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Monetary Policy Analysis and Forecasting in the Group of Twenty: A Panel Unobserved Components Approach

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Abstract

This paper develops a panel unobserved components model of the monetary transmission mechanism in the world economy, disaggregated into twenty national economies along the lines of the Group of Twenty. This structural macroeconometric model features extensive linkages between the real and financial sectors, both within and across economies. A variety of monetary policy analysis and forecasting applications of the estimated model are demonstrated, based on a Bayesian framework for conditioning on judgment.

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I. INTRODUCTION

The Group of Twenty has recently emerged as the premier forum for international macroeconomic policy coordination. Reflecting its balanced membership of advanced and emerging economies, and their large collective share of the world economy, the Group of Twenty is also a focal point of multilateral surveillance at the International Monetary Fund.

Any attempt to develop and estimate a structural macroeconometric model to inform monetary policy analysis and forecasting in the Group of Twenty must confront formidable challenges related to its scale and complexity. To our knowledge, this paper represents the first fully disaggregated attempt to do so. Our approach is based on the panel unobserved components model introduced by Vitek (2009), which is related to the global vector autoregressive model introduced by Pesaran and others (2004). Both models are designed to inform monetary policy analysis and forecasting in the world economy while internalizing spillovers transmitted via international trade and financial linkages. But they strike a different balance between theoretical coherence and empirical adequacy. Global vector autoregressive models consist of a large number of interconnected reduced form vector autoregressive models of large open economies which are estimated individually subject to small open economy restrictions. In contrast, panel unobserved components models consist of a large number of interconnected structural unobserved components models of large open economies which are estimated jointly subject to cross economy parameter restrictions.

This paper develops a panel unobserved components model of the monetary transmission mechanism in the world economy, disaggregated into twenty national economies along the lines of the Group of Twenty. This structural macroeconometric model features extensive linkages between the real and financial sectors, both within and across economies. The major advanced and emerging economies under consideration are Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Korea, Mexico, Russia, Saudi Arabia, South Africa, Spain, Turkey, the United Kingdom, and the United States. A variety of monetary policy analysis and forecasting applications of the estimated model are demonstrated. These include the measurement of monetary conditions, the analysis of the monetary transmission mechanism, and the generation of conditional forecasts of inflation and output growth. They are based on a Bayesian framework for incorporating judgment concerning the paths of unobserved variables into estimation and forecasting.

This structural macroeconometric model of the world economy fills a gap in the suite of multilateral surveillance models in use at the International Monetary Fund. The Global Projection Model (GPM) documented in Carabenciov and others (2008) is also designed to inform monetary policy analysis and forecasting in the world economy, and strikes a similar balance between theoretical coherence and empirical adequacy. However, estimated variants of it currently cover about five economies, and feature lower levels of disaggregation within their output and financial markets. The Global Integrated Monetary and Fiscal Model (GIMF) documented in Kumhof and others (2010) provides a theoretically coherent framework for the joint analysis of monetary and fiscal policy in the world economy, which is beyond the scope of both of these alternative models. However, calibrated variants of it currently also cover about five economies, and have yet to be adapted to forecasting.

The organization of this paper is as follows. The next section describes a panel unobserved components model of the world economy. Estimation of this model is the subject of section three. Monetary policy analysis within the framework of the estimated model is conducted in section four, while forecasting is undertaken in section five. Finally, section six offers conclusions and recommendations for further research.

II. The Panel Unobserved Components Model

Our panel unobserved components model of the world economy consists of multiple structural unobserved components models of large open economies connected by trade and financial linkages. Within each economy, cyclical components are modeled as a multivariate linear rational expectations model of the monetary transmission mechanism derived from postulated behavioral relationships. These behavioral relationships approximately nest those associated with a variety of alternative structural macroeconomic models derived from microeconomic foundations, conferring robustness to model misspecification. In the interest of parsimony, cross economy equality restrictions are imposed on the structural parameters of these behavioral relationships, the response coefficients of which vary across economies with their structural characteristics. Trend components are modeled as independent random walks, conferring robustness to intermittent structural breaks.

The monetary transmission mechanism in each economy operates via interest rate and exchange rate channels, both of which link the short term nominal interest rate, which serves as the instrument of monetary policy, to consumption price inflation and the output gap, which are generally target variables. Under the interest rate channel, monetary policy affects the output gap and by implication inflation by inducing intertemporal substitution in domestic demand in response to changes in the long term real interest rate. Under the exchange rate channel, monetary policy both directly affects inflation, and indirectly affects the output gap and by implication inflation via intratemporal substitution between domestic and foreign demand, by inducing changes in the real effective exchange rate. A financial accelerator mechanism linked to the real value of an internationally diversified equity portfolio amplifies and propagates both of these channels.

In what follows, $\hat{x}_{i,t}$ denotes the cyclical component of variable $x_{i,t}$, while $\bar{x}_{i,t}$ denotes the trend component of variable $x_{i,t}$. Cyclical and trend components are additively separable, that is $x_{i,t} = \hat{x}_{i,t} + \bar{x}_{i,t}$. Furthermore, $\mathrm{E}_t\, x_{i,t+s}$ denotes the rational expectation of variable $x_{i,t+s}$ associated with economy i, conditional on information available at time t. Finally, $x^f_{i,t}$ denotes the trade weighted average of variable $x_{i,t}$ across the trading partners of economy i, $x^p_{i,t}$ denotes the portfolio weighted average of domestic currency denominated variable $x_{i,t}$

across the investment destinations of economy i, and x_t^w denotes the output weighted average of variable $x_{i,t}$ across all economies.

A. Cyclical Components

The cyclical component of output price inflation $\hat{\pi}_{i,t}^Y$ depends on a linear combination of its past and expected future cyclical components driven by the contemporaneous cyclical component of output according to domestic supply relationship,

$$\hat{\pi}_{i,t}^Y = \phi_{1,1}\hat{\pi}_{i,t-1}^Y + \phi_{1,2}\,\mathrm{E}_t\,\hat{\pi}_{i,t+1}^Y + \theta_{1,1}\ln\hat{Y}_{i,t} + \theta_{1,2}\sum_z \frac{X_i^{COM^z}}{Y_i}\phi_1(L)\Delta\ln(\hat{S}_{i,t}^{USA}\hat{P}_t^{COM^z}) + \varepsilon_{i,t}^{\hat{P}^Y}, \quad (1)$$

where domestic supply shock $\varepsilon_{i,t}^{\hat{P}^Y} \sim \text{iid } \mathcal{N}(0,\sigma_{\hat{P}^Y,i}^2)$. The cyclical component of output price inflation also depends on contemporaneous, past, and expected future changes in the cyclical components of the domestic currency denominated prices of energy and nonenergy commodity exports, where polynomial in the lag operator $\phi_1(L) = 1 - \phi_{1,1}L - \phi_{1,2}\,\mathrm{E}_t\,L^{-1}$. The response coefficients of this relationship vary across economies with their commodity export intensity, measured by the ratio of energy or nonenergy commodity exports to output $\frac{X_i^{COM^z}}{Y_i}$.

The cyclical component of consumption price inflation $\hat{\pi}_{i,t}^C$ depends on a linear combination of its past and expected future cyclical components driven by the contemporaneous cyclical component of output according to supply relationship,

$$\begin{aligned}\hat{\pi}_{i,t}^C &= \phi_{1,1}\hat{\pi}_{i,t-1}^C + \phi_{1,2}\,\mathrm{E}_t\,\hat{\pi}_{i,t+1}^C + \theta_{1,1}\ln\hat{Y}_{i,t} \\ &\quad + \theta_{2,1}\frac{M_i}{Y_i}\phi_1(L)\Delta\ln\hat{Q}_{i,t} + \theta_{2,2}\sum_z\frac{M_i^{COM^z}}{Y_i}\phi_1(L)\Delta\ln(\hat{S}_{i,t}^{USA}\hat{P}_t^{COM^z}) + \varepsilon_{i,t}^{\hat{P}^Y} + \phi_1(L)\varepsilon_{i,t}^{\hat{P}^M},\end{aligned} \quad (2)$$

where foreign supply shock $\varepsilon_{i,t}^{\hat{P}^M} \sim \text{iid } \mathcal{N}(0,\sigma_{\hat{P}^M,i}^2)$. The cyclical component of consumption price inflation also depends on contemporaneous, past, and expected future changes in the cyclical components of the real effective exchange rate and the domestic currency denominated prices of energy and nonenergy commodity imports. The response coefficients of this relationship vary across economies with their commodity import intensity, measured by the ratio of energy or nonenergy commodity imports to output $\frac{M_i^{COM^z}}{Y_i}$.

The cyclical component of output $\ln\hat{Y}_{i,t}$ follows a stationary first order autoregressive process driven by a monetary conditions index according to demand relationship,

$$\begin{aligned}\ln\hat{Y}_{i,t} &= \phi_{3,1}\ln\hat{Y}_{i,t-1} + \theta_{3,1}\left(1-\frac{M_i}{Y_i}\right)\left(\hat{r}_{i,t}^L + \theta_{3,2}\ln\frac{\hat{P}_{i,t}^{STK,p}}{\hat{P}_{i,t}^C}\right) \\ &\quad + \theta_{4,1}\frac{X_i}{Y_i}\phi_3(L)\ln\hat{D}_{i,t}^f + \theta_{4,2}\frac{X_i+M_i}{Y_i}\phi_3(L)\ln\hat{Q}_{i,t} + \left(1-\frac{M_i}{Y_i}\right)\nu_{i,t}^{\hat{D}} + \frac{X_i}{Y_i}\phi_3(L)\nu_{i,t}^{\hat{X}},\end{aligned} \quad (3)$$

where foreign demand shock $\nu^{\hat{X}}_{i,t} = \rho_{\hat{X}} \nu^{\hat{X}}_{i,t-1} + \varepsilon^{\hat{X}}_{i,t}$ with $\varepsilon^{\hat{X}}_{i,t} \sim \text{iid } \mathcal{N}(0, \sigma^2_{\hat{X},i})$. Reflecting the existence of international trade and financial linkages, this monetary conditions index is defined as a linear combination of a financial conditions index and the contemporaneous and past cyclical components of the real effective exchange rate.[2] The cyclical component of output also depends on the contemporaneous and past cyclical components of foreign demand, where polynomial in the lag operator $\phi_3(L) = 1 - \phi_{3,1} L$. The response coefficients of this relationship vary across economies with their trade openness, measured by the ratio of exports to output $\frac{X_i}{Y_i}$ or imports to output $\frac{M_i}{Y_i}$.

The cyclical component of domestic demand $\ln \hat{D}_{i,t}$ follows a stationary first order autoregressive process driven by a financial conditions index according to domestic demand relationship,

$$\ln \hat{D}_{i,t} = \phi_{3,1} \ln \hat{D}_{i,t-1} + \theta_{3,1} \left(\hat{r}^L_{i,t} + \theta_{3,2} \ln \frac{\hat{P}^{STK,p}_{i,t}}{\hat{P}^C_{i,t}} \right) + \nu^{\hat{D}}_{i,t}, \tag{4}$$

where domestic demand shock $\nu^{\hat{D}}_{i,t} = \rho_{\hat{D}} \nu^{\hat{D}}_{i,t-1} + \varepsilon^{\hat{D}}_{i,t}$ with $\varepsilon^{\hat{D}}_{i,t} \sim \text{iid } \mathcal{N}(0, \sigma^2_{\hat{D},i})$. This financial conditions index is defined as a linear combination of the contemporaneous cyclical components of the long term real interest rate and the real value of an internationally diversified equity portfolio.

The cyclical component of the short term nominal interest rate $\hat{i}^S_{i,t}$ depends on a weighted average of its past and desired cyclical components according to monetary policy rule,

$$\hat{i}^S_{i,t} = \phi_{5,1} \hat{i}^S_{i,t-1} + (1 - \phi_{5,1}) \left[I_i (\theta_{5,1} \hat{\pi}^C_{i,t} + \theta_{5,2} \ln \hat{Y}_{i,t}) + (1 - I_i) \theta_{5,3} \ln \hat{S}^{USA}_{i,t} \right] + \varepsilon^{\hat{i}^S}_{i,t}, \tag{5}$$

where monetary policy shock $\varepsilon^{\hat{i}^S}_{i,t} \sim \text{iid } \mathcal{N}(0, \sigma^2_{\hat{i}^S,i})$. Under a flexible inflation targeting regime $I_i = 1$ and the desired cyclical component of the short term nominal interest rate responds to the contemporaneous cyclical components of consumption price inflation and output, while under a fixed exchange rate regime $I_i = 0$ and it responds to the contemporaneous cyclical component of the nominal bilateral exchange rate. For economies belonging to a currency union, the target variables entering into their common monetary policy rule are expressed as output weighted averages across union members. The cyclical component of the short term real interest rate $\hat{r}^S_{i,t}$ satisfies $\hat{r}^S_{i,t} = \hat{i}^S_{i,t} - \mathrm{E}_t \hat{\pi}^C_{i,t+1}$.

The cyclical component of the long term real interest rate $\hat{r}^L_{i,t}$ depends on a linear combination of its past and expected future cyclical components driven by the contemporaneous cyclical component of the short term real interest rate according to term structure relationship,

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[2]This monetary conditions index $\hat{I}^{MCI}_{i,t}$ is defined as $\hat{I}^{MCI}_{i,t} = \hat{I}^{FCI}_{i,t} + \frac{\theta_{4,2}}{\theta_{3,1}} \frac{X_i + M_i}{Y_i} \left(1 - \frac{M_i}{Y_i}\right)^{-1} \phi_3(L) \ln \hat{Q}_{i,t}$, where financial conditions index $\hat{I}^{FCI}_{i,t}$ satisfies $\hat{I}^{FCI}_{i,t} = \hat{r}^L_{i,t} + \theta_{3,2} \ln \frac{\hat{P}^{STK,p}_{i,t}}{\hat{P}^C_{i,t}}$.

$$\hat{r}_{i,t}^{L} = \phi_{6,1}\hat{r}_{i,t-1}^{L} + \phi_{6,2}\,\mathrm{E}_t\,\hat{r}_{i,t+1}^{L} + \theta_{6,1}\hat{r}_{i,t}^{S} + \varepsilon_{i,t}^{\hat{i}^L}, \tag{6}$$

where liquidity risk premium shock $\varepsilon_{i,t}^{\hat{i}^L} \sim \text{iid } \mathcal{N}(0,\sigma_{\hat{i}^L,i}^2)$. The cyclical component of the long term nominal interest rate $\hat{i}_{i,t}^{L}$ satisfies $\hat{r}_{i,t}^{L} = \hat{i}_{i,t}^{L} - \mathrm{E}_t\,\hat{\bar{\pi}}_{i,t+1}^{C}$.

The cyclical component of the price of equity $\ln \hat{P}_{i,t}^{STK}$, deflated by the price of consumption, depends on a linear combination of its past and expected future cyclical components driven by the contemporaneous cyclical components of output and the short term real interest rate,

$$\ln\frac{\hat{P}_{i,t}^{STK}}{\hat{P}_{i,t}^{C}} = \phi_{7,1}\ln\frac{\hat{P}_{i,t-1}^{STK}}{\hat{P}_{i,t-1}^{C}} + \phi_{7,2}\,\mathrm{E}_t\ln\frac{\hat{P}_{i,t+1}^{STK}}{\hat{P}_{i,t+1}^{C}} + \theta_{7,1}\ln\hat{Y}_{i,t} + \theta_{7,2}\hat{r}_{i,t}^{S} + \varepsilon_{i,t}^{\hat{P}^{STK}}, \tag{7}$$

where equity risk premium shock $\varepsilon_{i,t}^{\hat{P}^{STK}} \sim \text{iid } \mathcal{N}(0,\sigma_{\hat{P}^{STK},i}^2)$.

The cyclical component of the real bilateral exchange rate $\ln \hat{Q}_{i,t}^{USA}$ depends on a linear combination of its past and expected future cyclical components driven by the contemporaneous cyclical component of the short term real interest rate differential,

$$\ln\hat{Q}_{i,t}^{USA} = \phi_{8,1}\ln\hat{Q}_{i,t-1}^{USA} + \phi_{8,2}\,\mathrm{E}_t\ln\hat{Q}_{i,t+1}^{USA} + \theta_{8,j}(\hat{r}_{i,t}^{S} - \hat{r}_{USA,t}^{S}) + \varepsilon_{i,t}^{\hat{S}}, \tag{8}$$

where exchange rate risk premium shock $\varepsilon_{i,t}^{\hat{S}} \sim \text{iid } \mathcal{N}(0,\sigma_{\hat{S},i}^2)$. The sensitivity of the real bilateral exchange rate to changes in the short term real interest rate differential depends on capital controls, with $j=1$ in their absence and $j=2$ in their presence. The cyclical component of the nominal bilateral exchange rate $\ln\hat{S}_{i,t}^{USA}$ satisfies $\ln\hat{Q}_{i,t}^{USA} = \ln\hat{S}_{i,t}^{USA} + \ln\hat{P}_{USA,t}^{C} - \ln\hat{P}_{i,t}^{C}$.[3]

The cyclical component of the change in the price of energy or nonenergy commodities $\ln\hat{P}_{t}^{COM^z}$ depends on a linear combination of its past and expected future cyclical components driven by the contemporaneous cyclical component of world output,

$$\Delta\ln\hat{P}_{t}^{COM^z} = \phi_{9,1}\Delta\ln\hat{P}_{t-1}^{COM^z} + \phi_{9,2}\,\mathrm{E}_t\,\Delta\ln\hat{P}_{t+1}^{COM^z} + \theta_{9,j}\ln\hat{Y}_{t}^{w} + \varepsilon_{t}^{\hat{P}^{COM^z}}, \tag{9}$$

where commodity price shock $\varepsilon_{t}^{\hat{P}^{COM^z}} \sim \text{iid } \mathcal{N}(0,\sigma_{\hat{P}^{COM},z}^2)$. The sensitivity of the change in the price of commodities to changes in world output depends on their type $z\in\{e,n\}$, with $j=1$ for energy commodities and $j=2$ for nonenergy commodities. As an identifying restriction, all innovations are assumed to be independent, which combined with our distributional assumptions implies multivariate normality.

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[3]It can be shown that the cyclical component of the nominal effective exchange rate $\ln\hat{S}_{i,t}$ satisfies $\ln\hat{S}_{i,t} = \ln\hat{S}_{i,t}^{USA} - \sum_{j=1}^{N} w_{i,j}\ln\hat{S}_{j,t}^{USA}$, while the cyclical component of the real effective exchange rate $\ln\hat{Q}_{i,t}$ satisfies $\ln\hat{Q}_{i,t} = \ln\hat{Q}_{i,t}^{USA} - \sum_{j=1}^{N} w_{i,j}\ln\hat{Q}_{j,t}^{USA}$, where $w_{i,j}$ denotes the bilateral trade weight for economy i with respect to economy j, and N denotes the number of economies. Note that $\ln\hat{Q}_{i,t} = \ln\hat{S}_{i,t} + \ln\hat{P}_{i,t}^{C,f} - \ln\hat{P}_{i,t}^{C}$.

B. Trend Components

The growth rates of the trend components of the price of output $\ln \overline{P}^{Y}_{i,t}$, the price of consumption $\ln \overline{P}^{C}_{i,t}$, output $\ln \overline{Y}_{i,t}$, domestic demand $\ln \overline{D}_{i,t}$, the price of equity $\ln \overline{P}^{STK}_{i,t}$, and the price of energy or nonenergy commodities $\ln \overline{P}^{COM^z}_{t}$ follow random walks:

$$\Delta \ln \overline{P}^{Y}_{i,t} = \Delta \ln \overline{P}^{Y}_{i,t-1} + \varepsilon^{\overline{P}^Y}_{i,t},\ \varepsilon^{\overline{P}^Y}_{i,t} \sim \text{iid } \mathcal{N}(0, \sigma^2_{\overline{P}^Y,i}), \tag{10}$$

$$\Delta \ln \overline{P}^{C}_{i,t} = \Delta \ln \overline{P}^{C}_{i,t-1} + \varepsilon^{\overline{P}^C}_{i,t},\ \varepsilon^{\overline{P}^C}_{i,t} \sim \text{iid } \mathcal{N}(0, \sigma^2_{\overline{P}^C,i}), \tag{11}$$

$$\Delta \ln \overline{Y}_{i,t} = \Delta \ln \overline{Y}_{i,t-1} + \varepsilon^{\overline{Y}}_{i,t},\ \varepsilon^{\overline{Y}}_{i,t} \sim \text{iid } \mathcal{N}(0, \sigma^2_{\overline{Y},i}), \tag{12}$$

$$\Delta \ln \overline{D}_{i,t} = \Delta \ln \overline{D}_{i,t-1} + \varepsilon^{\overline{D}}_{i,t},\ \varepsilon^{\overline{D}}_{i,t} \sim \text{iid } \mathcal{N}(0, \sigma^2_{\overline{D},i}), \tag{13}$$

$$\Delta \ln \overline{P}^{STK}_{i,t} = \Delta \ln \overline{P}^{STK}_{i,t-1} + \varepsilon^{\overline{P}^{STK}}_{i,t},\ \varepsilon^{\overline{P}^{STK}}_{i,t} \sim \text{iid } \mathcal{N}(0, \sigma^2_{\overline{P}^{STK},i}), \tag{14}$$

$$\Delta \ln \overline{P}^{COM^z}_{t} = \Delta \ln \overline{P}^{COM^z}_{t-1} + \varepsilon^{\overline{P}^{COM^z}}_{t},\ \varepsilon^{\overline{P}^{COM^z}}_{t} \sim \text{iid } \mathcal{N}(0, \sigma^2_{\overline{P}^{COM},z}). \tag{15}$$

The trend components of the short term nominal interest rate $\overline{i}^{S}_{i,t}$, long term nominal interest rate $\overline{i}^{L}_{i,t}$, and growth rate of the nominal bilateral exchange rate $\ln \overline{S}^{USA}_{i,t}$ also follow random walks:

$$\overline{i}^{S}_{i,t} = \overline{i}^{S}_{i,t-1} + \varepsilon^{\overline{i}^S}_{i,t},\ \varepsilon^{\overline{i}^S}_{i,t} \sim \text{iid } \mathcal{N}(0, \sigma^2_{\overline{i}^S,i}), \tag{16}$$

$$\overline{i}^{L}_{i,t} = \overline{i}^{L}_{i,t-1} + \varepsilon^{\overline{i}^L}_{i,t},\ \varepsilon^{\overline{i}^L}_{i,t} \sim \text{iid } \mathcal{N}(0, \sigma^2_{\overline{i}^L,i}), \tag{17}$$

$$\Delta \ln \overline{S}^{USA}_{i,t} = \Delta \ln \overline{S}^{USA}_{i,t-1} + \varepsilon^{\overline{S}}_{i,t},\ \varepsilon^{\overline{S}}_{i,t} \sim \text{iid } \mathcal{N}(0, \sigma^2_{\overline{S},i}). \tag{18}$$

The trend component of the short term real interest rate $\overline{r}^{S}_{i,t}$ satisfies $\overline{r}^{S}_{i,t} = \overline{i}^{S}_{i,t} - \mathrm{E}_t\, \overline{\pi}^{C}_{i,t+1}$, the trend component of the long term real interest rate $\overline{r}^{L}_{i,t}$ satisfies $\overline{r}^{L}_{i,t} = \overline{i}^{L}_{i,t} - \mathrm{E}_t\, \overline{\pi}^{C}_{i,t+1}$, and the trend component of the real bilateral exchange rate $\ln \overline{Q}^{USA}_{i,t}$ satisfies $\ln \overline{Q}^{USA}_{i,t} = \ln \overline{S}^{USA}_{i,t} + \ln \overline{P}^{C}_{USA,t} - \ln \overline{P}^{C}_{i,t}$. As an identifying restriction, all innovations are assumed to be independent.

III. Estimation

The traditional econometric interpretation of this panel unobserved components model of the world economy regards it as a representation of the joint probability distribution of the data. We employ a Bayesian estimation procedure which respects this traditional econometric interpretation while conditioning on prior information concerning the values of structural parameters, and judgment concerning the paths of trend components. In addition to mitigating potential model misspecification and identification problems, exploiting this additional information may be expected to yield efficiency gains in estimation.

A. Estimation Procedure

Let $\boldsymbol{x}_t$ denote a vector stochastic process consisting of the levels of $N_{\boldsymbol{x}}$ nonpredetermined endogenous variables, of which $N_{\boldsymbol{y}}$ are observed. The cyclical components of this vector stochastic process satisfy second order stochastic linear difference equation

$$\boldsymbol{A}_0\hat{\boldsymbol{x}}_t = \boldsymbol{A}_1\hat{\boldsymbol{x}}_{t-1} + \boldsymbol{A}_2\mathrm{E}_t\hat{\boldsymbol{x}}_{t+1} + \boldsymbol{A}_3\hat{\boldsymbol{v}}_t, \tag{19}$$

where vector stochastic process $\hat{\boldsymbol{v}}_t$ consists of the cyclical components of $N_{\boldsymbol{v}}$ exogenous variables. This vector stochastic process satisfies stationary first order stochastic linear difference equation

$$\hat{\boldsymbol{v}}_t = \boldsymbol{B}_1\hat{\boldsymbol{v}}_{t-1} + \boldsymbol{\varepsilon}_{1,t}, \tag{20}$$

where $\boldsymbol{\varepsilon}_{1,t} \sim \text{iid } \mathcal{N}(\boldsymbol{0}, \boldsymbol{\Sigma}_1)$. If there exists a unique stationary solution to this multivariate linear rational expectations model, then it may be expressed as:

$$\hat{\boldsymbol{x}}_t = \boldsymbol{C}_1\hat{\boldsymbol{x}}_{t-1} + \boldsymbol{C}_2\hat{\boldsymbol{v}}_t. \tag{21}$$

This unique stationary solution is calculated with the procedure due to Klein (2000).

The trend components of vector stochastic process $\boldsymbol{x}_t$ satisfy first order stochastic linear difference equation

$$\boldsymbol{D}_0\bar{\boldsymbol{x}}_t = \boldsymbol{D}_1\boldsymbol{u}_t + \boldsymbol{D}_2\bar{\boldsymbol{x}}_{t-1} + \boldsymbol{\varepsilon}_{2,t}, \tag{22}$$

where $\boldsymbol{\varepsilon}_{2,t} \sim \text{iid } \mathcal{N}(\boldsymbol{0}, \boldsymbol{\Sigma}_2)$. Vector stochastic process $\boldsymbol{u}_t$ consists of the levels of $N_{\boldsymbol{u}}$ common stochastic trends, and satisfies nonstationary first order stochastic linear difference equation

$$\boldsymbol{u}_t = \boldsymbol{u}_{t-1} + \boldsymbol{\varepsilon}_{3,t}, \tag{23}$$

where $\boldsymbol{\varepsilon}_{3,t} \sim \text{iid } \mathcal{N}(\boldsymbol{0}, \boldsymbol{\Sigma}_3)$. Cyclical and trend components are additively separable, that is $\boldsymbol{x}_t = \hat{\boldsymbol{x}}_t + \bar{\boldsymbol{x}}_t$.

Let $\boldsymbol{y}_t$ denote a vector stochastic process consisting of the levels of $N_{\boldsymbol{y}}$ observed nonpredetermined endogenous variables. Also, let $\boldsymbol{z}_t$ denote a vector stochastic process consisting of the levels of $N_{\boldsymbol{x}} - N_{\boldsymbol{y}}$ unobserved nonpredetermined endogenous variables, the cyclical components of $N_{\boldsymbol{x}}$ nonpredetermined endogenous variables, the trend components of $N_{\boldsymbol{x}}$ nonpredetermined endogenous variables, the cyclical components of $N_{\boldsymbol{v}}$ exogenous variables, and the levels of $N_{\boldsymbol{u}}$ common stochastic trends. Given unique stationary solution (21), these vector stochastic processes have linear state space representation

$$\boldsymbol{y}_t = \boldsymbol{F}_1\boldsymbol{z}_t, \tag{24}$$

$$\boldsymbol{z}_t = \boldsymbol{G}_1\boldsymbol{z}_{t-1} + \boldsymbol{G}_2\boldsymbol{\varepsilon}_{4,t}, \tag{25}$$

where $\boldsymbol{\varepsilon}_{4,t} \sim \text{iid } \mathcal{N}(\mathbf{0}, \boldsymbol{\Sigma}_4)$ and $\boldsymbol{z}_0 \sim \mathcal{N}(\boldsymbol{z}_{0|0}, \boldsymbol{P}_{0|0})$. Let $\boldsymbol{w}_t$ denote a vector stochastic process consisting of alternative estimates or forecasts of $N_{\boldsymbol{w}}$ linearly independent linear combinations of unobserved state variables. Following Vitek (2009), suppose that this vector stochastic process satisfies

$$\boldsymbol{w}_t = \boldsymbol{H}_1 \boldsymbol{z}_t + \boldsymbol{\varepsilon}_{5,t}, \tag{26}$$

where $\boldsymbol{\varepsilon}_{5,t} \sim \text{iid } \mathcal{N}(\mathbf{0}, \boldsymbol{\Sigma}_{5,t})$. Conditional on known parameter values, this signal equation imposes judgment on linear combinations of unobserved state variables in the form of a set of stochastic restrictions of time dependent tightness. The signal and state innovation vectors are assumed to be independent, while the initial state vector is assumed to be independent from the signal and state innovation vectors, which combined with our distributional assumptions implies multivariate normality.

Conditional on the parameters associated with these signal and state equations, estimates of unobserved state vector $\boldsymbol{z}_t$ and its mean squared error matrix $\boldsymbol{P}_t$ may be calculated with the filter due to Kalman (1960). Given initial conditions $\boldsymbol{z}_{0|0}$ and $\boldsymbol{P}_{0|0}$, estimates conditional on information available at time $t-1$ satisfy prediction equations:

$$\boldsymbol{z}_{t|t-1} = \boldsymbol{G}_1 \boldsymbol{z}_{t-1|t-1}, \tag{27}$$

$$\boldsymbol{P}_{t|t-1} = \boldsymbol{G}_1 \boldsymbol{P}_{t-1|t-1} \boldsymbol{G}_1^\top + \boldsymbol{G}_2 \boldsymbol{\Sigma}_4 \boldsymbol{G}_2^\top, \tag{28}$$

$$\boldsymbol{y}_{t|t-1} = \boldsymbol{F}_1 \boldsymbol{z}_{t|t-1}, \tag{29}$$

$$\boldsymbol{Q}_{t|t-1} = \boldsymbol{F}_1 \boldsymbol{P}_{t|t-1} \boldsymbol{F}_1^\top, \tag{30}$$

$$\boldsymbol{w}_{t|t-1} = \boldsymbol{H}_1 \boldsymbol{z}_{t|t-1}, \tag{31}$$

$$\boldsymbol{R}_{t|t-1} = \boldsymbol{H}_1 \boldsymbol{P}_{t|t-1} \boldsymbol{H}_1^\top + \boldsymbol{\Sigma}_{5,t}. \tag{32}$$

Given these predictions, under the assumption of multivariate normally distributed signal and state innovation vectors, together with conditionally contemporaneously uncorrelated signal vectors, estimates conditional on information available at time t, and judgment concerning the paths of linear combinations of state variables through time t, satisfy Bayesian updating equations

$$\boldsymbol{z}_{t|t} = \boldsymbol{z}_{t|t-1} + \boldsymbol{K}_{\boldsymbol{y}_t} (\boldsymbol{y}_t - \boldsymbol{y}_{t|t-1}) + \boldsymbol{K}_{\boldsymbol{w}_t} (\boldsymbol{w}_t - \boldsymbol{w}_{t|t-1}), \tag{33}$$

$$\boldsymbol{P}_{t|t} = \boldsymbol{P}_{t|t-1} - \boldsymbol{K}_{\boldsymbol{y}_t} \boldsymbol{F}_1 \boldsymbol{P}_{t|t-1} - \boldsymbol{K}_{\boldsymbol{w}_t} \boldsymbol{H}_1 \boldsymbol{P}_{t|t-1}, \tag{34}$$

where $\boldsymbol{K}_{\boldsymbol{y}_t} = \boldsymbol{P}_{t|t-1} \boldsymbol{F}_1^\top \boldsymbol{Q}_{t|t-1}^{-1}$ and $\boldsymbol{K}_{\boldsymbol{w}_t} = \boldsymbol{P}_{t|t-1} \boldsymbol{H}_1^\top \boldsymbol{R}_{t|t-1}^{-1}$. Given terminal conditions $\boldsymbol{z}_{T|T}$ and $\boldsymbol{P}_{T|T}$ obtained from the final evaluation of these prediction and updating equations, estimates conditional on information available at time T, and judgment concerning the paths of linear combinations of state variables through time T, satisfy Bayesian smoothing equations

$$z_{t|T} = z_{t|t} + J_t(z_{t+1|T} - z_{t+1|t}), \tag{35}$$

$$P_{t|T} = P_{t|t} + J_t(P_{t+1|T} - P_{t+1|t})J_t^{\mathsf{T}}, \tag{36}$$

where $J_t = P_{t|t} G_2^{\mathsf{T}} P_{t+1|t}^{-1}$. Under our distributional assumptions, recursive forward evaluation of equations (27) through (34), followed by recursive backward evaluation of equations (35) and (36), yields mean squared error optimal conditional estimates of the unobserved state vector.

Let $\theta \in \Theta \subset \mathbb{R}^K$ denote a K dimensional vector containing the parameters associated with the signal and state equations of this linear state space model. The Bayesian estimator of this parameter vector has posterior density function

$$f(\theta \mid \mathcal{I}_T) \propto f(\mathcal{I}_T \mid \theta) f(\theta), \tag{37}$$

where $\mathcal{I}_t = \{\{y_s\}_{s=1}^t, \{w_s\}_{s=1}^t\}$. Under the assumption of multivariate normally distributed signal and state innovation vectors, together with conditionally contemporaneously uncorrelated signal vectors, conditional density function $f(\mathcal{I}_T \mid \theta)$ satisfies:

$$f(\mathcal{I}_T \mid \theta) = \prod_{t=1}^{T} f(y_t \mid \mathcal{I}_{t-1}, \theta) \cdot \prod_{t=1}^{T} f(w_t \mid \mathcal{I}_{t-1}, \theta). \tag{38}$$

Under our distributional assumptions, conditional density functions $f(y_t \mid \mathcal{I}_{t-1}, \theta)$ and $f(w_t \mid \mathcal{I}_{t-1}, \theta)$ satisfy:

$$f(y_t \mid \mathcal{I}_{t-1}, \theta) = (2\pi)^{-\frac{N_y}{2}} \mid Q_{t|t-1} \mid^{-\frac{1}{2}} \exp\left\{-\frac{1}{2}(y_t - y_{t|t-1})^{\mathsf{T}} Q_{t|t-1}^{-1}(y_t - y_{t|t-1})\right\}, \tag{39}$$

$$f(w_t \mid \mathcal{I}_{t-1}, \theta) = (2\pi)^{-\frac{N_w}{2}} \mid R_{t|t-1} \mid^{-\frac{1}{2}} \exp\left\{-\frac{1}{2}(w_t - w_{t|t-1})^{\mathsf{T}} R_{t|t-1}^{-1}(w_t - w_{t|t-1})\right\}. \tag{40}$$

Prior information concerning parameter vector θ is summarized by a multivariate normal prior distribution having mean vector θ_1 and covariance matrix Ω:

$$f(\theta) = (2\pi)^{-\frac{K}{2}} \mid \Omega \mid^{-\frac{1}{2}} \exp\left\{-\frac{1}{2}(\theta - \theta_1)^{\mathsf{T}} \Omega^{-1}(\theta - \theta_1)\right\}. \tag{41}$$

Independent priors are represented by a diagonal covariance matrix, under which diffuse priors are represented by infinite variances.

Inference on the parameters is based on an asymptotic normal approximation to the posterior distribution around its mode. Under regularity conditions stated in Geweke (2005), posterior mode $\hat{\theta}_T$ satisfies

$$\sqrt{T}(\hat{\theta}_T - \theta_0) \overset{d}{\to} \mathcal{N}(\mathbf{0}, -\mathcal{H}_0^{-1}), \tag{42}$$

where $\boldsymbol{\theta}_0 \in \boldsymbol{\Theta}$ denotes the pseudotrue parameter vector. Following Engle and Watson (1981), Hessian $\mathcal{H}_0$ is estimated by:

$$\begin{aligned}\hat{\mathcal{H}}_T = &-\frac{1}{T}\sum_{t=1}^{T}\left[\nabla_{\theta}\boldsymbol{y}_{t|t-1}^{\mathsf{T}}\boldsymbol{Q}_{t|t-1}^{-1}\nabla_{\theta}\boldsymbol{y}_{t|t-1}+\frac{1}{2}\nabla_{\theta}\boldsymbol{Q}_{t|t-1}^{\mathsf{T}}(\boldsymbol{Q}_{t|t-1}^{-1}\otimes\boldsymbol{Q}_{t|t-1}^{-1})\nabla_{\theta}\boldsymbol{Q}_{t|t-1}\right]\\ &-\frac{1}{T}\sum_{t=1}^{T}\left[\nabla_{\theta}\boldsymbol{w}_{t|t-1}^{\mathsf{T}}\boldsymbol{R}_{t|t-1}^{-1}\nabla_{\theta}\boldsymbol{w}_{t|t-1}+\frac{1}{2}\nabla_{\theta}\boldsymbol{R}_{t|t-1}^{\mathsf{T}}(\boldsymbol{R}_{t|t-1}^{-1}\otimes\boldsymbol{R}_{t|t-1}^{-1})\nabla_{\theta}\boldsymbol{R}_{t|t-1}\right]-\frac{1}{T}\boldsymbol{\Omega}^{-1}.\end{aligned} \tag{43}$$

This estimator of the Hessian depends only on first derivatives and is negative semidefinite.

B. Estimation Results

Joint estimation of the parameters and unobserved components of our panel unobserved components model of the world economy is based on the levels of a total of one hundred fifty six endogenous variables observed for twenty economies over the period 1999Q1 through 2009Q4. The economies under consideration are Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Korea, Mexico, Russia, Saudi Arabia, South Africa, Spain, Turkey, the United Kingdom, and the United States. The observed endogenous variables under consideration are the price of output, the price of consumption, the quantity of output, the quantity of domestic demand, the short term nominal interest rate, the long term nominal interest rate, the price of equity, the nominal bilateral exchange rate, and the prices of energy and nonenergy commodities. For a detailed description of the data set, please refer to the Appendix.

Parameters

The set of parameters associated with our panel unobserved components model is partitioned into two subsets. Those parameters associated with the conditional mean function are estimated conditional on informative independent priors, while those parameters associated exclusively with the conditional variance function are estimated conditional on diffuse priors.

The marginal prior distributions of those parameters associated with the conditional mean function are centered within the range of estimates reported in the existing empirical literature, where available. The conduct of monetary policy is represented by a flexible inflation targeting regime in all economies except for China and Saudi Arabia, where it is represented by a fixed exchange rate regime. Capital controls apply in Argentina, China, India, and Russia. Great ratios and bilateral trade and equity portfolio weights entering into the conditional mean function are calibrated to match their observed values in 2005. All world output shares and bilateral trade and equity portfolio weights are normalized to sum to one.

Judgment concerning the paths of trend components is generated by passing the levels of all observed endogenous variables through the filter described in Hodrick and Prescott (1997). Stochastic restrictions on the trend components of all observed endogenous variables are derived from these preliminary estimates, with a time varying innovation covariance matrix set equal to that obtained from unrestricted estimation. Initial conditions for the cyclical components of exogenous variables are given by their unconditional means and variances, while the initial values of all other state variables are treated as parameters, and are calibrated to match functions of initial realizations of the levels of observed endogenous variables, or preliminary estimates of their trend components calculated with the filter due to Hodrick and Prescott (1997).

The posterior mode is calculated by numerically maximizing the logarithm of the posterior density kernel with a modified steepest ascent algorithm. Parameter estimation results pertaining to the period 1999Q3 through 2009Q4 are reported in Table 1. The sufficient condition for the existence of a unique stationary rational expectations equilibrium due to Klein (2000) is satisfied in a neighborhood around the posterior mode, while our estimator of the Hessian is not nearly singular at the posterior mode, suggesting that the linear state space representation of our panel unobserved components model is locally identified.

The posterior modes of most structural parameters are close to their prior means, reflecting the imposition of tight priors to preserve empirically plausible impulse response dynamics. The estimated variances of shocks driving variation in cyclical components are all well within the range of estimates reported in the existing empirical literature, after accounting for data rescaling. The estimated variances of shocks driving variation in trend components vary considerably across economies and observed endogenous variables.

Unobserved Components

The output gap and the monetary conditions gap are both theoretically motivated candidate indicators of inflationary pressure. The monetary conditions gap is also a theoretically motivated candidate indicator of business cycle fluctuations. Smoothed estimates of the output gap are plotted in Figure 1, while smoothed estimates of the monetary conditions gap are plotted in Figure 2. These estimates are conditional on past, present and future information.

The output gap is a measure of the position of the business cycle. Within the framework of our panel unobserved components model, the estimated output gap may be decomposed into contributions from domestic demand and net exports. Our output gap estimates reveal that business cycle fluctuations have become increasingly synchronized within the Group of Twenty during the estimation sample under consideration, highlighting the rising relevance of global considerations to monetary policy analysis and forecasting. Indeed, a strong synchronized global expansion followed by a precipitous synchronized global contraction, referred to as the Great Recession, marks the end of this sample period. In most economies, this contraction in economic activity was primarily attributable to a collapse in domestic demand. A notable exception is China, where robust domestic demand was dominated by a collapse in net exports. In spite of an incipient synchronized global recovery, our terminal output gap estimates generally remain negative and large. Notable exceptions are Brazil, China and Indonesia, where they are positive but small. Also notable are Argentina, Australia and India, where they are negative but small.

The monetary conditions gap is a composite of those determinants of the output gap, and by implication inflation, over which monetary policy exerts relatively direct control. Within the framework of our panel unobserved components model, the estimated monetary conditions gap may be decomposed into contributions from the estimated financial conditions gap and the real effective exchange rate. The estimated financial conditions gap may in turn be decomposed into contributions from the long term real interest rate and the real value of an internationally diversified equity portfolio. Loose financial conditions generally prevailed throughout the Group of Twenty during the build up to the Great Recession, translating into loose monetary conditions in most economies. In the Euro Area and the United States, loose monetary and financial conditions were attributable originally to low long term real interest rates, and subsequently to high real equity prices. During the Great Recession, collapses in real equity prices and real effective currency appreciations contributed to an abrupt tightening of monetary and financial conditions in these economies.

IV. MONETARY POLICY ANALYSIS

We analyze the interaction between inflation, the business cycle, and monetary policy in the Group of Twenty within the framework of our estimated panel unobserved components model with reference to the empirical properties of key target and indicator variables. In particular, we quantify dynamic interrelationships among consumption price inflation, the output gap, and the monetary conditions gap with vector autocorrelations and impulse response functions. We also identify the structural determinants of these target and indicator variables with forecast error variance decompositions and historical decompositions.

A. Vector Autocorrelations

Business cycle fluctuations are manifestations of the cumulative effects of a variety of nominal and real shocks originating domestically and abroad. Vector autocorrelations measure the degree of comovement between endogenous variables at particular lags, on average over the business cycle. Estimated vector autocorrelations between inflation, the output gap, and the monetary conditions gap are plotted in Figure 3.

Estimated vector autocorrelations reveal that the output gap and the monetary conditions gap are both leading indicators of inflation. However, the usefulness of these indicators for predicting deviations of inflation from its implicit target rate varies across economies and horizons. These deviations are relatively unpredictable in Australia, Canada and the United

Kingdom, which are small open economies with well established flexible inflation targeting regimes. In contrast, they are relatively predictable in China and Saudi Arabia, reflecting their fixed exchange rate regimes. They are also relatively predictable within the Euro Area, the member economies of which also lack autonomous monetary policies. Due to lags in the monetary transmission mechanism, the output gap is generally more useful for predicting inflation at short horizons, while the monetary conditions gap tends to be more useful at longer horizons.

Estimated vector autocorrelations also indicate that the monetary conditions gap is a leading indicator of the position of the business cycle. The monetary conditions gap is most useful for predicting the output gap in China and Saudi Arabia, reflecting their fixed exchange rate regimes. This indicator is also relatively useful for predicting the output gap within the Euro Area.

B. Impulse Response Functions

Impulse response functions measure the dynamic responses of endogenous variables to isolated structural shocks. Within the framework of our panel unobserved components model, the effects of nominal and real shocks are transmitted throughout the world economy via trade and financial linkages, necessitating monetary policy responses to spillovers. The estimated impulse responses of inflation, the output gap, the short term nominal interest rate gap, and the real effective exchange rate gap to domestic and foreign supply, demand, monetary policy, and commodity price shocks are plotted in Figure 4 through Figure 11.

In response to a domestic supply shock, inflation rises and the output gap falls in all economies, confronting flexible inflation targeting central banks with a monetary policy tradeoff. To control inflation at the cost of exacerbating the decline in economic activity, monetary conditions are tightened by raising the short term nominal interest rate, inducing an appreciation of the currency in real effective terms. Following a foreign supply shock which raises inflation and reduces the output gap in the United States, inflation falls in all other economies except for China and Saudi Arabia, reflecting their fixed exchange rate regimes. Meanwhile, the output gap falls in only Canada and Mexico, due to their high trade integration with the United States.

In response to a domestic demand shock, inflation and the output gap both rise in all economies, and flexible inflation targeting central banks do not face a monetary policy tradeoff. Monetary conditions are tightened to control inflation and moderate economic activity by raising the short term nominal interest rate, inducing an appreciation of the currency in real effective terms. Following a foreign demand shock which raises inflation and the output gap in the United States, inflation and the output gap both rise in all other economies. The strength of transmission of this foreign demand shock is increasing in trade integration with the United States, with the largest output response exhibited by Canada, followed by Mexico.

In response to a domestic monetary policy shock, the short term nominal interest rate rises in all economies, inducing an appreciation of the currency in real effective terms. This tightening of monetary conditions causes inflation and the output gap to fall. For those economies where the conduct of monetary policy is represented by a flexible inflation targeting regime, peak inflation control effects are generally realized after six quarters, while peak output stabilization effects occur with a delay of five quarters. Following a foreign monetary policy shock which reduces inflation and the output gap in the United States, inflation and the output gap eventually fall in all other economies. The strength of transmission of this foreign monetary policy shock is increasing in trade integration with the United States, and is decreasing in nominal bilateral exchange rate flexibility, with the largest output responses exhibited by China and Saudi Arabia, followed by Canada and Mexico.

In response to a world commodity price shock, inflation rises and the output gap falls in most economies. Monetary conditions are generally tightened to control inflation at the cost of exacerbating the decline in economic activity by raising the short term nominal interest rate. The largest inflation responses to world energy and nonenergy commodity price shocks are exhibited by Korea and China respectively, reflecting their high commodity import intensities.

C. Forecast Error Variance Decompositions

Forecast error variance decompositions measure the proportion of unpredictable variation in endogenous variables at particular horizons attributable to different structural shocks. Estimated forecast error variance decompositions of inflation, the output gap, and the monetary conditions gap are plotted in Figure 12 through Figure 14.

At short horizons, estimated forecast error variance decompositions attribute unpredictable fluctuations in inflation, the business cycle, and monetary conditions to different sources. The primary determinants of unpredictable variation in inflation are domestic and foreign supply shocks, or world commodity price shocks. In contrast, the primary determinants of unpredictable variation in the output gap are domestic and foreign demand shocks. The relative contribution of foreign demand shocks to the unpredictable component of business cycle fluctuations is increasing with trade openness, and approaches that of domestic demand shocks in export intensive economies such as China and Germany. The primary determinants of unpredictable variation in the monetary conditions gap are domestic monetary policy or world risk premium shocks.

At long horizons, estimated forecast error variance decompositions attribute unpredictable fluctuations in inflation, the business cycle, and monetary conditions to common sources. In particular, the primary determinants of unpredictable variation in inflation, the output gap, and the monetary conditions gap are domestic and foreign supply shocks, or world commodity price shocks.

D. Historical Decompositions

Historical decompositions measure the contributions of different structural shocks to realizations of endogenous variables. Estimated historical decompositions of inflation, the output gap, and the monetary conditions gap are plotted in Figure 15 through Figure 17.

Estimated historical decompositions of inflation attribute deviations from implicit targets primarily to diverse economy specific combinations of domestic and foreign supply and demand shocks, together with world risk premium and commodity price shocks. Implicit inflation targets have generally stabilized at relatively low levels in advanced economies, particularly those with well established flexible inflation targeting regimes such as Australia, Canada and the United Kingdom. Estimated historical decompositions of the output gap attribute business cycle dynamics within the Group of Twenty primarily to economy specific combinations of domestic and foreign demand shocks. Business cycle fluctuations in relatively closed economies such as the United States have been primarily driven by domestic demand shocks, whereas fluctuations in relatively open economies such as China and Germany have been primarily driven by foreign demand shocks. Estimated historical decompositions of the monetary conditions gap attribute tightening and loosening cycles primarily to diverse economy specific combinations of domestic monetary policy and world risk premium shocks.

During the build up to the Great Recession, positive domestic demand shocks contributed to the accumulation of excess demand pressure throughout the Group of Twenty, often amplified by foreign demand shocks or world risk premium shocks. Indeed, monetary conditions were loose in the Euro Area and the United States throughout this period due originally to exceptionally loose monetary policies, and subsequently to exuberantly low risk premia. This accumulation of excess demand pressure was reflected in a synchronized global rise in inflation, amplified by positive world commodity price shocks. During the precipitous synchronized global contraction which ensued, economy specific combinations of negative domestic and foreign demand shocks, often amplified by world risk premium shocks, rapidly eliminated this excess demand pressure, supplanting it with excess supply pressure to varying degrees. A notable exception is China, where positive domestic demand shocks were dominated by negative foreign demand shocks. This rapid accumulation of excess supply pressure was exacerbated by an abrupt tightening of monetary conditions in many economies driven by risk premia reversals, in spite of unsystematic monetary policy interventions. It was reflected in a synchronized global fall in inflation, amplified by negative world commodity price shocks.

V. Forecasting

The world economy is complex, and any structural macroeconometric model of it is necessarily misspecified to some extent, while any forecasts generated by such a model are necessarily based on an incomplete information set. In order to mitigate these problems while respecting monetary policy relevant constraints, we employ a Bayesian forecasting procedure which combines restricted forecasts generated from our estimated panel unobserved components model with judgment.

A. Forecasting Procedure

Consider the linear state space model consisting of signal equations (24) and (26), and state equation (25). Given initial conditions $\boldsymbol{z}_{T|T}$ and $\boldsymbol{P}_{T|T}$, dynamic out of sample forecasts at horizon h conditional on information available at time T, and judgment concerning the paths of linear combinations of state variables through time $T+h-1$, satisfy prediction equations:

$$\boldsymbol{z}_{T+h|T+h-1} = \boldsymbol{G}_1 \boldsymbol{z}_{T+h-1|T+h-1}, \tag{44}$$

$$\boldsymbol{P}_{T+h|T+h-1} = \boldsymbol{G}_1 \boldsymbol{P}_{T+h-1|T+h-1} \boldsymbol{G}_1^\top + \boldsymbol{G}_2 \boldsymbol{\Sigma}_4 \boldsymbol{G}_2^\top, \tag{45}$$

$$\boldsymbol{y}_{T+h|T+h-1} = \boldsymbol{F}_1 \boldsymbol{z}_{T+h|T+h-1}, \tag{46}$$

$$\boldsymbol{Q}_{T+h|T+h-1} = \boldsymbol{F}_1 \boldsymbol{P}_{T+h|T+h-1} \boldsymbol{F}_1^\top, \tag{47}$$

$$\boldsymbol{w}_{T+h|T+h-1} = \boldsymbol{H}_1 \boldsymbol{z}_{T+h|T+h-1}, \tag{48}$$

$$\boldsymbol{R}_{T+h|T+h-1} = \boldsymbol{H}_1 \boldsymbol{P}_{T+h|T+h-1} \boldsymbol{H}_1^\top + \boldsymbol{\Sigma}_{5,T+h}. \tag{49}$$

Given these predictions, under the assumption of multivariate normally distributed signal and state innovation vectors, dynamic out of sample forecasts at horizon h conditional on information available at time T, and judgment concerning the paths of linear combinations of state variables through time $T+h$, satisfy Bayesian updating equations

$$\boldsymbol{z}_{T+h|T+h} = \boldsymbol{z}_{T+h|T+h-1} + \boldsymbol{K}_{\boldsymbol{w}_{T+h}} (\boldsymbol{w}_{T+h} - \boldsymbol{w}_{T+h|T+h-1}), \tag{50}$$

$$\boldsymbol{P}_{T+h|T+h} = \boldsymbol{P}_{T+h|T+h-1} - \boldsymbol{K}_{\boldsymbol{w}_{T+h}} \boldsymbol{H}_1 \boldsymbol{P}_{T+h|T+h-1}, \tag{51}$$

$$\boldsymbol{y}_{T+h|T+h} = \boldsymbol{F}_1 \boldsymbol{z}_{T+h|T+h}, \tag{52}$$

$$\boldsymbol{Q}_{T+h|T+h} = \boldsymbol{F}_1 \boldsymbol{P}_{T+h|T+h} \boldsymbol{F}_1^\top, \tag{53}$$

where $\boldsymbol{K}_{\boldsymbol{w}_{T+h}} = \boldsymbol{P}_{T+h|T+h-1} \boldsymbol{H}_1^\top \boldsymbol{R}_{T+h|T+h-1}^{-1}$. Given terminal forecasts $\boldsymbol{z}_{T+H|T+H}$ and $\boldsymbol{P}_{T+H|T+H}$ obtained from the final evaluation of these prediction and updating equations, dynamic out of sample forecasts at horizon h conditional on information available at time T, and judgment concerning the paths of linear combinations of state variables through time $T+H$, satisfy Bayesian smoothing equations

$$\boldsymbol{z}_{T+h|T+H} = \boldsymbol{z}_{T+h|T+h} + \boldsymbol{J}_{T+h} (\boldsymbol{z}_{T+h+1|T+H} - \boldsymbol{z}_{T+h+1|T+h}), \tag{54}$$

$$\boldsymbol{P}_{T+h|T+H} = \boldsymbol{P}_{T+h|T+h} + \boldsymbol{J}_{T+h} (\boldsymbol{P}_{T+h+1|T+H} - \boldsymbol{P}_{T+h+1|T+h}) \boldsymbol{J}_{T+h}^\top, \tag{55}$$

$$\boldsymbol{y}_{T+h|T+H} = \boldsymbol{F}_1 \boldsymbol{z}_{T+h|T+H}, \tag{56}$$

$$\boldsymbol{Q}_{T+h|T+H} = \boldsymbol{F}_1 \boldsymbol{P}_{T+h|T+H} \boldsymbol{F}_1^{\top}, \tag{57}$$

where $\boldsymbol{J}_{T+h} = \boldsymbol{P}_{T+h|T+h} \boldsymbol{G}_2^{\top} \boldsymbol{P}_{T+h+1|T+h}^{-1}$. Under our distributional assumptions, recursive forward evaluation of equations (44) through (53), followed by recursive backward evaluation of equations (54) through (57), yields mean squared error optimal conditional forecasts.

B. Forecasting Results

We analyze the predictive accuracy of our panel unobserved components model for inflation and output growth with sequential unconditional forecasts in sample. We then generate conditional forecasts of these target variables out of sample with Bayesian updating, and analyze the revisions to unconditional forecasts resulting from imposing judgment on them with conditional forecast decompositions. The results of this forecasting exercise are plotted in Figure 18 through Figure 23.

Sequential Unconditional Forecasts

Sequential unconditional forecasts of inflation and output growth indicate that our panel unobserved components model is capable of predicting business cycle turning points. Indeed, our sequential unconditional forecasts of output growth suggest that a synchronized global moderation was overdue by the time of the Great Recession. However, the model generally underpredicted the severity of this synchronized global contraction, while overpredicting its disinflationary impact.

Conditional Forecasts

We generate forecasts of inflation and output growth conditional on monetary policy relevant constraints, and judgment concerning the paths of these variables. These combined forecasts are recursive weighted averages of restricted forecasts generated from our panel unobserved components model, and judgmental forecasts produced by the International Monetary Fund. To facilitate comparability with the World Economic Outlook of April 2010, the restricted forecasts are generated subject to common global assumptions concerning the paths of energy and nonenergy commodity prices, and constant real effective exchange rates. The weight assigned to the restricted forecasts is decreasing in the objective uncertainty surrounding them, measured by their time varying forecast error covariance matrix, and is increasing in the subjective uncertainty associated with the judgmental forecasts, represented by the same forecast error covariance matrix.

The combined forecasts of inflation and output growth generally lie further from the restricted forecasts than the judgmental forecasts, reflecting the relative smoothness of the latter. Nevertheless, these alternative forecasts tend to have similar profiles, and unanimously point towards a sustained synchronized global recovery. The restricted forecasts generally indicate that this recovery will be stronger but less durable than is envisaged in the World Economic Outlook, which incorporates structural rebalancing.

Conditional Forecast Decompositions

Our conditional forecast decompositions measure the contributions of different structural shocks to revisions to the restricted forecasts, given the judgmental forecasts. These conditional forecast decompositions are estimated by the difference between unconditional forecast decompositions of the combined and restricted forecasts, which in turn are estimated by out of sample extensions of unconditional historical decompositions.

The restricted forecasts of inflation and output growth generally point towards a stronger synchronized global recovery than is envisaged in the World Economic Outlook. Estimated conditional forecast decompositions attribute the pessimism embodied in the judgmental forecasts of output growth primarily to economy specific combinations of negative domestic and foreign demand shocks.

VI. Conclusion

This paper develops a panel unobserved components model of the monetary transmission mechanism in the world economy, disaggregated into twenty national economies along the lines of the Group of Twenty. A variety of monetary policy analysis and forecasting applications of the estimated model are demonstrated. These include the measurement of monetary conditions, the analysis of the monetary transmission mechanism, and the generation of conditional forecasts of inflation and output growth. They are based on a Bayesian framework for incorporating judgment concerning the paths of unobserved variables into estimation and forecasting.

This estimated panel unobserved components model consolidates much existing theoretical and empirical knowledge concerning the monetary transmission mechanism in the world economy, provides a framework for a progressive research strategy, and suggests explanations for its own deficiencies. Indeed, it implicitly treats fiscal policy as a source of business cycle fluctuations to which monetary policy must respond. Yet the Great Recession accentuated the countercyclical stabilization role of fiscal policy. Augmenting this model of the monetary transmission mechanism with a fiscal transmission mechanism remains an objective for future research.

Appendix. Description of the Data Set

Estimation is based on quarterly data on several macroeconomic and financial market variables for twenty economies over the period 1999Q1 through 2009Q4. The economies under consideration are Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Korea, Mexico, Russia, Saudi Arabia, South Africa, Spain, Turkey, the United Kingdom, and the United States. This data was obtained from the GDS database maintained by the International Monetary Fund where available, and from the CEIC database compiled by Internet Securities Incorporated otherwise. Where necessary, annual data was quadratically interpolated to the quarterly frequency.

The macroeconomic variables under consideration are the price of output, the price of consumption, the quantity of output, the quantity of domestic demand, and the prices of energy and nonenergy commodities. The price of output is measured by the seasonally adjusted gross domestic product price deflator, while the price of consumption is proxied by the seasonally adjusted consumer price index. The quantity of output is measured by seasonally adjusted real gross domestic product, while the quantity of domestic demand is measured by the sum of seasonally adjusted real consumption and investment expenditures. The prices of energy and nonenergy commodities are proxied by broad commodity price indexes denominated in United States dollars.

The financial market variables under consideration are the short term nominal interest rate, the long term nominal interest rate, the price of equity, and the nominal bilateral exchange rate. The short term nominal interest rate is measured by the three month treasury bill yield where available, and a three month money market rate otherwise, expressed as a period average. The long term nominal interest rate is measured by the ten year government bond yield where available, and a ten year commercial bank lending or deposit rate otherwise, expressed as a period average. The price of equity is proxied by a broad stock price index denominated in domestic currency units. The nominal bilateral exchange rate is measured by the domestic currency price of one United States dollar expressed as a period average.

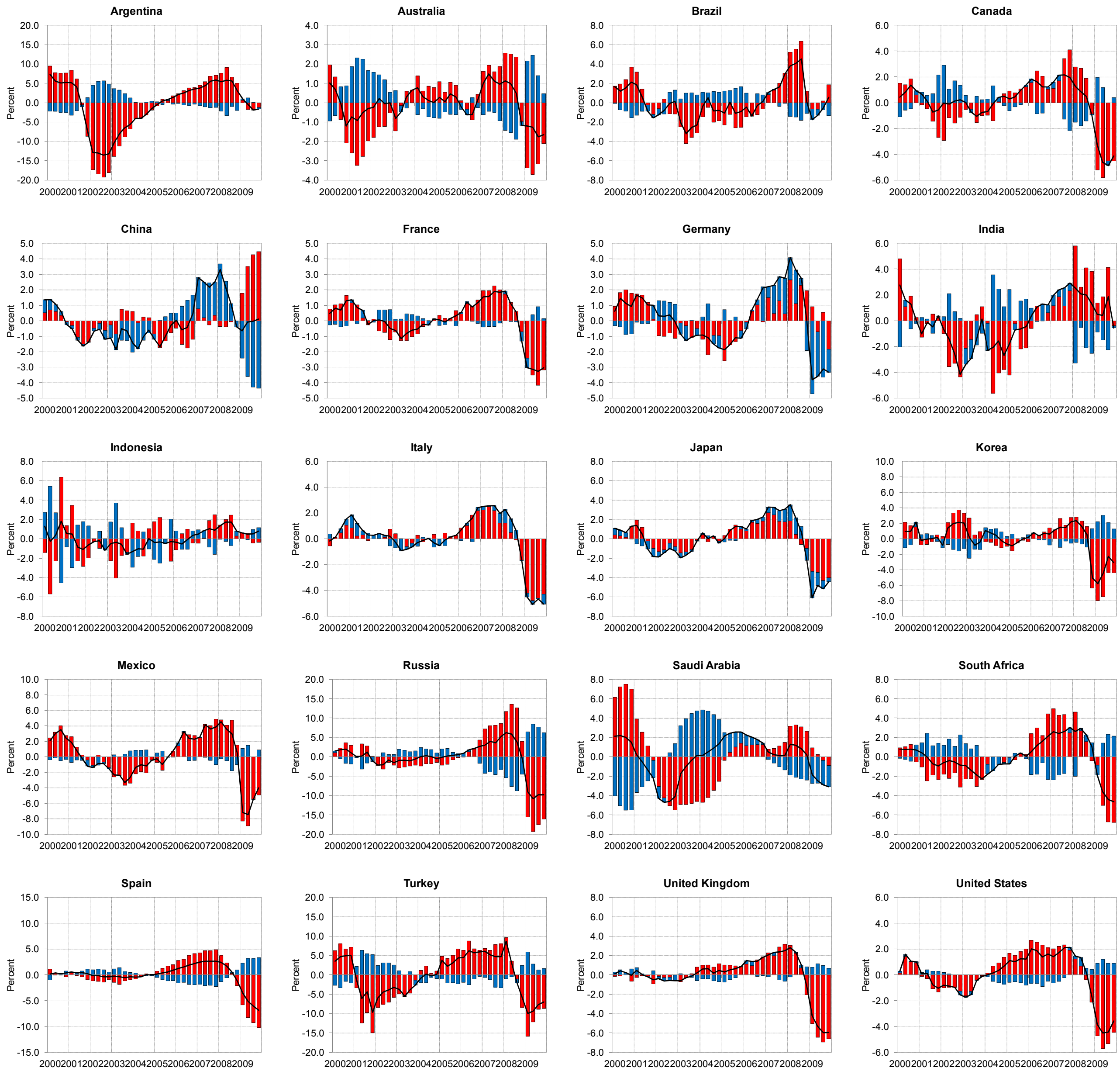
Calibration is based on annual data extracted from databases maintained by the International Monetary Fund where available, and from the World Bank Group otherwise. Great ratios are derived from the WEO and WDI databases, bilateral trade weights are derived from the DOTS database, and bilateral equity portfolio weights are derived from the CPIS and WDI databases.

Table 1. Parameter Estimation Results

	Prior		Posterior																																									
			World		Argentina		Australia		Brazil		Canada		China		France		Germany		India		Indonesia		Italy		Japan		Korea		Mexico		Russia		Saudi Arabia		South Africa		Spain		Turkey		United Kingdom		United States	
	Mean	SE	Mode	SE	Mode	SE	Mode	SE	Mode	SE	Mode	SE	Mode	SE	Mode	SE	Mode	SE	Mode	SE	Mode	SE	Mode	SE	Mode	SE	Mode	SE	Mode	SE	Mode	SE	Mode	SE	Mode	SE	Mode	SE	Mode	SE	Mode	SE	Mode	SE
$\phi_{1,1}$	0.490	4.9e–4	0.489	4.8e–4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
$\phi_{1,2}$	0.490	4.9e–4	0.490	4.8e–4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
$\theta_{1,1}$	0.010	1.0e–4	0.010	9.9e–5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
$\theta_{1,2}$	1.000	1.0e–2	0.929	8.3e–3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
$\theta_{2,1}$	0.100	1.0e–3	0.100	1.0e–3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
$\theta_{2,2}$	1.000	1.0e–2	0.966	9.0e–3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
$\phi_{3,1}$	0.490	4.9e–4	0.490	4.9e–4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
$\theta_{3,1}$	–0.850	8.5e–3	–0.871	8.1e–3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
$\theta_{3,2}$	–0.010	1.0e–4	–0.010	9.9e–5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
$\theta_{4,1}$	1.000	1.0e–2	0.997	9.9e–3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
$\theta_{4,2}$	0.050	5.0e–4	0.050	5.0e–4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
$\phi_{5,1}$	0.800	8.0e–4	0.798	7.6e–4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
$\theta_{5,1}$	1.500	1.5e–2	...	...	1.534	1.1e–2	1.534	1.1e–2	1.534	1.1e–2	1.534	1.1e–2	...	...	...	...	1.534	1.1e–2	1.534	1.1e–2	1.534	1.1e–2	...	...	1.534	1.1e–2	1.534	1.1e–2	1.534	1.1e–2	1.534	1.1e–2	...	...	1.534	1.1e–2	...	...	1.534	1.1e–2	1.534	1.1e–2	1.534	1.1e–2
$\theta_{5,2}$	0.125	1.3e–3	...	...	0.125	1.2e–3	0.125	1.2e–3	0.125	1.2e–3	0.125	1.2e–3	...	...	...	...	0.125	1.2e–3	0.125	1.2e–3	0.125	1.2e–3	...	...	0.125	1.2e–3	0.125	1.2e–3	0.125	1.2e–3	0.125	1.2e–3	...	...	0.125	1.2e–3	...	...	0.125	1.2e–3	0.125	1.2e–3	0.125	1.2e–3
$\theta_{5,3}$	0.250	2.5e–3	...	...	...	...	...	...	...	...	...	...	0.259	2.3e–3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	0.259	2.3e–3	...	...	...	...	...	...	...	...	...	...
$\phi_{6,1}$	0.490	4.9e–4	0.491	4.1e–4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
$\phi_{6,2}$	0.490	4.9e–4	0.492	3.5e–4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
$\theta_{6,1}$	0.100	1.0e–3	0.081	8.5e–4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
$\phi_{7,1}$	0.490	4.9e–4	0.487	4.4e–4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
$\phi_{7,2}$	0.490	4.9e–4	0.487	3.9e–4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
$\theta_{7,1}$	1.000	1.0e–2	0.960	9.4e–3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
$\theta_{7,2}$	–1.000	1.0e–2	–1.002	1.0e–2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
$\phi_{8,1}$	0.490	4.9e–4	0.490	4.7e–4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
$\phi_{8,2}$	0.490	4.9e–4	0.490	4.6e–4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
$\theta_{8,1}$	–0.100	1.0e–3	...	...	...	...	–0.098	9.8e–4	–0.098	9.8e–4	–0.098	9.8e–4	...	...	...	...	–0.098	9.8e–4	...	...	–0.098	9.8e–4	...	...	–0.098	9.8e–4	–0.098	9.8e–4	–0.098	9.8e–4	...	...	–0.098	9.8e–4	–0.098	9.8e–4	...	...	–0.098	9.8e–4	–0.098	9.8e–4	–0.098	9.8e–4
$\theta_{8,2}$	–0.025	2.5e–4	...	...	–0.025	2.5e–4	...	...	...	...	...	...	–0.025	2.5e–4	...	...	...	...	–0.025	2.5e–4	...	...	...	...	...	...	...	...	...	...	–0.025	2.5e–4	...	...	...	...	...	...	...	...	...	...	...	...
$\phi_{9,1}$	0.490	4.9e–4	0.489	4.9e–4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
$\phi_{9,2}$	0.490	4.9e–4	0.490	4.9e–4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
$\theta_{9,1}$	0.250	2.5e–3	0.250	2.5e–3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
$\theta_{9,2}$	0.100	1.0e–3	0.100	1.0e–3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
$\rho_{\hat{v}}$	0.600	6.0e–3	0.608	5.8e–3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
$\rho_{\hat{D}}$	0.600	6.0e–3	0.600	5.8e–3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
$\sigma^2_{\hat{D}^Y,i}$	...	∞	...	...	1.3e+1	6.1e–7	8.3e–1	9.8e–6	4.0e+0	1.7e–6	4.7e–1	2.8e–5	1.6e+0	2.9e–6	8.1e–2	1.8e–2	2.2e–1	4.7e–2	5.7e–1	1.6e–5	3.3e+0	2.5e–6	4.8e–1	1.8e–5	3.2e–1	7.0e–2	1.3e+0	5.6e–6	4.2e+0	1.6e–6	1.1e+1	8.3e–7	6.6e+1	2.3e–7	2.2e+0	3.3e–6	9.3e–2	2.0e–2	1.2e+1	5.3e–7	5.9e–1	1.6e–5	5.5e–2	1.2e–2
$\sigma^2_{\hat{D}^M,i}$	...	∞	...	...	4.9e+0	8.1e–7	7.3e–1	3.5e–6	2.1e+0	7.4e–7	3.2e–1	7.0e–2	1.9e+0	1.3e–6	6.8e–2	1.5e–2	1.3e–1	2.9e–2	2.1e+0	1.3e–6	1.4e+0	3.4e–6	2.5e–1	5.3e–2	1.5e–1	3.3e–2	1.4e+0	2.5e–6	1.8e+0	9.6e–7	6.1e+0	1.0e–6	4.5e+1	2.8e–7	1.4e+0	2.0e–6	1.2e–1	2.5e–2	5.3e+0	3.2e–7	3.3e–1	7.2e–2	9.3e–2	2.0e–2
$\sigma^2_{\hat{v},i}$	...	∞	...	...	6.2e+0	2.6e–7	7.5e+0	2.3e–8	1.1e+1	4.5e–8	1.7e+0	2.0e–7	1.8e+0	3.0e–7	1.2e+0	1.4e–5	2.8e+0	4.4e–7	3.1e+1	2.4e–8	1.4e+1	1.3e–8	1.5e+0	1.7e–5	1.1e+1	5.7e–8	2.1e+0	1.8e–7	1.6e+0	1.3e–7	1.8e+1	3.0e–8	2.9e+0	1.2e–6	7.9e+0	2.4e–8	2.5e+0	4.6e–7	1.8e+1	1.2e–8	7.9e–1	9.2e–7	4.6e+0	1.8e–7
$\sigma^2_{\hat{D},i}$	...	∞	...	...	5.1e+0	1.5e–7	6.6e–1	5.5e–7	1.2e+0	3.5e–7	9.0e–1	2.8e–7	4.3e–1	2.6e–6	2.6e–1	5.7e–2	1.1e+0	8.6e–7	3.9e+0	1.1e–7	5.5e+0	6.7e–8	3.1e–1	6.8e–2	4.6e–1	1.2e–6	2.1e+0	1.8e–7	2.9e+0	1.5e–7	8.4e+0	4.2e–6	1.6e+0	2.9e–6	1.6e+0	2.4e–7	8.6e–1	2.8e–6	8.2e+0	9.5e–8	4.9e–1	3.6e–6	3.8e–1	7.7e–6
$\sigma^2_{\hat{S},i}$	...	∞	...	...	2.2e+0	4.9e–7	2.9e–2	6.3e–3	1.5e–1	3.3e–2	2.1e–2	4.6e–3	1.2e–2	2.6e–3	...	...	1.0e–2	2.2e–3	1.1e–1	2.3e–2	1.9e–1	4.2e–2	...	...	1.4e–2	3.1e–3	2.7e–2	6.0e–3	9.0e–2	2.0e–2	1.1e+0	2.6e–5	2.0e–2	4.3e–3	3.8e–2	8.3e–3	...	...	4.6e+0	2.5e–7	1.6e–2	3.4e–3	4.0e–2	8.7e–3
$\sigma^2_{\hat{L},i}$	...	∞	...	...	9.0e–2	1.9e–2	5.6e–3	1.2e–3	1.3e–2	2.9e–3	3.0e–3	6.6e–4	6.4e–3	1.4e–3	3.0e–3	6.6e–4	2.5e–3	5.4e–4	1.4e–2	3.2e–3	1.7e–2	3.7e–3	2.0e–3	4.4e–4	2.0e–3	4.4e–4	9.0e–3	2.0e–3	2.7e–2	6.1e–3	5.7e–1	6.5e–5	9.0e–3	1.9e–3	1.8e–2	4.0e–3	3.6e–3	7.8e–4	8.2e–1	2.7e–6	2.5e–3	5.4e–4	6.4e–3	1.4e–3
$\sigma^2_{\hat{D}^{STK},i}$	...	∞	...	...	2.3e+2	1.8e–7	2.4e+1	7.3e–8	9.2e+1	2.0e–8	3.4e+1	5.6e–8	1.3e+2	4.0e–8	5.7e+1	5.8e–8	1.0e+2	1.9e–8	9.7e+1	2.8e–8	8.2e+1	3.1e–8	4.6e+1	1.5e–7	4.1e+1	4.2e–8	9.6e+1	1.9e–8	6.4e+1	6.9e–8	3.2e+2	7.2e–8	7.0e+1	5.0e–7	5.4e+1	3.4e–8	6.0e+1	2.8e–8	3.2e+2	7.3e–9	2.8e+1	6.7e–8	3.3e+1	5.2e–8
$\sigma^2_{\hat{e},i}$	...	∞	...	...	3.3e+1	1.0e–7	1.3e+1	2.4e–7	2.3e+1	1.4e–7	5.0e+0	7.0e–7	3.7e–1	5.6e–6	...	...	5.9e+0	5.4e–7	2.1e+0	1.5e–6	1.7e+1	1.9e–7	...	...	7.8e+0	3.6e–7	8.2e+0	4.2e–7	8.9e+0	3.7e–7	7.6e+0	4.3e–7	2.0e–1	4.4e–2	2.2e+1	1.5e–7	...	...	4.7e+1	6.7e–8	5.3e+0	7.4e–7	...	...
$\sigma^2_{\hat{D}^{COM}}$	...	∞	1.7e+2	5.9e–9	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
$\sigma^2_{\hat{D}^{COM}}$	...	∞	2.9e+1	1.7e–8	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
$\sigma^2_{\bar{D}^Y,i}$	...	∞	...	...	1.1e–4	2.1e–5	1.4e–5	5.7e–6	1.2e–4	5.1e–5	1.2e–5	8.8e–6	1.3e–4	3.7e–5	1.2e–6	4.6e–7	1.2e–6	2.5e–7	3.8e–5	1.0e–5	2.0e–4	6.9e–5	3.1e–6	1.2e–6	3.2e–6	9.4e–7	2.2e–5	9.6e–6	3.8e–5	9.3e–6	1.1e–4	1.8e–5	8.9e–4	6.1e–4	3.4e–5	1.7e–5	2.2e–5	1.0e–5	5.3e–3	1.4e–3	1.9e–6	6.4e–7	8.7e–6	3.9e–6
$\sigma^2_{\bar{D}^C,i}$	...	∞	...	...	1.7e–4	7.2e–5	5.8e–6	1.5e–6	1.6e–4	7.0e–5	2.2e–6	5.3e–7	6.1e–5	1.6e–5	1.0e–6	9.0e–7	2.9e–6	1.2e–6	9.8e–5	3.1e–5	1.8e–5	1.2e–5	5.7e–7	1.6e–7	5.7e–6	1.7e–6	1.4e–6	9.5e–7	4.0e–5	1.0e–5	3.1e–4	7.6e–5	2.2e–4	4.8e–5	1.4e–4	1.2e–4	3.4e–6	2.5e–6	6.3e–3	1.8e–3	1.5e–5	4.2e–6	4.6e–6	6.9e–6
$\sigma^2_{\bar{v},i}$	...	∞	...	...	1.0e–3	4.2e–4	3.6e–6	3.0e–6	3.3e–5	1.5e–5	2.4e–5	7.0e–6	4.1e–5	1.2e–5	8.9e–6	3.1e–6	1.4e–5	1.0e–5	9.0e–5	2.8e–5	1.5e–5	4.3e–6	2.3e–5	7.2e–6	5.2e–5	3.8e–5	2.1e–5	4.2e–6	5.4e–5	6.8e–5	8.6e–5	5.0e–5	5.4e–5	4.0e–5	3.8e–5	2.7e–5	3.6e–5	1.4e–5	3.6e–4	2.5e–4	4.2e–5	1.9e–5	3.1e–5	3.0e–5
$\sigma^2_{\bar{D},i}$	...	∞	...	...	1.8e–3	7.2e–4	3.7e–5	1.8e–5	1.2e–4	3.9e–5	5.1e–5	4.4e–5	1.8e–5	5.2e–6	1.3e–5	9.3e–6	1.8e–5	8.3e–6	1.5e–4	4.3e–5	1.9e–5	5.5e–6	2.6e–5	8.4e–6	2.6e–5	1.4e–5	4.4e–5	9.7e–6	5.9e–5	8.0e–5	2.4e–4	3.0e–4	2.2e–4	5.6e–5	1.3e–4	8.0e–5	1.4e–4	6.9e–5	7.5e–4	5.3e–4	6.4e–5	2.6e–5	6.7e–5	3.0e–5
$\sigma^2_{\bar{S},i}$	...	∞	...	...	1.9e–3	5.9e–4	3.7e–5	2.0e–5	1.8e–4	1.4e–5	3.1e–5	4.0e–6	1.3e–5	5.2e–6	...	...	1.4e–5	3.5e–6	2.5e–4	6.1e–5	1.7e–3	3.3e–4	...	...	7.0e–6	2.9e–6	1.0e–4	2.1e–5	3.2e–3	7.8e–4	3.1e–2	9.0e–3	4.1e–4	1.2e–4	2.9e–4	7.5e–5	...	...	1.7e–2	2.3e–3	4.8e–5	1.2e–5	1.0e–4	2.1e–5
$\sigma^2_{\bar{L},i}$	...	∞	...	...	5.2e–4	2.5e–4	2.6e–6	4.3e–7	3.0e–5	1.8e–6	7.9e–7	1.9e–8	3.1e–5	1.3e–5	8.4e–6	1.1e–6	2.8e–6	2.1e–7	7.0e–4	2.2e–4	1.7e–4	1.9e–5	2.2e–5	5.7e–6	4.4e–6	1.7e–6	1.4e–4	3.2e–5	3.4e–3	8.1e–4	6.4e–2	1.6e–2	2.1e–4	4.9e–5	4.6e–4	8.5e–5	2.1e–5	4.1e–6	1.8e–2	2.5e–3	2.1e–6	2.2e–7	8.3e–6	7.4e–7
$\sigma^2_{\bar{D}^{STK},i}$	...	∞	...	...	2.1e–2	1.6e–2	2.4e–3	1.9e–3	5.0e–3	3.0e–3	2.8e–3	1.3e–3	1.9e–2	5.7e–3	4.7e–3	2.4e–3	8.3e–3	3.4e–3	9.7e–3	4.3e–3	1.4e–2	4.9e–3	5.5e–3	3.6e–3	7.8e–3	4.0e–3	3.4e–3	1.4e–3	6.8e–3	3.5e–3	1.2e–2	9.0e–3	2.3e–2	1.1e–2	2.1e–3	1.4e–3	5.6e–3	2.1e–3	5.4e–3	6.0e–3	3.3e–3	1.2e–3	3.5e–3	1.4e–3
$\sigma^2_{\bar{e},i}$	...	∞	...	...	7.5e–3	2.2e–3	1.1e–3	4.8e–4	5.5e–3	1.4e–3	5.8e–4	2.6e–4	1.9e–4	4.1e–5	...	...	6.2e–4	2.2e–4	3.3e–4	1.5e–4	2.6e–4	1.1e–4	...	...	1.8e–4	5.2e–5	1.4e–3	1.1e–3	1.0e–4	6.8e–5	1.0e–3	4.3e–4	2.1e–8	2.5e–8	3.3e–3	1.8e–3	...	...	1.2e–2	3.4e–3	1.0e–3	7.3e–4	...	...
$\sigma^2_{\bar{D}^{COM}}$	...	∞	2.4e–3	2.4e–3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
$\sigma^2_{\bar{D}^{COM}}$	...	∞	1.5e–3	6.8e–4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

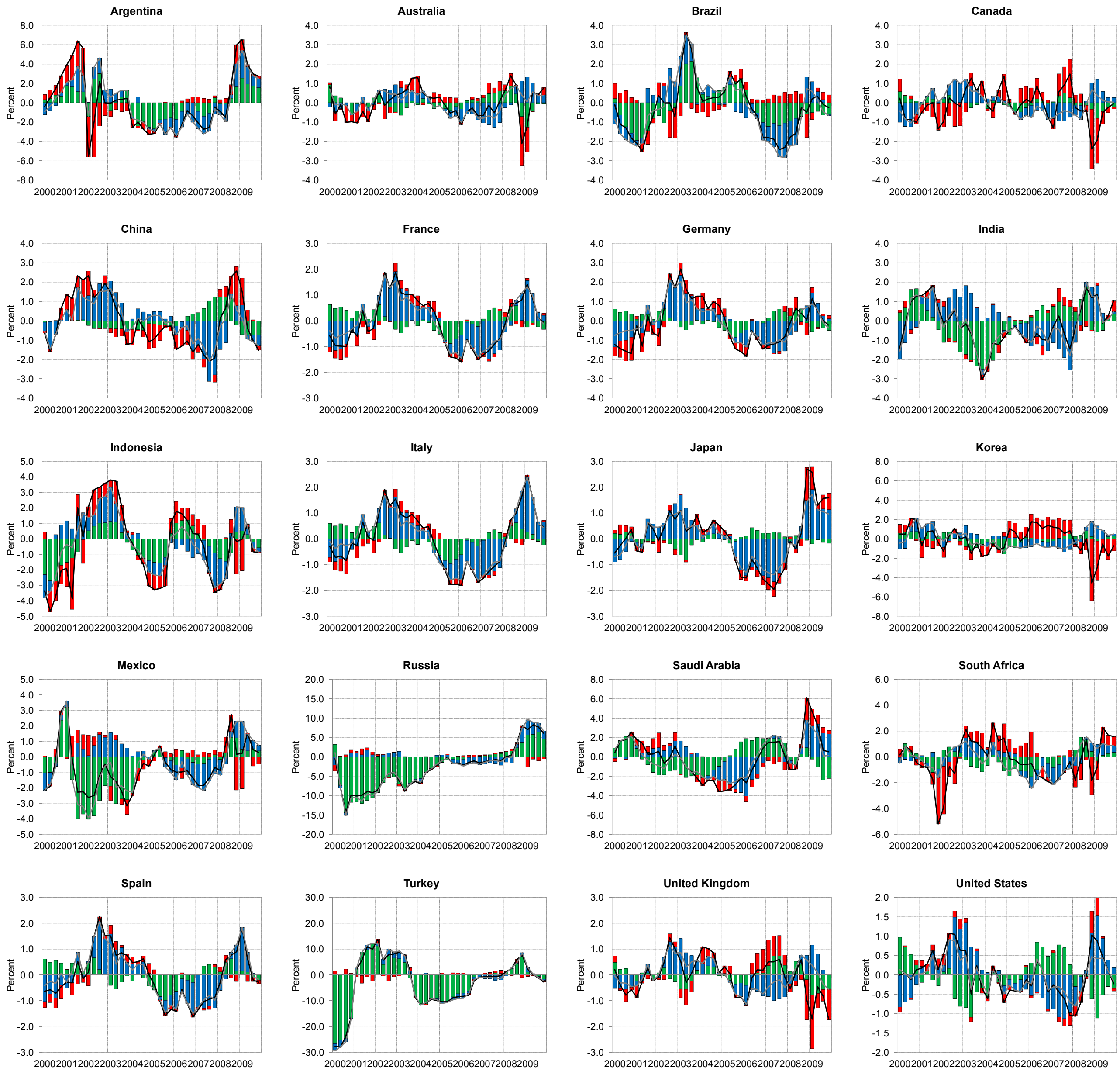
Note: All priors are normally distributed, while all posteriors are asymptotically normally distributed. All observed endogenous variables are rescaled by a factor of 100.

Figure 1. Output Gap Estimates



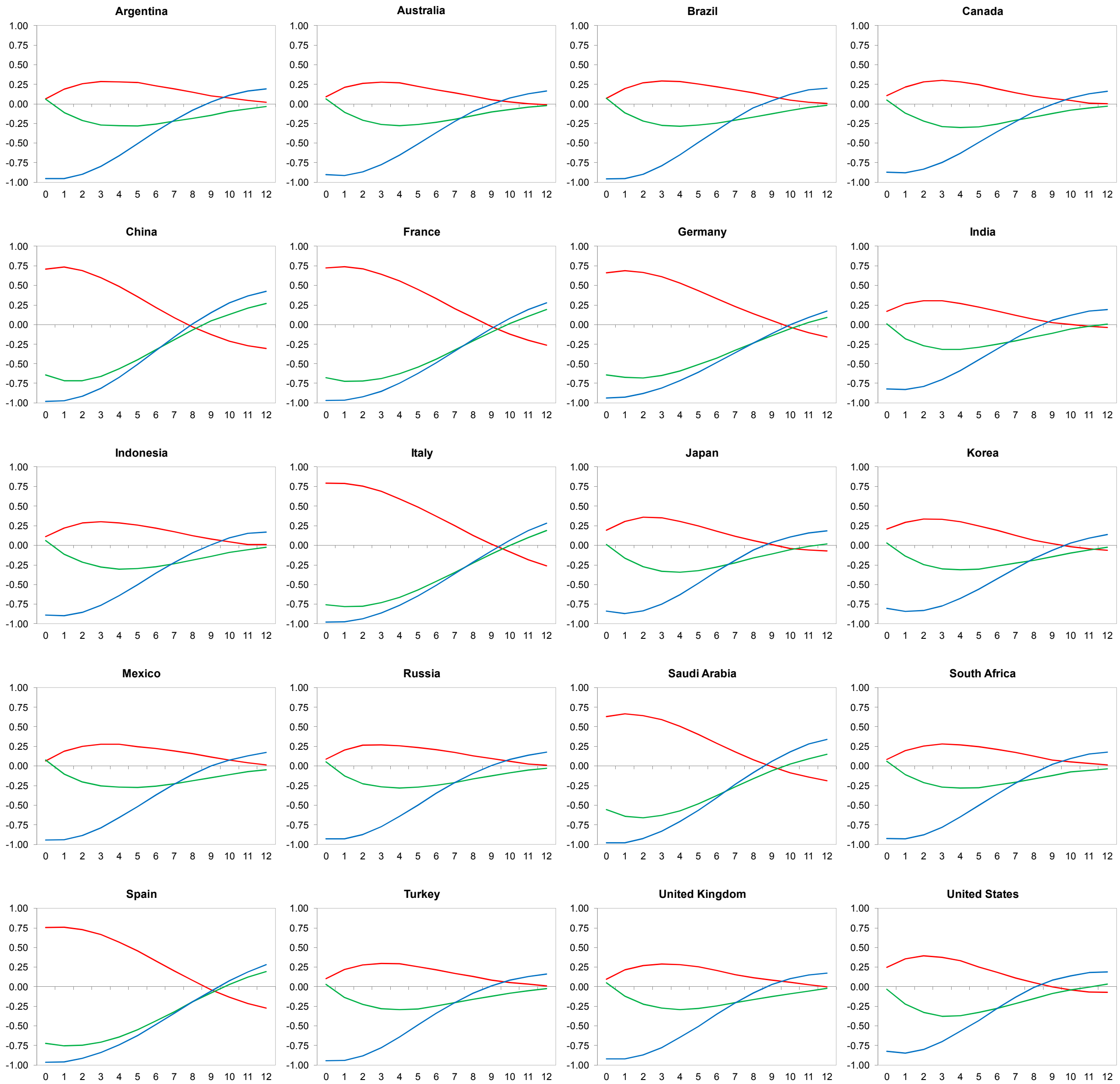
Note: Decomposes smoothed estimates of the output gap ■ into contributions from domestic demand ■ and net exports ■.

Figure 2. Monetary Conditions Gap Estimates



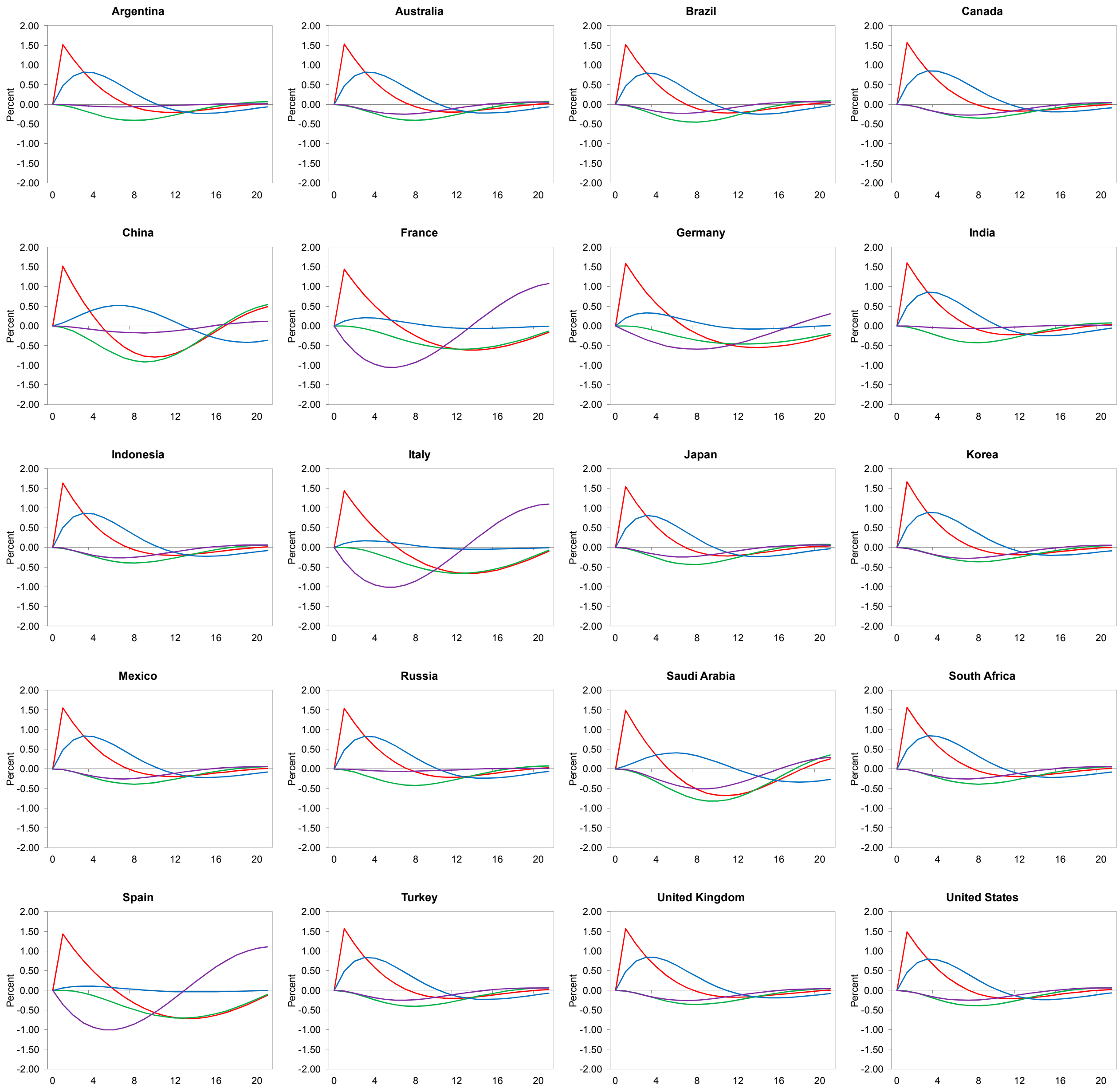
Note: Decomposes smoothed estimates of the monetary conditions gap ■ into contributions from the financial conditions gap ■ and the real effective exchange rate ■. Smoothed estimates of the financial conditions gap ■ are decomposed into contributions from the long term real interest rate ■ and the real value of an internationally diversified equity portfolio ■.

Figure 3. Vector Autocorrelations



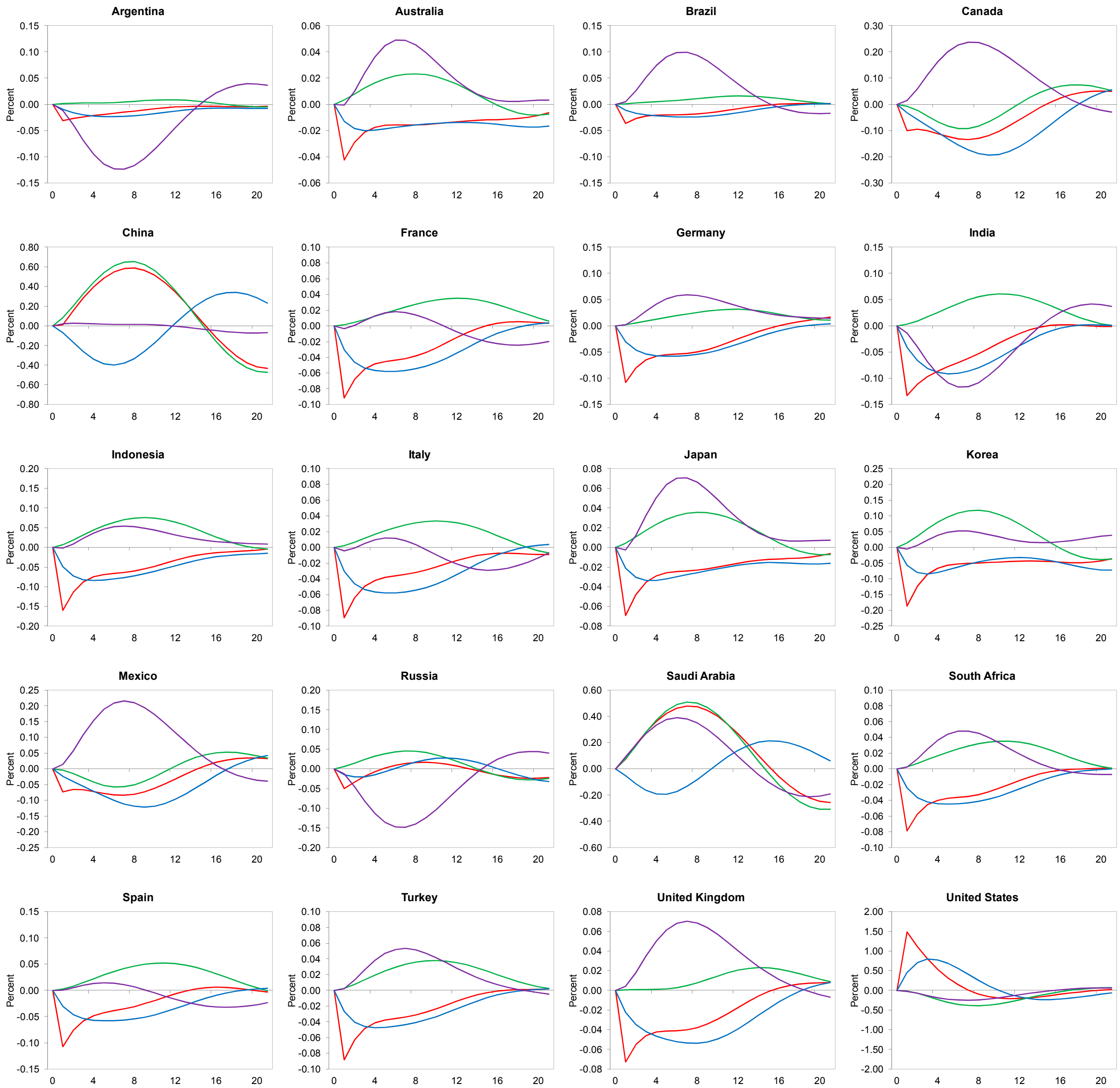
Note: Depicts the correlations of consumption price inflation with the lagged output gap ■, of consumption price inflation with the lagged monetary conditions gap ■, and of the output gap with the lagged monetary conditions gap ■. These correlations are calculated with a Monte Carlo simulation with 999 replications for *2T* periods, discarding the first *T* simulated observations to eliminate dependence on initial conditions, where *T* denotes the observed sample size.

Figure 4. Impulse Responses to a Domestic Supply Shock



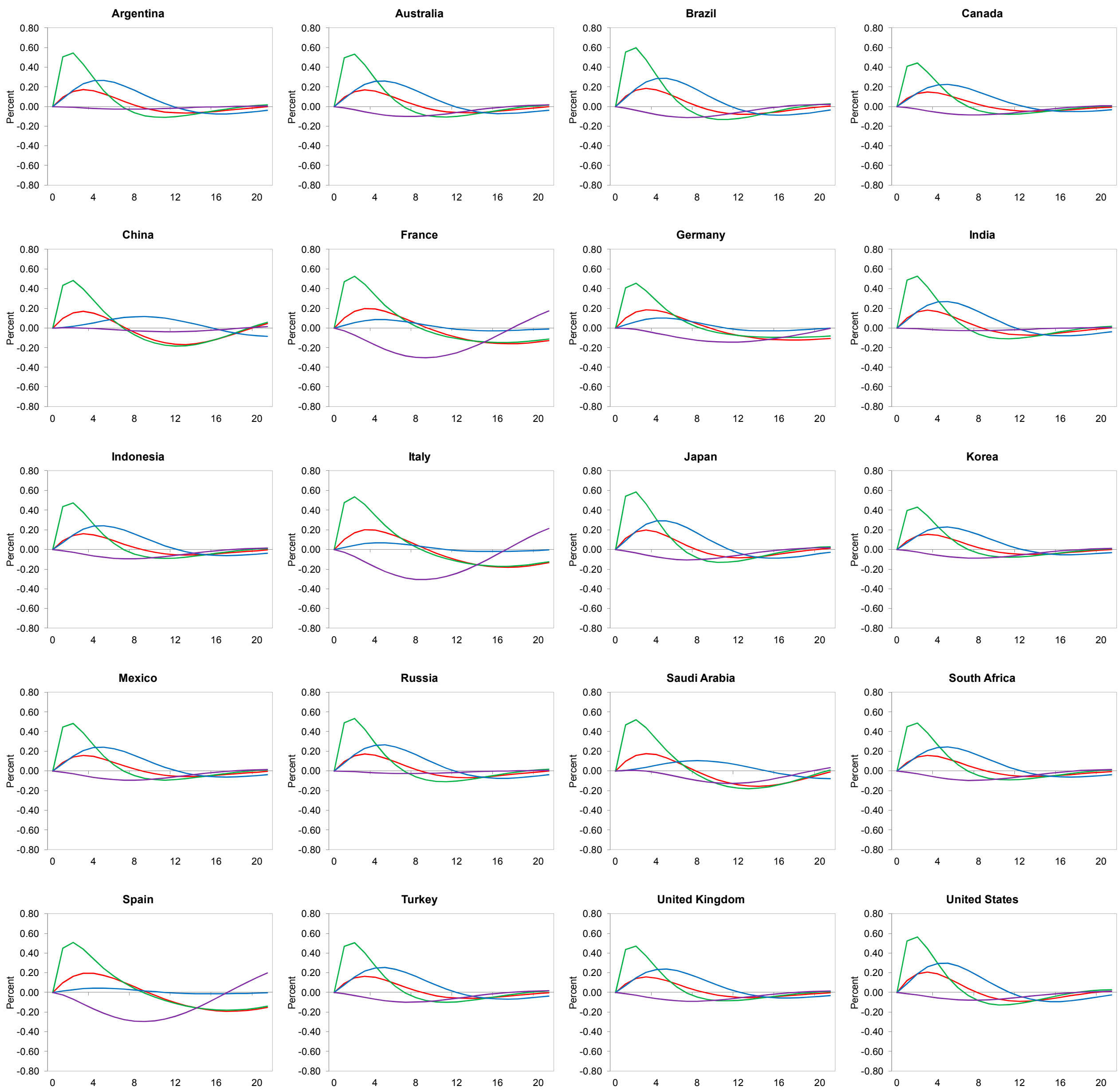
Note: Depicts the impulse responses of consumption price inflation ■, the output gap ■, the short term nominal interest rate gap ■, and the real effective exchange rate gap ■ to domestic supply shocks of size normalized to one standard deviation in the United States. Inflation and the short term nominal interest rate are expressed as annual percentage rates.

Figure 5. Impulse Responses to a Foreign Supply Shock



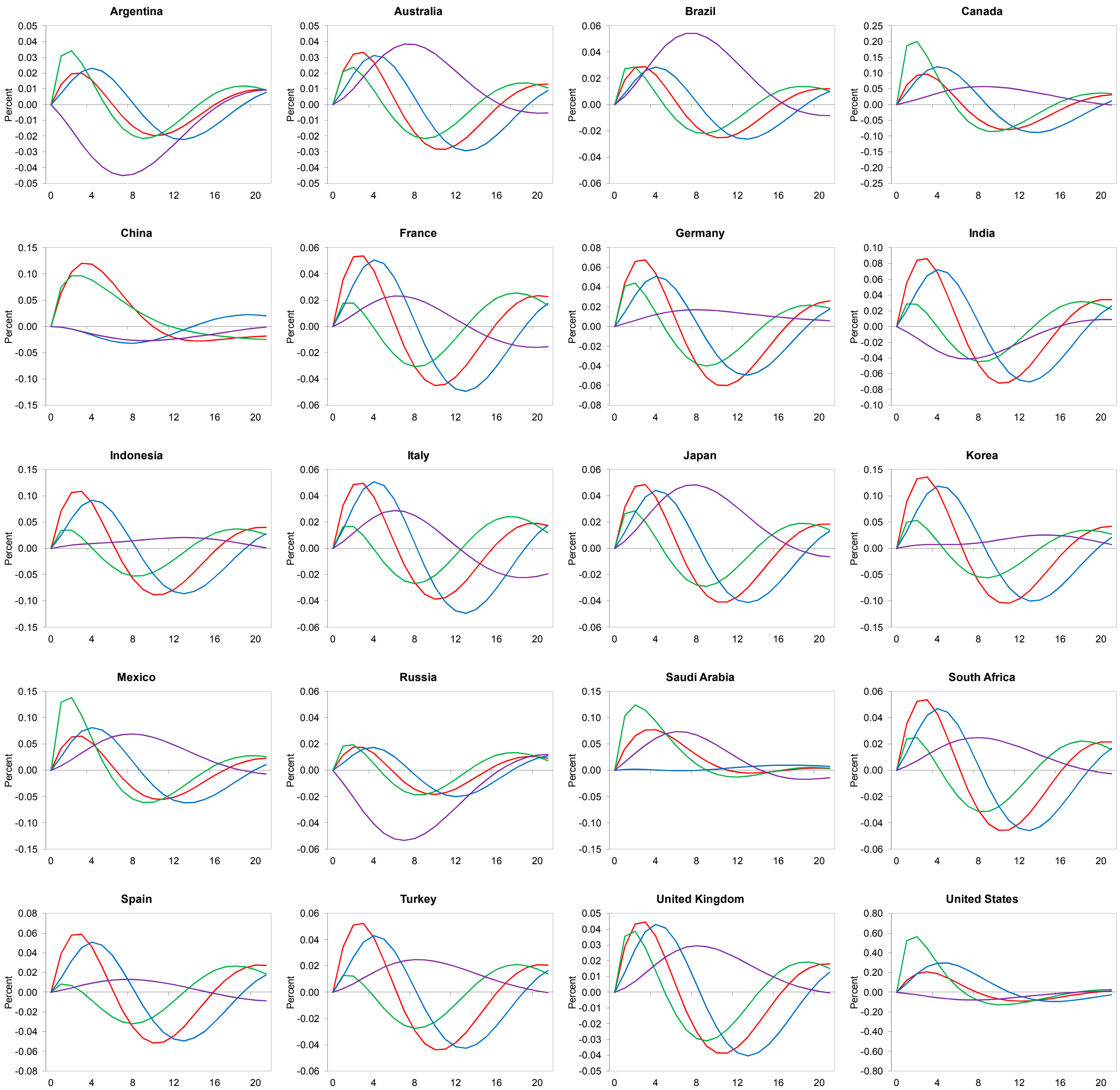
Note: Depicts the impulse responses of consumption price inflation ■, the output gap ■, the short term nominal interest rate gap ■, and the real effective exchange rate gap ■ to a one standard deviation supply shock in the United States. Inflation and the short term nominal interest rate are expressed as annual percentage rates.

Figure 6. Impulse Responses to a Domestic Demand Shock



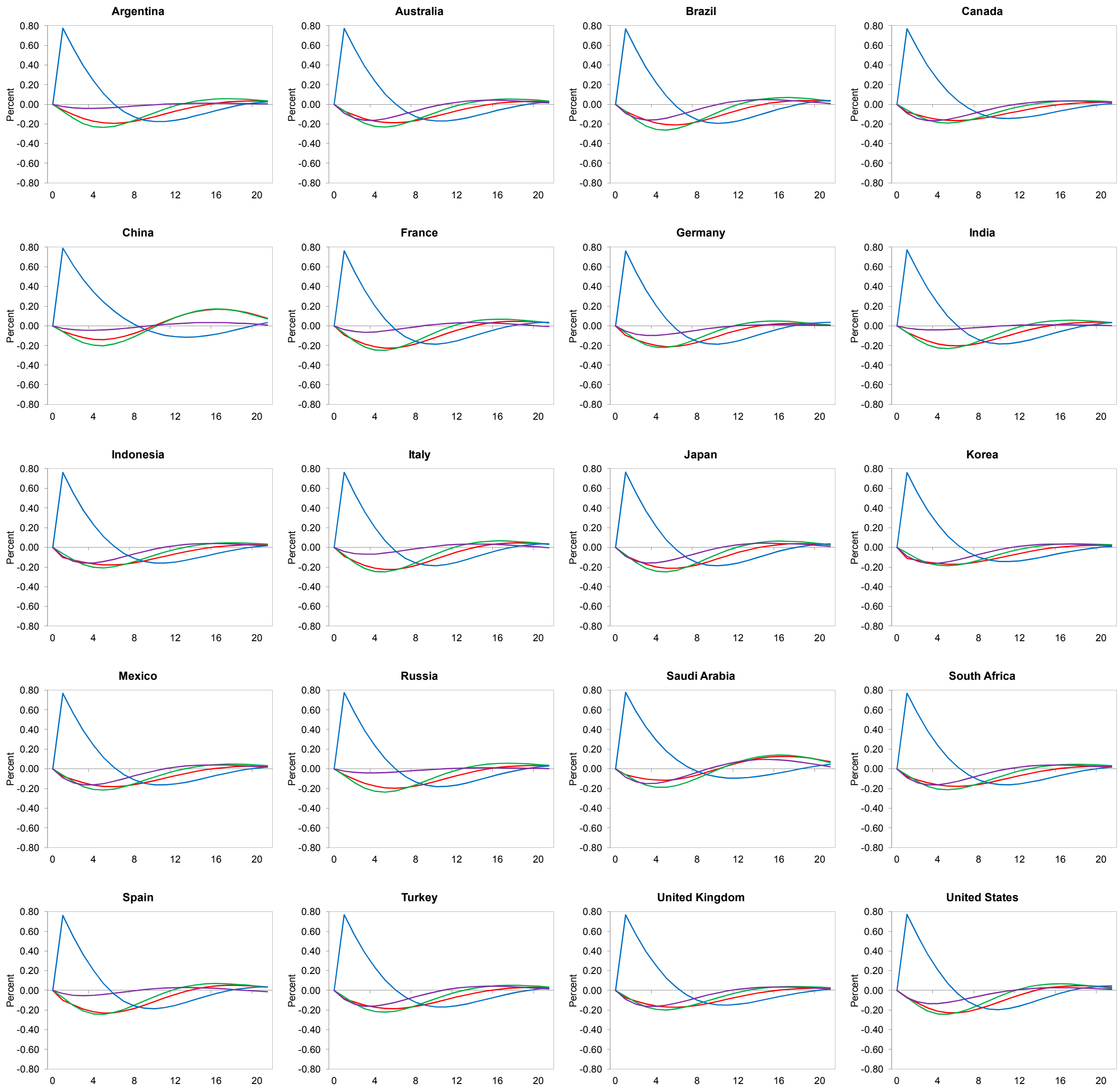
Note: Depicts the impulse responses of consumption price inflation ■, the output gap ■, the short term nominal interest rate gap ■, and the real effective exchange rate gap ■ to domestic demand shocks of size normalized to one standard deviation in the United States. Inflation and the short term nominal interest rate are expressed as annual percentage rates.

Figure 7. Impulse Responses to a Foreign Demand Shock



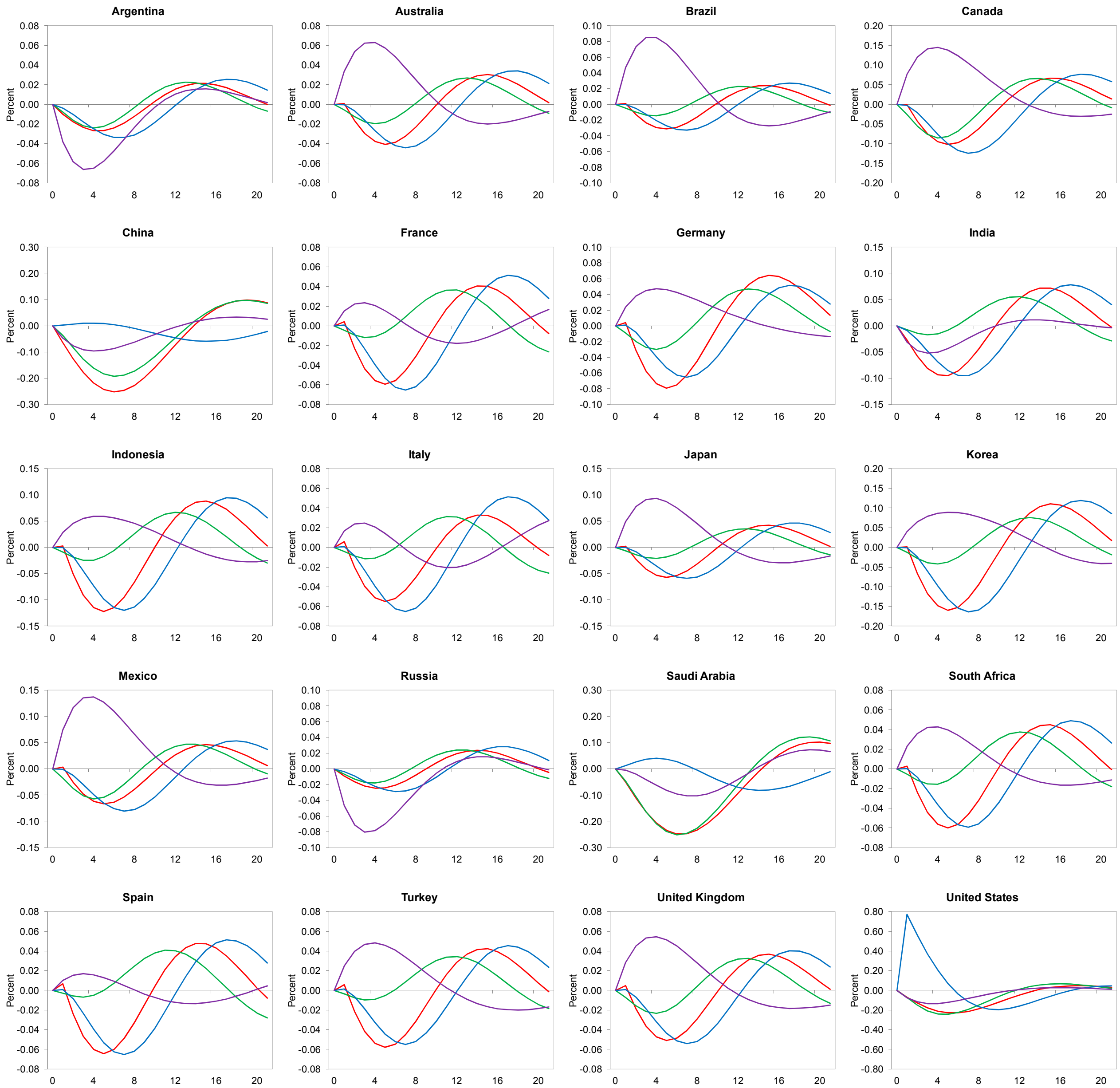
Note: Depicts the impulse responses of consumption price inflation ■, the output gap ■, the short term nominal interest rate gap ■, and the real effective exchange rate gap ■ to a one standard deviation demand shock in the United States. Inflation and the short term nominal interest rate are expressed as annual percentage rates.

Figure 8. Impulse Responses to a Domestic Monetary Policy Shock



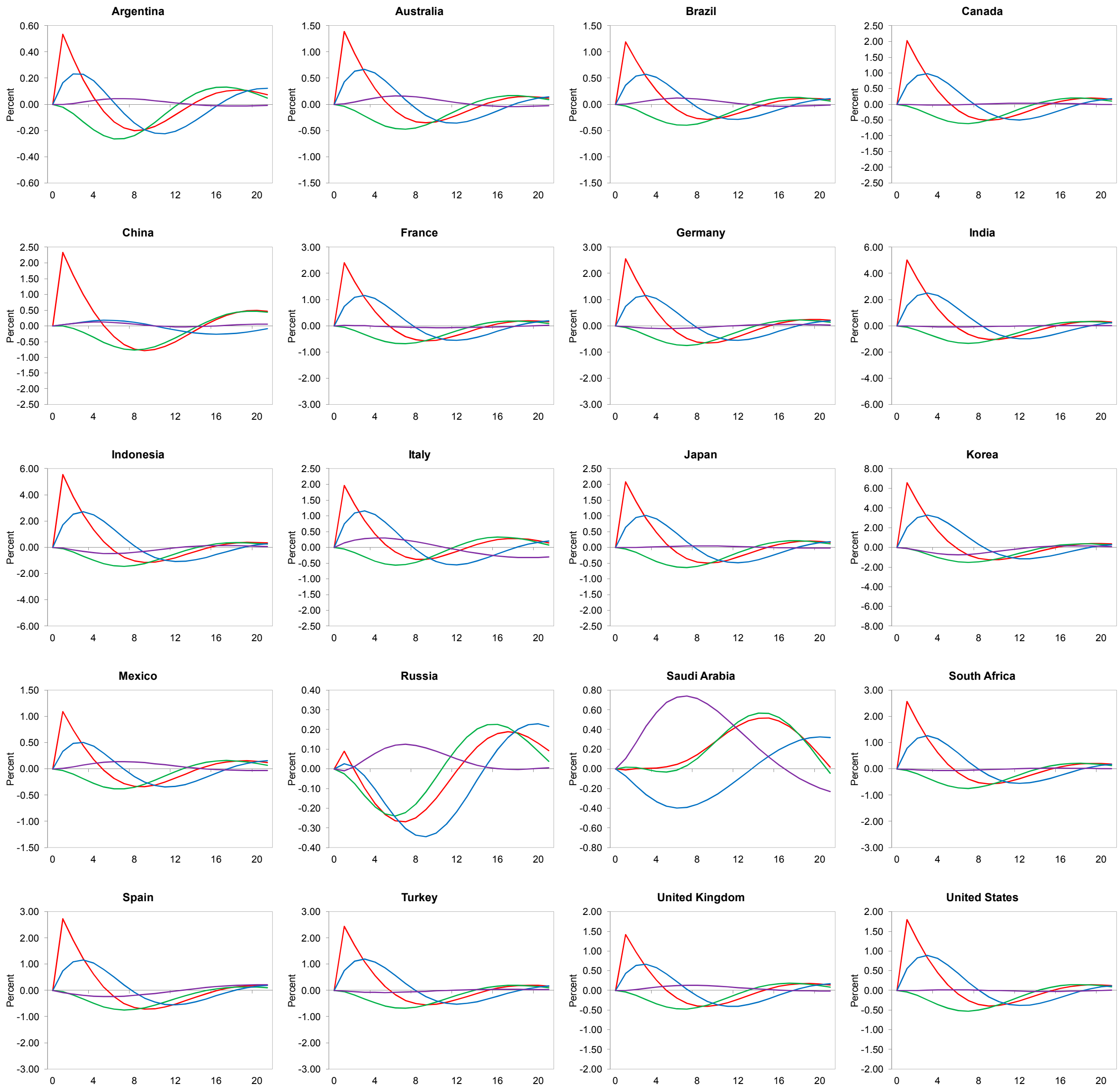
Note: Depicts the impulse responses of consumption price inflation ■, the output gap ■, the short term nominal interest rate gap ■, and the real effective exchange rate gap ■ to domestic monetary policy shocks of size normalized to one standard deviation in the United States. Inflation and the short term nominal interest rate are expressed as annual percentage rates.

Figure 9. Impulse Responses to a Foreign Monetary Policy Shock



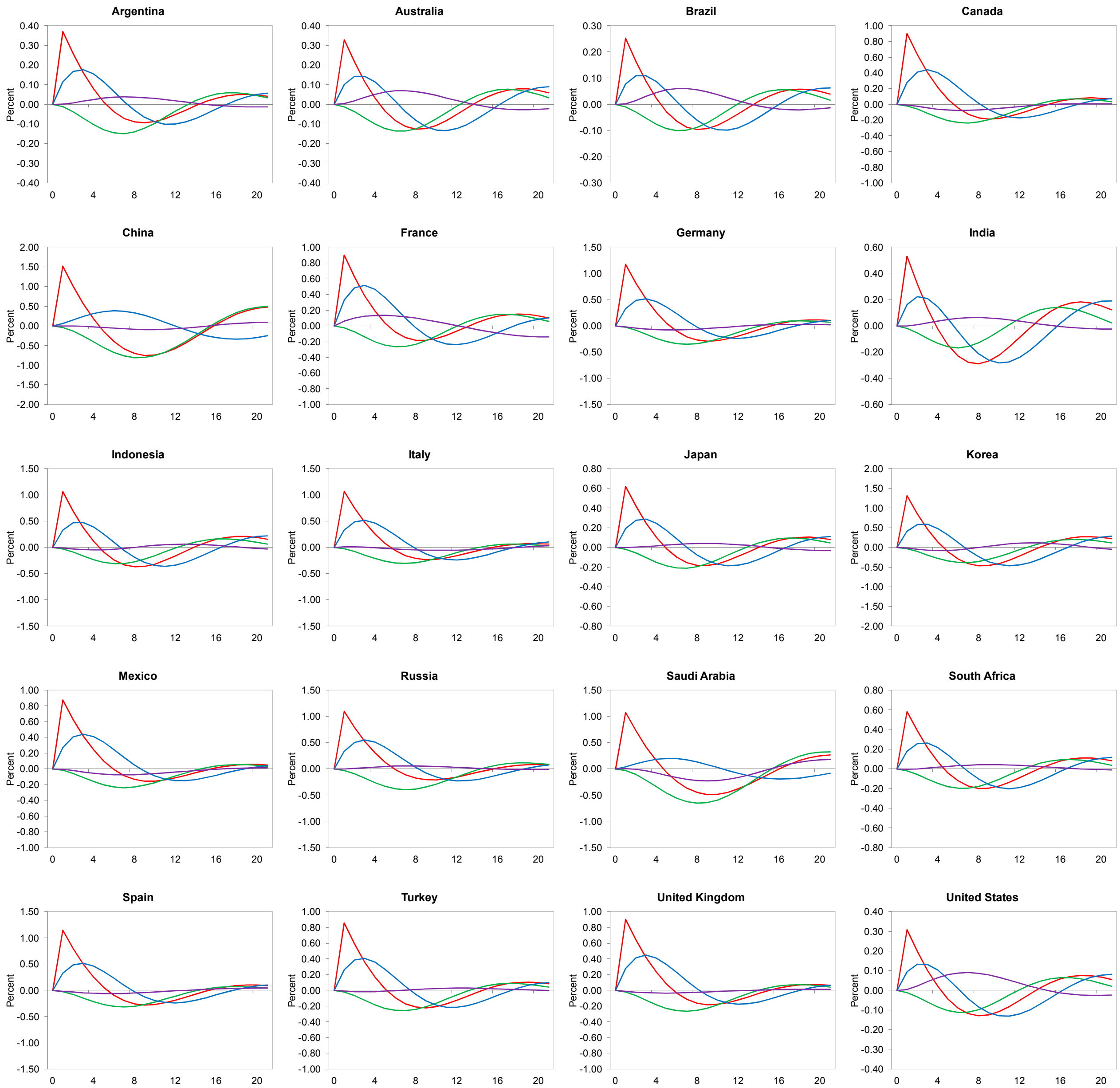
Note: Depicts the impulse responses of consumption price inflation ■, the output gap ■, the short term nominal interest rate gap ■, and the real effective exchange rate gap ■ to a one standard deviation monetary policy shock in the United States. Inflation and the short term nominal interest rate are expressed as annual percentage rates.

Figure 10. Impulse Responses to a World Energy Commodity Price Shock



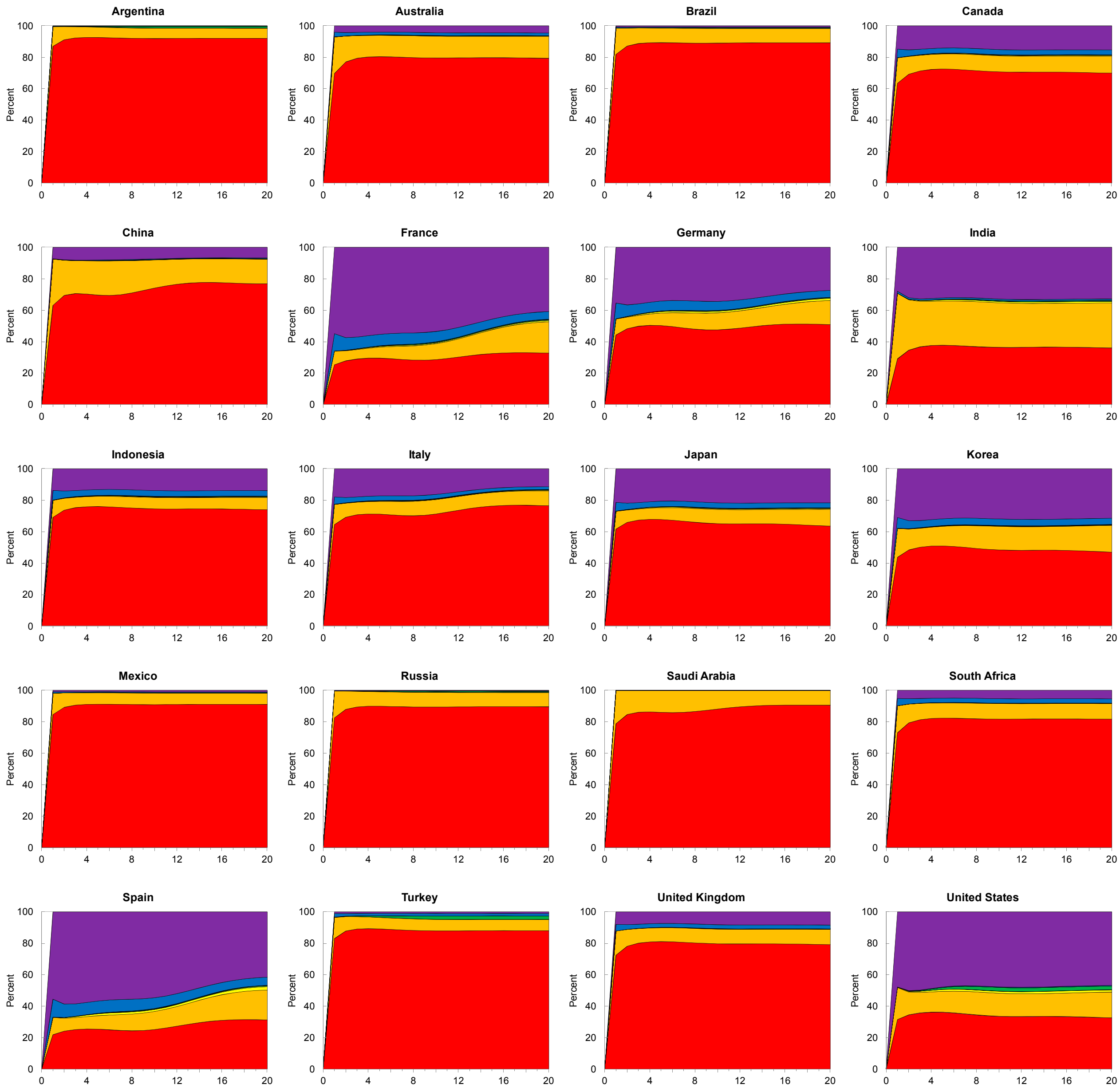
Note: Depicts the impulse responses of consumption price inflation ■, the output gap ■, the short term nominal interest rate gap ■, and the real effective exchange rate gap ■ to a one standard deviation world energy commodity price shock. Inflation and the short term nominal interest rate are expressed as annual percentage rates.

Figure 11. Impulse Responses to a World Nonenergy Commodity Price Shock



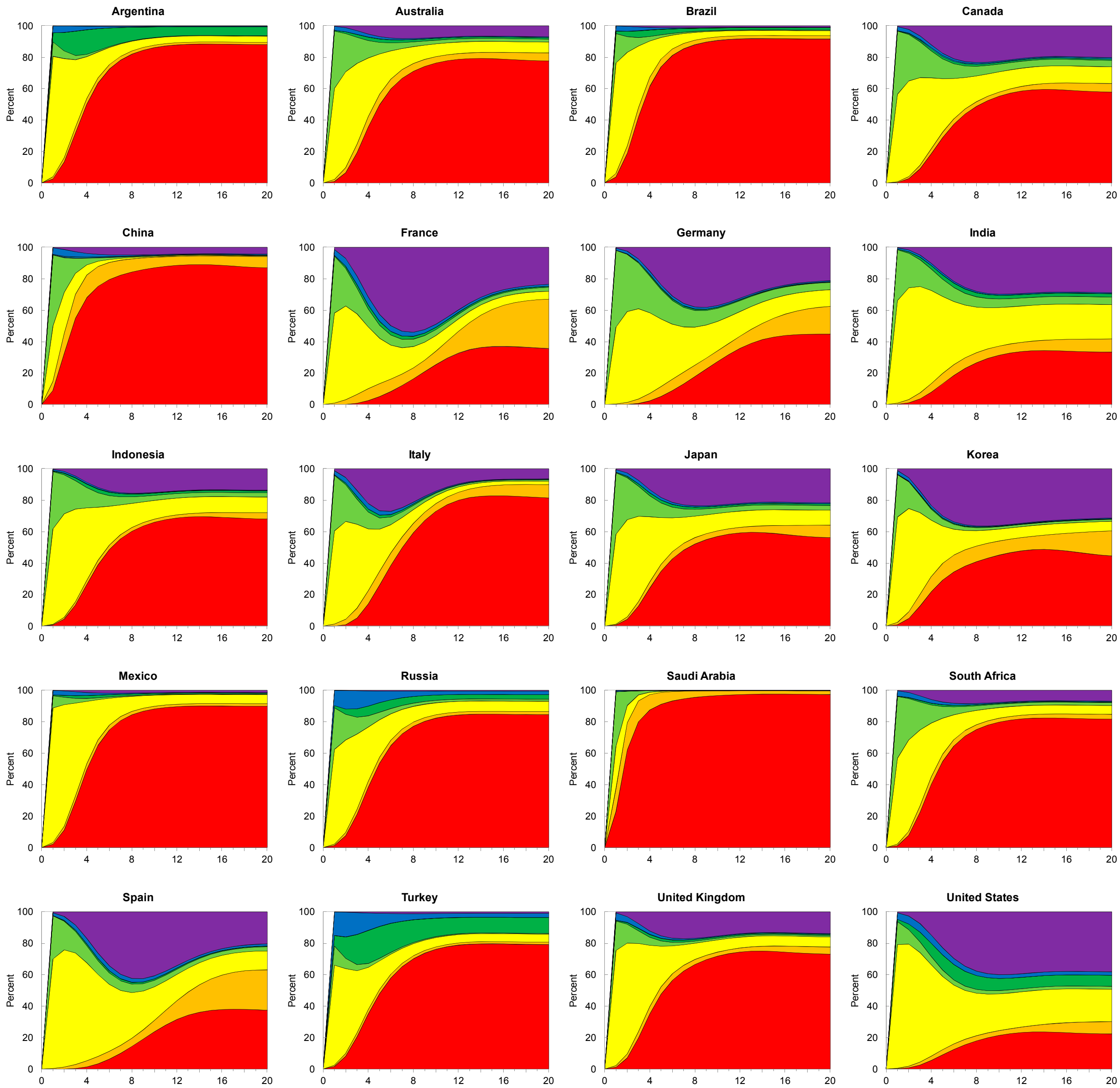
Note: Depicts the impulse responses of consumption price inflation ■, the output gap ■, the short term nominal interest rate gap ■, and the real effective exchange rate gap ■ to a one standard deviation world nonenergy commodity price shock. Inflation and the short term nominal interest rate are expressed as annual percentage rates.

Figure 12. Forecast Error Variance Decompositions of Inflation



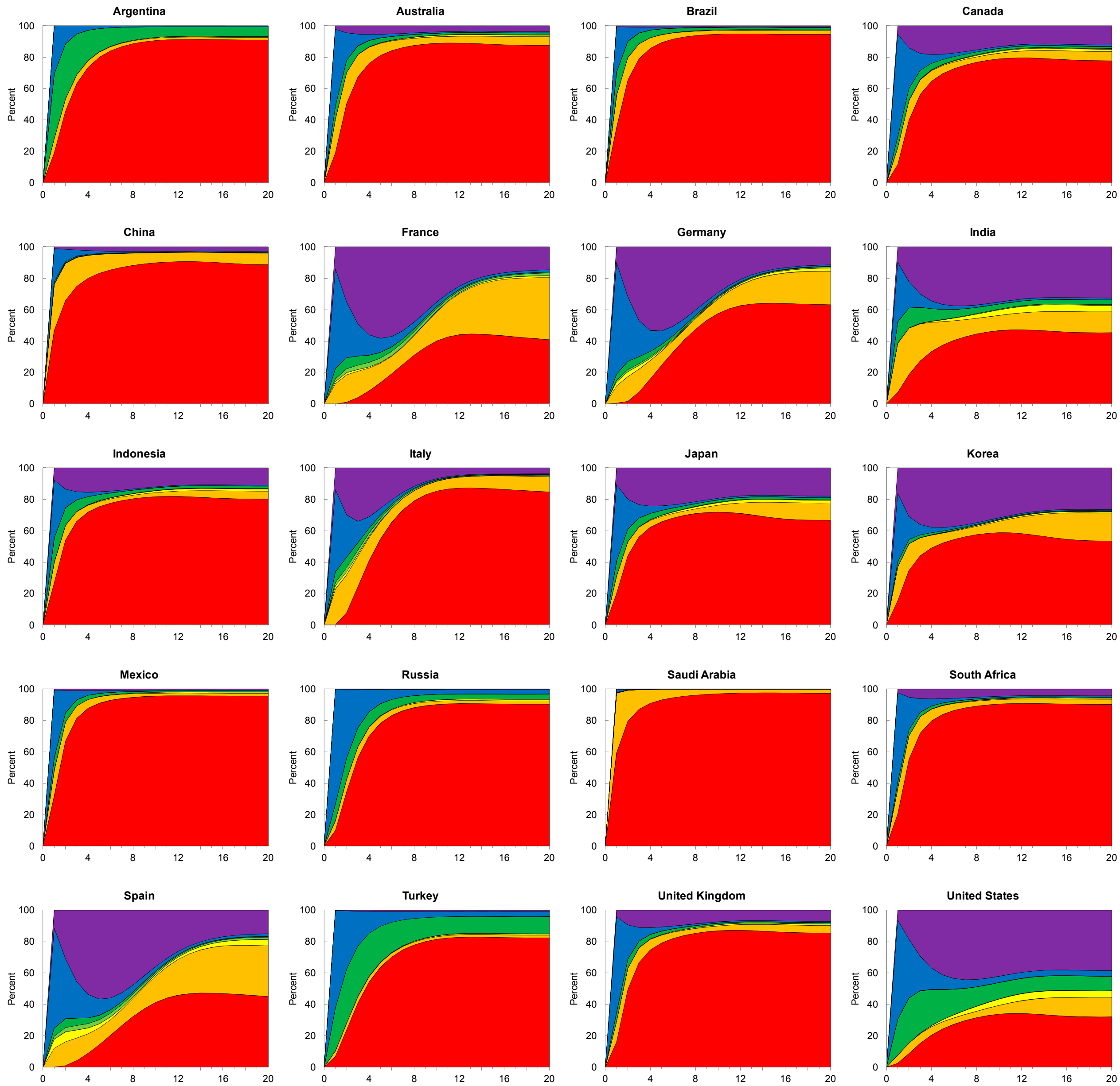
Note: Decomposes the horizon dependent forecast error variance of consumption price inflation into contributions from domestic supply ■, foreign supply ■, domestic demand ■, foreign demand ■, domestic monetary policy ■, foreign monetary policy ■, world risk premium ■, and world commodity price ■ shocks.

Figure 13. Forecast Error Variance Decompositions of the Output Gap



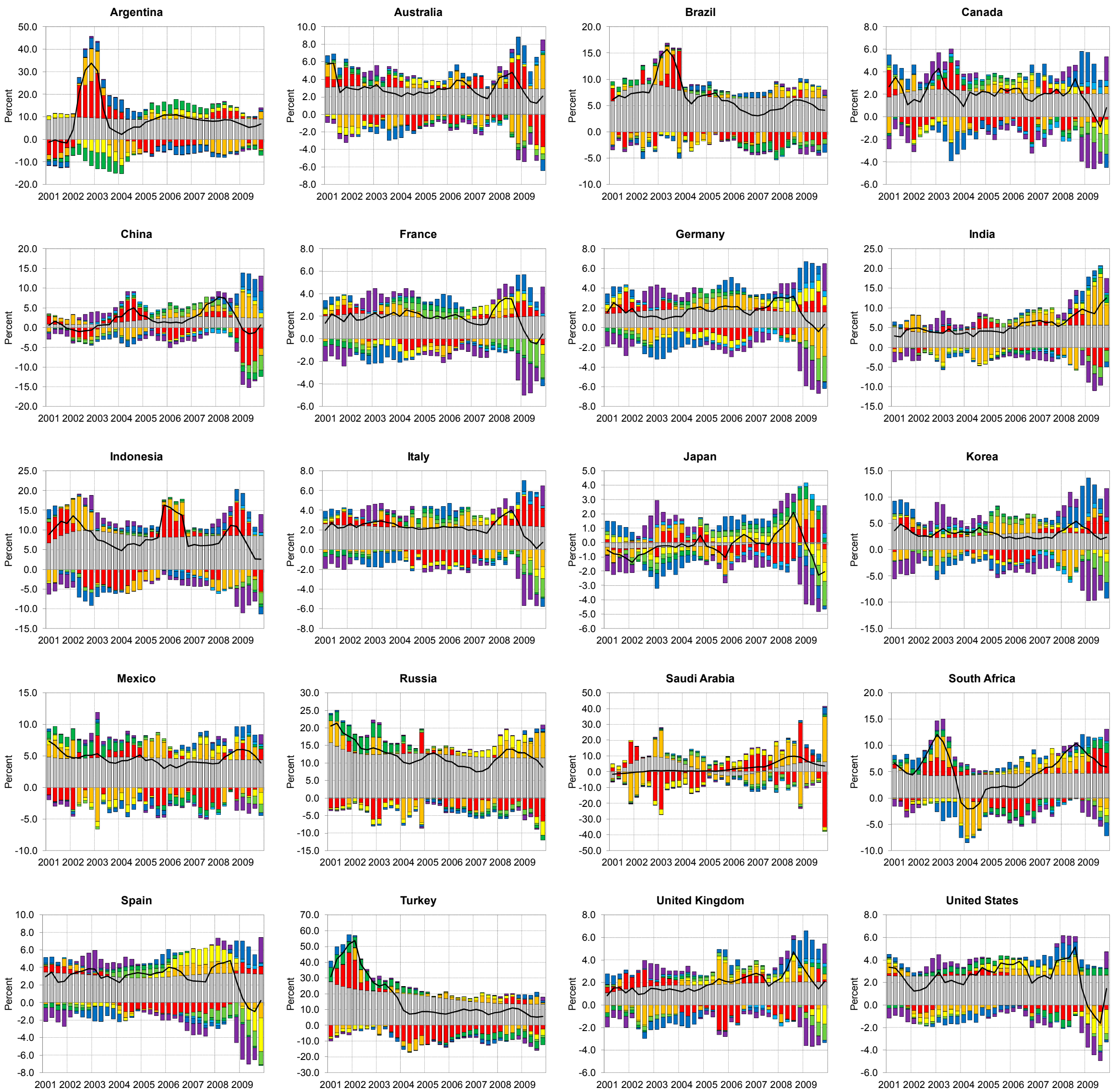
Note: Decomposes the horizon dependent forecast error variance of the output gap into contributions from domestic supply ■, foreign supply ■, domestic demand ■, foreign demand ■, domestic monetary policy ■, foreign monetary policy ■, world risk premium ■, and world commodity price ■ shocks.

Figure 14. Forecast Error Variance Decompositions of the Monetary Conditions Gap



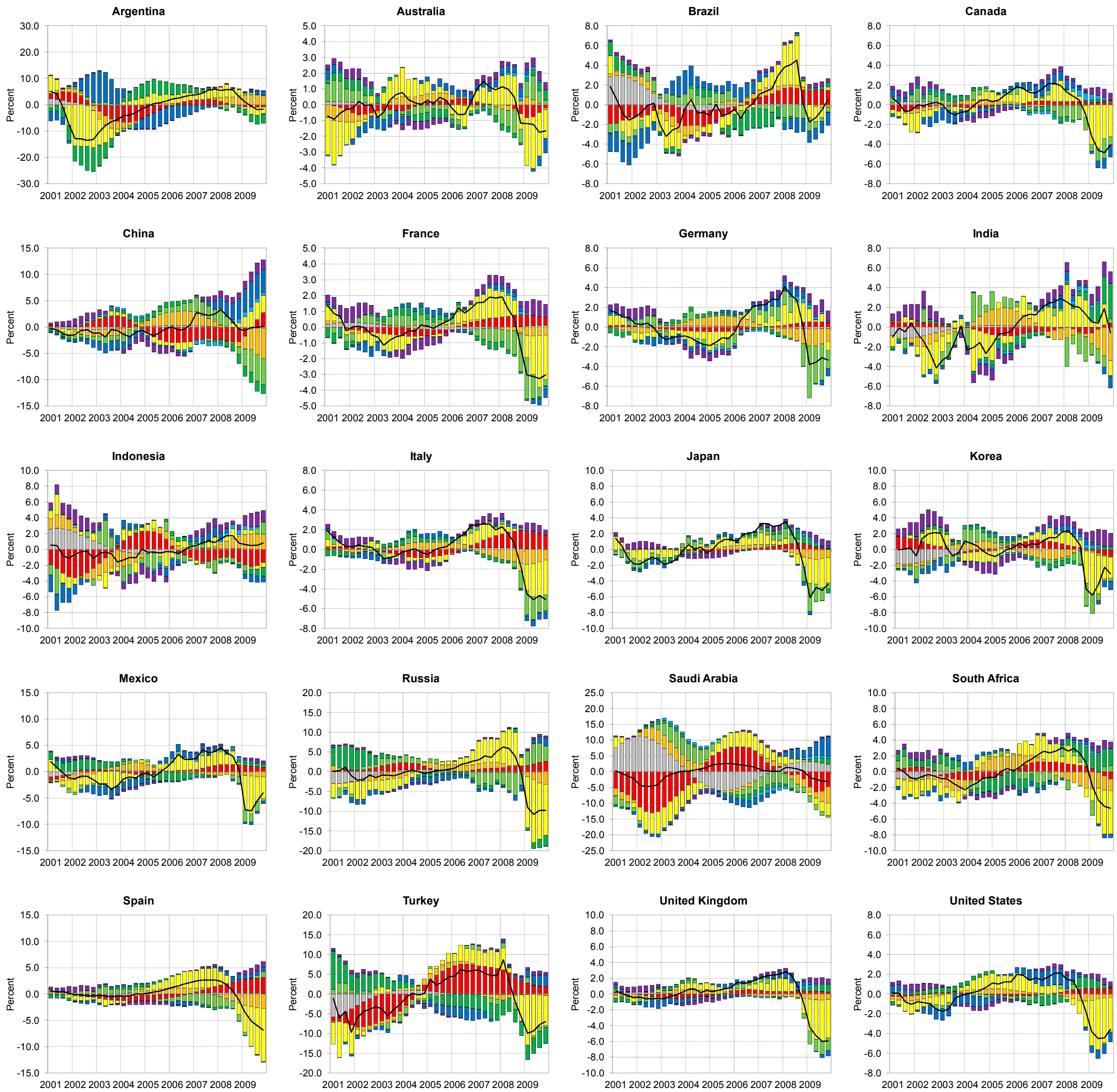
Note: Decomposes the horizon dependent forecast error variance of the monetary conditions gap into contributions from domestic supply ■, foreign supply ■, domestic demand ■, foreign demand ■, domestic monetary policy ■, foreign monetary policy ■, world risk premium ■, and world commodity price ■ shocks.

Figure 15. Historical Decompositions of Inflation



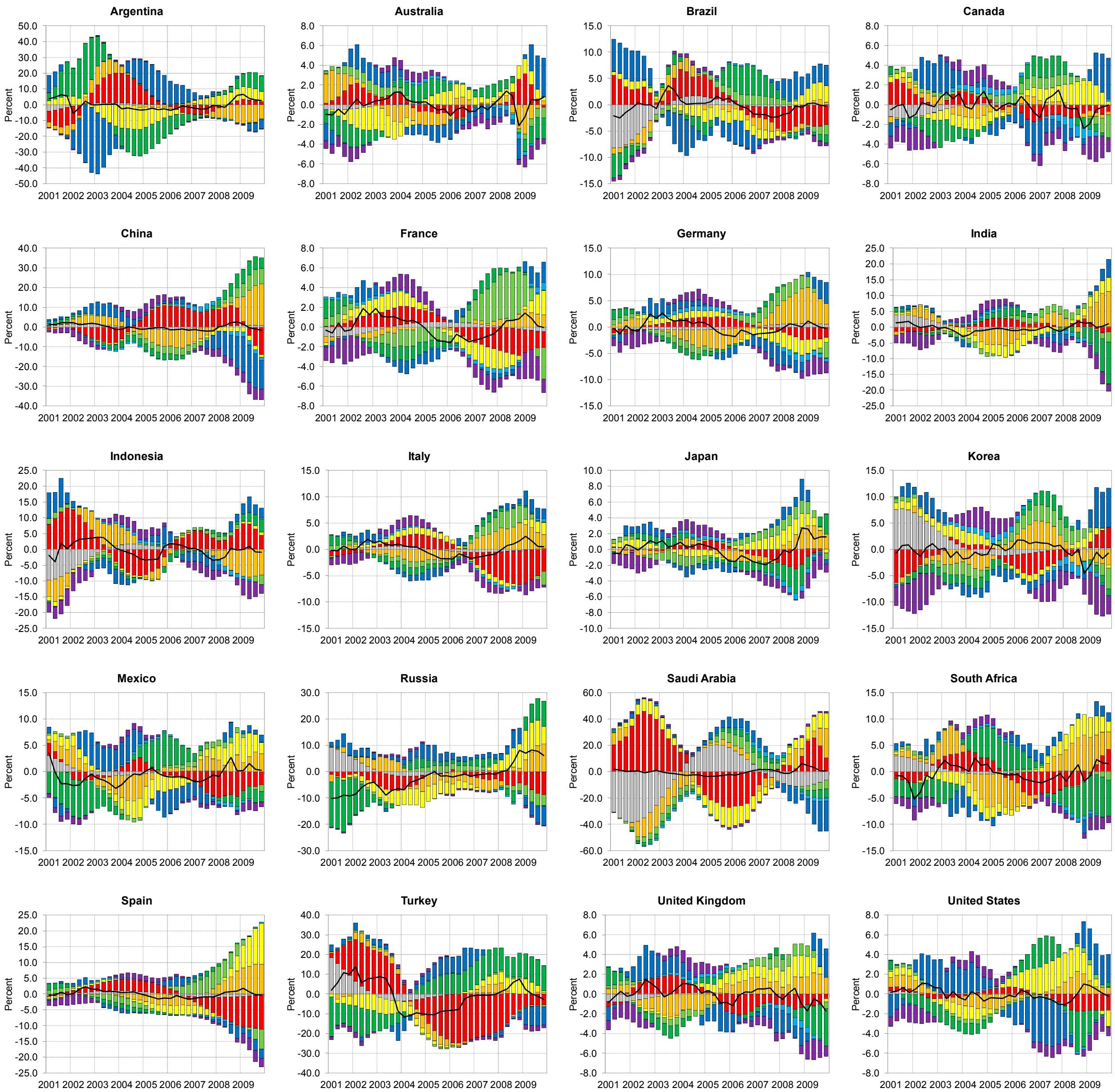
Note: Decomposes observed consumption price inflation as measured by the seasonal logarithmic difference of the consumption price level into the sum of a trend component and contributions from domestic supply, foreign supply, domestic demand, foreign demand, domestic monetary policy, foreign monetary policy, world risk premium, and world commodity price shocks.

Figure 16. Historical Decompositions of the Output Gap



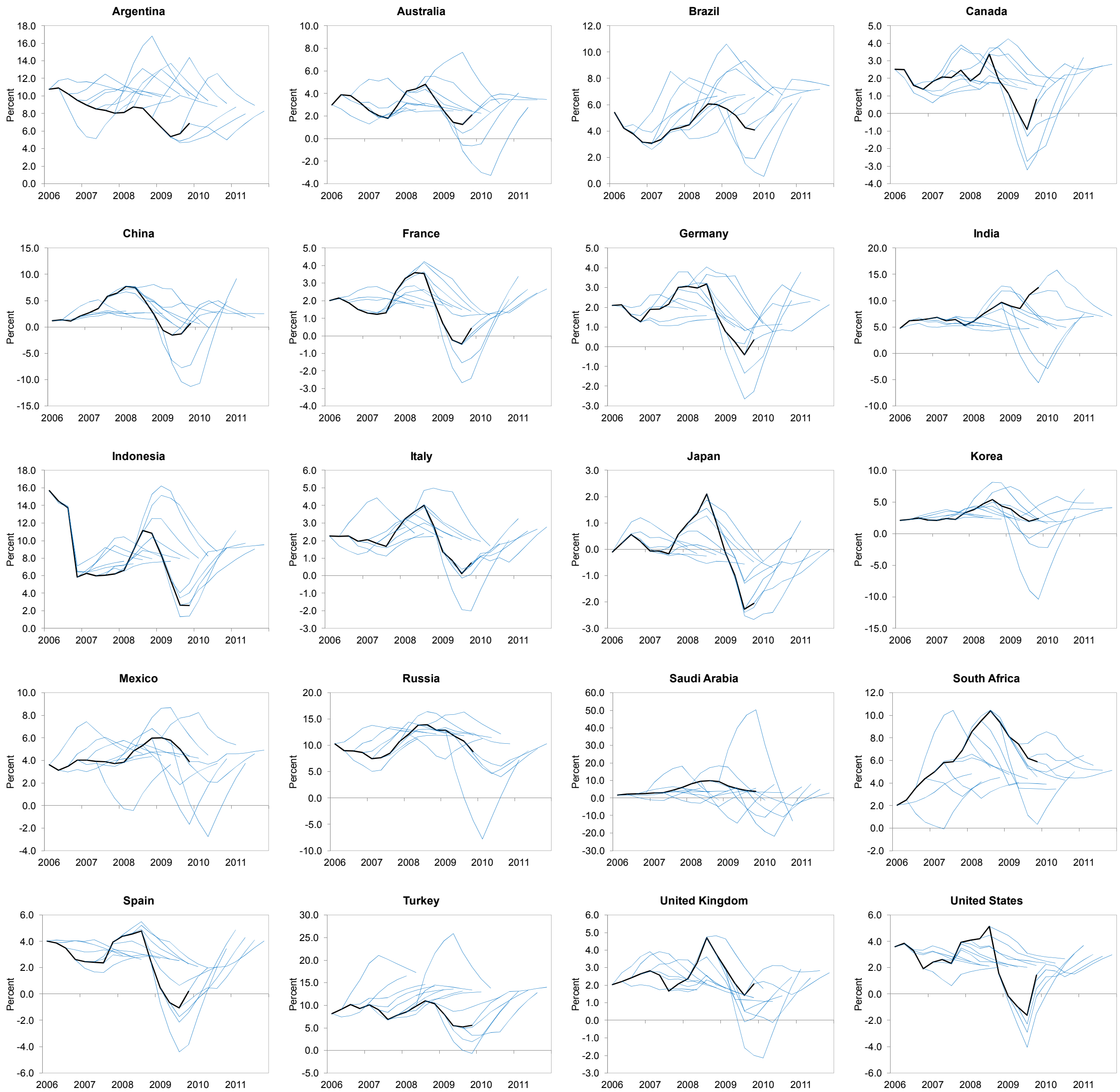
Note: Decomposes smoothed estimates of the output gap ■ into the sum of a deterministic component ■ and contributions from domestic supply ■, foreign supply ■, domestic demand ■, foreign demand ■, domestic monetary policy ■, foreign monetary policy ■, world risk premium ■, and world commodity price ■ shocks.

Figure 17. Historical Decompositions of the Monetary Conditions Gap



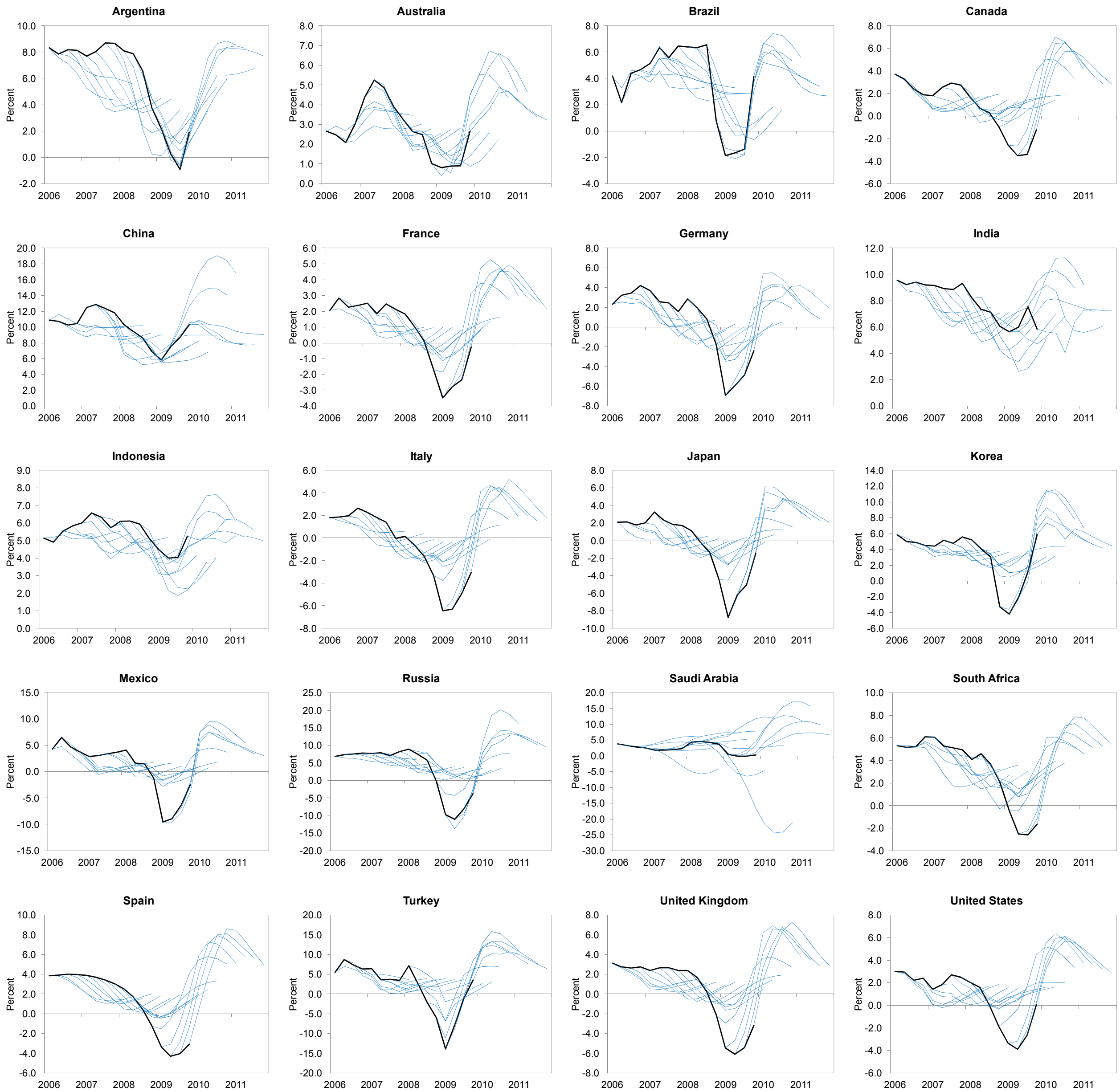
Note: Decomposes smoothed estimates of the monetary conditions gap ■ into the sum of a deterministic component ■ and contributions from domestic supply ■, foreign supply ■, domestic demand ■, foreign demand ■, domestic monetary policy ■, foreign monetary policy ■, world risk premium ■, and world commodity price ■ shocks.

Figure 18. Sequential Unconditional Forecasts of Inflation



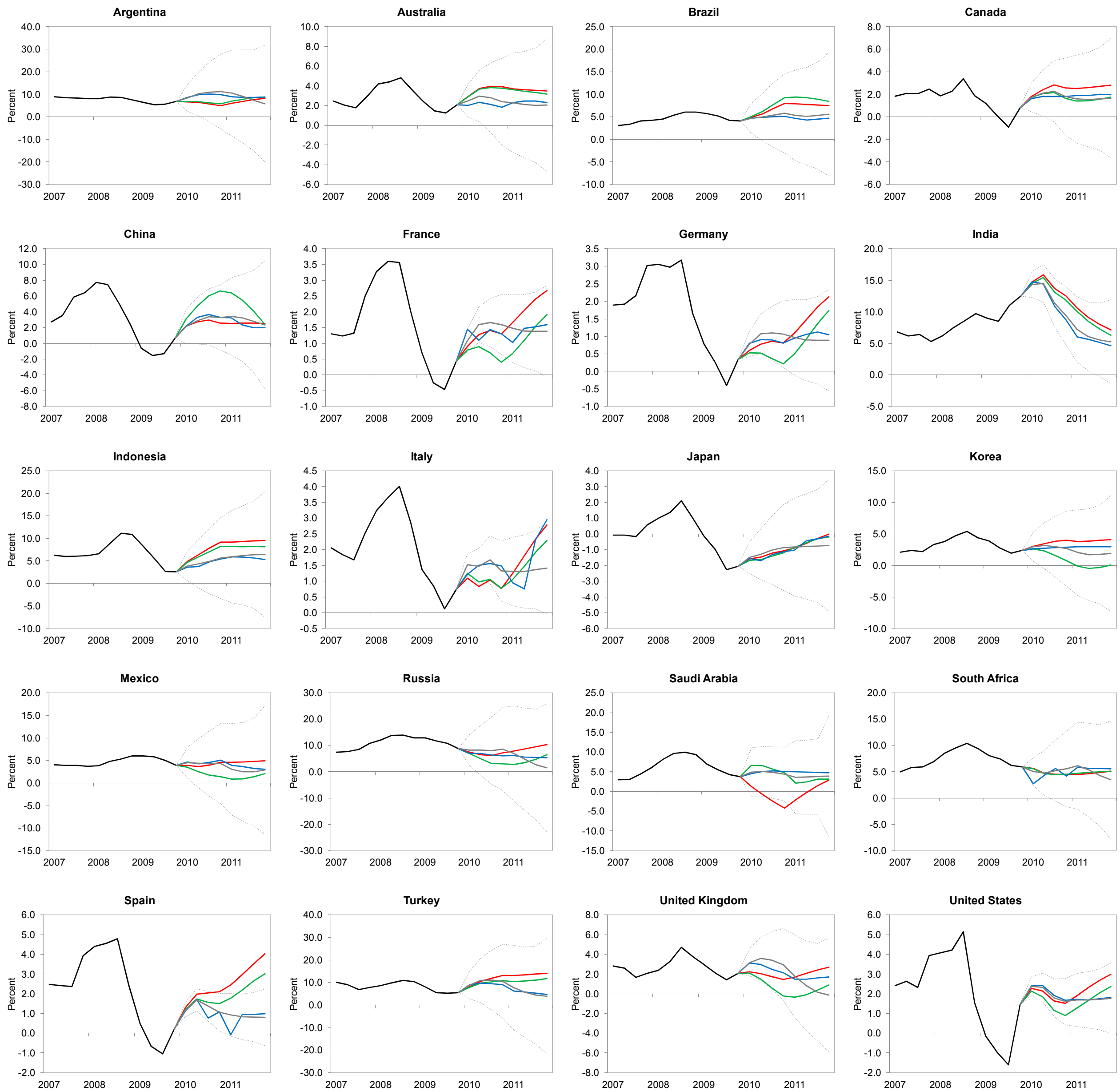
Note: Depicts observed consumption price inflation ■ as measured by the seasonal logarithmic difference of the consumption price level versus sequential unrestricted forecasts ■.

Figure 19. Sequential Unconditional Forecasts of Output Growth



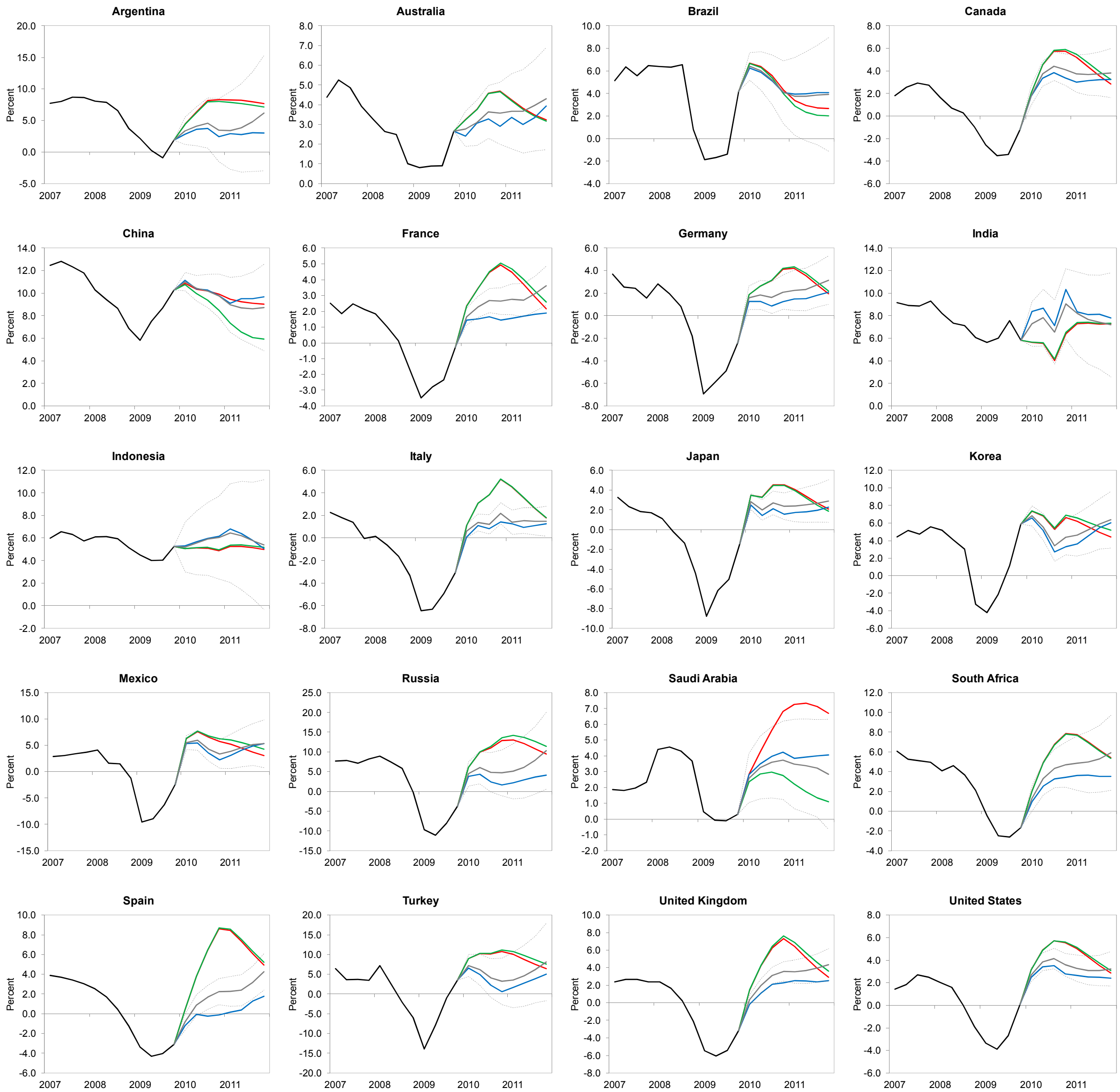
Note: Depicts observed output growth ■ as measured by the seasonal logarithmic difference of the level of output versus sequential unrestricted forecasts ■.

Figure 20. Conditional Forecasts of Inflation



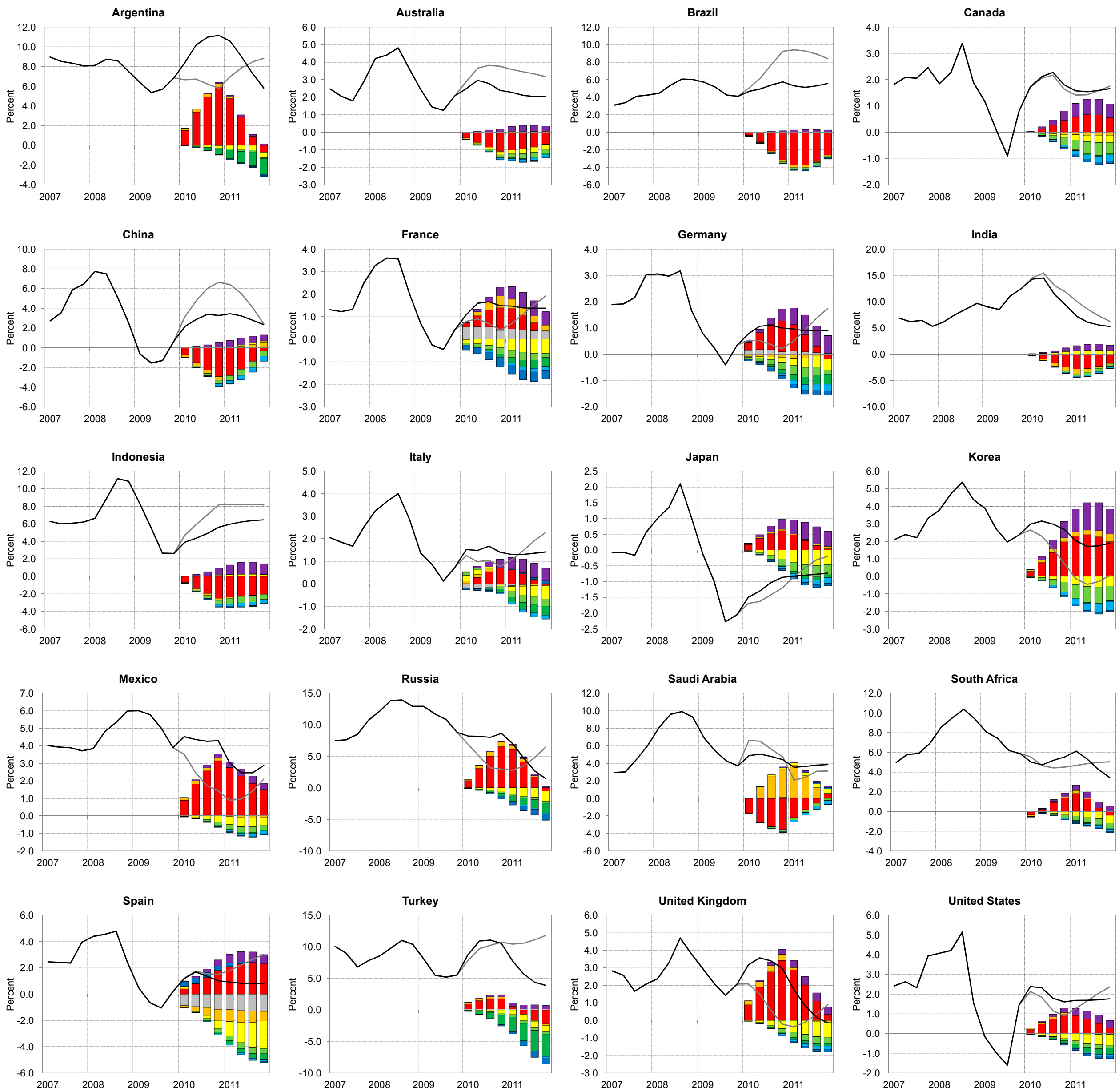
Note: Depicts observed consumption price inflation ■ as measured by the seasonal logarithmic difference of the consumption price level together with unrestricted forecasts ■, restricted forecasts ■, judgmental forecasts ■, and combined forecasts ■. Symmetric 90 percent confidence intervals represented by dashed lines assume normally distributed innovations and known parameters.

Figure 21. Conditional Forecasts of Output Growth



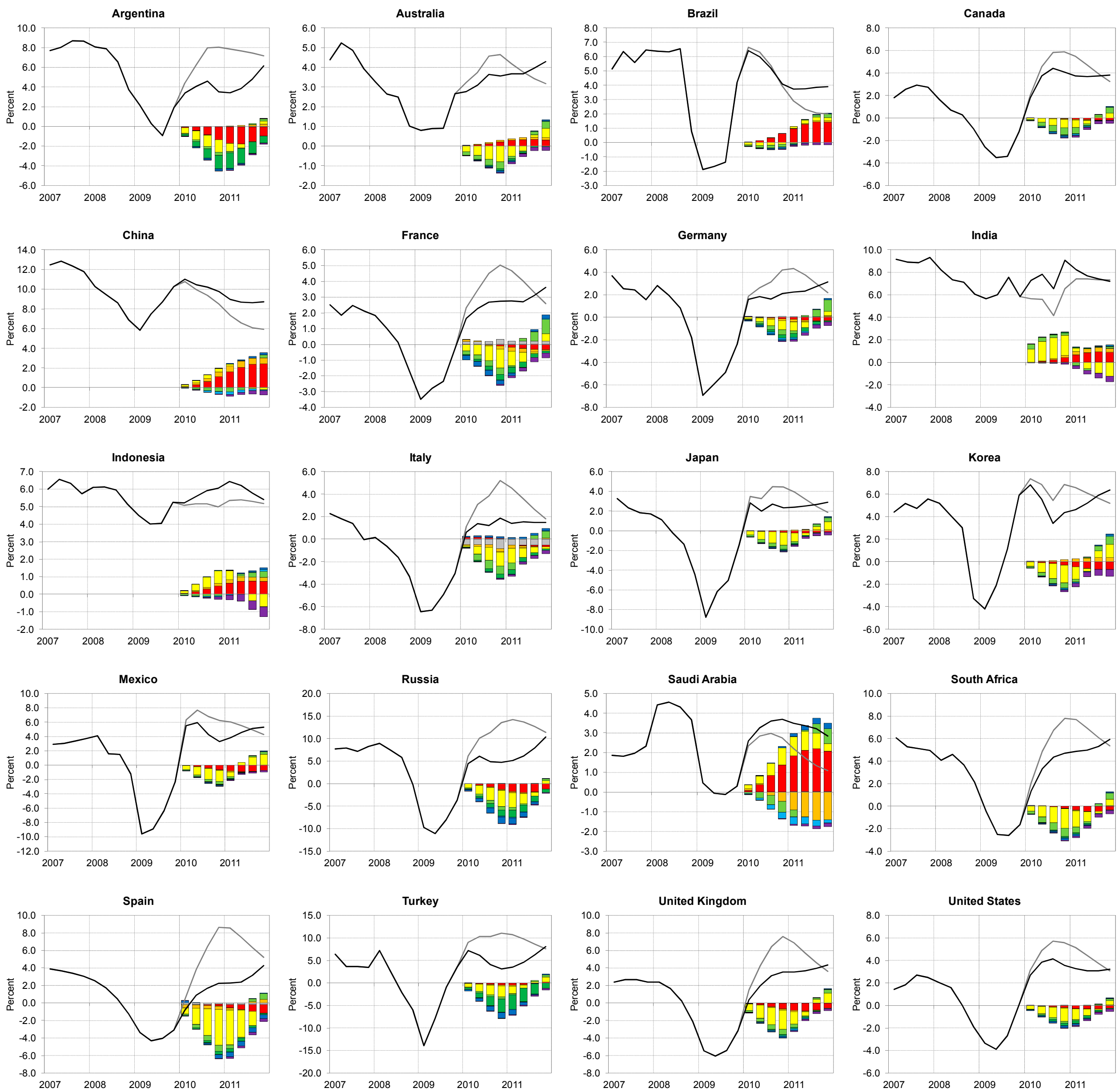
Note: Depicts observed output growth ■ as measured by the seasonal logarithmic difference of the level of output together with unrestricted forecasts ■, restricted forecasts ■, judgmental forecasts ■, and combined forecasts ■. Symmetric 90 percent confidence intervals represented by dashed lines assume normally distributed innovations and known parameters.

Figure 22. Conditional Forecast Decompositions for Inflation



Note: Decomposes the difference between combined forecasts ■ and restricted forecasts ■ of consumption price inflation into the sum of a trend component ■ and contributions from domestic supply ■, foreign supply ■, domestic demand ■, foreign demand ■, domestic monetary policy ■, foreign monetary policy ■, world risk premium ■, and world commodity price ■ shocks.

Figure 23. Conditional Forecast Decompositions for Output Growth



Note: Decomposes the difference between combined forecasts ■ and restricted forecasts ■ of output growth into the sum of a trend component ■ and contributions from domestic supply ■, foreign supply ■, domestic demand ■, foreign demand ■, domestic monetary policy ■, foreign monetary policy ■, world risk premium ■, and world commodity price ■ shocks.

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