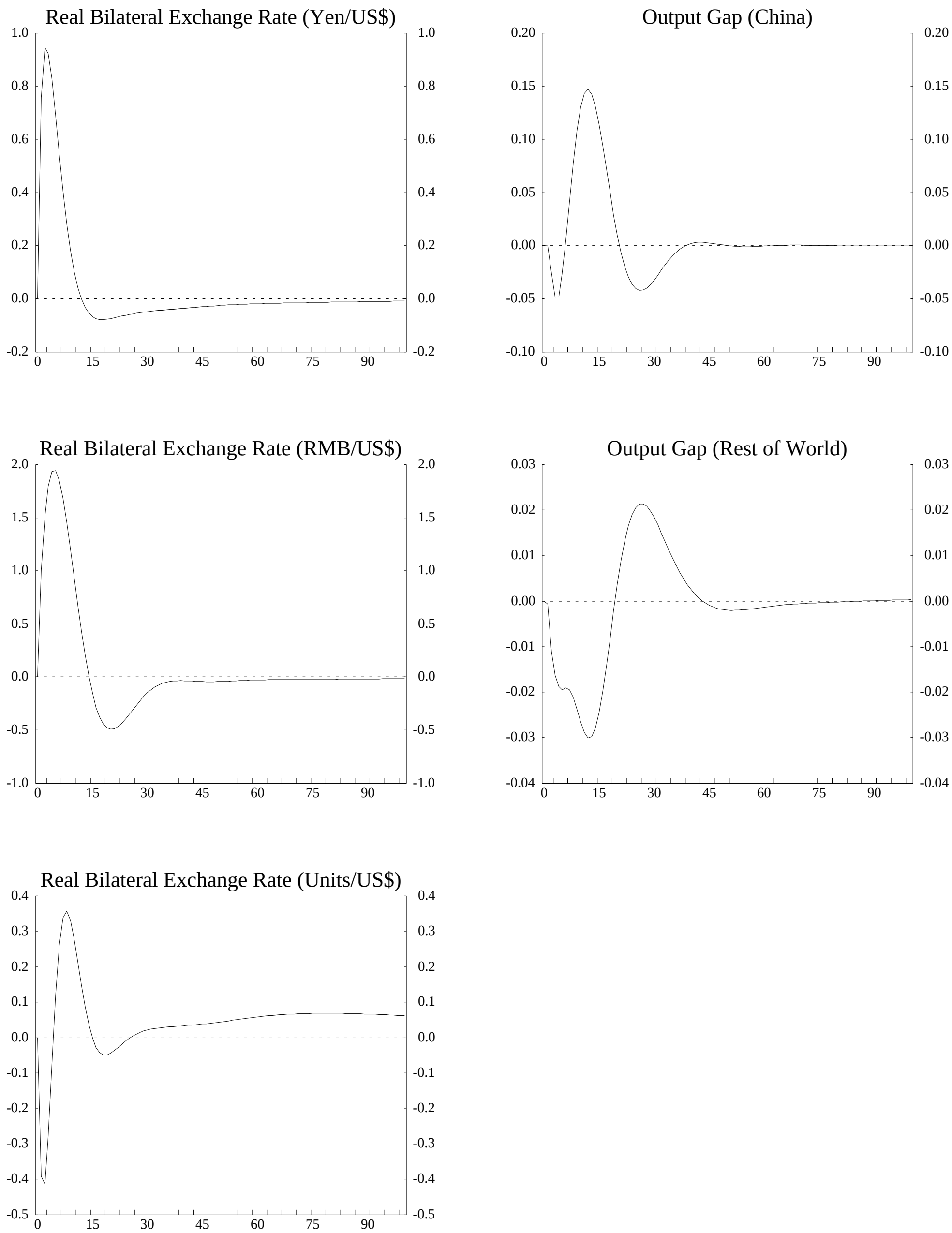
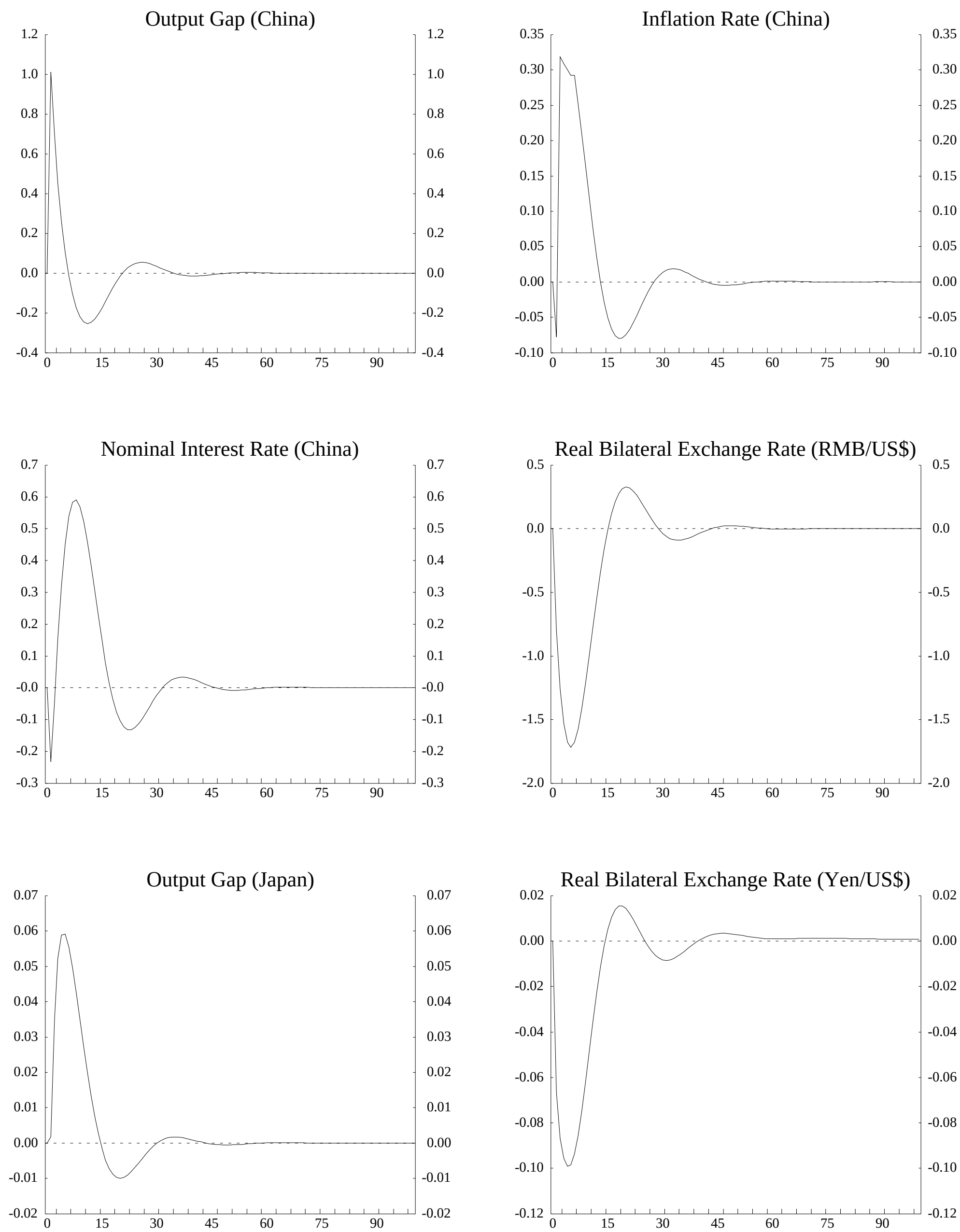


Figure E15:

Chinese Output Shock



Chinese Output Shock (Continued)

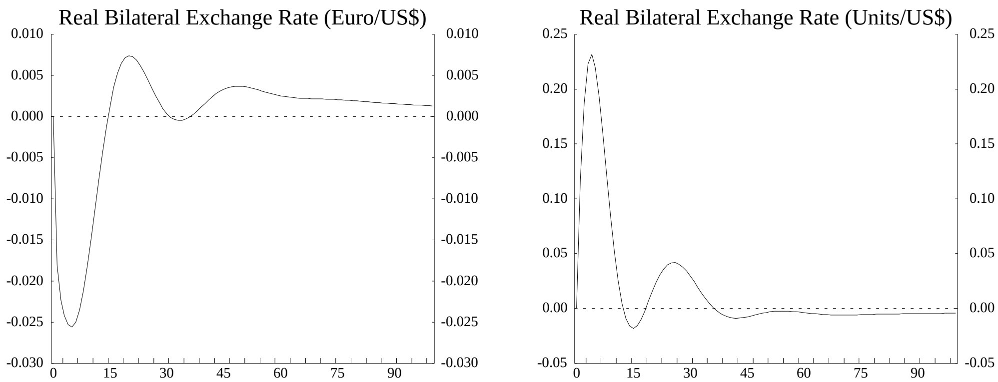


Figure E16:

Euro Area Nominal Interest Rate Shock

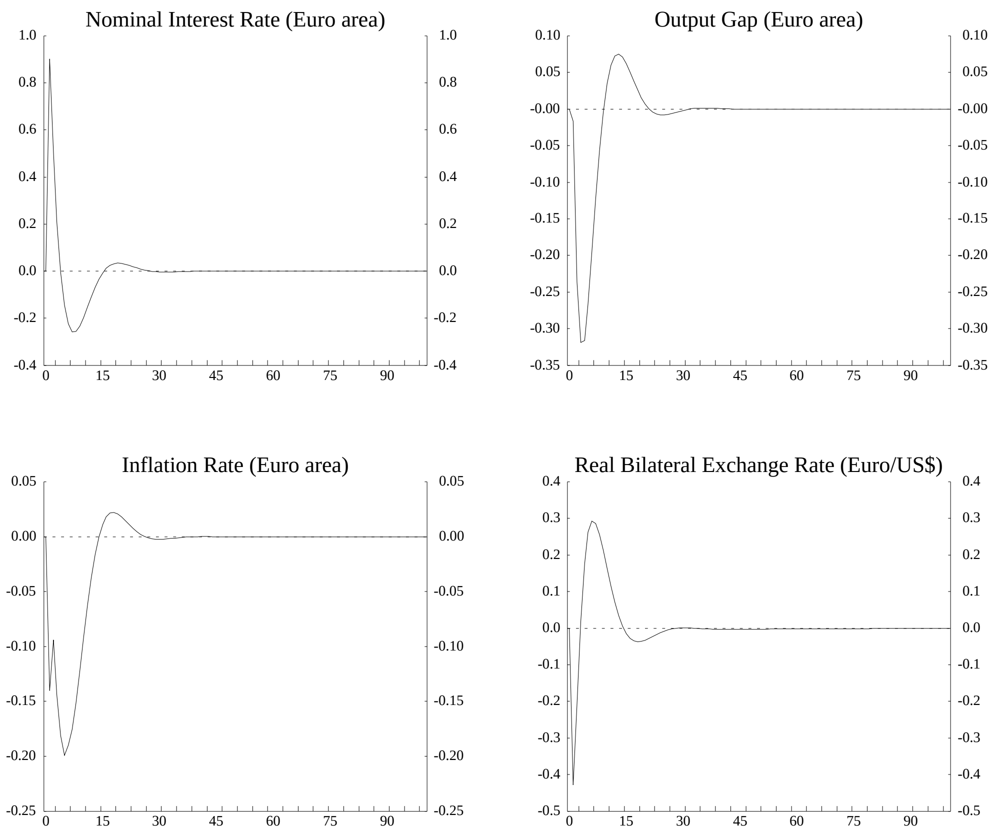


Figure E17:

Japanese Potential Output Shock

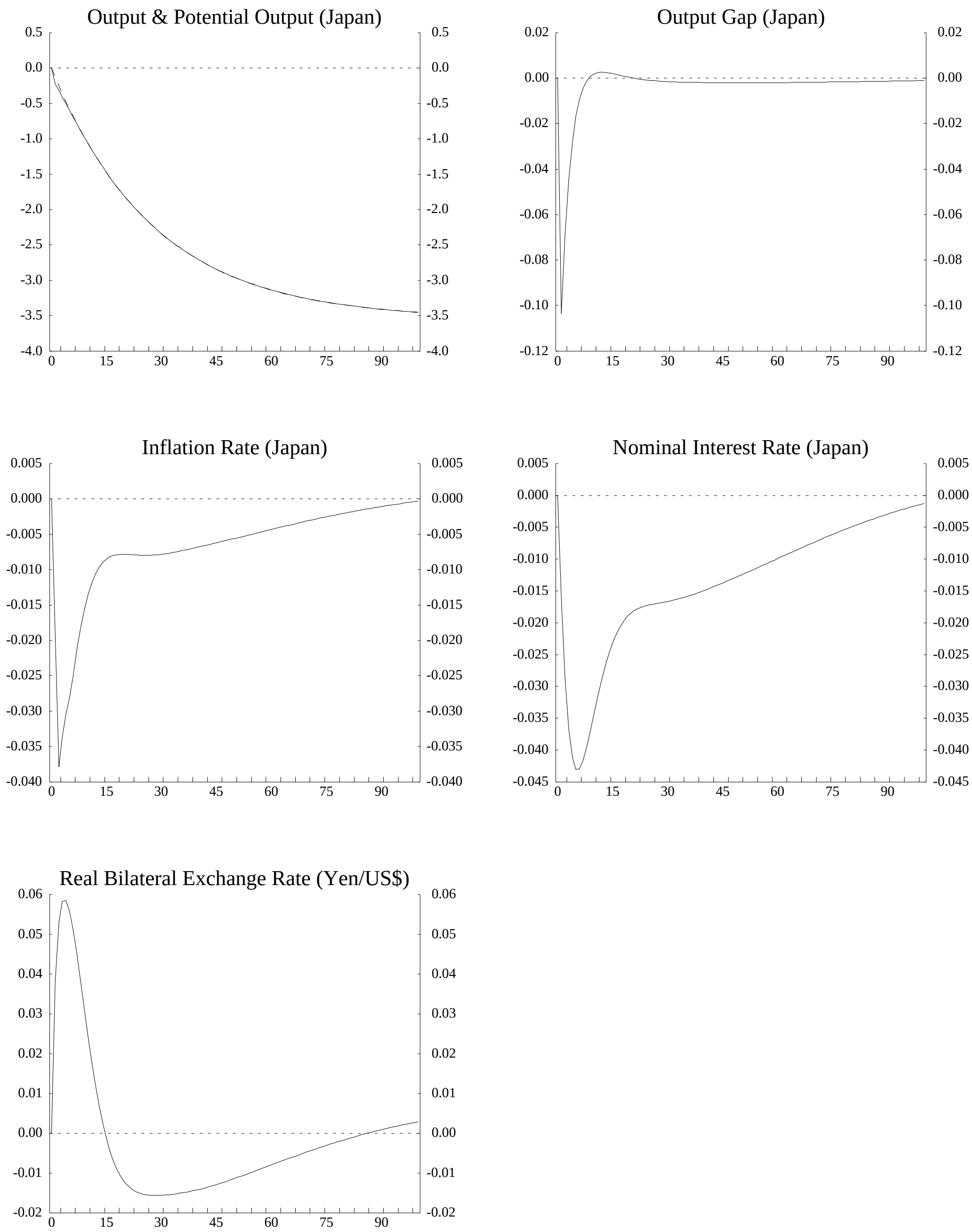
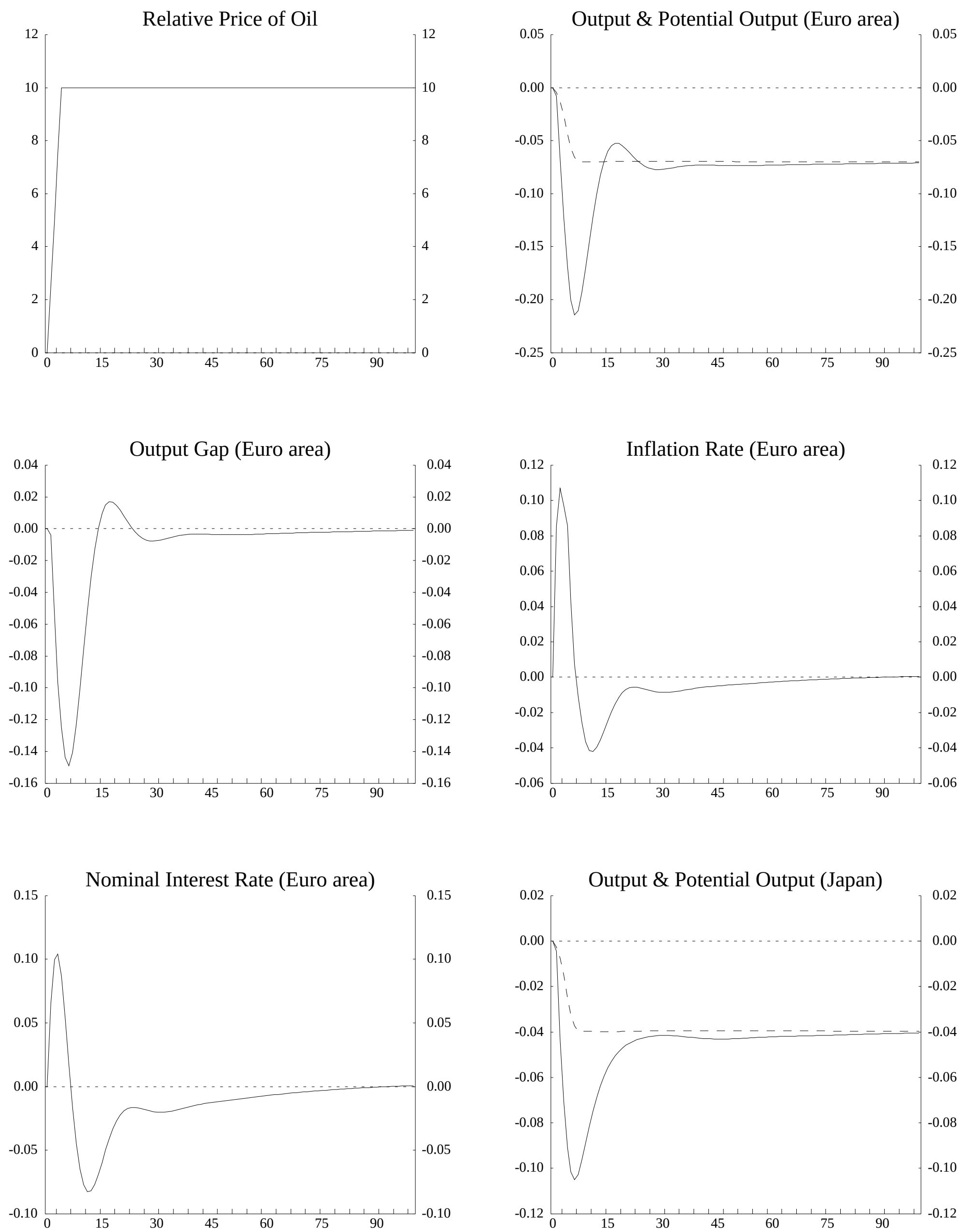
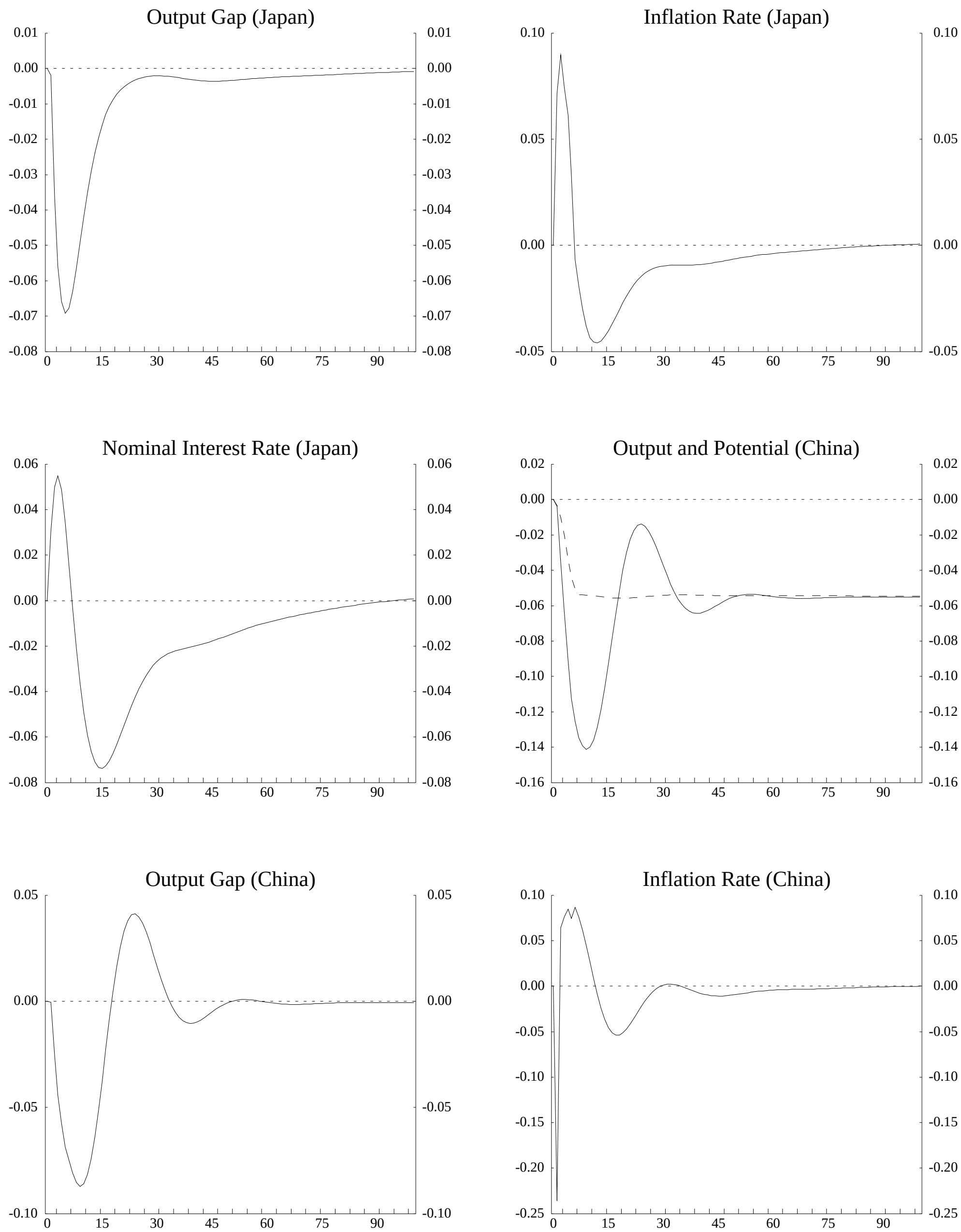


Figure E18:

Oil-Price Shock



Oil-Price Shock (Continued)



Oil-Price Shock (Continued)

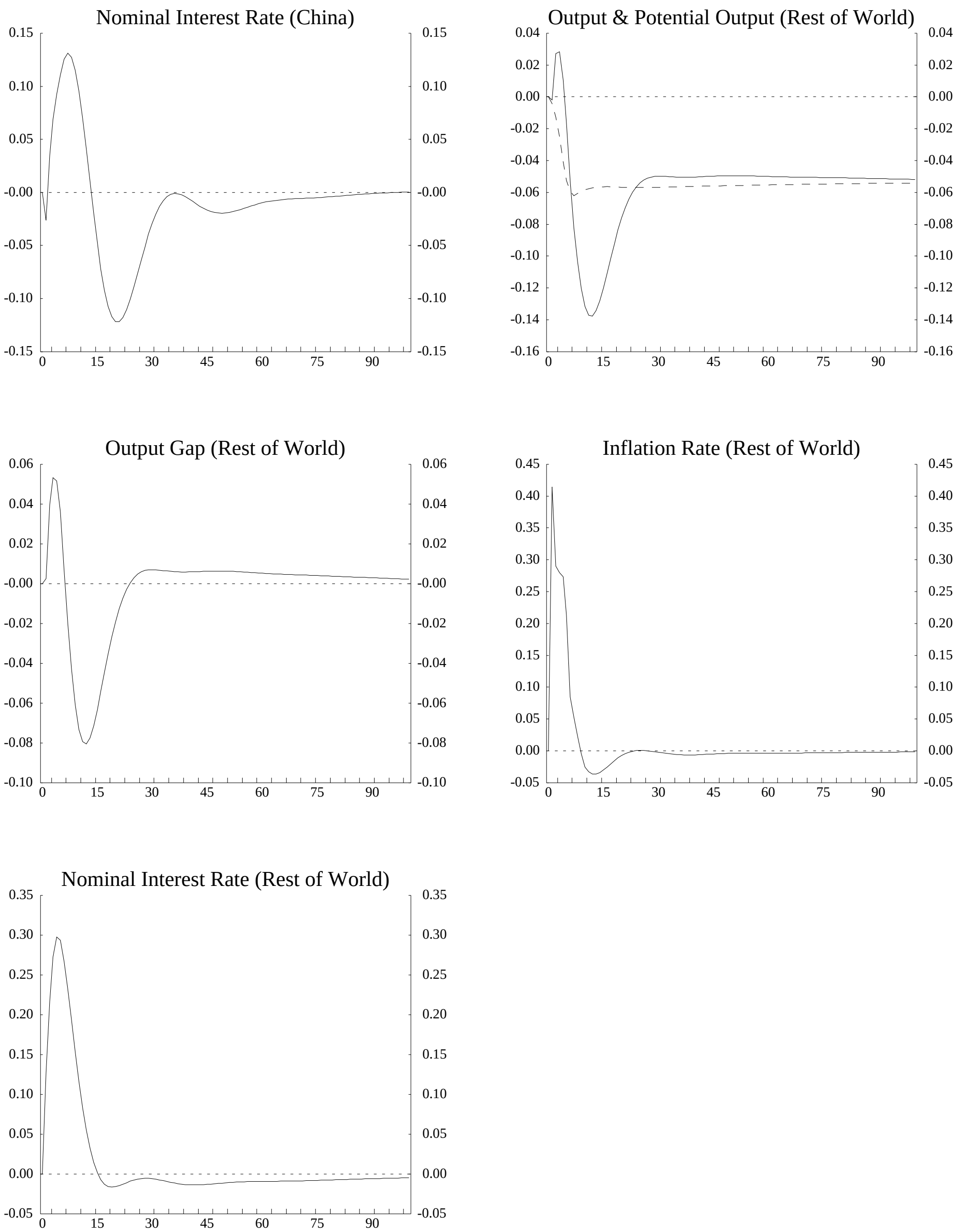
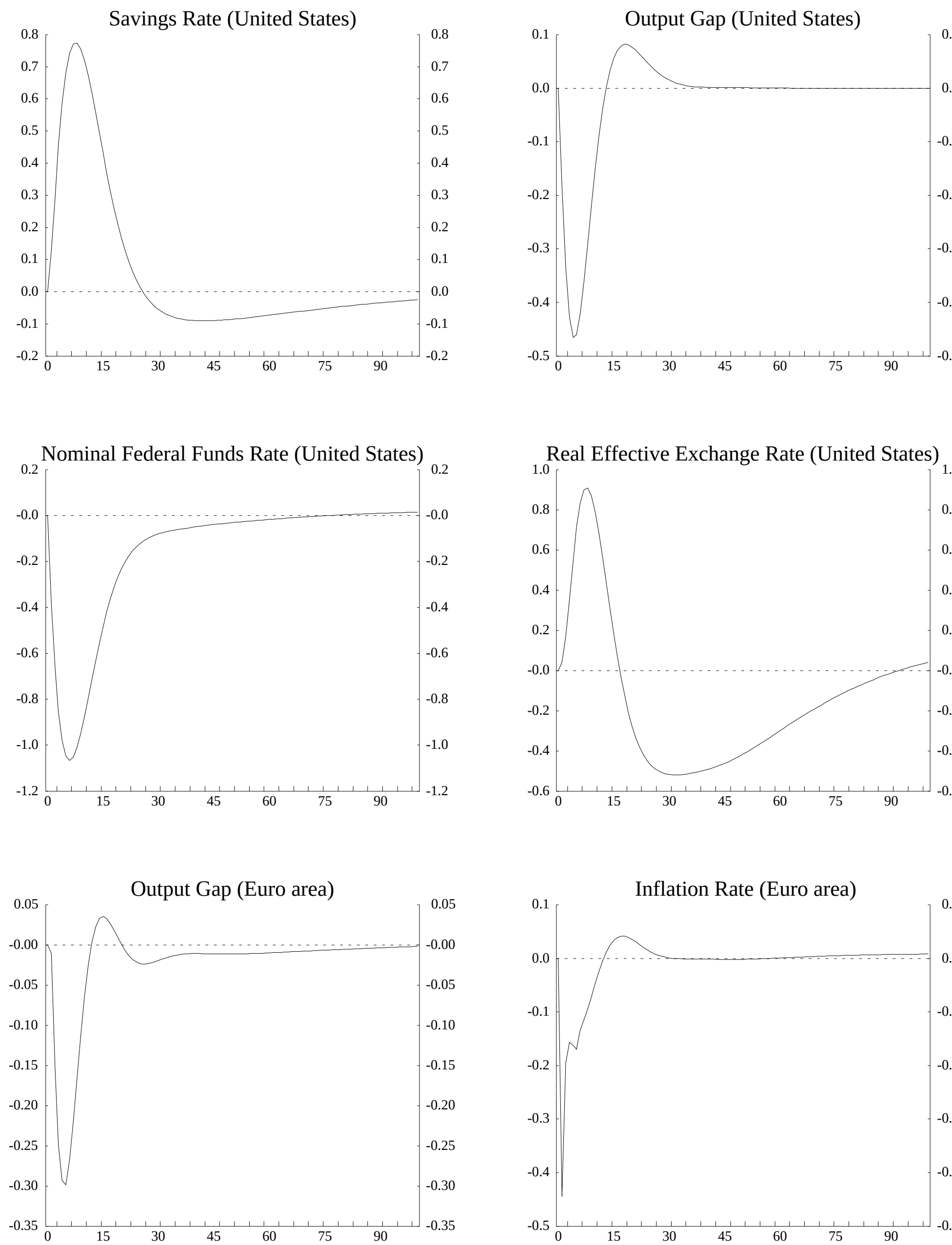
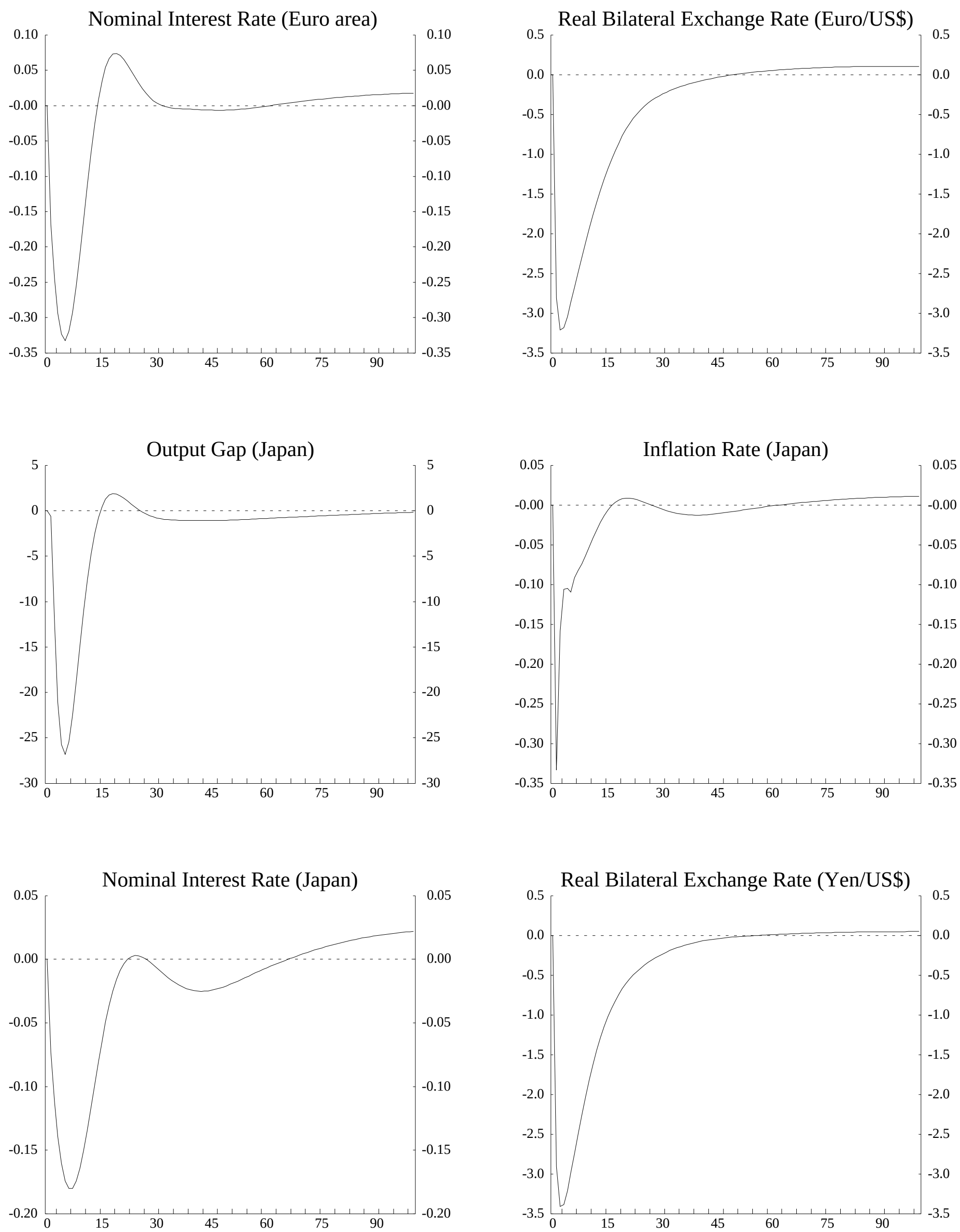


Figure E19:

Application: U.S. Savings Rate Shock



Application: U.S. Savings Rate Shock (Continued)



Application: U.S. Savings Rate Shock (Continued)

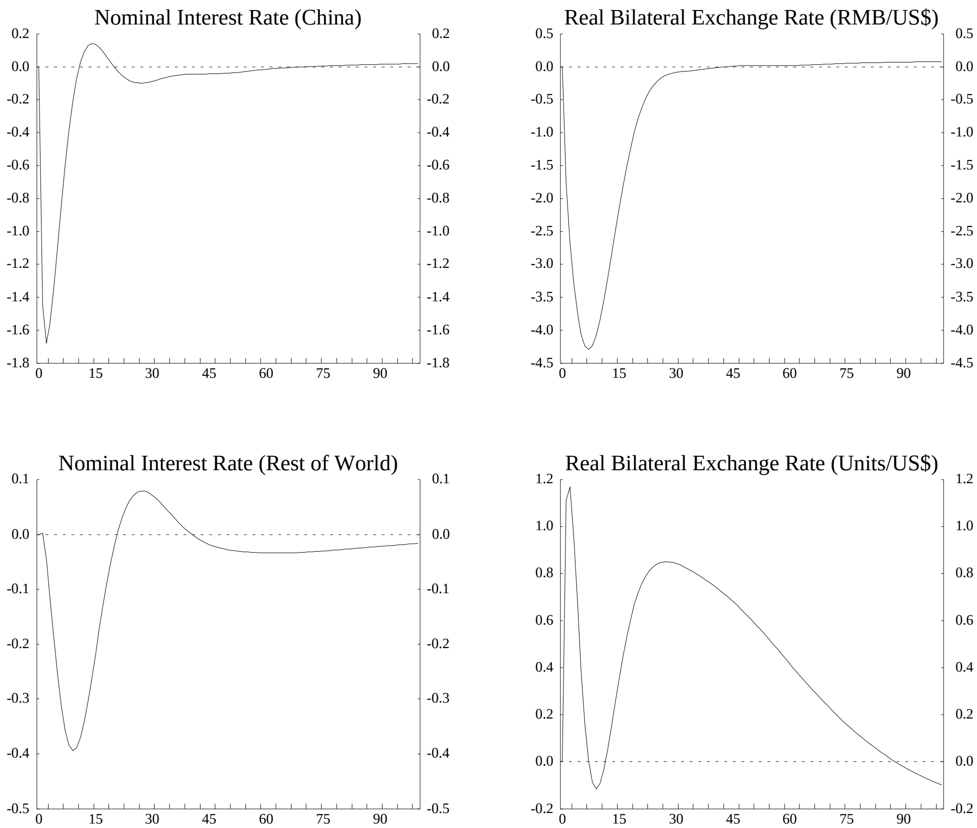
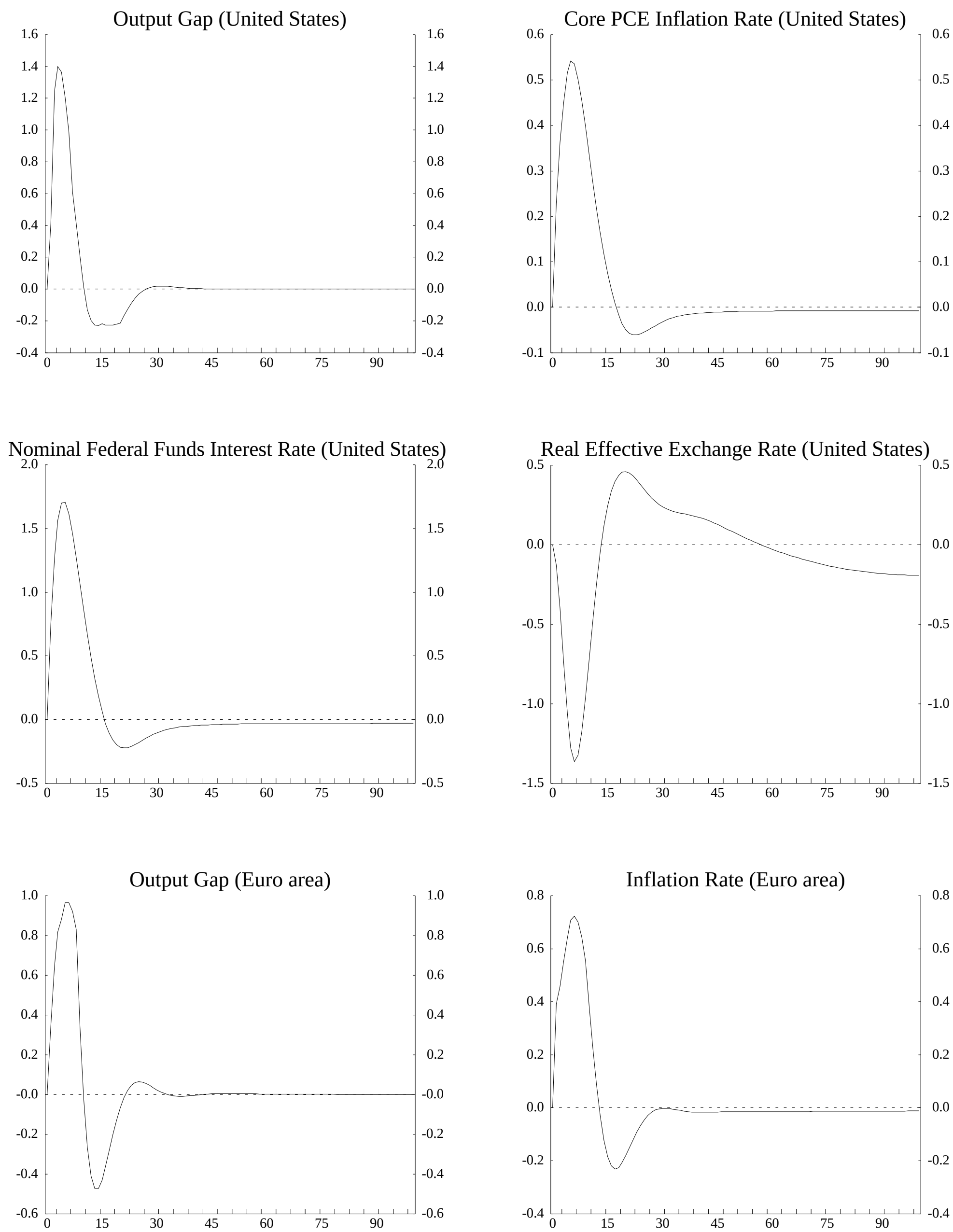
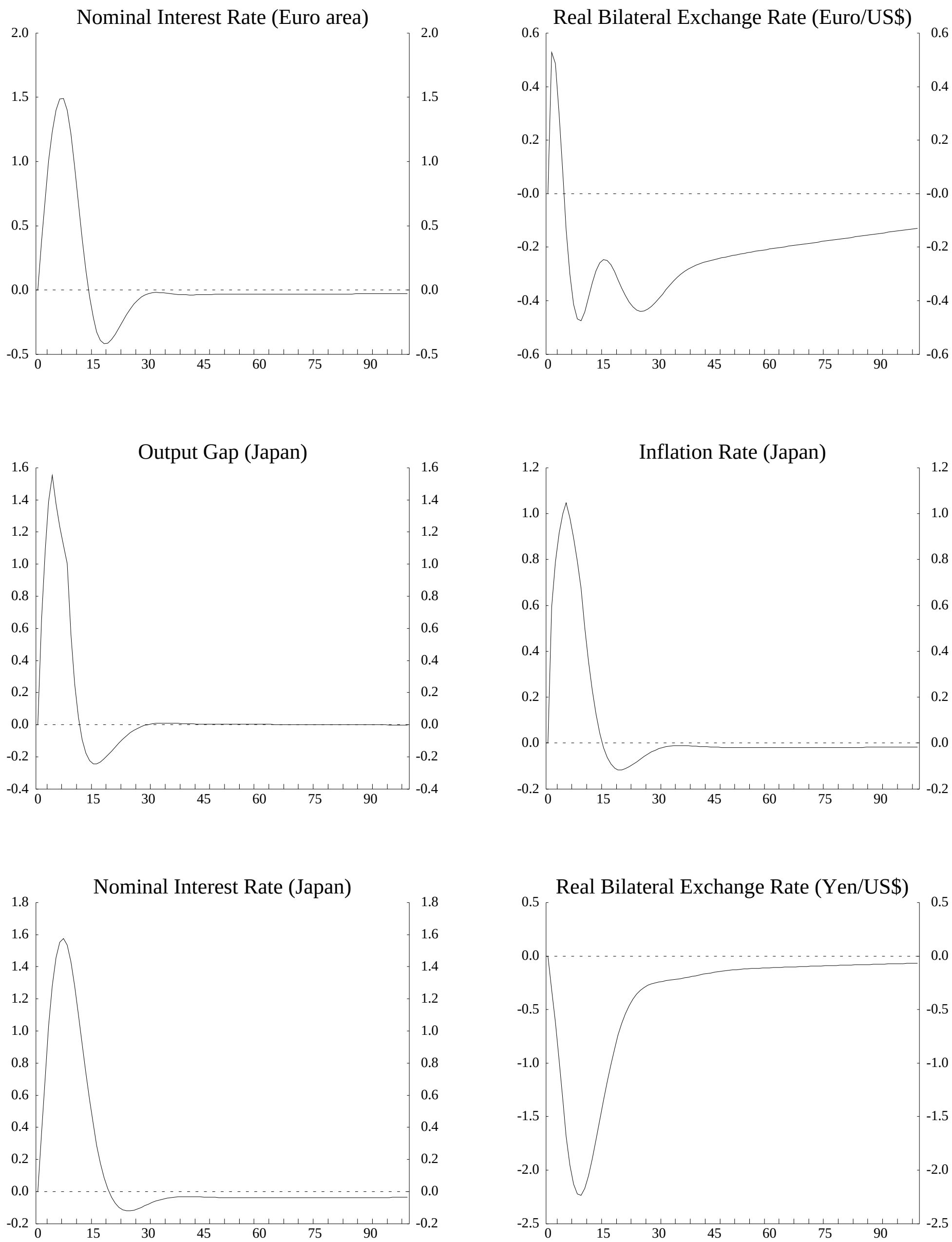


Figure E20:

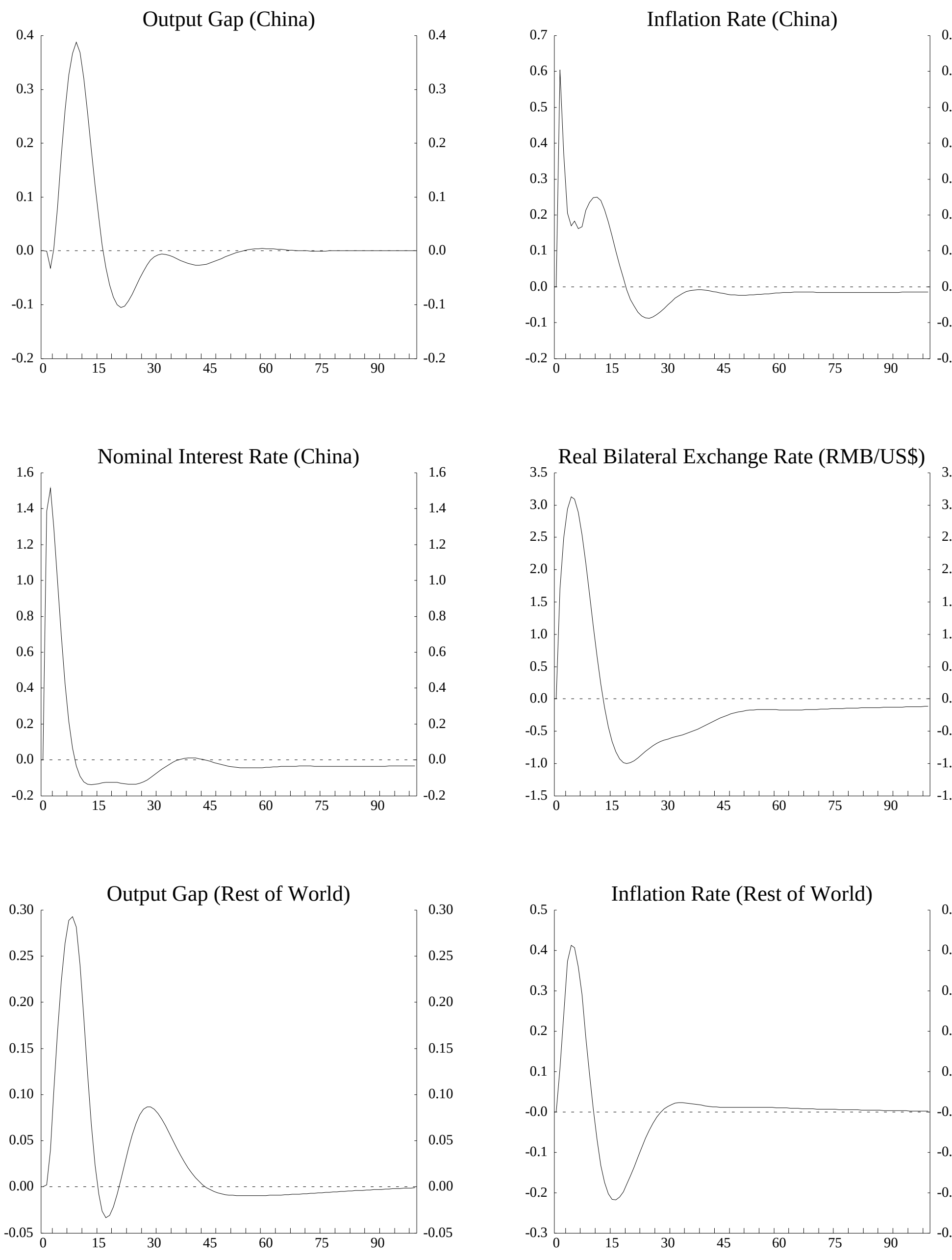
Application: G-3 Fiscal Stimulus Shock



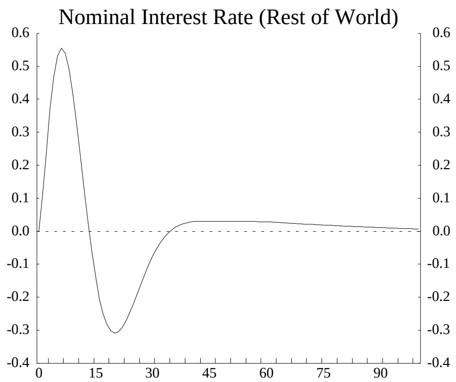
Application: G-3 Fiscal Stimulus Shock (Continued)

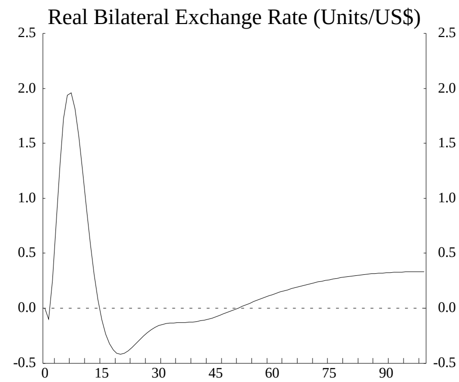


Application: G-3 Fiscal Stimulus Shock (Continued)



Application: G-3 Fiscal Stimulus Shock (Continued)





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