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Policy Analysis and Forecasting in the World Economy: A Panel Dynamic Stochastic General Equilibrium Approach

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Abstract

This paper develops a structural macroeconometric model of the world economy, disaggregated into thirty five national economies. This panel unobserved components model encompasses an approximate linear panel dynamic stochastic general equilibrium model featuring a monetary transmission mechanism, a fiscal transmission mechanism, and extensive macrofinancial linkages, both within and across economies. A variety of monetary policy analysis, fiscal policy analysis, spillover 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 dominant empirical framework for the conduct of quantitative monetary and fiscal policy analysis is the estimated approximate linear dynamic stochastic general equilibrium model. This class of structural macroeconometric models has many variants, encompassing a wide variety of markets and transmission mechanisms. Its unifying feature is the derivation of approximate linear equilibrium conditions from constrained optimization problems facing households and firms, which interact with governments in an uncertain environment to determine equilibrium prices and quantities under rational expectations.

This mathematically rigorous approach to structural macroeconometric model development is a blessing, imposing theoretical coherence on dynamic interrelationships among endogenous variables while identifying exogenous variables explaining their variation. However, as discussed in Pesaran and Smith (2011), deriving approximate linear equilibrium conditions from microeconomic foundations can also be a curse, restricting their empirical adequacy or suitability for particular applications by complicating or preventing the resolution of systematic prediction errors. Accordingly, estimated approximate linear dynamic stochastic general equilibrium models are less widely used for spillover analysis, where they generally fail to fully account for international business cycle comovement, probably reflecting insufficient conduits for spillover transmission. They are also less widely used for forecasting, where they often fail to fully adjust to intermittent structural breaks, likely reflecting overly restrictive cointegrating restrictions.

This paper develops a structural macroeconometric model of the world economy, disaggregated into thirty five national economies. This panel unobserved components model encompasses an approximate linear panel dynamic stochastic general equilibrium model, imposing theoretical coherence at cyclical frequencies, while preserving robustness to intermittent structural breaks at trend frequencies. This panel dynamic stochastic general equilibrium model features a variety of nominal and real rigidities, to generate endogenous persistence, as well as extensive macrofinancial linkages, to further amplify and propagate the effects of shocks. It also features a variety of international trade, financial and commodity price linkages, to serve as conduits for spillover transmission. To circumvent tracking bilateral trade and financial flows, its derivation imposes functional form restrictions on selected aggregators, and parameter restrictions on selected equilibrium conditions. A variety of monetary policy analysis, fiscal policy analysis, spillover analysis, and forecasting applications of the estimated panel unobserved components model are demonstrated. These include accounting for business cycle fluctuations, quantifying the monetary and fiscal transmission mechanisms, and generating conditional forecasts of inflation and output growth. They are based on a Bayesian framework for conditioning on judgment in estimation and forecasting.

This paper is the sequel to Vitek (2012), which also develops a structural macroeconometric model of the world economy to facilitate multilaterally consistent monetary policy analysis, fiscal policy analysis, spillover analysis, and forecasting. These closely related panel unobserved components models are complements, covering the same economies and markets, while striking a different balance between theoretical coherence and empirical adequacy. Deriving the equations governing the evolution of its cyclical components from microeconomic foundations enhances the theoretical coherence of this panel unobserved components model relative to its predecessor, while retaining flexible trend component specifications preserves much of its empirical adequacy. This renders it more suitable for most policy and spillover analysis applications, but less suitable for forecasting applications.

The organization of this paper is as follows. The next section develops a panel dynamic stochastic general equilibrium model of the world economy, while the following section describes an approximate linear panel unobserved components representation of it. Estimation of this panel unobserved components model of the world economy is the subject of section four. Monetary and fiscal policy analysis within the framework of the estimated model is conducted in section five, while spillover analysis is undertaken in section six, and forecasting in section seven. Finally, section eight offers conclusions and recommendations for further research.

II. The Panel Dynamic Stochastic General Equilibrium Model

Consider a finite set of structurally isomorphic national economies indexed by $i \in \{1, \ldots, N\}$ which constitutes the world economy. Each of these economies consists of households, firms and a government, which in turn consists of a monetary authority and a fiscal authority. Households and firms optimize intertemporally, interacting with governments in an uncertain environment to determine equilibrium prices and quantities under rational expectations in internationally integrated output, money, bond, and stock markets. Economy $i*$ issues the quotation currency for transactions in the foreign exchange market.

A. The Household Sector

There exists a continuum of households indexed by $h \in [0,1]$. Households are differentiated according to whether they are credit constrained, but are otherwise identical. Credit unconstrained households of type $Z = U$ and measure ϕ^U have access to financial markets where they trade financial assets, whereas credit constrained households of type $Z = C$ and measure ϕ^C do not, where $0 < \phi^U \leq 1$, $0 \leq \phi^C < 1$ and $\phi^U + \phi^C = 1$. Credit constrained households are endowed only with one share of each domestic firm.

The representative infinitely lived household has preferences defined over consumption $C_{h,i,s}$, labor supply $L_{h,i,s}$, and real financial wealth $A^H_{h,i,s+1} / P^C_{i,s}$ represented by intertemporal utility function

$$U_{h,i,t} = \mathrm{E}_t \sum_{s=t}^{\infty} \beta^{s-t} u\left(C_{h,i,s}, L_{h,i,s}, \frac{A^H_{h,i,s+1}}{P^C_{i,s}} \right), \tag{1}$$

where E_t denotes the expectations operator conditional on information available in period t, and $0<\beta<1$. The intratemporal utility function is additively separable and represents external habit formation preferences in consumption,

$$u\left(C_{h,i,s},L_{h,i,s},\frac{A^H_{h,i,s+1}}{P^C_{i,s}}\right)=\nu^C_{i,s}\left[\frac{1}{1-1/\sigma}\left(C_{h,i,s}-\alpha\frac{C^Z_{i,s-1}}{\phi^Z}\right)^{1-1/\sigma}-\frac{\nu^L_i}{1+1/\eta}(L_{h,i,s})^{1+1/\eta}+\frac{\nu^A_i}{1-1/\sigma}\left(\frac{A^H_{h,i,s+1}}{P^C_{i,s}}\right)^{1-1/\sigma}\right], \quad (2)$$

where $0\le\alpha<1$. This intratemporal utility function is strictly increasing with respect to consumption if and only if serially correlated intertemporal substitution shock $\nu^C_{i,s}$ satisfies $\nu^C_{i,s}>0$, and given this parameter restriction is strictly decreasing with respect to labor supply if and only if $\nu^L_i>0$, and is strictly increasing with respect to real financial wealth if and only if $\nu^A_i>0$. Given these parameter restrictions, this intratemporal utility function is strictly concave if $\sigma>0$ and $\eta>0$. In steady state equilibrium, ν^A_i equates the marginal rate of substitution between real financial wealth and consumption to one.

The representative household has a precautionary savings motive for holding real financial wealth, and a portfolio diversification motive over its allocation across alternative financial assets which are imperfect substitutes. The set of financial assets under consideration consists of internationally traded and local currency denominated short term bonds, long term bonds, and stocks. Short term bonds are discount bonds, while long term bonds are perpetual bonds. Preferences over the real values of internationally diversified short term bond $B^{S,H}_{h,i,s+1}/P^C_{i,s}$, long term bond $B^{L,H}_{h,i,s+1}/P^C_{i,s}$ and stock $S^H_{h,i,s+1}/P^C_{i,s}$ portfolios are represented by constant elasticity of substitution intratemporal subutility function

$$\frac{A^H_{h,i,s+1}}{P^C_{i,s}}=\left[(\phi^A_{i,M})^{\frac{1}{\psi^A}}\left(\frac{B^{S,H}_{h,i,s+1}}{P^C_{i,s}}\right)^{\frac{\psi^A-1}{\psi^A}}+(\phi^A_{i,B})^{\frac{1}{\psi^A}}\left(\upsilon^B_{i,s}\frac{B^{L,H}_{h,i,s+1}}{P^C_{i,s}}\right)^{\frac{\psi^A-1}{\psi^A}}+(\phi^A_{i,S})^{\frac{1}{\psi^A}}\left(\upsilon^S_{i,s}\frac{S^H_{h,i,s+1}}{P^C_{i,s}}\right)^{\frac{\psi^A-1}{\psi^A}}\right]^{\frac{\psi^A}{\psi^A-1}}, \quad (3)$$

where internationally and serially correlated duration risk premium shock $\upsilon^B_{i,s}$ satisfies $\upsilon^B_{i,s}>0$, and internationally and serially correlated equity risk premium shock $\upsilon^S_{i,s}$ satisfies $\upsilon^S_{i,s}>0$, while $0\le\phi^A_{i,M}\le1$, $0\le\phi^A_{i,B}\le1$, $0\le\phi^A_{i,S}\le1$, $\phi^A_{i,M}+\phi^A_{i,B}+\phi^A_{i,S}=1$ and $\psi^A>0$. Preferences over the real values of economy specific short term bond $\{\mathcal{E}_{i,j,s}B^{S,H}_{h,i,j,s+1}/P^C_{i,s}\}^N_{j=1}$, long term bond $\{\mathcal{E}_{i,j,s}B^{L,H}_{h,i,j,s+1}/P^C_{i,s}\}^N_{j=1}$ and stock $\{\mathcal{E}_{i,j,s}S^H_{h,i,j,s+1}/P^C_{i,s}\}^N_{j=1}$ portfolios are in turn represented by constant elasticity of substitution intratemporal subutility functions

$$\frac{B^{S,H}_{h,i,s+1}}{P^C_{i,s}}=\left[\sum_{j=1}^N(\phi^B_{i,j})^{\frac{1}{\psi^A}}\left(\nu^{\mathcal{E}}_{j,s}\frac{\mathcal{E}_{i,j,s}B^{S,H}_{h,i,j,s+1}}{P^C_{i,s}}\right)^{\frac{\psi^A-1}{\psi^A}}\right]^{\frac{\psi^A}{\psi^A-1}}, \quad (4)$$

$$\frac{B^{L,H}_{h,i,s+1}}{P^C_{i,s}}=\left[\sum_{j=1}^N(\phi^B_{i,j})^{\frac{1}{\psi^A}}\left(\nu^{\mathcal{E}}_{j,s}\frac{\mathcal{E}_{i,j,s}B^{L,H}_{h,i,j,s+1}}{P^C_{i,s}}\right)^{\frac{\psi^A-1}{\psi^A}}\right]^{\frac{\psi^A}{\psi^A-1}}, \quad (5)$$

$$\frac{S^H_{h,i,s+1}}{P^C_{i,s}} = \left[\sum_{j=1}^{N} (\phi^S_{i,j})^{\frac{1}{\psi^A}} \left(\nu^{\mathcal{E}}_{j,s} \frac{\mathcal{E}_{i,j,s} S^H_{h,i,j,s+1}}{P^C_{i,s}} \right)^{\frac{\psi^A - 1}{\psi^A}} \right]^{\frac{\psi^A}{\psi^A - 1}}, \tag{6}$$

where serially correlated currency risk premium shocks $\nu^{\mathcal{E}}_{j,s}$ satisfy $\nu^{\mathcal{E}}_{j,s} > 0$, while $0 \le \phi^B_{i,j} \le 1$, $\sum_{j=1}^{N} \phi^B_{i,j} = 1$, $0 \le \phi^S_{i,j} \le 1$ and $\sum_{j=1}^{N} \phi^S_{i,j} = 1$. Finally, preferences over the real values of economy and vintage specific long term bonds $\{\{\mathcal{E}_{i,j,s} V^B_{j,k,s} B^{L,H}_{h,i,j,k,s+1} / P^C_{i,s}\}_{k=1}^{s}\}_{j=1}^{N}$ and economy, industry and firm specific shares $\{\{\{\mathcal{E}_{i,j,s} V^S_{j,k,l,s} S^H_{h,i,j,k,l,s+1} / P^C_{i,s}\}_{l=0}^{1}\}_{k=1}^{M}\}_{j=1}^{N}$ are represented by constant elasticity of substitution intratemporal subutility functions

$$\frac{\mathcal{E}_{i,j,s} B^{L,H}_{h,i,j,s+1}}{P^C_{i,s}} = \left[\sum_{k=1}^{s} (\phi^B_{i,j,k,s})^{\frac{1}{\psi^A}} \left(\frac{\mathcal{E}_{i,j,s} V^B_{j,k,s} B^{L,H}_{h,i,j,k,s+1}}{P^C_{i,s}} \right)^{\frac{\psi^A - 1}{\psi^A}} \right]^{\frac{\psi^A}{\psi^A - 1}}, \tag{7}$$

$$\frac{\mathcal{E}_{i,j,s} S^H_{h,i,j,s+1}}{P^C_{i,s}} = \left[\sum_{k=1}^{M} (\phi^S_{i,j,k})^{\frac{1}{\psi^A}} \int_0^1 \left(\frac{\mathcal{E}_{i,j,s} V^S_{j,k,l,s} S^H_{h,i,j,k,l,s+1}}{P^C_{i,s}} \right)^{\frac{\psi^A - 1}{\psi^A}} dl \right]^{\frac{\psi^A}{\psi^A - 1}}, \tag{8}$$

where $0 \le \phi^B_{i,j,k,s} \le 1$, $\sum_{k=1}^{s} \phi^B_{i,j,k,s} = 1$, $0 \le \phi^S_{i,j,k} \le 1$ and $\sum_{k=1}^{M} \phi^S_{i,j,k} = 1$. In the limit as $\nu^A_i \to 0$ there is no precautionary savings motive for holding real financial wealth, while in the limit as $\psi^A \to \infty$ there is no portfolio diversification motive over its allocation across alternative financial assets which in this case are perfect substitutes.

The representative household enters period s in possession of previously accumulated financial wealth $A^H_{h,i,s}$ which yields return $i^{A^H}_{h,i,s}$. This financial wealth is distributed across the values of internationally diversified short term bond $B^{S,H}_{h,i,s}$, long term bond $B^{L,H}_{h,i,s}$ and stock $S^H_{h,i,s}$ portfolios which yield returns $i^{B^{S,H}}_{h,i,s}$, $i^{B^{L,H}}_{h,i,s}$ and $i^{S^H}_{h,i,s}$, respectively. It follows that $(1+i^{A^H}_{h,i,s})A^H_{h,i,s} = (1+i^{B^{S,H}}_{h,i,s})B^{S,H}_{h,i,s} + (1+i^{B^{L,H}}_{h,i,s})B^{L,H}_{h,i,s} + (1+i^{S^H}_{h,i,s})S^H_{h,i,s}$. The values of these internationally diversified short term bond, long term bond and stock portfolios are in turn distributed across the domestic currency denominated values of economy specific short term bond $\{\mathcal{E}_{i,j,s} B^{S,H}_{h,i,j,s}\}_{j=1}^{N}$, long term bond $\{\mathcal{E}_{i,j,s} B^{L,H}_{h,i,j,s}\}_{j=1}^{N}$ and stock $\{\mathcal{E}_{i,j,s} S^H_{h,i,j,s}\}_{j=1}^{N}$ portfolios, where nominal bilateral exchange rate $\mathcal{E}_{i,j,s}$ measures the price of foreign currency in terms of domestic currency. It follows that $(1+i^{B^{S,H}}_{h,i,s})B^{S,H}_{h,i,s} = \sum_{j=1}^{N} \mathcal{E}_{i,j,s}(1+i^S_{j,s-1})B^{S,H}_{h,i,j,s}$ where $i^S_{j,s-1}$ denotes the economy specific yield to maturity on short term bonds, $(1+i^{B^{L,H}}_{h,i,s})B^{L,H}_{h,i,s} = \sum_{j=1}^{N} \mathcal{E}_{i,j,s}(1+i^{B^{L,H}}_{h,i,j,s})B^{L,H}_{h,i,j,s}$ where $i^{B^{L,H}}_{h,i,j,s}$ denotes the economy specific return on long term bonds, and $(1+i^{S^H}_{h,i,s})S^H_{h,i,s} = \sum_{j=1}^{N} \mathcal{E}_{i,j,s}(1+i^{S^H}_{h,i,j,s})S^H_{h,i,j,s}$ where $i^{S^H}_{h,i,j,s}$ denotes the economy specific return on stocks. The local currency denominated values of economy specific long term bond portfolios $\{B^{L,H}_{h,i,j,s}\}_{j=1}^{N}$ are in turn distributed across the values of economy and vintage specific long term bonds $\{\{V^B_{j,k,s} B^{L,H}_{h,i,j,k,s}\}_{k=1}^{s-1}\}_{j=1}^{N}$, where $V^B_{j,k,s}$ denotes the local currency denominated price per long term bond, with $V^B_{j,k,k} = 1$. It follows that $(1+i^{B^{L,H}}_{h,i,j,s})B^{L,H}_{h,i,j,s} = \sum_{k=1}^{s-1}(\Pi^B_{j,k,s} + V^B_{j,k,s})B^{L,H}_{h,i,j,k,s}$, where $\Pi^B_{j,k,s} = i^L_{j,k} V^B_{j,k,k}$ denotes the local currency denominated coupon payment per long term bond, and $i^L_{j,k}$ denotes the economy and vintage specific yield to maturity on long term bonds at issuance. In parallel, the local currency denominated values of economy specific stock portfolios $\{S_{h,i,j,s}^{H}\}_{j=1}^{N}$ are distributed across the values of economy, industry and firm specific shares $\{\{\{V_{j,k,l,s}^{S} S_{h,i,j,k,l,s}^{H}\}_{l=0}^{1}\}_{k=1}^{M}\}_{j=1}^{N}$, where $V_{j,k,l,s}^{S}$ denotes the local currency denominated price per share. It follows that $(1+i_{h,i,j,s}^{S^H})S_{h,i,j,s}^{H} = \sum_{k=1}^{M}\int_0^1 (\Pi_{j,k,l,s}^{S} + V_{j,k,l,s}^{S}) S_{h,i,j,k,l,s}^{H} dl$, where $\Pi_{j,k,l,s}^{S}$ denotes the local currency denominated dividend payment per share. During period s, the representative household supplies labor service $L_{h,i,s}$, earning labor income at nominal wage $W_{i,s}$. The government levies a tax on labor income at rate $\tau_{i,s}$. These sources of wealth are summed in household dynamic budget constraint:

$$A_{h,i,s+1}^{H} = (1+i_{h,i,s}^{A^H})A_{h,i,s}^{H} + (1-\tau_{i,s})W_{i,s}L_{h,i,s} - P_{i,s}^{C}C_{h,i,s}. \tag{9}$$

According to this dynamic budget constraint, at the end of period s, the representative household holds financial wealth $A_{h,i,s+1}^{H}$, which it allocates between the values of internationally diversified short term bond $B_{h,i,s+1}^{S,H}$, long term bond $B_{h,i,s+1}^{L,H}$ and stock portfolios $S_{h,i,s+1}^{H}$, that is $A_{h,i,s+1}^{H} = B_{h,i,s+1}^{S,H} + B_{h,i,s+1}^{L,H} + S_{h,i,s+1}^{H}$. The values of these internationally diversified short term bond, long term bond and stock portfolios are in turn allocated across the domestic currency denominated values of economy specific short term bond $\{\mathcal{E}_{i,j,s} B_{h,i,j,s+1}^{S,H}\}_{j=1}^{N}$, long term bond $\{\mathcal{E}_{i,j,s} B_{h,i,j,s+1}^{L,H}\}_{j=1}^{N}$ and stock $\{\mathcal{E}_{i,j,s} S_{h,i,j,s+1}^{H}\}_{j=1}^{N}$ portfolios subject to $B_{h,i,s+1}^{S,H} = \sum_{j=1}^{N} \mathcal{E}_{i,j,s} B_{h,i,j,s+1}^{S,H}$, $B_{h,i,s+1}^{L,H} = \sum_{j=1}^{N} \mathcal{E}_{i,j,s} B_{h,i,j,s+1}^{L,H}$ and $S_{h,i,s+1}^{H} = \sum_{j=1}^{N} \mathcal{E}_{i,j,s} S_{h,i,j,s+1}^{H}$, respectively. The local currency denominated values of economy specific long term bond portfolios $\{B_{h,i,j,s+1}^{L,H}\}_{j=1}^{N}$ are in turn allocated across the local currency denominated values of economy and vintage specific long term bonds $\{\{V_{j,k,s}^{B} B_{h,i,j,k,s+1}^{L,H}\}_{k=1}^{s}\}_{j=1}^{N}$ subject to $B_{h,i,j,s+1}^{L,H} = \sum_{k=1}^{s} V_{j,k,s}^{B} B_{h,i,j,k,s+1}^{L,H}$. In parallel, the local currency denominated values of economy specific stock portfolios $\{S_{h,i,j,s+1}^{H}\}_{j=1}^{N}$ are allocated across the local currency denominated values of economy, industry and firm specific shares $\{\{\{V_{j,k,l,s}^{S} S_{h,i,j,k,l,s+1}^{H}\}_{l=0}^{1}\}_{k=1}^{M}\}_{j=1}^{N}$ subject to $S_{h,i,j,s+1}^{H} = \sum_{k=1}^{M}\int_0^1 V_{j,k,l,s}^{S} S_{h,i,j,k,l,s+1}^{H} dl$. Finally, the representative household purchases final private consumption good $C_{h,i,s}$ at price $P_{i,s}^{C}$.

Credit Unconstrained Households

In period t, the representative credit unconstrained household chooses state contingent sequences for consumption $\{C_{h,i,s}\}_{s=t}^{\infty}$, labor supply $\{L_{h,i,s}\}_{s=t}^{\infty}$, financial wealth $\{A_{h,i,s+1}^{H}\}_{s=t}^{\infty}$, short term bond holdings $\{\{B_{h,i,j,s+1}^{S,H}\}_{j=1}^{N}\}_{s=t}^{\infty}$, long term bond holdings $\{\{\{B_{h,i,j,k,s+1}^{L,H}\}_{k=1}^{t}\}_{j=1}^{N}\}_{s=t}^{\infty}$, and stock holdings $\{\{\{\{S_{h,i,j,k,l,s+1}^{H}\}_{l=0}^{1}\}_{k=1}^{M}\}_{j=1}^{N}\}_{s=t}^{\infty}$ to maximize intertemporal utility function (1) subject to dynamic budget constraint (9) and terminal nonnegativity constraints $B_{h,i,j,T+1}^{S,H} \geq 0$, $B_{h,i,j,k,T+1}^{L,H} \geq 0$ and $S_{h,i,j,k,l,T+1}^{H} \geq 0$ for $T \to \infty$. In equilibrium, abstracting from the precautionary savings motive the solutions to this utility maximization problem satisfy intertemporal optimality condition

$$\mathrm{E}_t \frac{\beta u_C(h,i,t+1)}{u_C(h,i,t)} \frac{P_{i,t}^{C}}{P_{i,t+1}^{C}} (1+i_{h,i,t+1}^{A^H}) = 1, \tag{10}$$

which equates the expected present value of the gross real risk adjusted portfolio return to one. In addition, these solutions satisfy intratemporal optimality condition

$$-\frac{u_L(h,i,t)}{u_C(h,i,t)} = (1-\tau_{i,t})\frac{W_{i,t}}{P^C_{i,t}}, \tag{11}$$

which equates the marginal rate of substitution between leisure and consumption to the after tax real wage. Abstracting from risk premium shocks, the expected present value of the gross real risk adjusted portfolio return satisfies intratemporal optimality condition

$$\begin{aligned}
&\phi^A_{i,M}\sum_{j=1}^{N}\phi^B_{i,j}\left\{1+\mathrm{E}_t\,\frac{\beta u_C(h,i,t+1)}{u_C(h,i,t)}\frac{u_C(h,i,t)}{u_A(h,i,t)}\frac{P^C_{i,t}}{P^C_{i,t+1}}\left[(1+i^{A^H}_{h,i,t+1})-(1+i^S_{j,t})\frac{\mathcal{E}_{i,j,t+1}}{\mathcal{E}_{i,j,t}}\right]\right\}^{1-\psi^A}\\
&+\phi^A_{i,B}\sum_{j=1}^{N}\phi^B_{i,j}\sum_{k=1}^{t}\phi^B_{i,j,k,t}\left\{1+\mathrm{E}_t\,\frac{\beta u_C(h,i,t+1)}{u_C(h,i,t)}\frac{u_C(h,i,t)}{u_A(h,i,t)}\frac{P^C_{i,t}}{P^C_{i,t+1}}\left[(1+i^{A^H}_{h,i,t+1})-\frac{i^L_{j,k}+V^B_{j,k,t+1}}{V^B_{j,k,t}}\frac{\mathcal{E}_{i,j,t+1}}{\mathcal{E}_{i,j,t}}\right]\right\}^{1-\psi^A}\\
&+\phi^A_{i,S}\sum_{j=1}^{N}\phi^S_{i,j}\sum_{k=1}^{M}\phi^S_{i,j,k}\int_0^1\left\{1+\mathrm{E}_t\,\frac{\beta u_C(h,i,t+1)}{u_C(h,i,t)}\frac{u_C(h,i,t)}{u_A(h,i,t)}\frac{P^C_{i,t}}{P^C_{i,t+1}}\left[(1+i^{A^H}_{h,i,t+1})-\frac{\Pi^S_{j,k,l,t+1}+V^S_{j,k,l,t+1}}{V^S_{j,k,l,t}}\frac{\mathcal{E}_{i,j,t+1}}{\mathcal{E}_{i,j,t}}\right]\right\}^{1-\psi^A}dl=1,
\end{aligned} \tag{12}$$

which relates it to the expected present values of the gross real risk adjusted returns on domestic and foreign short term bonds, long term bonds, and stocks. Furthermore, abstracting from the portfolio diversification motive these solutions satisfy intratemporal optimality condition

$$\mathrm{E}_t\,\frac{\beta u_C(h,i,t+1)}{u_C(h,i,t)}\frac{P^C_{i,t}}{P^C_{i,t+1}}\left[(1+i^S_{i,t})-(1+i^S_{j,t})\frac{\mathcal{E}_{i,j,t+1}}{\mathcal{E}_{i,j,t}}\right] = -\frac{u_A(h,i,t)}{u_C(h,i,t)}(\nu^{\mathcal{E}}_{i,t}-\nu^{\mathcal{E}}_{j,t}), \tag{13}$$

which equates the expected present values of the gross real risk adjusted returns on domestic and foreign short term bonds. In addition, abstracting from the portfolio diversification motive these solutions satisfy intratemporal optimality condition

$$\mathrm{E}_t\,\frac{\beta u_C(h,i,t+1)}{u_C(h,i,t)}\frac{P^C_{i,t}}{P^C_{i,t+1}}\left[(1+i^S_{i,t})-\frac{i^L_{i,k}+V^B_{i,k,t+1}}{V^B_{i,k,t}}\right] = -\frac{u_A(h,i,t)}{u_C(h,i,t)}\nu^{\mathcal{E}}_{i,t}(1-\upsilon^B_{i,t}), \tag{14}$$

which equates the expected present values of the gross real risk adjusted returns on domestic short and long term bonds. Finally, abstracting from the portfolio diversification motive these solutions satisfy intratemporal optimality condition

$$\mathrm{E}_t\,\frac{\beta u_C(h,i,t+1)}{u_C(h,i,t)}\frac{P^C_{i,t}}{P^C_{i,t+1}}\left[(1+i^S_{i,t})-\frac{\Pi^S_{i,k,l,t+1}+V^S_{i,k,l,t+1}}{V^S_{i,k,l,t}}\right] = -\frac{u_A(h,i,t)}{u_C(h,i,t)}\nu^{\mathcal{E}}_{i,t}(1-\upsilon^S_{i,t}), \tag{15}$$

which equates the expected present values of the gross real risk adjusted returns on domestic short term bonds and stocks. Provided that the intertemporal utility function is bounded and strictly concave, together with other optimality conditions, and transversality conditions derived from necessary complementary slackness conditions associated with the terminal nonnegativity constraints, these optimality conditions are sufficient for the unique utility maximizing state contingent sequence of credit unconstrained household allocations.

Credit Constrained Households

In period t, the representative credit constrained household chooses state contingent sequences for consumption $\{C_{h,i,s}\}_{s=t}^{\infty}$ and labor supply $\{L_{h,i,s}\}_{s=t}^{\infty}$ to maximize intertemporal utility function (1) subject to dynamic budget constraint (9). In equilibrium, the solutions to this utility maximization problem satisfy household static budget constraint

$$P_{i,t}^{C}C_{h,i,t} = \Pi_{i,t}^{S} + (1-\tau_{i,t})W_{i,t}L_{h,i,t}, \tag{16}$$

which equates consumption expenditures to the sum of profit and disposable labor income. These solutions also satisfy intratemporal optimality condition

$$-\frac{u_L(h,i,t)}{u_C(h,i,t)} = (1-\tau_{i,t})\frac{W_{i,t}}{P_{i,t}^{C}}, \tag{17}$$

which equates the marginal rate of substitution between leisure and consumption to the after tax real wage. Provided that the intertemporal utility function is bounded and strictly concave, these optimality conditions are sufficient for the unique utility maximizing state contingent sequence of credit constrained household allocations.

B. The Production Sector

The production sector consists of a finite set of industries indexed by $k \in \{1,\dots,M\}$, of which the first M^* produce commodities. In particular, the energy commodity industry labeled $k=1$ and the nonenergy commodity industry labeled $k=2$ produce internationally homogeneous goods for foreign consumption under decreasing returns to scale, while all other industries produce internationally differentiated goods for domestic and foreign consumption under constant returns to scale. Labor is perfectly mobile across industries.

Output Demand

There exist a large number of perfectly competitive firms which combine industry specific final output goods $\{Y_{i,k,t}\}_{k=1}^{M}$ to produce final output good $Y_{i,t}$ according to Leontief production function

$$Y_{i,t} = \min\left\{\frac{Y_{i,k,t}}{\phi_{i,k}^{Y}}\right\}_{k=1}^{M}, \tag{18}$$

where $0 \le \phi_{i,k}^{Y} \le 1$ and $\sum_{k=1}^{M}\phi_{i,k}^{Y} = 1$. The representative final output good firm maximizes profits derived from production of the final output good with respect to inputs of industry specific final output goods, implying demand functions:

$$Y_{i,k,t} = \phi_{i,k}^{Y}Y_{i,t}. \tag{19}$$

Since the production function exhibits constant returns to scale, in equilibrium the representative final output good firm generates zero profit, implying aggregate output price index:

$$P_{i,t}^{Y}=\sum_{k=1}^{M}\phi_{i,k}^{Y}P_{i,k,t}^{Y}. \tag{20}$$

This aggregate output price index equals the minimum cost of producing one unit of the final output good, given the prices of industry specific final output goods.

There exist a large number of perfectly competitive firms which combine industry specific differentiated intermediate output goods $Y_{i,k,l,t}$ supplied by industry specific intermediate output good firms to produce industry specific final output good $Y_{i,k,t}$ according to constant elasticity of substitution production function

$$Y_{i,k,t}=\left[\int_{0}^{1}(Y_{i,k,l,t})^{\frac{\theta_{i,k,t}^{Y}-1}{\theta_{i,k,t}^{Y}}}dl\right]^{\frac{\theta_{i,k,t}^{Y}}{\theta_{i,k,t}^{Y}-1}}, \tag{21}$$

where serially uncorrelated output price markup shock $\theta_{i,k,t}^{Y}$ satisfies $\theta_{i,k,t}^{Y}>1$ with $\theta_{i,k}^{Y}=\theta^{Y}$, while $\theta_{i,k,t}^{Y}=\theta_{k,t}^{Y}$ for $1\leq k\leq M^{*}$ and $\theta_{i,k,t}^{Y}=\theta_{i,t}^{Y}$ otherwise. The representative industry specific final output good firm maximizes profits derived from production of the industry specific final output good with respect to inputs of industry specific intermediate output goods, implying demand functions:

$$Y_{i,k,l,t}=\left(\frac{P_{i,k,l,t}^{Y}}{P_{i,k,t}^{Y}}\right)^{-\theta_{i,k,t}^{Y}}Y_{i,k,t}. \tag{22}$$

Since the production function exhibits constant returns to scale, in equilibrium the representative industry specific final output good firm generates zero profit, implying industry specific aggregate output price index:

$$P_{i,k,t}^{Y}=\left[\int_{0}^{1}(P_{i,k,l,t}^{Y})^{1-\theta_{i,k,t}^{Y}}dl\right]^{\frac{1}{1-\theta_{i,k,t}^{Y}}}. \tag{23}$$

As the price elasticity of demand for industry specific intermediate output goods $\theta_{i,k,t}^{Y}$ increases, they become closer substitutes, and individual industry specific intermediate output good firms have less market power.

Output Supply

There exist continuums of monopolistically competitive industry specific intermediate output good firms indexed by $l\in[0,1]$. Intermediate output good firms supply industry specific differentiated intermediate output goods, but are otherwise identical.

The representative industry specific intermediate output good firm sells shares to domestic and foreign households at price $V_{i,k,l,t}^{S}$. Acting in the interests of its shareholders, it maximizes its pre-dividend stock market value, which abstracting from the precautionary savings motive equals the expected present value of current and future dividend payments

$$\Pi^S_{i,k,l,t} + V^S_{i,k,l,t} = \mathrm{E}_t \sum_{s=t}^{\infty} \frac{\beta^{s-t}\lambda_{i,s}}{\lambda_{i,t}} \Pi^S_{i,k,l,s}, \tag{24}$$

where $\lambda_{i,s}$ denotes the Lagrange multiplier associated with the period s household dynamic budget constraint. The derivation of this result imposes a transversality condition which rules out self-fulfilling speculative asset price bubbles.

Shares entitle households to dividend payments equal to profits $\Pi^S_{i,k,l,s}$, where earnings are defined as revenues derived from sales of industry specific differentiated intermediate output good $Y_{i,k,l,s}$ at price $P^Y_{i,k,l,s}$ less expenditures on labor service $L_{i,k,l,s}$:

$$\Pi^S_{i,k,l,s} = (1-\tau_{i,s})(P^Y_{i,k,l,s}Y_{i,k,l,s} - W_{i,s}L_{i,k,l,s}). \tag{25}$$

The government levies a tax on earnings at rate $\tau_{i,s}$. The representative industry specific intermediate output good firm rents labor service $L_{i,k,l,s}$ to produce differentiated intermediate output good $Y_{i,k,l,s}$ according to production function

$$Y_{i,k,l,s} = \mathcal{A}_{i,s}(L_{i,k,l,s})^{\phi^L_k}, \tag{26}$$

where serially correlated productivity shock $\mathcal{A}_{i,s}$ satisfies $\mathcal{A}_{i,s} > 0$, while $0 < \phi^L_k \leq 1$ with $\phi^L_k < 1$ for $1 \leq k \leq M^*$ and $\phi^L_k = 1$ otherwise.

In period t, the representative industry specific intermediate output good firm chooses a state contingent sequence for employment $\{L_{i,k,l,s}\}_{s=t}^{\infty}$ to maximize pre-dividend stock market value (24) subject to production function (26). In equilibrium, labor demand satisfies necessary first order condition

$$\Phi_{i,k,l,t} = \frac{1}{\phi^L_k}(1-\tau_{i,t})\frac{W_{i,t}L_{i,k,l,t}}{P^Y_{i,k,t}Y_{i,k,l,t}}, \tag{27}$$

where $P^Y_{i,k,s}\Phi_{i,k,l,s}$ denotes the Lagrange multiplier associated with the period s production technology constraint. This necessary first order condition equates real marginal cost $\Phi_{i,k,l,t}$ to the ratio of the after tax industry specific real wage to the marginal product of labor.

In an extension of the model of nominal output price rigidity proposed by Calvo (1983) along the lines of Smets and Wouters (2003), each period a randomly selected fraction $1-\omega^Y_k$ of industry specific intermediate output good firms adjust their price optimally, where $0 \leq \omega^Y_k < 1$ with $\omega^Y_k = \omega^Y$ for $k > M^*$. The remaining fraction ω^Y_k of intermediate output good firms adjust their price to account for past industry specific output price inflation according to partial indexation rule

$$P^Y_{i,k,l,t} = \left(\frac{P^Y_{i,k,t-1}}{P^Y_{i,k,t-2}}\right)^{\gamma^Y_k}\left(\frac{\bar{P}^Y_{i,k,t-1}}{\bar{P}^Y_{i,k,t-2}}\right)^{1-\gamma^Y_k} P^Y_{i,k,l,t-1}, \tag{28}$$

where $0 \le \gamma_k^Y \le 1$ with $\gamma_k^Y = 0$ for $1 \le k \le M^*$ and $\gamma_k^Y = \gamma^Y$ otherwise. Under this specification, although intermediate output good firms adjust their price every period, they infrequently do so optimally, and the interval between optimal price adjustments is a random variable.

If the representative industry specific intermediate output good firm can adjust its price optimally in period t, then it does so to maximize pre-dividend stock market value (24) subject to production function (26), industry specific intermediate output good demand function (22), and the assumed form of nominal output price rigidity. Since all intermediate output good firms that adjust their price optimally in period t solve an identical value maximization problem, in equilibrium they all choose a common price $P_{i,k,t}^{Y,*}$ given by necessary first order condition:

$$\frac{P_{i,k,t}^{Y,*}}{P_{i,k,t}^{Y}} = \frac{\mathrm{E}_t \sum_{s=t}^{\infty} (\omega_k^Y)^{s-t} \frac{\beta^{s-t}\lambda_{i,s}}{\lambda_{i,t}} \theta_{i,k,s}^Y \Phi_{i,k,l,s} \left[\left(\frac{P_{i,k,t-1}^Y}{P_{i,k,s-1}^Y} \right)^{\gamma_k^Y} \left(\frac{\bar{P}_{i,k,t-1}^Y}{\bar{P}_{i,k,s-1}^Y} \right)^{1-\gamma_k^Y} \frac{P_{i,k,s}^Y}{P_{i,k,t}^Y} \right]^{\theta_{i,k,s}^Y} \left(\frac{P_{i,k,t}^{Y,*}}{P_{i,k,t}^Y} \right)^{-\theta_{i,k,s}^Y} P_{i,k,s}^Y Y_{i,k,s}}{\mathrm{E}_t \sum_{s=t}^{\infty} (\omega_k^Y)^{s-t} \frac{\beta^{s-t}\lambda_{i,s}}{\lambda_{i,t}} (\theta_{i,k,s}^Y - 1)(1-\tau_{i,s}) \left[\left(\frac{P_{i,k,t-1}^Y}{P_{i,k,s-1}^Y} \right)^{\gamma_k^Y} \left(\frac{\bar{P}_{i,k,t-1}^Y}{\bar{P}_{i,k,s-1}^Y} \right)^{1-\gamma_k^Y} \frac{P_{i,k,s}^Y}{P_{i,k,t}^Y} \right]^{\theta_{i,k,s}^Y - 1} \left(\frac{P_{i,k,t}^{Y,*}}{P_{i,k,t}^Y} \right)^{-\theta_{i,k,s}^Y} P_{i,k,s}^Y Y_{i,k,s}}. \tag{29}$$

This necessary first order condition equates the expected present value of the after tax revenue benefit generated by an additional unit of output supply to the expected present value of its production cost. Aggregate output price index (23) equals an average of the price set by the fraction $1-\omega_k^Y$ of intermediate output good firms that adjust their price optimally in period t, and the average of the prices set by the remaining fraction ω_k^Y of intermediate output good firms that adjust their price according to partial indexation rule (28):

$$P_{i,k,t}^Y = \left\{ (1-\omega_k^Y)(P_{i,k,t}^{Y,*})^{1-\theta_{i,k,t}^Y} + \omega_k^Y \left[\left(\frac{P_{i,k,t-1}^Y}{P_{i,k,t-2}^Y} \right)^{\gamma_k^Y} \left(\frac{\bar{P}_{i,k,t-1}^Y}{\bar{P}_{i,k,t-2}^Y} \right)^{1-\gamma_k^Y} P_{i,k,t-1}^Y \right]^{1-\theta_{i,k,t}^Y} \right\}^{\frac{1}{1-\theta_{i,k,t}^Y}}. \tag{30}$$

Since those intermediate output good firms able to adjust their price optimally in period t are selected randomly from among all intermediate output good firms, the average price set by the remaining intermediate output good firms equals the value of the industry specific aggregate output price index that prevailed during period $t-1$, rescaled to account for past industry specific output price inflation.

C. The Trade Sector

The nominal effective exchange rate $\mathcal{E}_{i,t}$ measures the trade weighted average price of foreign currency in terms of domestic currency, while the real effective exchange rate $\mathcal{Q}_{i,t}$ measures the trade weighted average price of foreign output in terms of domestic output,

$$\mathcal{E}_{i,t} = \prod_{j=1}^{N} (\mathcal{E}_{i,j,t})^{w_{i,j,t}^T}, \ \mathcal{Q}_{i,t} = \prod_{j=1}^{N} (\mathcal{Q}_{i,j,t})^{w_{i,j,t}^T}, \tag{31}$$

where the real bilateral exchange rate $\mathcal{Q}_{i,j,t}$ satisfies $\mathcal{Q}_{i,j,t} = \frac{\mathcal{E}_{i,j,t} P^Y_{j,t}}{P^Y_{i,t}}$, and bilateral trade weight $w^T_{i,j,t}$ satisfies $w^T_{i,j,t} = \frac{1}{2}\left(\frac{\bar{P}^X_{i,j,t}\bar{X}_{i,j,t}}{\bar{P}^X_{i,t}\bar{X}_{i,t}} + \frac{\bar{P}^M_{i,j,t}\bar{M}_{i,j,t}}{\bar{P}^M_{i,t}\bar{M}_{i,t}}\right)$. Furthermore, the terms of trade $\mathcal{T}_{i,t}$ equals the ratio of the internal terms of trade to the external terms of trade,

$$\mathcal{T}_{i,t} = \frac{\mathcal{T}^X_{i,t}}{\mathcal{T}^M_{i,t}},\ \mathcal{T}^X_{i,t} = \frac{P^X_{i,t}}{P_{i,t}},\ \mathcal{T}^M_{i,t} = \frac{P^M_{i,t}}{P_{i,t}}, \tag{32}$$

where the internal terms of trade $\mathcal{T}^X_{i,t}$ measures the relative price of exports, and the external terms of trade $\mathcal{T}^M_{i,t}$ measures the relative price of imports, while $P_{i,t}$ denotes the price of the final noncommodity output good. Finally, under the law of one price $\mathcal{E}_{i*,i,t} P^Y_{i,k,t} = P^Y_{k,t}$ for $1 \le k \le M*$, which implies that

$$P^Y_{k,t} = \sum_{i=1}^{N} w^Y_{i,t} \mathcal{E}_{i*,i,t} P^Y_{i,k,t}, \tag{33}$$

where $P^Y_{k,t}$ denotes the quotation currency denominated price of energy or nonenergy commodities, and world output weight $w^Y_{i,t}$ satisfies $w^Y_{i,t} = \frac{\bar{\mathcal{E}}_{i*,i,t}\bar{P}^Y_{i,t}\bar{Y}_{i,t}}{\bar{P}^Y_t \bar{Y}_t}$ with $\bar{P}^Y_t \bar{Y}_t = \sum_{i=1}^{N} \bar{\mathcal{E}}_{i*,i,t}\bar{P}^Y_{i,t}\bar{Y}_{i,t}$.

The Export Sector

There exist a large number of perfectly competitive firms which combine industry specific final output goods $\{X_{i,k,t}\}_{k=1}^{M}$ to produce final export good $X_{i,t}$ according to Leontief production function

$$X_{i,t} = \min\left\{\frac{X_{i,k,t}}{\phi^X_{i,k}}\right\}_{k=1}^{M}, \tag{34}$$

where $X_{i,k,t} = Y_{i,k,t}$ for $1 \le k \le M*$, while $0 \le \phi^X_{i,k} \le 1$ and $\sum_{k=1}^{M} \phi^X_{i,k} = 1$. The representative final export good firm maximizes profits derived from production of the final export good with respect to inputs of industry specific final output goods, implying demand functions:

$$X_{i,k,t} = \phi^X_{i,k} X_{i,t}. \tag{35}$$

Since the production function exhibits constant returns to scale, in equilibrium the representative final export good firm generates zero profit, implying aggregate export price index:

$$P^X_{i,t} = \sum_{k=1}^{M} \phi^X_{i,k} P^Y_{i,k,t}. \tag{36}$$

This aggregate export price index equals the minimum cost of producing one unit of the final export good, given the prices of industry specific final output goods.

The Import Sector

There exist a large number of perfectly competitive firms which combine the final noncommodity output good $Z^h_{i,t} \in \{C^h_{i,t}, G^h_{i,t}\}$ with the final import good $Z^f_{i,t} \in \{C^f_{i,t}, G^f_{i,t}\}$ to produce final private or public consumption good $Z_{i,t} \in \{C_{i,t}, G_{i,t}\}$ according to constant elasticity of substitution production function

$$Z_{i,t} = \left[(\phi_{i,Y}^D)^{\frac{1}{\psi^M}} (Z_{i,t}^h)^{\frac{\psi^M - 1}{\psi^M}} + (\phi_{i,M}^D)^{\frac{1}{\psi^M}} (\nu_{i,t}^M Z_{i,t}^f)^{\frac{\psi^M - 1}{\psi^M}} \right]^{\frac{\psi^M}{\psi^M - 1}}, \tag{37}$$

where serially correlated import demand shock $\nu_{i,t}^M$ satisfies $\nu_{i,t}^M > 0$, while $0 \le \phi_{i,Y}^D \le 1$, $0 \le \phi_{i,M}^D \le 1$, $\phi_{i,Y}^D + \phi_{i,M}^D = 1$ and $\psi^M > 0$. The representative final consumption good firm maximizes profits derived from production of the final private or public consumption good, with respect to inputs of the final noncommodity output and import goods, implying demand functions:

$$Z_{i,t}^h = \phi_{i,Y}^D \left(\frac{P_{i,t}}{P_{i,t}^Z} \right)^{-\psi^M} Z_{i,t}, \; Z_{i,t}^f = \phi_{i,M}^D \left(\frac{1}{\nu_{i,t}^M} \frac{P_{i,t}^M}{P_{i,t}^Z} \right)^{-\psi^M} \frac{Z_{i,t}}{\nu_{i,t}^M}. \tag{38}$$

Since the production function exhibits constant returns to scale, in equilibrium the representative final consumption good firm generates zero profit, implying aggregate consumption price index:

$$P_{i,t}^Z = \left[\phi_{i,Y}^D (P_{i,t})^{1-\psi^M} + \phi_{i,M}^D \left(\frac{P_{i,t}^M}{\nu_{i,t}^M} \right)^{1-\psi^M} \right]^{\frac{1}{1-\psi^M}}. \tag{39}$$

Combination of this aggregate consumption price index with final noncommodity output and import good demand functions (38) yields:

$$Z_{i,t}^h = \phi_{i,Y}^D \left[\phi_{i,Y}^D + \phi_{i,M}^D \left(\frac{\mathcal{T}_{i,t}^M}{\nu_{i,t}^M} \right)^{1-\psi^M} \right]^{\frac{\psi^M}{1-\psi^M}} Z_{i,t}, \; Z_{i,t}^f = \phi_{i,M}^D \left[\phi_{i,M}^D + \phi_{i,Y}^D \left(\frac{\mathcal{T}_{i,t}^M}{\nu_{i,t}^M} \right)^{\psi^M - 1} \right]^{\frac{\psi^M}{1-\psi^M}} \frac{Z_{i,t}}{\nu_{i,t}^M}. \tag{40}$$

These demand functions for the final noncommodity output and import goods are directly proportional to final private or public consumption good demand, with a proportionality coefficient that varies with the external terms of trade.

Import Demand

There exist a large number of perfectly competitive firms which combine economy specific final import goods $\{M_{i,j,t}\}_{j=1}^N$ to produce final import good $M_{i,t}$ according to Leontief production function

$$M_{i,t} = \min \left\{ \nu_{j,t}^X \frac{M_{i,j,t}}{\phi_{i,j}^M} \right\}_{j=1}^N, \tag{41}$$

where serially correlated export demand shock $\nu_{i,t}^X$ satisfies $\nu_{i,t}^X > 0$, while $\phi_{i,i}^M = 0$, $0 \le \phi_{i,j}^M \le 1$ and $\sum_{j=1}^N \phi_{i,j}^M = 1$. The representative final import good firm maximizes profits derived from production of the final import good with respect to inputs of economy specific final import goods, implying demand functions:

$$M_{i,j,t} = \phi_{i,j}^{M} \frac{M_{i,t}}{v_{j,t}^{X}}. \tag{42}$$

Since the production function exhibits constant returns to scale, in equilibrium the representative final import good firm generates zero profit, implying aggregate import price index:

$$P_{i,t}^{M} = \sum_{j=1}^{N} \phi_{i,j}^{M} \frac{P_{i,j,t}^{M}}{v_{j,t}^{X}}. \tag{43}$$

This aggregate import price index equals the minimum cost of producing one unit of the final import good, given the prices of economy specific final import goods.

There exist a large number of perfectly competitive firms which combine economy specific differentiated intermediate import goods $M_{i,j,l,t}$ supplied by economy specific intermediate import good firms to produce economy specific final import good $M_{i,j,t}$ according to constant elasticity of substitution production function

$$M_{i,j,t} = \left[\int_0^1 (M_{i,j,l,t})^{\frac{\theta_{i,t}^{M}-1}{\theta_{i,t}^{M}}} dl \right]^{\frac{\theta_{i,t}^{M}}{\theta_{i,t}^{M}-1}}, \tag{44}$$

where serially uncorrelated import price markup shock $\theta_{i,t}^{M}$ satisfies $\theta_{i,t}^{M} > 1$ with $\theta_{i}^{M} = \theta^{M}$. The representative economy specific final import good firm maximizes profits derived from production of the economy specific final import good with respect to inputs of economy specific intermediate import goods, implying demand functions:

$$M_{i,j,l,t} = \left(\frac{P_{i,j,l,t}^{M}}{P_{i,j,t}^{M}} \right)^{-\theta_{i,t}^{M}} M_{i,j,t}. \tag{45}$$

Since the production function exhibits constant returns to scale, in equilibrium the representative economy specific final import good firm generates zero profit, implying economy specific aggregate import price index:

$$P_{i,j,t}^{M} = \left[\int_0^1 (P_{i,j,l,t}^{M})^{1-\theta_{i,t}^{M}} dl \right]^{\frac{1}{1-\theta_{i,t}^{M}}}. \tag{46}$$

As the price elasticity of demand for economy specific intermediate import goods $\theta_{i,t}^{M}$ increases, they become closer substitutes, and individual economy specific intermediate import good firms have less market power.

Import Supply

There exist continuums of monopolistically competitive economy specific intermediate import good firms indexed by $l \in [0,1]$. Intermediate import good firms supply economy specific differentiated intermediate import goods, but are otherwise identical.

The representative economy specific intermediate import good firm sells shares to domestic and foreign households at price $V_{i,j,l,t}^{M}$. Acting in the interests of its shareholders, it maximizes its pre-dividend stock market value, which abstracting from the precautionary savings motive equals the expected present value of current and future dividend payments:

$$\Pi_{i,j,l,t}^{M} + V_{i,j,l,t}^{M} = \mathrm{E}_t \sum_{s=t}^{\infty} \frac{\beta^{s-t}\lambda_{i,s}}{\lambda_{i,t}} \Pi_{i,j,l,s}^{M}. \tag{47}$$

The derivation of this result imposes a transversality condition which rules out self-fulfilling speculative asset price bubbles.

Shares entitle households to dividend payments equal to profits $\Pi_{i,j,l,s}^{M}$, defined as earnings less fixed costs $F_{i,j,s}$:

$$\Pi_{i,j,l,s}^{M} = P_{i,j,l,s}^{M} M_{i,j,l,s} - \mathcal{E}_{i,j,s} P_{j,s}^{X} M_{i,j,l,s} - F_{i,j,s}. \tag{48}$$

Earnings are defined as revenues derived from sales of economy specific differentiated intermediate import good $M_{i,j,l,s}$ at price $P_{i,j,l,s}^{M}$ less expenditures on foreign final export good $M_{i,j,l,s}$. The representative economy specific intermediate import good firm purchases the foreign final export good and differentiates it, generating zero profit on average.

In an extension of the model of nominal import price rigidity proposed by Monacelli (2005) along the lines of Smets and Wouters (2003), each period a randomly selected fraction $1-\omega^{M}$ of economy specific intermediate import good firms adjust their price optimally, where $0 \le \omega^{M} < 1$. The remaining fraction ω^{M} of intermediate import good firms adjust their price to account for past economy specific import price inflation, as well as contemporaneous changes in the domestic currency denominated prices of energy and nonenergy commodities, according to partial indexation rule

$$P_{i,j,l,t}^{M} = \left[\left(\frac{P_{i,j,t-1}^{M}}{P_{i,j,t-2}^{M}}\right)^{1-\mu_i} \prod_{k=1}^{M^*}\left(\frac{\mathcal{E}_{i*,i,t}P_{k,t}^{Y}}{\mathcal{E}_{i*,i,t-1}P_{k,t-1}^{Y}}\right)^{\mu_{i,k}}\right]^{\gamma^M} \left[\left(\frac{\bar{P}_{i,j,t-1}^{M}}{\bar{P}_{i,j,t-2}^{M}}\right)^{1-\mu_i} \prod_{k=1}^{M^*}\left(\frac{\bar{\mathcal{E}}_{i*,i,t}\bar{P}_{k,t}^{Y}}{\bar{\mathcal{E}}_{i*,i,t-1}\bar{P}_{k,t-1}^{Y}}\right)^{\mu_{i,k}}\right]^{1-\gamma^M} P_{i,j,l,t-1}^{M}, \tag{49}$$

where $0 \le \gamma^{M} \le 1$, while $\mu_i = \sum_{k=1}^{M^*} \mu_{i,k}$ with $\mu_{i,k} = \mu \frac{\bar{M}_{i,k,t}}{\bar{M}_{i,t}}$ and $\mu \ge 0$. Under this specification, the probability that an intermediate import good firm has adjusted its price optimally is time dependent but state independent.

If the representative economy specific intermediate import good firm can adjust its price optimally in period t, then it does so to maximize pre-dividend stock market value (47) subject to economy specific intermediate import good demand function (45), and the assumed form of nominal import price rigidity. Since all intermediate import good firms that adjust their price optimally in period t solve an identical value maximization problem, in equilibrium they all choose a common price $P_{i,j,t}^{M,*}$ given by necessary first order condition:

$$\frac{P_{i,j,t}^{M,*}}{P_{i,j,t}^{M}}=\frac{\mathrm{E}_t\sum_{s=t}^{\infty}(\omega^M)^{s-t}\frac{\beta^{s-t}\lambda_{i,s}}{\lambda_{i,t}}\theta_{i,s}^{M}\frac{\mathcal{E}_{i,j,s}P_{j,s}^{X}}{P_{i,j,s}^{M}}\left\{\left[\left(\frac{P_{i,j,t-1}^{M}}{P_{i,j,s-1}^{M}}\right)^{1-\mu_i}\prod_{k=1}^{M*}\left(\frac{\mathcal{E}_{i*,i,t}P_{k,t}^{Y}}{\mathcal{E}_{i*,i,s}P_{k,s}^{Y}}\right)^{\mu_{i,k}}\right]^{\gamma^M}\left[\left(\frac{\bar{P}_{i,j,t-1}^{M}}{\bar{P}_{i,j,s-1}^{M}}\right)^{1-\mu_i}\prod_{k=1}^{M*}\left(\frac{\bar{\mathcal{E}}_{i*,i,t}\bar{P}_{k,t}^{Y}}{\bar{\mathcal{E}}_{i*,i,s}\bar{P}_{k,s}^{Y}}\right)^{\mu_{i,k}}\right]^{1-\gamma^M}\frac{P_{i,j,s}^{M}}{P_{i,j,t}^{M}}\right\}^{\theta_{i,s}^{M}}\left(\frac{P_{i,j,t}^{M,*}}{P_{i,j,t}^{M}}\right)^{-\theta_{i,s}^{M}}P_{i,j,s}^{M}M_{i,j,s}}{\mathrm{E}_t\sum_{s=t}^{\infty}(\omega^M)^{s-t}\frac{\beta^{s-t}\lambda_{i,s}}{\lambda_{i,t}}(\theta_{i,s}^{M}-1)\left\{\left[\left(\frac{P_{i,j,t-1}^{M}}{P_{i,j,s-1}^{M}}\right)^{1-\mu_i}\prod_{k=1}^{M*}\left(\frac{\mathcal{E}_{i*,i,t}P_{k,t}^{Y}}{\mathcal{E}_{i*,i,s}P_{k,s}^{Y}}\right)^{\mu_{i,k}}\right]^{\gamma^M}\left[\left(\frac{\bar{P}_{i,j,t-1}^{M}}{\bar{P}_{i,j,s-1}^{M}}\right)^{1-\mu_i}\prod_{k=1}^{M*}\left(\frac{\bar{\mathcal{E}}_{i*,i,t}\bar{P}_{k,t}^{Y}}{\bar{\mathcal{E}}_{i*,i,s}\bar{P}_{k,s}^{Y}}\right)^{\mu_{i,k}}\right]^{1-\gamma^M}\frac{P_{i,j,s}^{M}}{P_{i,j,t}^{M}}\right\}^{\theta_{i,s}^{M}-1}\left(\frac{P_{i,j,t}^{M,*}}{P_{i,j,t}^{M}}\right)^{-\theta_{i,s}^{M}}P_{i,j,s}^{M}M_{i,j,s}}. \tag{50}$$

This necessary first order condition equates the expected present value of the revenue benefit generated by an additional unit of import supply to the expected present value of its production cost. Aggregate import price index (46) equals an average of the price set by the fraction $1-\omega^M$ of intermediate import good firms that adjust their price optimally in period t, and the average of the prices set by the remaining fraction ω^M of intermediate import good firms that adjust their price according to partial indexation rule (49):

$$P_{i,j,t}^{M}=\left\{(1-\omega^M)(P_{i,j,t}^{M,*})^{1-\theta_{i,t}^{M}}+\omega^M\left\{\left[\left(\frac{P_{i,j,t-1}^{M}}{P_{i,j,t-2}^{M}}\right)^{1-\mu_i}\prod_{k=1}^{M*}\left(\frac{\mathcal{E}_{i*,i,t}P_{k,t}^{Y}}{\mathcal{E}_{i*,i,t-1}P_{k,t-1}^{Y}}\right)^{\mu_{i,k}}\right]^{\gamma^M}\left[\left(\frac{\bar{P}_{i,j,t-1}^{M}}{\bar{P}_{i,j,t-2}^{M}}\right)^{1-\mu_i}\prod_{k=1}^{M*}\left(\frac{\bar{\mathcal{E}}_{i*,i,t}\bar{P}_{k,t}^{Y}}{\bar{\mathcal{E}}_{i*,i,t-1}\bar{P}_{k,t-1}^{Y}}\right)^{\mu_{i,k}}\right]^{1-\gamma^M}P_{i,j,t-1}^{M}\right\}^{1-\theta_{i,t}^{M}}\right\}^{\frac{1}{1-\theta_{i,t}^{M}}}. \tag{51}$$

Since those intermediate import good firms able to adjust their price optimally in period t are selected randomly from among all intermediate import good firms, the average price set by the remaining intermediate import good firms equals the value of the economy specific aggregate import price index that prevailed during period $t-1$, rescaled to account for past economy specific import price inflation.

D. Monetary and Fiscal Policy

The government consists of a monetary authority and a fiscal authority. The monetary authority implements monetary policy, while the fiscal authority implements fiscal policy.

The Monetary Authority

The monetary authority implements monetary policy through control of the nominal policy interest rate according to a monetary policy rule exhibiting partial adjustment dynamics of the form

$$\begin{aligned} i_{i,t}^{P}-\bar{i}_{i,t}^{P} &= \rho_j^i(i_{i,t-1}^{P}-\bar{i}_{i,t-1}^{P})+(1-\rho_j^i)\Big[\xi_j^{\pi}(\pi_{i,t}^{C}-\bar{\pi}_{i,t}^{C})+\xi_j^{Y}(\ln Y_{i,t}-\ln\bar{Y}_{i,t})+\xi_j^{Q}(\ln Q_{i,t}-\ln\bar{Q}_{i,t}) \\ &\quad +\xi_j^{i}(i_{k,t}^{P}-\bar{i}_{k,t}^{P})+\xi_j^{\mathcal{E}}(\ln\mathcal{E}_{i,k,t}-\ln\bar{\mathcal{E}}_{i,k,t})\Big]+v_{i,t}^{i^P}, \end{aligned} \tag{52}$$

where $0\le\rho_j^i<1$, $\xi_j^{\pi}\ge 0$, $\xi_j^{Y}\ge 0$, $\xi_j^{Q}\ge 0$, $\xi_j^{i}\ge 0$ and $\xi_j^{\mathcal{E}}\ge 0$. This rule prescribing the conduct of monetary policy is consistent with achieving some combination of inflation control, output stabilization, and exchange rate stabilization objectives. As specified, the deviation of the nominal policy interest rate from its steady state equilibrium value depends on a weighted average of its past deviation and its desired deviation. Under a flexible inflation targeting regime $j=0$, and this desired deviation is increasing in the contemporaneous deviation of consumption price inflation from its target value with $\xi_j^{\pi}>1$, as well as the contemporaneous deviation of output from its steady state equilibrium value with $\xi_j^{Y}>0$. Under a managed exchange rate regime $j=1$, and it is also increasing in the contemporaneous deviation of the real effective exchange rate from its steady state equilibrium value with $\xi_j^Q > 0$. Under a fixed exchange rate regime $j=2$, and the deviation of the nominal policy interest rate from its steady state equilibrium value is instead increasing in the contemporaneous deviation of the nominal policy interest rate for the economy that issues the anchor currency from its steady state equilibrium value with $\xi_j^i = 1$, as well as the contemporaneous deviation of the corresponding nominal bilateral exchange rate from its steady state equilibrium value with $\xi_j^{\mathcal{E}} = 1$. 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. Deviations from this monetary policy rule are captured by mean zero and serially uncorrelated monetary policy shock $\nu_{i,t}^{i^P}$.

The Fiscal Authority

The fiscal authority implements fiscal policy through control of public consumption and the tax rate applicable to the labor income of households and the earnings of intermediate good firms. It can transfer its budgetary resources intertemporally through transactions in the domestic money and bond markets. Considered jointly, the rules prescribing the conduct of this distortionary fiscal policy are countercyclical, representing automatic fiscal stabilizers, and are consistent with achieving a public financial wealth stabilization objective.

Public consumption satisfies an acyclical fiscal expenditure rule exhibiting partial adjustment dynamics of the form

$$\frac{G_{i,t}}{\bar{Y}_{i,t}} - \frac{\bar{G}_{i,t}}{\bar{Y}_{i,t}} = \rho_G \left(\frac{G_{i,t-1}}{\bar{Y}_{i,t-1}} - \frac{\bar{G}_{i,t-1}}{\bar{Y}_{i,t-1}} \right) + (1-\rho_G)\zeta^G \left(\frac{A_{i,t+1}}{P_{i,t}^Y Y_{i,t}} - \frac{\bar{A}_{i,t+1}}{\bar{P}_{i,t}^Y \bar{Y}_{i,t}} \right) + \nu_{i,t}^G, \tag{53}$$

where $0 \le \rho_G < 1$ and $\zeta^G > 0$. As specified, the deviation of the ratio of public consumption to steady state equilibrium output from its steady state equilibrium value depends on a weighted average of its past deviation and its desired deviation, which in turn is increasing in the contemporaneous deviation of the ratio of national financial wealth to nominal output from its target value. Deviations from this fiscal expenditure rule are captured by mean zero and serially uncorrelated fiscal expenditure shock $\nu_{i,t}^G$.

The tax rate applicable to the labor income of households and the earnings of intermediate good firms satisfies a procyclical fiscal revenue rule exhibiting partial adjustment dynamics of the form

$$\tau_{i,t} - \bar{\tau}_{i,t} = \rho_\tau (\tau_{i,t-1} - \bar{\tau}_{i,t-1}) + (1-\rho_\tau)\zeta^\tau \left(\frac{A_{i,t+1}^G}{P_{i,t}^Y Y_{i,t}} - \frac{\bar{A}_{i,t+1}^G}{\bar{P}_{i,t}^Y \bar{Y}_{i,t}} \right) + \nu_{i,t}^T, \tag{54}$$

where $0 \le \rho_\tau < 1$ and $\zeta^\tau < 0$. As specified, the deviation of the tax rate from its steady state equilibrium value depends on a weighted average of its past deviation and its desired deviation, which in turn is decreasing in the contemporaneous deviation of the ratio of public financial wealth to nominal output from its target value. Deviations from this fiscal revenue rule are captured by mean zero and serially uncorrelated fiscal revenue shock $\nu_{i,t}^{T}$.

The yield to maturity on short term bonds depends on the contemporaneous nominal policy interest rate according to money market relationship:

$$i_{i,t}^{S} = i_{i,t}^{P} + \upsilon_{i,t}^{i^S}. \tag{55}$$

Deviations from this money market relationship are captured by mean zero and internationally and serially correlated credit risk premium shock $\upsilon_{i,t}^{i^S}$.

The fiscal authority enters period t in possession of previously accumulated financial wealth $A_{i,t}^{G}$ which yields return $i_{i,t}^{A^G}$. This financial wealth is distributed across the values of domestic short term bond $B_{i,i,t}^{S,G}$ and long term bond $B_{i,i,t}^{L,G}$ portfolios which yield returns $i_{i,t}^{B^{S,G}}$ and $i_{i,t}^{B^{L,G}}$, respectively. It follows that $(1+i_{i,t}^{A^G})A_{i,t}^{G} = (1+i_{i,t-1}^{S})B_{i,i,t}^{S,G} + (1+i_{i,i,t}^{B^{L,G}})B_{i,i,t}^{L,G}$, where $(1+i_{i,i,t}^{B^{L,G}})B_{i,i,t}^{L,G} = \sum_{k=1}^{t-1}(\Pi_{i,k,t}^{B} + V_{i,k,t}^{B})B_{i,i,k,t}^{L,G}$ with $\Pi_{i,k,t}^{B} = i_{i,k}^{L}V_{i,k,k}^{B}$ and $V_{i,k,k}^{B} = 1$. At the end of period t, the fiscal authority levies taxes on the labor income of households and the earnings of industry specific intermediate output good firms at rate $\tau_{i,t}$. In equilibrium, this distortionary tax collection framework corresponds to proportional output taxation, and tax revenues satisfy $T_{i,t} = \tau_{i,t}P_{i,t}^{Y}Y_{i,t}$. These sources of public wealth are summed in government dynamic budget constraint:

$$A_{i,t+1}^{G} = (1+i_{i,t}^{A^G})A_{i,t}^{G} + \int_0^1 \tau_{i,t}W_{i,t}L_{h,i,t}dh + \sum_{k=1}^{M}\int_0^1 \tau_{i,t}(P_{i,k,l,t}^{Y}Y_{i,k,l,t} - W_{i,t}L_{i,k,l,t})dl - P_{i,t}^{G}G_{i,t}. \tag{56}$$

According to this dynamic budget constraint, at the end of period t, the fiscal authority holds financial wealth $A_{i,t+1}^{G}$, which it allocates between the values of domestic short term bond $B_{i,i,t+1}^{S,G}$ and long term bond $B_{i,i,t+1}^{L,G}$ portfolios, that is $A_{i,t+1}^{G} = B_{i,i,t+1}^{S,G} + B_{i,i,t+1}^{L,G}$ where $B_{i,i,t+1}^{L,G} = \sum_{k=1}^{t}V_{i,k,t}^{B}B_{i,i,k,t+1}^{L,G}$ Finally, the fiscal authority purchases final public consumption good $G_{i,t}$ at price $P_{i,t}^{G}$.

E. Market Clearing Conditions

A rational expectations equilibrium in this panel dynamic stochastic general equilibrium model of the world economy consists of state contingent sequences of allocations for the households and firms of all economies which solve their constrained optimization problems given prices and policies, together with state contingent sequences of allocations for the governments of all economies which satisfy their policy rules and constraints given prices, with supporting prices such that all markets clear.

Clearing of the final output good market requires that exports $X_{i,t}$ equal production of the domestic final output good less the total demand of domestic households and the government,

$$X_{i,t} = Y_{i,t} - C_{i,t}^{h} - G_{i,t}^{h}, \tag{57}$$

where $X_{i,t} = \sum_{j=1}^{N} X_{i,j,t}$ and $X_{i,j,t} = M_{j,i,t}$. Clearing of the final import good market requires that imports $M_{i,t}$ equal the total demand of domestic households and the government for the foreign final export good:

$$M_{i,t} = C_{i,t}^{f} + G_{i,t}^{f}. \tag{58}$$

In equilibrium, combination of these final output and import good market clearing conditions yields aggregate resource constraint,

$$P_{i,t}^{Y} Y_{i,t} = P_{i,t}^{D} D_{i,t} + P_{i,t}^{X} X_{i,t} - P_{i,t}^{M} M_{i,t}, \tag{59}$$

where the price of domestic demand satisfies $P_{i,t}^{D} = P_{i,t}^{C} = P_{i,t}^{G}$, which implies that domestic demand satisfies $D_{i,t} = C_{i,t} + G_{i,t}$.

Let $A_{i,t+1}$ denote the net foreign asset position, which equals the sum of private financial wealth $A_{i,t+1}^{P}$ and public financial wealth $A_{i,t+1}^{G}$,

$$A_{i,t+1} = A_{i,t+1}^{P} + A_{i,t+1}^{G}, \tag{60}$$

where private financial wealth equals the sum of household financial wealth $A_{i,t+1}^{H}$ and firm financial wealth $A_{i,t+1}^{F}$, that is $A_{i,t+1}^{P} = A_{i,t+1}^{H} + A_{i,t+1}^{F}$ with $A_{i,t+1}^{F} = -V_{i,t}^{S}$. Abstracting from all financial asset holdings but domestic short term bond and stock holdings, the imposition of equilibrium conditions on household dynamic budget constraint (9) reveals that the increase in private financial wealth equals private saving:

$$A_{i,t+1}^{P} - A_{i,t}^{P} = i_{i,t-1}^{S} B_{i,i,t}^{S,P} + \Pi_{i,t}^{S} + (1-\tau_{i,t}) W_{i,t} L_{i,t} - P_{i,t}^{C} C_{i,t}. \tag{61}$$

Abstracting from domestic long term bond holdings, the imposition of equilibrium conditions on government dynamic budget constraint (56) reveals that the increase in public financial wealth equals public saving, or equivalently that the fiscal balance $FB_{i,t} = A_{i,t+1}^{G} - A_{i,t}^{G}$ equals the sum of net interest income and the primary fiscal balance $PB_{i,t} = \tau_{i,t} P_{i,t}^{Y} Y_{i,t} - P_{i,t}^{G} G_{i,t}$:

$$A_{i,t+1}^{G} - A_{i,t}^{G} = i_{i,t-1}^{S} B_{i,i,t}^{S,G} + \tau_{i,t} P_{i,t}^{Y} Y_{i,t} - P_{i,t}^{G} G_{i,t}. \tag{62}$$

Combination of these household and government dynamic budget constraints with aggregate resource constraint (59) reveals that the increase in net foreign assets equals national saving, or equivalently that the current account balance $CA_{i,t} = A_{i,t+1} - A_{i,t}$ equals the sum of net international investment income and the trade balance $TB_{i,t} = P_{i,t}^{X} X_{i,t} - P_{i,t}^{M} M_{i,t}$:

$$A_{i,t+1} - A_{i,t} = i_{i,t-1}^{S} B_{i,i,t}^{S} + P_{i,t}^{X} X_{i,t} - P_{i,t}^{M} M_{i,t}. \tag{63}$$

The trade balance equals export revenues less import expenditures, or equivalently nominal output less nominal domestic demand.

III. The Panel Unobserved Components Model

Estimation, inference and forecasting are based on an approximate linear panel unobserved components representation of this panel dynamic stochastic general equilibrium model of the world economy. Cyclical components are modeled by linearizing equilibrium conditions around a stationary deterministic steady state equilibrium which unless stated otherwise abstracts from long run balanced growth, featuring zero inflation and net financial asset holdings.[2] In contrast, trend components are modeled as independent random walks, conferring robustness to intermittent structural breaks. As an identifying restriction, all innovations are assumed to be independent, which combined with our distributional assumptions implies multivariate normality.

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. In addition, bilateral weights $w_{i,j}^Z$ for evaluating the trade weighted average of variable $x_{i,t}$ across the trading partners of economy i are based on exports for $Z = X$, imports for $Z = M$, and their average for $Z = T$. In parallel, bilateral weights $w_{i,j}^Z$ for evaluating the portfolio weighted average of domestic currency denominated variable $x_{i,t}$ across the investment destinations of economy i are based on debt for $Z = B$ and equity for $Z = S$. Finally, world weights w_i^Z for evaluating the weighted average of variable $x_{i,t}$ across all economies are based on output for $Z = Y$, money market capitalization for $Z = M$, bond market capitalization for $Z = B$, and stock market capitalization for $Z = S$.

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 components of the labor income share, output and the internal terms of trade according to output price Phillips curve,

$$\begin{aligned}\hat{\pi}_{i,t}^Y = {} & \frac{\gamma^Y}{1+\gamma^Y\beta}\hat{\pi}_{i,t-1}^Y + \frac{\beta}{1+\gamma^Y\beta}\mathrm{E}_t\hat{\pi}_{i,t+1}^Y + \frac{(1-\omega^Y)(1-\omega^Y\beta)}{\omega^Y(1+\gamma^Y\beta)}\left\{\frac{1}{\theta^Y-1}\left[\ln\hat{Y}_{i,t} - \frac{1}{1-\tau_i}\hat{\tau}_{i,t} - \ln\frac{\hat{\Pi}_{i,t}^S}{\hat{P}_{i,t}^Y} - \ln\hat{\theta}_{i,t}^Y\right]\right. \\ & \left. + \frac{1}{\theta^Y}\ln\frac{\hat{Y}_{i,t}}{\hat{\mathcal{A}}_{i,t}} + \frac{X_i}{Y_i}\ln\hat{\mathcal{T}}_{i,t}^X\right\} + \frac{X_i}{Y_i}\mathcal{P}_1(L)\Delta\ln\hat{\mathcal{T}}_{i,t}^X,\end{aligned} \tag{64}$$

where output price markup shock $\ln\hat{\theta}_{i,t}^Y = \varepsilon_{i,t}^{\theta^Y}$ with $\varepsilon_{i,t}^{\theta^Y} \sim \text{iid } \mathcal{N}(0,\sigma_{\theta^Y,i}^2)$. The cyclical component of output price inflation also depends on contemporaneous, past and expected future changes in the cyclical component of the internal terms of trade, where polynomial in the lag operator $\mathcal{P}_1(L) = 1 - \frac{\gamma^Y}{1+\gamma^Y\beta}L - \frac{\beta}{1+\gamma^Y\beta}\mathrm{E}_t L^{-1}$. The response coefficients of this relationship vary across economies with their trade openness.

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

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[2] In steady state equilibrium $\mathcal{A}_i = \nu_i^C = \nu_i^X = \nu_i^B = \nu_i^S = \nu_i^{\mathcal{E}} = 1$, $\nu_i^{i^P} = \nu_i^{i^S} = \nu_i^G = \nu_i^T = 0$, $\nu_i^M = \theta^M/(\theta^M - 1)$, and $\sigma_{\theta^Y,i}^2 = \sigma_{\theta^M,i}^2 = \sigma_{A,i}^2 = \sigma_{\nu^C,i}^2 = \sigma_{\nu^X,i}^2 = \sigma_{\nu^M,i}^2 = \sigma_{\nu^{i,P},i}^2 = \sigma_{\nu^{i,S},i}^2 = \sigma_{\nu^B,i}^2 = \sigma_{\nu^S,i}^2 = \sigma_{\nu^{\mathcal{E}},i}^2 = \sigma_{\nu^G,i}^2 = \sigma_{\nu^T,i}^2 = \sigma_{\theta^Y,k}^2 = 0$.

components of the labor income share, output and the internal terms of trade according to consumption price Phillips curve,

$$\hat{\pi}_{i,t}^{C}=\frac{\gamma^{Y}}{1+\gamma^{Y}\beta}\hat{\pi}_{i,t-1}^{C}+\frac{\beta}{1+\gamma^{Y}\beta}\mathrm{E}_{t}\hat{\pi}_{i,t+1}^{C}+\frac{(1-\omega^{Y})(1-\omega^{Y}\beta)}{\omega^{Y}(1+\gamma^{Y}\beta)}\left\{\frac{1}{\theta^{Y}-1}\left[\ln\hat{Y}_{i,t}-\frac{1}{1-\tau_{i}}\hat{\tau}_{i,t}-\ln\frac{\hat{\Pi}_{i,t}^{S}}{\hat{P}_{i,t}^{Y}}-\ln\hat{\theta}_{i,t}^{Y}\right]\right.$$
$$\left.+\frac{1}{\theta^{Y}}\ln\frac{\hat{Y}_{i,t}}{\hat{\mathcal{A}}_{i,t}}+\frac{X_{i}}{Y_{i}}\ln\hat{\mathcal{T}}_{i,t}^{X}\right\}+\frac{M_{i}}{D_{i}}\mathcal{P}_{1}(L)\Delta\ln\frac{\hat{\mathcal{T}}_{i,t}^{M}}{\hat{\nu}_{i,t}^{M}}, \quad (65)$$

where import demand shock $\ln\hat{\nu}_{i,t}^{M}=\rho_{\nu^{M}}\ln\hat{\nu}_{i,t-1}^{M}+\varepsilon_{i,t}^{\nu^{M}}$ with $\varepsilon_{i,t}^{\nu^{M}}\sim$ iid $\mathcal{N}(0,\sigma_{\nu^{M},i}^{2})$. The cyclical component of consumption price inflation also depends on contemporaneous, past, and expected future changes in the cyclical component of the external terms of trade. The response coefficients of this relationship vary across economies with their trade openness.

The cyclical component of output $\ln\hat{Y}_{i,t}$ depends on a weighted average of its past and expected future cyclical components driven by the contemporaneous cyclical component of the real ex ante portfolio return according to output demand relationship,

$$\ln\hat{Y}_{i,t}=\frac{\alpha}{1+\alpha}\ln\hat{Y}_{i,t-1}+\frac{1}{1+\alpha}\mathrm{E}_{t}\ln\hat{Y}_{i,t+1}-\left(1-\frac{X_{i}}{Y_{i}}\right)\left\{\frac{C_{i}}{D_{i}}\left\{(1-\phi^{C})\sigma\frac{1-\alpha}{1+\alpha}\mathrm{E}_{t}\left(\hat{r}_{i,t+1}^{A^{H}}+\ln\frac{\hat{\nu}_{i,t+1}^{C}}{\hat{\nu}_{i,t}^{C}}\right)\right.\right.$$
$$\left.\left.-\phi^{C}\mathcal{P}_{2}(L)\left[\ln\hat{Y}_{i,t}-\frac{1}{1-\tau_{i}}\hat{\tau}_{i,t}+\frac{X_{i}}{Y_{i}}\left(\ln\frac{\hat{\mathcal{T}}_{i,t}^{X}}{\hat{\mathcal{T}}_{i,t}^{M}}+\ln\hat{\nu}_{i,t}^{M}\right)\right]\right\}-\frac{G_{i}}{D_{i}}\mathcal{P}_{2}(L)\ln\hat{G}_{i,t}\right\} \quad (66)$$
$$+\mathcal{P}_{2}(L)\left\{\frac{X_{i}}{Y_{i}}\left(\sum_{j=1}^{N}w_{i,j}^{X}\ln\frac{\hat{D}_{j,t}}{\hat{\nu}_{j,t}^{M}}-\ln\hat{\nu}_{i,t}^{X}\right)-\psi^{M}\left[\frac{X_{i}}{Y_{i}}\sum_{j=1}^{N}w_{i,j}^{X}\left(1-\frac{M_{j}}{D_{j}}\right)\ln\frac{\hat{\mathcal{T}}_{j,t}^{M}}{\hat{\nu}_{j,t}^{M}}-\frac{M_{i}}{Y_{i}}\left(1-\frac{M_{i}}{D_{i}}\right)\ln\frac{\hat{\mathcal{T}}_{i,t}^{M}}{\hat{\nu}_{i,t}^{M}}\right]\right\},$$

where export demand shock $\ln\hat{\nu}_{i,t}^{X}=\rho_{\nu^{X}}\ln\hat{\nu}_{i,t-1}^{X}+\varepsilon_{i,t}^{\nu^{X}}$ with $\varepsilon_{i,t}^{\nu^{X}}\sim$ iid $\mathcal{N}(0,\sigma_{\nu^{X},i}^{2})$. Reflecting the existence of credit constraints, the cyclical component of output also depends on the contemporaneous, past and expected future cyclical components of output, the output tax rate and the terms of trade, where polynomial in the lag operator $\mathcal{P}_{2}(L)=1-\frac{\alpha}{1+\alpha}L-\frac{1}{1+\alpha}\mathrm{E}_{t}L^{-1}$. In addition, the cyclical component of output depends on the contemporaneous, past, and expected future cyclical components of public domestic demand. Finally, reflecting the existence of international trade linkages, the cyclical component of output depends on the contemporaneous, past and expected future cyclical components of export weighted foreign demand, as well as the export weighted average foreign external terms of trade and the domestic external terms of trade. The response coefficients of this relationship vary across economies with the size of their government and their trade patterns.

The cyclical component of domestic demand $\ln\hat{D}_{i,t}$ depends on a weighted average of its past and expected future cyclical components driven by the contemporaneous cyclical component of the real ex ante portfolio return according to domestic demand relationship,

$$\ln \hat{D}_{i,t} = \frac{\alpha}{1+\alpha}\ln \hat{D}_{i,t-1} + \frac{1}{1+\alpha}\mathrm{E}_t \ln \hat{D}_{i,t+1} - \frac{C_i}{D_i}\left\{(1-\phi^C)\sigma\frac{1-\alpha}{1+\alpha}\mathrm{E}_t\left(\hat{r}^{A^H}_{i,t+1} + \ln\frac{\hat{\nu}^C_{i,t+1}}{\hat{\nu}^C_{i,t}}\right)\right.$$
$$\left. -\phi^C \mathcal{P}_2(L)\left[\ln \hat{Y}_{i,t} - \frac{1}{1-\tau_i}\hat{\tau}_{i,t} + \frac{X_i}{Y_i}\left(\ln\frac{\hat{\mathcal{T}}^X_{i,t}}{\hat{\mathcal{T}}^M_{i,t}} + \ln \hat{\nu}^M_{i,t}\right)\right]\right\} + \frac{G_i}{D_i}\mathcal{P}_2(L)\ln \hat{G}_{i,t}, \tag{67}$$

where intertemporal substitution shock $\ln \hat{\nu}^C_{i,t} = \rho_{\nu^C}\ln \hat{\nu}^C_{i,t-1} + \varepsilon^{\nu^C}_{i,t}$ with $\varepsilon^{\nu^C}_{i,t} \sim \text{iid } \mathcal{N}(0, \sigma^2_{\nu^C,i})$. Reflecting the existence of credit constraints, the cyclical component of domestic demand also depends on the contemporaneous, past and expected future cyclical components of output, the output tax rate, and the terms of trade. Finally, the cyclical component of domestic demand depends on the contemporaneous, past, and expected future cyclical components of public domestic demand. The response coefficients of this relationship vary across economies with the size of their government and their trade openness.

The cyclical component of the nominal ex ante portfolio return $\mathrm{E}_t\hat{i}^{A^H}_{i,t+1}$ depends on the contemporaneous cyclical component of the short term nominal market interest rate according to return function:

$$\mathrm{E}_t\hat{i}^{A^H}_{i,t+1} = \hat{i}^S_{i,t} - \chi^B\frac{B^{L,H}_i}{A^H_i}\sum_{j=1}^{N} w^B_{i,j}\left(\ln \hat{\upsilon}^B_{j,t} + \frac{B^H_i}{B^{L,H}_i}\ln\frac{\hat{\nu}^{\mathcal{E}}_{j,t}}{\hat{\nu}^{\mathcal{E}}_{i,t}}\right) - \chi^S\frac{S^H_i}{A^H_i}\sum_{j=1}^{N} w^S_{i,j}\left(\ln \hat{\upsilon}^S_{j,t} + \ln\frac{\hat{\nu}^{\mathcal{E}}_{j,t}}{\hat{\nu}^{\mathcal{E}}_{i,t}}\right). \tag{68}$$

Reflecting the existence of internal and external macrofinancial linkages, the cyclical component of the nominal ex ante portfolio return also depends on contemporaneous domestic and foreign duration risk premium, equity risk premium, and currency risk premium shocks. Auxiliary parameters χ^B and χ^S are theoretically predicted to equal one, and satisfy $\chi^B > 0$ and $\chi^S > 0$. The response coefficients of this relationship vary across economies with their domestic and foreign financial exposures. The cyclical component of the real ex ante portfolio return $\mathrm{E}_t\hat{r}^{A^H}_{i,t+1}$ satisfies $\mathrm{E}_t\hat{r}^{A^H}_{i,t+1} = \mathrm{E}_t\hat{i}^{A^H}_{i,t+1} - \mathrm{E}_t\,\hat{\pi}^C_{i,t+1}$.

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

$$\hat{i}^P_{i,t} = \rho^i_j\hat{i}^P_{i,t-1} + (1-\rho^i_j)(\xi^\pi_j\hat{\pi}^C_{i,t} + \xi^Y_j\ln \hat{Y}_{i,t} + \xi^{\mathcal{Q}}_j\ln \hat{\mathcal{Q}}_{i,t} + \xi^i_j\hat{i}^P_{k,t} + \xi^{\mathcal{E}}_j\ln \hat{\mathcal{E}}_{i,k,t}) + \varepsilon^{\nu^{i,P}}_{i,t}, \tag{69}$$

where monetary policy shock $\varepsilon^{\nu^{i,P}}_{i,t} \sim \text{iid } \mathcal{N}(0, \sigma^2_{\nu^{i,P},i})$. Under a flexible inflation targeting regime $j = 0$, and the desired cyclical component of the nominal policy interest rate responds to the contemporaneous cyclical components of consumption price inflation and output. Under a managed exchange rate regime $j = 1$, and it also responds to the contemporaneous cyclical component of the real effective exchange rate. Under a fixed exchange rate regime $j = 2$, and the cyclical component of the nominal policy interest rate instead responds to the contemporaneous cyclical component of the nominal policy interest rate for the economy that issues the anchor currency, as well as the contemporaneous cyclical component of the corresponding 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 real policy interest rate $\hat{r}^P_{i,t}$ satisfies $\hat{r}^P_{i,t} = \hat{i}^P_{i,t} - \mathrm{E}_t\,\hat{\pi}^C_{i,t+1}$.

The cyclical component of the short term nominal market interest rate $\hat{i}^S_{i,t}$ depends on the contemporaneous cyclical component of the nominal policy interest rate according to money market relationship,

$$\hat{i}^S_{i,t} = \hat{i}^P_{i,t} + \hat{\upsilon}^{i^S}_{i,t}, \tag{70}$$

where credit risk premium shock $\hat{\upsilon}^{i^S}_{i,t} = \lambda^M_k \sum_{j=1}^N w^M_j \hat{\nu}^{i^S}_{j,t} + (1-\lambda^M_k w^M_i)\hat{\nu}^{i^S}_{i,t}$ with $\hat{\nu}^{i^S}_{i,t} = \rho_{\nu^{i,S}} \hat{\nu}^{i^S}_{i,t-1} + \varepsilon^{\nu^{i,S}}_{i,t}$ and $\varepsilon^{\nu^{i,S}}_{i,t} \sim \text{iid } \mathcal{N}(0, \sigma^2_{\nu^{i,S},i})$. The intensity of international money market contagion varies across economies, with $k=0$ for advanced economies, $k=1$ for emerging economies with capital controls, and $k=2$ for emerging economies without capital controls. The cyclical component of the short term real market 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 nominal market interest rate $\hat{i}^L_{i,t}$ depends on its expected future cyclical component driven by the contemporaneous cyclical component of the short term nominal market interest rate according to bond market relationship,

$$\hat{i}^L_{i,t} = \beta \mathrm{E}_t \hat{i}^L_{i,t+1} + \frac{1-\beta}{\beta}(\hat{i}^S_{i,t} - \ln \hat{\upsilon}^B_{i,t}), \tag{71}$$

where duration risk premium shock $\ln \hat{\upsilon}^B_{i,t} = \lambda^B_k \sum_{j=1}^N w^B_j \ln \hat{\nu}^B_{j,t} + (1-\lambda^B_k w^B_i)\ln \hat{\nu}^B_{i,t}$ with $\ln \hat{\nu}^B_{i,t} = \rho_{\nu^B} \ln \hat{\nu}^B_{i,t-1} + \varepsilon^{\nu^B}_{i,t}$ and $\varepsilon^{\nu^B}_{i,t} \sim \text{iid } \mathcal{N}(0, \sigma^2_{\nu^B,i})$. The intensity of international bond market contagion varies across economies, with $k=0$ for advanced economies, $k=1$ for emerging economies with capital controls, and $k=2$ for emerging economies without capital controls. The cyclical component of the long term real market interest rate $\hat{r}^L_{i,t}$ satisfies the same bond market relationship, driven by the contemporaneous cyclical component of the short term real market interest rate.

The cyclical component of the price of equity $\ln \hat{V}^S_{i,t}$ depends on its expected future cyclical component driven by the expected future cyclical component of profits and the contemporaneous cyclical component of the short term nominal market interest rate according to stock market relationship,

$$\ln \hat{V}^S_{i,t} = \beta \mathrm{E}_t \ln \hat{V}^S_{i,t+1} + (1-\beta)\mathrm{E}_t \ln \hat{\Pi}^S_{i,t+1} - (\hat{i}^S_{i,t} - \ln \hat{\upsilon}^S_{i,t}), \tag{72}$$

where equity risk premium shock $\ln \hat{\upsilon}^S_{i,t} = \lambda^S_k \sum_{j=1}^N w^S_j \ln \hat{\nu}^S_{j,t} + (1-\lambda^S_k w^S_i)\ln \hat{\nu}^S_{i,t}$ with $\ln \hat{\nu}^S_{i,t} = \rho_{\nu^S} \ln \hat{\nu}^S_{i,t-1} + \varepsilon^{\nu^S}_{i,t}$ and $\varepsilon^{\nu^S}_{i,t} \sim \text{iid } \mathcal{N}(0, \sigma^2_{\nu^S,i})$. The intensity of international stock market contagion varies across economies, with $k=0$ for advanced economies, $k=1$ for emerging economies with capital controls, and $k=2$ for emerging economies without capital controls.

The cyclical component of profits $\ln \hat{\Pi}^S_{i,t}$ depends on the contemporaneous cyclical components of nominal output, the output tax rate, and the labor income share according to profit function,

$$\ln \frac{\hat{\Pi}_{i,t}^{S}}{\hat{P}_{i,t}^{Y}} = \theta^{Y}\left(\ln \hat{Y}_{i,t} - \frac{\tau}{1-\tau_i}\hat{\tau}_{i,t}\right) - (\theta^{Y}-1)\left\{\frac{1+\eta}{\eta}\frac{\theta^{Y}-1}{\theta^{Y}}\ln\frac{\hat{Y}_{i,t}}{\hat{\mathcal{A}}_{i,t}} + \frac{1}{\sigma}\frac{1}{1-\alpha}\left(\frac{C_i}{Y_i}\right)^{-1}\left[\left(\frac{D_i}{Y_i}\ln \hat{D}_{i,t} - \frac{G_i}{Y_i}\ln \hat{G}_{i,t}\right)\right.\right. \quad (73)$$

$$\left.\left. -\alpha\left(\frac{D_i}{Y_i}\ln \hat{D}_{i,t-1} - \frac{G_i}{Y_i}\ln \hat{G}_{i,t-1}\right)\right] - \frac{X_i}{Y_i}\left(\ln\frac{\hat{\mathcal{T}}_{i,t}^{X}}{\hat{\mathcal{T}}_{i,t}^{M}} + \ln \hat{\nu}_{i,t}^{M}\right)\right\},$$

where productivity shock $\ln \hat{\mathcal{A}}_{i,t} = \rho_{\mathcal{A}} \ln \hat{\mathcal{A}}_{i,t-1} + \varepsilon_{i,t}^{\mathcal{A}}$ with $\varepsilon_{i,t}^{\mathcal{A}} \sim \text{iid } \mathcal{N}(0, \sigma_{\mathcal{A},i}^2)$. Auxiliary parameter τ is theoretically predicted to equal one, and satisfies $\tau = \frac{1}{\theta^{Y}}$. The response coefficients of this relationship vary across economies with the size of their government and their trade openness.

The cyclical component of the nominal bilateral exchange rate $\ln \hat{\mathcal{E}}_{i,i*,t}$ depends on its expected future cyclical component driven by the contemporaneous cyclical component of the short term nominal market interest rate differential according to foreign exchange market relationship,

$$\ln \hat{\mathcal{E}}_{i,i*,t} = \mathrm{E}_t \ln \hat{\mathcal{E}}_{i,i*,t+1} - \left[(\hat{i}_{i,t}^{S} - \hat{i}_{i*,t}^{S}) + \ln \frac{\hat{\nu}_{i,t}^{\mathcal{E}}}{\hat{\nu}_{i*,t}^{\mathcal{E}}}\right], \quad (74)$$

where currency risk premium shock $\ln \hat{\nu}_{i,t}^{\mathcal{E}} = \rho_{\nu^{\mathcal{E}}} \ln \hat{\nu}_{i,t-1}^{\mathcal{E}} + \varepsilon_{i,t}^{\nu^{\mathcal{E}}}$ with $\varepsilon_{i,t}^{\nu^{\mathcal{E}}} \sim \text{iid } \mathcal{N}(0, \sigma_{\nu^{\mathcal{E}},i}^2)$. For economies belonging to a currency union, the variables entering into their common foreign exchange market relationship are expressed as output weighted averages across union members. The cyclical component of the real bilateral exchange rate $\ln \hat{\mathcal{Q}}_{i,i*,t}$ satisfies $\ln \hat{\mathcal{Q}}_{i,i*,t} = \ln \hat{\mathcal{E}}_{i,i*,t} + \ln \hat{P}_{i*,t}^{Y} - \ln \hat{P}_{i,t}^{Y}$.[3]

The cyclical component of the internal terms of trade $\ln \hat{\mathcal{T}}_{i,t}^{X}$ depends on the contemporaneous cyclical components of the relative domestic currency denominated prices of energy and nonenergy commodities according to internal terms of trade function:

$$\ln \hat{\mathcal{T}}_{i,t}^{X} = \left(1 - \frac{X_i}{Y_i}\sum_{k=1}^{M*}\frac{X_{i,k}}{X_i}\right)^{-1}\sum_{k=1}^{M*}\frac{X_{i,k}}{X_i}\ln\frac{\hat{\mathcal{E}}_{i,i*,t}\hat{P}_{k,t}^{Y}}{\hat{P}_{i,t}^{Y}}. \quad (75)$$

The response coefficients of this relationship vary across economies with their trade openness and commodity export intensities.

The change in the cyclical component of the external terms of trade $\ln \hat{\mathcal{T}}_{i,t}^{M}$ depends on a linear combination of its past and expected future cyclical components driven by the contemporaneous cyclical component of the deviation of the import weighted average real bilateral exchange rate from the external terms of trade according to import price Phillips curve,

[3] The cyclical component of the nominal effective exchange rate $\ln \hat{\mathcal{E}}_{i,t}$ satisfies $\ln \hat{\mathcal{E}}_{i,t} = \ln \hat{\mathcal{E}}_{i,i*,t} - \sum_{j=1}^{N} w_{i,j}^{T} \ln \hat{\mathcal{E}}_{j,i*,t}$, while the cyclical component of the real effective exchange rate $\ln \hat{\mathcal{Q}}_{i,t}$ satisfies $\ln \hat{\mathcal{Q}}_{i,t} = \ln \hat{\mathcal{Q}}_{i,i*,t} - \sum_{j=1}^{N} w_{i,j}^{T} \ln \hat{\mathcal{Q}}_{j,i*,t}$.

$$\begin{aligned}\Delta\ln\hat{\mathcal{T}}_{i,t}^{M} &= \frac{\gamma^{M}(1-\mu_i)}{1+\gamma^{M}\beta(1-\mu_i)}\Delta\ln\hat{\mathcal{T}}_{i,t-1}^{M}+\frac{\beta}{1+\gamma^{M}\beta(1-\mu_i)}\mathrm{E}_t\Delta\ln\hat{\mathcal{T}}_{i,t+1}^{M}\\ &+\frac{(1-\omega^{M})(1-\omega^{M}\beta)}{\omega^{M}(1+\gamma^{M}\beta(1-\mu_i))}\left\{\sum_{j=1}^{N}w_{i,j}^{M}\left[\ln\frac{\hat{\mathcal{Q}}_{i,j,t}}{\hat{\mathcal{T}}_{i,t}^{M}}+\frac{X_i}{Y_i}\ln\hat{\mathcal{T}}_{i,t}^{X}+\left(1-\frac{X_j}{Y_j}\right)\ln\hat{\mathcal{T}}_{j,t}^{X}-\ln\hat{\upsilon}_{i,t}^{X}\right]-\frac{1}{\theta^{M}-1}\ln\hat{\theta}_{i,t}^{M}\right\} \quad (76)\\ &-\mathcal{P}_3(L)\left(\hat{\pi}_{i,t}^{Y}-\frac{X_i}{Y_i}\Delta\ln\hat{\mathcal{T}}_{i,t}^{X}+\Delta\ln\hat{\upsilon}_{i,t}^{X}\right)+\frac{\gamma^{M}(1+\beta)}{1+\gamma^{M}\beta(1-\mu_i)}\sum_{k=1}^{M*}\mu_{i,k}\mathcal{P}_4(L)\ln(\hat{\mathcal{E}}_{i*,i,t}\hat{P}_{k,t}^{Y}),\end{aligned}$$

where $\ln\hat{\upsilon}_{i,t}^{X}=\sum_{j=1}^{N}w_{i,j}^{M}\ln\hat{\nu}_{j,t}^{X}$, while import price markup shock $\ln\hat{\theta}_{i,t}^{M}=\varepsilon_{i,t}^{\theta^{M}}$ with $\varepsilon_{i,t}^{\theta^{M}}\sim\text{iid }\mathcal{N}(0,\sigma_{\theta^{M},i}^{2})$. The change in the cyclical component of the external terms of trade also depends on the contemporaneous cyclical components of the domestic and import weighted average foreign internal terms of trade. In addition, the change in the cyclical component of the external terms of trade depends on the contemporaneous, past and expected future cyclical components of output price inflation and the change in the internal terms of trade, where polynomial in the lag operator $\mathcal{P}_3(L)=1-\frac{\gamma^{M}(1-\mu_i)}{1+\gamma^{M}\beta(1-\mu_i)}L-\frac{\beta}{1+\gamma^{M}\beta(1-\mu_i)}\mathrm{E}_tL^{-1}$. Finally, the change in the cyclical component of the external terms of trade depends on the contemporaneous, past and expected future cyclical components of the domestic currency denominated prices of energy and nonenergy commodities, where polynomial in the lag operator $\mathcal{P}_4(L)=1-\frac{1}{1+\beta}L-\frac{\beta}{1+\beta}\mathrm{E}_tL^{-1}$. The response coefficients of this relationship vary across economies with their trade patterns and commodity import intensities.

The cyclical component of public domestic demand $\ln\hat{G}_{i,t}$ depends on a weighted average of its past and desired cyclical components according to fiscal expenditure rule,

$$\ln\hat{G}_{i,t}=\rho_G\ln\hat{G}_{i,t-1}+(1-\rho_G)\zeta^{G}\left(\frac{G_i}{Y_i}\right)^{-1}\frac{\hat{A}_{i,t+1}}{P_{i,t}^{Y}Y_{i,t}}+\left(\frac{G_i}{Y_i}\right)^{-1}\varepsilon_{i,t}^{\nu^{G}}, \quad (77)$$

where fiscal expenditure shock $\varepsilon_{i,t}^{\nu^{G}}\sim\text{iid }\mathcal{N}(0,\sigma_{\nu^{G},i}^{2})$. The desired cyclical component of public domestic demand responds to the contemporaneous cyclical component of the ratio of net foreign assets to nominal output.

The cyclical component of the output tax rate $\hat{\tau}_{i,t}$ depends on a weighted average of its past and desired cyclical components according to fiscal revenue rule,

$$\hat{\tau}_{i,t}=\rho_\tau\hat{\tau}_{i,t-1}+(1-\rho_\tau)\zeta^{\tau}\frac{\hat{A}_{i,t+1}^{G}}{P_{i,t}^{Y}Y_{i,t}}+\varepsilon_{i,t}^{\nu^{T}}, \quad (78)$$

where fiscal revenue shock $\varepsilon_{i,t}^{\nu^{T}}\sim\text{iid }\mathcal{N}(0,\sigma_{\nu^{T},i}^{2})$. The desired cyclical component of the output tax rate responds to the contemporaneous cyclical component of the ratio of net government assets to nominal output.

The cyclical component of the ratio of the fiscal balance to nominal output $\frac{FB_{i,t}}{P_{i,t}^{Y}Y_{i,t}}$ depends on the past cyclical component of the short term nominal market interest rate and the contemporaneous cyclical component of the ratio of the primary fiscal balance to nominal output according to government dynamic budget constraint:

$$\frac{FB_{i,t}}{P^Y_{i,t}Y_{i,t}} = \frac{1}{1+g}\left[\frac{B^{S,G}_{i,i}}{P^Y_iY_i}\hat{i}^S_{i,t-1} + \frac{1-\beta}{\beta}\left(\frac{\hat{A}^G_{i,t}}{P^Y_{i,t-1}Y_{i,t-1}} - \frac{B^{S,G}_{i,i}}{P^Y_iY_i}\ln\frac{\hat{P}^Y_{i,t}\hat{Y}_{i,t}}{\hat{P}^Y_{i,t-1}\hat{Y}_{i,t-1}}\right)\right] + \frac{PB_{i,t}}{P^Y_{i,t}Y_{i,t}}. \quad (79)$$

The cyclical component of the ratio of the primary fiscal balance to nominal output $\frac{PB_{i,t}}{P^Y_{i,t}Y_{i,t}}$ depends on the contemporaneous cyclical components of the output tax rate and the ratio of public domestic demand to output, as well as the terms of trade, according to:

$$\frac{PB_{i,t}}{P^Y_{i,t}Y_{i,t}} = \hat{\tau}_{i,t} - \frac{G_i}{Y_i}\left[\ln\frac{\hat{G}_{i,t}}{\hat{Y}_{i,t}} - \frac{X_i}{Y_i}\left(\ln\frac{\hat{\mathcal{T}}^X_{i,t}}{\hat{\mathcal{T}}^M_{i,t}} + \ln\hat{v}^M_{i,t}\right)\right]. \quad (80)$$

The cyclical component of the ratio of net government assets to nominal output $\frac{\hat{A}^G_{i,t+1}}{P^Y_{i,t}Y_{i,t}}$ follows a stationary first order autoregressive process driven by the contemporaneous cyclical components of the growth rate of nominal output and the ratio of the fiscal balance to nominal output according to:

$$\frac{\hat{A}^G_{i,t+1}}{P^Y_{i,t}Y_{i,t}} = \frac{1}{1+g}\left(\frac{\hat{A}^G_{i,t}}{P^Y_{i,t-1}Y_{i,t-1}} - \frac{A^G_i}{P^Y_iY_i}\ln\frac{\hat{P}^Y_{i,t}\hat{Y}_{i,t}}{\hat{P}^Y_{i,t-1}\hat{Y}_{i,t-1}}\right) + \frac{FB_{i,t}}{P^Y_{i,t}Y_{i,t}}. \quad (81)$$

The linearization of these relationships accounts for long run balanced growth at nominal rate g. Their response coefficients vary across economies with their public financial wealth, the size of their government, and their trade openness.

The cyclical component of the ratio of the current account balance to nominal output $\frac{CA_{i,t}}{P^Y_{i,t}Y_{i,t}}$ depends on the past cyclical component of the short term nominal market interest rate and the contemporaneous cyclical component of the ratio of the trade balance to nominal output according to national dynamic budget constraint:

$$\frac{CA_{i,t}}{P^Y_{i,t}Y_{i,t}} = \frac{1}{1+g}\left[\frac{B^S_{i,i}}{P^Y_iY_i}\hat{i}^S_{i,t-1} + \frac{1-\beta}{\beta}\left(\frac{\hat{A}_{i,t}}{P^Y_{i,t-1}Y_{i,t-1}} - \frac{B^S_{i,i}}{P^Y_iY_i}\ln\frac{\hat{P}^Y_{i,t}\hat{Y}_{i,t}}{\hat{P}^Y_{i,t-1}\hat{Y}_{i,t-1}}\right)\right] + \frac{TB_{i,t}}{P^Y_{i,t}Y_{i,t}}. \quad (82)$$

The cyclical component of the ratio of the trade balance to nominal output $\frac{TB_{i,t}}{P^Y_{i,t}Y_{i,t}}$ depends on the contemporaneous cyclical components of the ratio of output to domestic demand and the terms of trade according to:

$$\frac{TB_{i,t}}{P^Y_{i,t}Y_{i,t}} = \frac{D_i}{Y_i}\left[\ln\frac{\hat{Y}_{i,t}}{\hat{D}_{i,t}} + \frac{X_i}{Y_i}\left(\ln\frac{\hat{\mathcal{T}}^X_{i,t}}{\hat{\mathcal{T}}^M_{i,t}} + \ln\hat{v}^M_{i,t}\right)\right]. \quad (83)$$

The cyclical component of the ratio of net foreign assets to nominal output $\frac{\hat{A}_{i,t+1}}{P^Y_{i,t}Y_{i,t}}$ follows a stationary first order autoregressive process driven by the contemporaneous cyclical components of the growth rate of nominal output and the ratio of the current account balance to nominal output according to:

$$\frac{\hat{A}_{i,t+1}}{P^Y_{i,t}Y_{i,t}} = \frac{1}{1+g}\left(\frac{\hat{A}_{i,t}}{P^Y_{i,t-1}Y_{i,t-1}} - \frac{A_i}{P^Y_iY_i}\ln\frac{\hat{P}^Y_{i,t}\hat{Y}_{i,t}}{\hat{P}^Y_{i,t-1}\hat{Y}_{i,t-1}}\right) + \frac{CA_{i,t}}{P^Y_{i,t}Y_{i,t}}. \quad (84)$$

The linearization of these relationships accounts for long run balanced growth at nominal rate g. Their response coefficients vary across economies with their national financial wealth and their trade openness.

The cyclical component of the price of commodities $\ln \hat{P}_{k,t}^{Y}$ depends on a weighted average of its past and expected future cyclical components driven by the contemporaneous cyclical components of the world output weighted average labor income share, output and the relative local currency denominated price of commodities according to commodity price Phillips curve,

$$\ln \hat{P}_{k,t}^{Y} = \frac{1}{1+\beta} \ln \hat{P}_{k,t-1}^{Y} + \frac{\beta}{1+\beta} \mathrm{E}_t \ln \hat{P}_{k,t+1}^{Y} + \frac{(1-\omega_k^Y)(1-\omega_k^Y \beta)}{\omega_k^Y (1+\beta)} \sum_{i=1}^{N} w_i^Y \left\{ \frac{1}{\theta^Y - 1} \left[\ln \hat{Y}_{i,t} - \frac{1}{1-\tau_i} \hat{\tau}_{i,t} - \ln \frac{\hat{\Pi}_{i,t}^S}{\hat{P}_{i,t}^Y} - \ln \hat{\theta}_{k,t}^Y \right] \right. \tag{85}$$

$$\left. + \left(\frac{1}{\phi_k^L} - \frac{\theta^Y - 1}{\theta^Y} \right) \ln \frac{\hat{Y}_{i,t}}{\hat{\mathcal{A}}_{i,t}} - \ln \frac{\hat{\mathcal{E}}_{i,i^*,t} \hat{P}_{k,t}^Y}{\hat{P}_{i,t}^Y} \right\} - \sum_{i=1}^{N} w_i^Y \mathcal{P}_4(L) \ln \hat{\mathcal{E}}_{i,i^*,t},$$

where commodity price markup shock $\ln \hat{\theta}_{k,t}^{Y} = \varepsilon_{k,t}^{\theta^Y}$ with $\varepsilon_{k,t}^{\theta^Y} \sim \text{iid } \mathcal{N}(0, \sigma_{\theta^Y,k}^2)$. The cyclical component of the price of commodities also depends on the contemporaneous, past and expected future cyclical components of the world output weighted average nominal bilateral exchange rate, where polynomial in the lag operator $\mathcal{P}_4(L) = 1 - \frac{1}{1+\beta} L - \frac{\beta}{1+\beta} \mathrm{E}_t L^{-1}$. The response coefficients of this relationship vary across commodity markets $1 \le k \le M^*$, with $k = 1$ for energy commodities and $k = 2$ for nonenergy commodities.

B. Trend Components

The changes in the trend components of the price of output $\ln \bar{P}_{i,t}^{Y}$, the price of consumption $\ln \bar{P}_{i,t}^{C}$, output $\ln \bar{Y}_{i,t}$, domestic demand $\ln \bar{D}_{i,t}$, public domestic demand $\ln \bar{G}_{i,t}$, and the price of commodities $\ln \bar{P}_{k,t}^{Y}$ follow random walks:

$$\Delta \ln \bar{P}_{i,t}^{Y} = \Delta \ln \bar{P}_{i,t-1}^{Y} + \varepsilon_{i,t}^{\bar{P}^Y},\ \varepsilon_{i,t}^{\bar{P}^Y} \sim \text{iid } \mathcal{N}(0, \sigma_{\bar{P}^Y,i}^2), \tag{86}$$

$$\Delta \ln \bar{P}_{i,t}^{C} = \Delta \ln \bar{P}_{i,t-1}^{C} + \varepsilon_{i,t}^{\bar{P}^C},\ \varepsilon_{i,t}^{\bar{P}^C} \sim \text{iid } \mathcal{N}(0, \sigma_{\bar{P}^C,i}^2), \tag{87}$$

$$\Delta \ln \bar{Y}_{i,t} = \Delta \ln \bar{Y}_{i,t-1} + \varepsilon_{i,t}^{\bar{Y}},\ \varepsilon_{i,t}^{\bar{Y}} \sim \text{iid } \mathcal{N}(0, \sigma_{\bar{Y},i}^2), \tag{88}$$

$$\Delta \ln \bar{D}_{i,t} = \Delta \ln \bar{D}_{i,t-1} + \varepsilon_{i,t}^{\bar{D}},\ \varepsilon_{i,t}^{\bar{D}} \sim \text{iid } \mathcal{N}(0, \sigma_{\bar{D},i}^2), \tag{89}$$

$$\Delta \ln \bar{G}_{i,t} = \Delta \ln \bar{G}_{i,t-1} + \varepsilon_{i,t}^{\bar{G}},\ \varepsilon_{i,t}^{\bar{G}} \sim \text{iid } \mathcal{N}(0, \sigma_{\bar{G},i}^2), \tag{90}$$

$$\Delta \ln \bar{P}_{k,t}^{Y} = \Delta \ln \bar{P}_{k,t-1}^{Y} + \varepsilon_{t}^{\bar{P}_k^Y},\ \varepsilon_{t}^{\bar{P}_k^Y} \sim \text{iid } \mathcal{N}(0, \sigma_{\bar{P}_k^Y}^2). \tag{91}$$

The changes in the trend components of the nominal policy interest rate $\bar{i}_{i,t}^{P}$, short term nominal market interest rate $\bar{i}_{i,t}^{S}$, and long term nominal market interest rate $\bar{i}_{i,t}^{L}$ also follow random walks:

$$\Delta \bar{i}_{i,t}^{P} = \Delta \bar{i}_{i,t-1}^{P} + \varepsilon_{i,t}^{\bar{i}^P},\ \varepsilon_{i,t}^{\bar{i}^P} \sim \text{iid } \mathcal{N}(0, \sigma_{\bar{i}^P,i}^2), \tag{92}$$

$$\Delta\overline{i}_{i,t}^{S} = \Delta\overline{i}_{i,t-1}^{S} + \varepsilon_{i,t}^{\overline{i}^{S}},\ \varepsilon_{i,t}^{\overline{i}^{S}} \sim \text{iid } \mathcal{N}(0, \sigma_{\overline{i}^{S},i}^{2}), \tag{93}$$

$$\Delta\overline{i}_{i,t}^{L} = \Delta\overline{i}_{i,t-1}^{L} + \varepsilon_{i,t}^{\overline{i}^{L}},\ \varepsilon_{i,t}^{\overline{i}^{L}} \sim \text{iid } \mathcal{N}(0, \sigma_{\overline{i}^{L},i}^{2}). \tag{94}$$

In addition, the changes in the trend components of the price of equity $\ln\overline{V}_{i,t}^{S}$ and the nominal bilateral exchange rate $\ln\overline{\mathcal{E}}_{i,i*,t}$ follow random walks:

$$\Delta\ln\overline{V}_{i,t}^{S} = \Delta\ln\overline{V}_{i,t-1}^{S} + \varepsilon_{i,t}^{\overline{V}^{S}},\ \varepsilon_{i,t}^{\overline{V}^{S}} \sim \text{iid } \mathcal{N}(0, \sigma_{\overline{V}^{S},i}^{2}), \tag{95}$$

$$\Delta\ln\overline{\mathcal{E}}_{i,i*,t} = \Delta\ln\overline{\mathcal{E}}_{i,i*,t-1} + \varepsilon_{i,t}^{\overline{\mathcal{E}}},\ \varepsilon_{i,t}^{\overline{\mathcal{E}}} \sim \text{iid } \mathcal{N}(0, \sigma_{\overline{\mathcal{E}},i}^{2}). \tag{96}$$

Furthermore, the changes in the trend components of the ratios of the fiscal balance to nominal output $\frac{\overline{FB}_{i,t}}{P_{i,t}^{Y}Y_{i,t}}$ and the trade balance to nominal output $\frac{\overline{TB}_{i,t}}{P_{i,t}^{Y}Y_{i,t}}$ follow random walks:

$$\Delta\frac{\overline{FB}_{i,t}}{P_{i,t}^{Y}Y_{i,t}} = \Delta\frac{\overline{FB}_{i,t-1}}{P_{i,t-1}^{Y}Y_{i,t-1}} + \varepsilon_{i,t}^{\overline{FB}},\ \varepsilon_{i,t}^{\overline{FB}} \sim \text{iid } \mathcal{N}(0, \sigma_{\overline{FB},i}^{2}), \tag{97}$$

$$\Delta\frac{\overline{TB}_{i,t}}{P_{i,t}^{Y}Y_{i,t}} = \Delta\frac{\overline{TB}_{i,t-1}}{P_{i,t-1}^{Y}Y_{i,t-1}} + \varepsilon_{i,t}^{\overline{TB}},\ \varepsilon_{i,t}^{\overline{TB}} \sim \text{iid } \mathcal{N}(0, \sigma_{\overline{TB},i}^{2}). \tag{98}$$

Finally, the trend component of the real policy interest rate $\overline{r}_{i,t}^{P}$ satisfies $\overline{r}_{i,t}^{P} = \overline{i}_{i,t}^{P} - \mathrm{E}_t\,\overline{\pi}_{i,t+1}^{C}$, the trend component of the short term real market interest rate $\overline{r}_{i,t}^{S}$ satisfies $\overline{r}_{i,t}^{S} = \overline{i}_{i,t}^{S} - \mathrm{E}_t\,\overline{\pi}_{i,t+1}^{C}$, the trend component of the long term real market interest rate $\overline{r}_{i,t}^{L}$ satisfies $\overline{r}_{i,t}^{L} = \overline{i}_{i,t}^{L} - \mathrm{E}_t\,\overline{\pi}_{i,t+1}^{C}$, and the trend component of the real bilateral exchange rate $\ln\overline{\mathcal{Q}}_{i,i*,t}$ satisfies $\ln\overline{\mathcal{Q}}_{i,i*,t} = \ln\overline{\mathcal{E}}_{i,i*,t} + \ln\overline{P}_{i*,t}^{Y} - \ln\overline{P}_{i,t}^{Y}$.

IV. 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 common values of structural parameters across economies, and judgment regarding 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

$$\boldsymbol{A}_0\hat{\boldsymbol{x}}_t = \boldsymbol{A}_1\hat{\boldsymbol{x}}_{t-1} + \boldsymbol{A}_2\mathrm{E}_t\hat{\boldsymbol{x}}_{t+1} + \boldsymbol{A}_3\hat{\boldsymbol{v}}_t, \tag{99}$$

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

$$\hat{\boldsymbol{v}}_t = \boldsymbol{B}_1 \hat{\boldsymbol{v}}_{t-1} + \boldsymbol{\varepsilon}_{1,t}, \tag{100}$$

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:

$$\hat{\boldsymbol{x}}_t = \boldsymbol{C}_1 \hat{\boldsymbol{x}}_{t-1} + \boldsymbol{C}_2 \hat{\boldsymbol{v}}_t. \tag{101}$$

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

$$\boldsymbol{D}_0 \bar{\boldsymbol{x}}_t = \boldsymbol{D}_1 \boldsymbol{u}_t + \boldsymbol{D}_2 \bar{\boldsymbol{x}}_{t-1} + \boldsymbol{\varepsilon}_{2,t}, \tag{102}$$

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

$$\boldsymbol{u}_t = \boldsymbol{u}_{t-1} + \boldsymbol{\varepsilon}_{3,t}, \tag{103}$$

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 (101), these vector stochastic processes have linear state space representation

$$\boldsymbol{y}_t = \boldsymbol{F}_1 \boldsymbol{z}_t, \tag{104}$$

$$\boldsymbol{z}_t = \boldsymbol{G}_1 \boldsymbol{z}_{t-1} + \boldsymbol{G}_2 \boldsymbol{\varepsilon}_{4,t}, \tag{105}$$

where $\boldsymbol{\varepsilon}_{4,t} \sim \text{iid } \mathcal{N}(\boldsymbol{0}, \boldsymbol{\Sigma}_4)$ 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. In an extension of Vitek (2012) to allow for a deterministically time varying coefficient matrix, suppose that this vector stochastic process satisfies

$$\boldsymbol{w}_t = \boldsymbol{H}_{1,t} \boldsymbol{z}_t + \boldsymbol{\varepsilon}_{5,t}, \tag{106}$$

where $\boldsymbol{\varepsilon}_{5,t} \sim \text{iid } \mathcal{N}(\boldsymbol{0}, \boldsymbol{\Sigma}_{5,t})$. Conditional on known parameter values, this signal equation imposes judgment on linear combinations of unobserved state variables in the form of a time dependent 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) or the smoother associated with de Jong (1989). Given initial conditions $\boldsymbol{z}_{0|0}$ and $\boldsymbol{P}_{0|0}$, estimates conditional on information available at time $t-1$ satisfy prediction equations

$$\boldsymbol{z}_{t|t-1} = \boldsymbol{G}_1 \boldsymbol{z}_{t-1|t-1}, \tag{107}$$

$$\boldsymbol{P}_{t|t-1} = \boldsymbol{G}_1 \boldsymbol{P}_{t-1|t-1} \boldsymbol{G}_1^\top + \boldsymbol{G}_2 \boldsymbol{\Sigma}_4 \boldsymbol{G}_2^\top, \tag{108}$$

$$\tilde{\boldsymbol{y}}_{t|t-1} = \tilde{\boldsymbol{F}}_{1,t} \boldsymbol{z}_{t|t-1}, \tag{109}$$

$$\tilde{\boldsymbol{Q}}_{t|t-1} = \tilde{\boldsymbol{F}}_{1,t} \boldsymbol{P}_{t|t-1} \tilde{\boldsymbol{F}}_{1,t}^\top + \tilde{\boldsymbol{\Sigma}}_{5,t}, \tag{110}$$

where $\tilde{\boldsymbol{y}}_t = \begin{bmatrix} \boldsymbol{y}_t \\ \boldsymbol{w}_t \end{bmatrix}$, $\tilde{\boldsymbol{F}}_{1,t} = \begin{bmatrix} \boldsymbol{F}_1 \\ \boldsymbol{H}_{1,t} \end{bmatrix}$ and $\tilde{\boldsymbol{\Sigma}}_{5,t} = \begin{bmatrix} \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \boldsymbol{\Sigma}_{5,t} \end{bmatrix}$. Given these predictions, under the assumption of multivariate normally distributed signal and state innovation 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

$$\boldsymbol{z}_{t|t} = \boldsymbol{z}_{t|t-1} + \boldsymbol{K}_t (\tilde{\boldsymbol{y}}_t - \tilde{\boldsymbol{y}}_{t|t-1}), \tag{111}$$

$$\boldsymbol{P}_{t|t} = \boldsymbol{P}_{t|t-1} - \boldsymbol{K}_t \tilde{\boldsymbol{F}}_{1,t} \boldsymbol{P}_{t|t-1}, \tag{112}$$

where $\boldsymbol{K}_t = \boldsymbol{P}_{t|t-1} \tilde{\boldsymbol{F}}_{1,t}^\top \tilde{\boldsymbol{Q}}_{t|t-1}^{-1}$. Given terminal conditions $\hat{\boldsymbol{z}}_{T+1|T} = \mathbf{0}$ and $\hat{\boldsymbol{P}}_{T+1|T} = \mathbf{0}$, estimates conditional on information available at time T, and judgment concerning the paths of linear combinations of state variables through time T, satisfy computationally efficient Bayesian smoothing equations

$$\hat{\boldsymbol{z}}_{t|T} = \boldsymbol{J}_t^\top \hat{\boldsymbol{z}}_{t+1|T} + \tilde{\boldsymbol{F}}_{1,t}^\top \tilde{\boldsymbol{Q}}_{t|t-1}^{-1} (\tilde{\boldsymbol{y}}_t - \tilde{\boldsymbol{y}}_{t|t-1}), \tag{113}$$

$$\boldsymbol{z}_{t|T} = \boldsymbol{z}_{t|t-1} + \boldsymbol{P}_{t|t-1} \hat{\boldsymbol{z}}_{t|T}, \tag{114}$$

$$\hat{\boldsymbol{P}}_{t|T} = \boldsymbol{J}_t^\top \hat{\boldsymbol{P}}_{t+1|T} \boldsymbol{J}_t - \tilde{\boldsymbol{F}}_{1,t}^\top \tilde{\boldsymbol{Q}}_{t|t-1}^{-1} \tilde{\boldsymbol{F}}_{1,t}, \tag{115}$$

$$\boldsymbol{P}_{t|T} = \boldsymbol{P}_{t|t-1} + \boldsymbol{P}_{t|t-1} \hat{\boldsymbol{P}}_{t|T} \boldsymbol{P}_{t|t-1}, \tag{116}$$

where $\boldsymbol{J}_t = \boldsymbol{G}_1 (\boldsymbol{I}_K - \boldsymbol{P}_{t|t-1} \tilde{\boldsymbol{F}}_{1,t}^\top \tilde{\boldsymbol{Q}}_{t|t-1}^{-1} \tilde{\boldsymbol{F}}_{1,t})$. Under our distributional assumptions, recursive forward evaluation of equations (107) through (112), followed by recursive backward evaluation of equations (113) through (116), yields mean squared error optimal conditional estimates of the unobserved state vector.

Let $\boldsymbol{\theta} \in \boldsymbol{\Theta} \subset \mathbb{R}^K$ denote a vector containing the K 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:

$$f(\boldsymbol{\theta} \mid \{\tilde{\boldsymbol{y}}_s\}_{s=1}^T) \propto f(\{\tilde{\boldsymbol{y}}_s\}_{s=1}^T \mid \boldsymbol{\theta}) f(\boldsymbol{\theta}). \tag{117}$$

Under the assumption of multivariate normally distributed signal and state innovation vectors, conditional density function $f(\{\tilde{\boldsymbol{y}}_s\}_{s=1}^T \mid \boldsymbol{\theta})$ satisfies:

$$f(\{\tilde{\boldsymbol{y}}_s\}_{s=1}^T \mid \boldsymbol{\theta}) = \prod_{t=1}^{T} (2\pi)^{-\frac{N_y+N_w}{2}} \mid \tilde{\boldsymbol{Q}}_{t|t-1} \mid^{-\frac{1}{2}} \exp\left\{-\frac{1}{2}(\tilde{\boldsymbol{y}}_t - \tilde{\boldsymbol{y}}_{t|t-1})^\mathsf{T} \tilde{\boldsymbol{Q}}_{t|t-1}^{-1} (\tilde{\boldsymbol{y}}_t - \tilde{\boldsymbol{y}}_{t|t-1})\right\}. \tag{118}$$

Prior information concerning parameter vector $\boldsymbol{\theta}$ is summarized by a multivariate normal prior distribution having mean vector $\boldsymbol{\theta}_1$ and covariance matrix $\boldsymbol{\Omega}$:

$$f(\boldsymbol{\theta}) = (2\pi)^{-\frac{K}{2}} \mid \boldsymbol{\Omega} \mid^{-\frac{1}{2}} \exp\left\{-\frac{1}{2}(\boldsymbol{\theta} - \boldsymbol{\theta}_1)^\mathsf{T} \boldsymbol{\Omega}^{-1} (\boldsymbol{\theta} - \boldsymbol{\theta}_1)\right\}. \tag{119}$$

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 $\hat{\boldsymbol{\theta}}_T$ satisfies

$$\sqrt{T}(\hat{\boldsymbol{\theta}}_T - \boldsymbol{\theta}_0) \xrightarrow{d} \mathcal{N}(\mathbf{0}, -\boldsymbol{\mathcal{H}}_0^{-1}), \tag{120}$$

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

$$\hat{\boldsymbol{\mathcal{H}}}_T = -\frac{1}{T}\sum_{t=1}^{T}\left[\nabla_\theta \tilde{\boldsymbol{y}}_{t|t-1}^\mathsf{T} \tilde{\boldsymbol{Q}}_{t|t-1}^{-1} \nabla_\theta \tilde{\boldsymbol{y}}_{t|t-1} + \frac{1}{2}\nabla_\theta \tilde{\boldsymbol{Q}}_{t|t-1}^\mathsf{T} (\tilde{\boldsymbol{Q}}_{t|t-1}^{-1} \otimes \tilde{\boldsymbol{Q}}_{t|t-1}^{-1}) \nabla_\theta \tilde{\boldsymbol{Q}}_{t|t-1}\right] - \frac{1}{T}\boldsymbol{\Omega}^{-1}. \tag{121}$$

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 four hundred one endogenous variables observed for thirty five economies over the sample period 1999Q1 through 2012Q4. The advanced and emerging economies under consideration are Argentina, Australia, Austria, Belgium, Brazil, Canada, China, the Czech Republic, Denmark, Finland, France, Germany, Greece, India, Indonesia, Ireland, Italy, Japan, Korea, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Russia, Saudi Arabia, South Africa, Spain, Sweden, Switzerland, Thailand, Turkey, the United Kingdom, and the United States. The observed macroeconomic and financial market variables under consideration are the price of output, the price of consumption, the quantity of output, the quantity of domestic demand, the nominal policy interest rate, the short term nominal market interest rate, the long term nominal market interest rate, the price of equity, the nominal bilateral exchange rate, the quantity of public domestic demand, the ratio of the fiscal balance to nominal output, the ratio of the trade balance to nominal output, and the prices of energy and nonenergy commodities. For a detailed description of this multivariate panel data set, please refer to Appendix A.

Parameters

The set of parameters associated with our panel unobserved components model is partitioned into two subsets. Structural parameters are either estimated conditional on informative independent priors or calibrated, while innovation variances are estimated conditional on diffuse priors.

Priors

The marginal prior distributions of structural parameters 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 Australia, Canada, the Czech Republic, the Euro Area, Japan, New Zealand, Norway, Poland, Sweden, Switzerland, the United Kingdom and the United States, by a managed exchange rate regime in Argentina, Brazil, China, India, Indonesia, Korea, Mexico, Russia, South Africa, Thailand and Turkey, and by a fixed exchange rate regime in Denmark and Saudi Arabia, consistent with IMF (2011). Capital controls apply in China, India, and Saudi Arabia. The quotation currency for transactions in the foreign exchange market is issued by the United States. Great ratios and bilateral trade and portfolio weights are calibrated to match their observed values in 2010. All weights are normalized to sum to one across economies, where applicable.

Posteriors

The posterior mode is calculated by numerically maximizing the logarithm of the posterior density kernel with a modified steepest ascent algorithm. To avoid finding a local as opposed to global maximum, starting values for structural parameters are generated with a customized implementation of the differential evolution algorithm proposed by Storn and Price (1997). Parameter estimation results pertaining to the sample period 1999Q3 through 2012Q4 are reported in Table 1 of Appendix B. The sufficient condition for the existence of a unique stationary rational expectations equilibrium stated in 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 functions. Nevertheless, the data are quite informative regarding some of these structural parameters, as evidenced by substantial updates from prior to posterior, which collectively result in substantial updates to impulse responses. The estimated variances of innovations 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 innovations driving variation in trend components vary considerably across economies and observed endogenous variables.

Unobserved Components

Intermittent structural breaks are prevalent in observed macroeconomic and financial market variables. They may manifest through slope or intercept shifts, and may trace their origins to a variety of sources, including but not limited to regime shifts and structural change, not all of which may be well understood. To control for structural breaks in forming judgment concerning the paths of trend components, we extend the filter described in Hodrick and Prescott (1997) to allow for a time varying smoothing parameter, and quantify the uncertainty surrounding the resultant prior estimates.

We generate conditional unobserved component estimates with Bayesian updating, imposing judgment on the trend components of all observed endogenous variables in the form of stochastic restrictions derived from our prior estimates, with a time varying innovation covariance matrix proportional to their estimated mean squared error matrix. To minimize the influence of this judgment on the posterior trend component estimates while ensuring stationarity of the implied posterior cyclical component estimates, including for those nominal variables which our panel unobserved components model predicts have nonstationary cyclical components, the factor of proportionality is set to 10^8. We allow each observed endogenous variable to have at most one structural break, and estimate its timing by minimizing the objective function from which our prior trend component estimator is derived with respect to its time varying smoothing parameter. This smoothing parameter is allowed to switch from 6400 to 1600 for one period, if the minimized value of the objective function, normalized by its minimized value in the absence of a switch, does not exceed that for output in the United States. This observed endogenous variable is chosen as a benchmark because it is widely believed to exhibit a structural break during the sample period under consideration associated with the global financial crisis. 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 their prior trend component estimates.

Priors

Suppose that observed univariate stochastic process $\{y_t\}_{t=1}^{T}$ is additively separable into cyclical and trend components, that is $y_t = \hat{y}_t + \bar{y}_t$. Define its trend component estimator $\{\bar{y}_{t|T}\}_{t=1}^{T}$ as that argument which minimizes objective function

$$S(\{\bar{y}_t\}_{t=1}^{T}) = \sum_{t=1}^{T}(y_t - \bar{y}_t)^2 + \sum_{t=2}^{T-1}\lambda_t(\Delta^2\bar{y}_{t+1})^2, \tag{122}$$

where time varying smoothing parameter $\lambda_t \geq 0$. This minimization problem strikes a balance between minimizing the sum of squares of the cyclical component and the weighted sum of squares of the second difference of the trend component. Using matrix notation, this objective function may be expressed as

$$S(\bar{\boldsymbol{y}}) = (\boldsymbol{y}-\bar{\boldsymbol{y}})^{\mathsf{T}}(\boldsymbol{y}-\bar{\boldsymbol{y}}) + (\boldsymbol{\Delta}^2\bar{\boldsymbol{y}})^{\mathsf{T}}\boldsymbol{\Lambda}(\boldsymbol{\Delta}^2\bar{\boldsymbol{y}}), \tag{123}$$

where diagonal smoothing parameter matrix $\boldsymbol{\Lambda}$ satisfies $\boldsymbol{\Lambda}_{t,t} = \lambda_t$, while ordinary difference operator matrix $\boldsymbol{\Delta}^d = \prod_{i=1}^{d}\left(\begin{bmatrix}\boldsymbol{0} & \boldsymbol{I}_{T-i}\end{bmatrix} - \begin{bmatrix}\boldsymbol{I}_{T-i} & \boldsymbol{0}\end{bmatrix}\right)$. The necessary first order condition associated with this minimization problem yields:

$$\bar{\boldsymbol{y}}_{|T} = \left[\boldsymbol{I}_T + (\boldsymbol{\Delta}^2)^{\mathsf{T}}\boldsymbol{\Lambda}(\boldsymbol{\Delta}^2)\right]^{-1}\boldsymbol{y}. \tag{124}$$

This necessary first order condition is sufficient for unique global minimum $\bar{\boldsymbol{y}}_{|T}$.[4] This linear filter reduces to that described in Hodrick and Prescott (1997) for $\boldsymbol{\Lambda} = \lambda\boldsymbol{I}_{T-2}$.

Consider the application of trend component estimator (124) to an observed N dimensional vector stochastic process,

$$\begin{bmatrix}\bar{\boldsymbol{y}}_{1|T} & \cdots & \bar{\boldsymbol{y}}_{N|T}\end{bmatrix} = \begin{bmatrix}\left[\boldsymbol{I}_T + (\boldsymbol{\Delta}^2)^{\mathsf{T}}\boldsymbol{\Lambda}_1(\boldsymbol{\Delta}^2)\right]^{-1} & \cdots & \left[\boldsymbol{I}_T + (\boldsymbol{\Delta}^2)^{\mathsf{T}}\boldsymbol{\Lambda}_N(\boldsymbol{\Delta}^2)\right]^{-1}\end{bmatrix} \odot \begin{bmatrix}\boldsymbol{y}_1 & \cdots & \boldsymbol{y}_N\end{bmatrix}, \tag{125}$$

where $\boldsymbol{y}_t = \hat{\boldsymbol{y}}_t + \bar{\boldsymbol{y}}_t$. Under the assumption that $\hat{\boldsymbol{y}}_t \sim \text{iid } \mathcal{N}(\boldsymbol{0}, \boldsymbol{\Sigma}_C)$ and $\boldsymbol{\Delta}^2\bar{\boldsymbol{y}}_t \sim \text{iid } \mathcal{N}(\boldsymbol{0}, \boldsymbol{\Sigma}_T)$ are independent, which could be relaxed to allow for autocorrelation, it can be shown that this trend component estimator is also multivariate normally distributed with mean squared error matrix

$$\text{Var}_t\left(\text{Vec}\begin{bmatrix}\bar{\boldsymbol{y}}_{1|T} & \cdots & \bar{\boldsymbol{y}}_{N|T}\end{bmatrix}\right) = \begin{bmatrix}\text{Var}(\bar{\boldsymbol{y}}_{1|T})_{t,t} & \cdots & \text{Cov}(\bar{\boldsymbol{y}}_{1|T}, \bar{\boldsymbol{y}}_{N|T})_{t,t} \\ \vdots & \ddots & \vdots \\ \text{Cov}(\bar{\boldsymbol{y}}_{N|T}, \bar{\boldsymbol{y}}_{1|T})_{t,t} & \cdots & \text{Var}(\bar{\boldsymbol{y}}_{N|T})_{t,t}\end{bmatrix}, \tag{126}$$

where $\text{Cov}(\bar{\boldsymbol{y}}_{i|T}, \bar{\boldsymbol{y}}_{j|T}) = \left[\boldsymbol{I}_T + (\boldsymbol{\Delta}^2)^{\mathsf{T}}\boldsymbol{\Lambda}_i(\boldsymbol{\Delta}^2)\right]^{-1}\left[\sigma_{C,i,j}\boldsymbol{I}_T + \sigma_{T,i,j}(\boldsymbol{\Lambda}_i\boldsymbol{\Delta}^2)^{\mathsf{T}}(\boldsymbol{\Lambda}_j\boldsymbol{\Delta}^2)\right]\left[\boldsymbol{I}_T + (\boldsymbol{\Delta}^2)^{\mathsf{T}}\boldsymbol{\Lambda}_j(\boldsymbol{\Delta}^2)\right]^{-1}$. We therefore propose mean squared error matrix estimator

$$\text{Var}_t\left(\text{Vec}\begin{bmatrix}\bar{\boldsymbol{y}}_{1|T} & \cdots & \bar{\boldsymbol{y}}_{N|T}\end{bmatrix}\right) = \begin{bmatrix}\text{Var}(\bar{\boldsymbol{y}}_{1|T})_{t,t} & \cdots & \text{Cov}(\bar{\boldsymbol{y}}_{1|T}, \bar{\boldsymbol{y}}_{N|T})_{t,t} \\ \vdots & \ddots & \vdots \\ \text{Cov}(\bar{\boldsymbol{y}}_{N|T}, \bar{\boldsymbol{y}}_{1|T})_{t,t} & \cdots & \text{Var}(\bar{\boldsymbol{y}}_{N|T})_{t,t}\end{bmatrix}, \tag{127}$$

where $\text{Cov}(\bar{\boldsymbol{y}}_{i|T}, \bar{\boldsymbol{y}}_{j|T}) = \left[\boldsymbol{I}_T + (\boldsymbol{\Delta}^2)^{\mathsf{T}}\boldsymbol{\Lambda}_i(\boldsymbol{\Delta}^2)\right]^{-1}\left[\hat{\sigma}_{C,i,j}\boldsymbol{I}_T + \hat{\sigma}_{T,i,j}(\boldsymbol{\Lambda}_i\boldsymbol{\Delta}^2)^{\mathsf{T}}(\boldsymbol{\Lambda}_j\boldsymbol{\Delta}^2)\right]\left[\boldsymbol{I}_T + (\boldsymbol{\Delta}^2)^{\mathsf{T}}\boldsymbol{\Lambda}_j(\boldsymbol{\Delta}^2)\right]^{-1}$ with $\hat{\sigma}_{C,i,j} = \frac{1}{T}\sum_{t=1}^{T}\hat{y}_{i,t}\hat{y}_{j,t}$ and $\hat{\sigma}_{T,i,j} = \frac{1}{T-2}\sum_{t=2}^{T-1}(\Delta^2\bar{y}_{i,t+1})(\Delta^2\bar{y}_{j,t+1})$.

Posteriors

Within the framework of our estimated panel unobserved components model, the output gap is an indicator of inflationary or disinflationary pressure. Smoothed estimates of the output gap are plotted in Figure 1 of Appendix B. These model consistent estimates are conditional on prior

[4] The Hessian matrix of the objective function $\frac{\partial^2 S(\bar{\boldsymbol{y}})}{\partial\bar{\boldsymbol{y}}\partial\bar{\boldsymbol{y}}^{\mathsf{T}}} = 2\left[\boldsymbol{I}_T + (\boldsymbol{\Delta}^2)^{\mathsf{T}}\boldsymbol{\Lambda}(\boldsymbol{\Delta}^2)\right]$ is positive definite throughout its domain, because $\boldsymbol{\alpha}^{\mathsf{T}}\frac{\partial^2 S(\bar{\boldsymbol{y}})}{\partial\bar{\boldsymbol{y}}\partial\bar{\boldsymbol{y}}^{\mathsf{T}}}\boldsymbol{\alpha} = 2\left[\boldsymbol{\alpha}^{\mathsf{T}}\boldsymbol{\alpha} + (\boldsymbol{\Lambda}^{1/2}\boldsymbol{\Delta}^2\boldsymbol{\alpha})^{\mathsf{T}}(\boldsymbol{\Lambda}^{1/2}\boldsymbol{\Delta}^2\boldsymbol{\alpha})\right] > 0$ for any $\boldsymbol{\alpha} \neq \boldsymbol{0}$.

information concerning the values of structural parameters, and judgment regarding the paths of trend components.

A decomposition of our output gap estimates into contributions from domestic demand and net exports indicates that the gradual global synchronized accumulation of excess demand pressure which occurred during the build up to the global financial crisis was primarily driven by the excessive expansion of private domestic demand in most economies. During this period of widening global current account imbalances, the excessive expansion of net exports was also a major contributor to the accumulation of excess demand pressure in major surplus economies such as China and Germany. The global financial crisis triggered the rapid global synchronized unwinding of this excess demand pressure, and resulted in the accumulation of substantial excess supply pressure in many economies. During this episode of narrowing global current account imbalances, collapses in private domestic demand in major deficit economies such as the United Kingdom and the United States coincided with collapses in net exports in major surplus economies.

V. Monetary and Fiscal Policy Analysis

We analyze the interaction between business cycle dynamics in the world economy, and the systematic and unsystematic components of monetary and fiscal policy, within the framework of our estimated panel unobserved components model. In particular, we quantify dynamic interrelationships among key instrument, indicator and target variables with estimated impulse response functions. We also identify the structural determinants of these instrument, indicator and target variables with estimated forecast error variance decompositions and historical decompositions.

A. Impulse Response Functions

Impulse response functions measure the dynamic effects of selected structural shocks on endogenous variables. The estimated impulse responses of consumption price inflation, output, domestic demand, the nominal policy interest rate, the real effective exchange rate, the ratio of the fiscal balance to nominal output, and the ratio of the current account balance to nominal output to a variety of structural shocks are plotted in Figure 2 through Figure 11. The structural shocks under consideration are domestic productivity shocks, domestic intertemporal substitution shocks, domestic monetary policy shocks, domestic credit risk premium shocks, domestic duration risk premium shocks, domestic equity risk premium shocks, domestic fiscal expenditure shocks, domestic fiscal revenue shocks, world energy commodity price markup shocks, and world nonenergy commodity price markup shocks.

In response to a domestic productivity shock which generates a persistent hump shaped increase in inflation, there arises a persistent hump shaped contraction of output. Facing a monetary policy tradeoff, the central bank generally raises the nominal policy interest rate to control inflation, and the currency appreciates in real effective terms. The fiscal balance tends to deteriorate due to the fall in output, while the current account balance generally improves reflecting the improvement in the terms of trade. In response to a domestic intertemporal substitution shock which generates a persistent hump shaped expansion of output, there arises a persistent hump shaped increase in inflation. Not facing a monetary policy tradeoff, the central bank tends to raise the nominal policy interest rate to stabilize inflation and output, and the currency appreciates in real effective terms. The fiscal balance improves due to the rise in output, while the current account balance deteriorates commensurate with the larger rise in domestic demand.

In response to a domestic monetary policy shock which generates a persistent increase in the nominal policy interest rate except under a fixed exchange rate regime, the currency appreciates in real effective terms. Reflecting the interest rate and exchange rate channels of monetary transmission, there arises a persistent hump shaped contraction of output, accompanied by a persistent decrease in inflation. In particular, in response to a one percentage point increase in the nominal policy interest rate, the median peak contraction of output is 0.3 percent across economies within a range of 0.1 to 0.4 percent, while the median peak decrease in inflation is 0.2 percentage points within a range of 0.2 to 0.3 percentage points. The fiscal balance deteriorates due to the fall in output, while the current account balance improves commensurate with the larger fall in domestic demand. Under a fixed exchange rate regime, a domestic monetary policy shock which generates a transient increase in the nominal policy interest rate only induces a transient appreciation of the currency in real effective terms.

In response to a domestic credit risk premium shock which generates a persistent increase in the short term nominal market interest rate, the currency appreciates in real effective terms except under a currency union, and there arises a persistent hump shaped contraction of output, accompanied by a persistent decrease in inflation. In particular, in response to a one percentage point increase in the short term nominal market interest rate, the median peak contraction of output is 0.2 percent across economies, within a range of 0.0 to 0.3 percent. The central bank generally cuts the nominal policy interest rate to stabilize inflation and output, but the fiscal balance deteriorates due to the fall in output, while the current account balance improves reflecting the larger fall in domestic demand. In response to a domestic duration risk premium shock which generates a persistent increase in the long term nominal market interest rate, there arises a persistent hump shaped contraction of output, accompanied by a persistent hump shaped decrease in inflation. In particular, in response to a one percentage point increase in the long term nominal market interest rate, the median peak contraction of output is 0.4 percent across economies, within a range of 0.1 to 0.8 percent. The central bank tends to cut the nominal policy interest rate to stabilize inflation and output, and the currency depreciates in real effective terms. The fiscal balance deteriorates due to the fall in output, while the current account balance improves commensurate with the larger fall in domestic demand. In response to a domestic equity risk premium shock which generates a persistent increase in the price of equity, there arises a persistent hump shaped expansion of output, accompanied by a persistent hump shaped increase in inflation. In particular, in response to a ten percent increase in the price of equity, the median peak expansion of output is 0.2 percent across economies, within a range of 0.0 to 0.5 percent. The central bank usually raises the nominal policy interest rate to stabilize inflation and output, and the currency appreciates in real effective terms. The fiscal balance improves due to the rise in output, while the current account balance deteriorates reflecting the larger rise in domestic demand.

In response to a domestic fiscal expenditure shock which generates a persistent improvement in the fiscal balance, there arises a persistent contraction of output, generally accompanied by a decrease in inflation. In particular, in response to a one percentage point increase in the ratio of the primary fiscal balance to nominal output, the median peak expansion of output is 1.1 percent within a range of 0.2 to 1.8 percent, and tends to decrease across economies with their trade openness. The central bank usually cuts the nominal policy interest rate to stabilize inflation and output, and the currency depreciates in real effective terms. The current account balance improves, reflecting the larger fall in domestic demand than in output. In response to a domestic fiscal revenue shock which generates a persistent improvement in the fiscal balance, there arises a persistent contraction of output, generally accompanied by a decrease in inflation. In particular, in response to a one percentage point increase in the ratio of the primary fiscal balance to nominal output, the median peak contraction of output is 0.5 percent within a range of 0.1 to 0.7 percent, and tends to decrease across economies with their trade openness. The central bank usually cuts the nominal policy interest rate to stabilize inflation and output, and the currency depreciates in real effective terms. The current account balance improves, commensurate with the larger fall in domestic demand than in output.

In response to a world energy or nonenergy commodity price markup shock which generates an increase in the price of energy or nonenergy commodities, inflation increases and the central bank raises the nominal policy interest rate. For net exporters of energy or nonenergy commodities, the currency generally appreciates in real effective terms, inducing a terms of trade driven expansion of domestic demand mitigated by monetary policy tightening, which translates into an expansion of output in spite of terms of trade driven expenditure switching. The fiscal and current account balances tend to improve. In contrast, for net importers of energy or nonenergy commodities, the currency generally depreciates in real effective terms, inducing a terms of trade driven contraction of domestic demand amplified by monetary policy tightening, which translates into a contraction of output in spite of terms of trade driven expenditure switching. The fiscal and current account balances tend to deteriorate.

B. Forecast Error Variance Decompositions

Forecast error variance decompositions measure the contributions of mutually exclusive sets of structural shocks to unpredictable variation in endogenous variables at different horizons, on average over the business cycle. The estimated forecast error variance decompositions of consumption price inflation, output, domestic demand, the nominal policy interest rate, the real effective exchange rate, the ratio of the fiscal balance to nominal output, and the ratio of the current account balance to nominal output are plotted in Figure 12 through Figure 18. The sets of structural shocks under consideration are domestic supply shocks, foreign supply shocks, domestic demand shocks, foreign demand shocks, world monetary policy shocks, world fiscal policy shocks, world risk premium shocks, and world terms of trade shocks.

Our estimated forecast error variance decompositions indicate that unpredictable variation in inflation is primarily driven by supply shocks, and to a lesser extent demand and monetary policy shocks, at all horizons. The contributions of domestic supply and demand shocks relative to foreign supply and demand shocks are generally decreasing across economies with their trade openness and increasing with their monetary policy autonomy. In contrast, unpredictable variation in output tends to be primarily attributable to demand shocks, together with monetary policy shocks, at high frequencies. The contribution of domestic demand shocks relative to foreign demand shocks is generally decreasing across economies with their trade openness. Nevertheless, supply shocks are major contributors to unpredictable output fluctuations at low frequencies. Estimated forecast error variance decompositions of domestic demand reveal a similar pattern, with the exception that domestic demand shocks are larger contributors to unpredictable variation at all frequencies, while foreign demand shocks are smaller contributors. In addition, fiscal policy shocks tend to be significant contributors to unpredictable domestic demand fluctuations at high frequencies.

Estimated forecast error variance decompositions indicate that unpredictable variation in the nominal policy interest rate is primarily driven by monetary policy shocks at all horizons. However, supply shocks are also major contributors to unpredictable variation at long horizons, where the relative contribution of domestic as opposed to foreign supply shocks is generally increasing across economies with their monetary policy autonomy. Estimated forecast error variance decompositions of the real effective exchange rate attribute most unpredictable variation to risk premium shocks, and to a lesser extent monetary policy shocks, at all frequencies. Nevertheless, supply and demand shocks are also major contributors to unpredictable real effective exchange rate fluctuations at low frequencies.

Our estimated forecast error variance decompositions reveal that unpredictable variation in the fiscal balance is primarily driven by fiscal policy shocks, and to a lesser extent demand and monetary policy shocks, at short horizons. The contribution of monetary policy shocks is generally increasing across economies with their net government debt positions. However, supply shocks are also major contributors to unpredictable variation at long horizons. Estimated forecast error variance decompositions of the current account balance attribute most unpredictable variation to demand and risk premium shocks at all horizons, together with monetary policy shocks for economies with high net foreign asset or debt positions. The contribution of domestic demand shocks relative to foreign demand shocks tends to be decreasing across economies with their trade openness.

C. Historical Decompositions

Historical decompositions measure the time varying contributions of mutually exclusive sets of structural shocks to the realizations of endogenous variables. The estimated historical decompositions of consumption price inflation and output growth are plotted in Figure 19 and Figure 20. The sets of structural shocks under consideration are domestic supply shocks, foreign supply shocks, domestic demand shocks, foreign demand shocks, world monetary policy shocks, world fiscal policy shocks, world risk premium shocks, and world terms of trade shocks.

Our estimated historical decompositions of inflation attribute deviations from implicit targets primarily to economy specific combinations of domestic and foreign supply and demand shocks, together with world risk premium and terms of trade 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, New Zealand, Norway, Sweden and the United Kingdom. Estimated historical decompositions of output growth attribute business cycle dynamics around relatively stable potential output growth rates primarily to economy specific combinations of domestic and foreign demand shocks, together with world fiscal policy and risk premium shocks. Business cycle fluctuations in major deficit economies such as the United Kingdom and the United States have been primarily driven by domestic demand shocks, whereas those in major surplus economies such as China and Germany have been primarily driven by foreign demand shocks. In both groups of economies, these business cycle fluctuations have usually been amplified by world risk premium shocks and mitigated by world fiscal policy shocks. Potential output growth rates have generally stabilized at relatively low levels in advanced economies, and at relatively high levels in emerging economies.

During the build up to the global financial crisis, positive domestic and foreign demand shocks generally contributed to the gradual accumulation of excess demand pressure throughout the world economy, amplified by world risk premium shocks. This synchronized global expansion was reflected in a synchronized global rise in inflation, usually amplified by world terms of trade shocks. During the global financial crisis, economy specific combinations of negative domestic and foreign demand shocks, amplified and accelerated by world risk premium shocks, rapidly eliminated this excess demand pressure, generally supplanting it with excess supply pressure to varying degrees. This synchronized global recession was mitigated by unsystematic monetary and fiscal policy interventions. It was reflected in a synchronized global fall in inflation, usually amplified by world terms of trade shocks. Since the global financial crisis, economy specific combinations of positive domestic and foreign demand shocks, generally amplified by world risk premium shocks, have gradually reduced this excess supply pressure. This synchronized global recovery has been decelerated by world fiscal policy shocks, particularly in the Euro Area periphery.

VI. Spillover Analysis

Within the framework of our estimated panel unobserved components model, the dynamic effects of macroeconomic and financial shocks are transmitted throughout the world economy via trade, financial and commodity price linkages, necessitating monetary and fiscal policy responses to spillovers. Macroeconomic shocks are transmitted via direct financial linkages, while financial shocks are also transmitted via indirect financial linkages representing contagion effects.

We analyze spillovers from macroeconomic and financial shocks in systemic economies to the rest of the world with simulated conditional betas and estimated impulse response functions. The systemic economies under consideration are China, the Euro Area, Japan, the United Kingdom and the United States, consistent with IMF (2013a). The macroeconomic shocks under consideration are productivity shocks, intertemporal substitution shocks, monetary policy shocks, fiscal expenditure shocks, and fiscal revenue shocks. The financial shocks under consideration are credit risk premium shocks, duration risk premium shocks, and equity risk premium shocks.

A. Simulated Conditional Betas

Simulated conditional betas measure contemporaneous comovement between endogenous variables driven by selected structural shocks, on average over the business cycle. They are ordinary least squares estimates of slope coefficients in bivariate regressions of endogenous variables on contemporaneous endogenous variables, averaged across a large number of simulated paths for the world economy. The simulated betas of the output gap with respect to the contemporaneous output gap in systemic economies, conditional on macroeconomic or financial shocks in each of these systemic economies, are plotted in Figure 21. They measure causality as opposed to correlation, because they abstract from structural shocks associated with other economies.

On average over the business cycle, output spillovers from systemic economies to the rest of the world in our estimated panel unobserved components model are primarily generated by macroeconomic shocks, which contribute more to business cycle fluctuations than financial shocks. This implies weak international business cycle comovement beyond close trading partners. However, during episodes of financial stress in systemic economies, such as during the global financial crisis, international business cycle comovement is more uniformly strong due to the prevalence of financial shocks, which propagate via elevated contagion effects.

Output spillovers generated by macroeconomic shocks are generally small but concentrated in our estimated panel unobserved components model. The pattern of international business cycle comovement driven by macroeconomic shocks primarily reflects bilateral trade relationships, and therefore exhibits gravity. That is, output spillovers generated by macroeconomic shocks tend to be concentrated among geographically close trading partners, which typically have strong bilateral trade relationships due in part to transportation costs. However, this pattern is diluted by supply shocks, which are primarily transmitted internationally via terms of trade shifts, unlike other macroeconomic shocks which are primarily transmitted internationally via domestic demand shifts.

Output spillovers generated by financial shocks are generally large and diffuse in our estimated panel unobserved components model. The pattern of international business cycle comovement driven by financial shocks transcends bilateral portfolio investment relationships, which tend to be weak reflecting home bias. Output spillovers generated by financial shocks are primarily transmitted via international comovement in financial asset prices. Given that bilateral trade relationships are typically weak beyond close trading partners, accounting for strong international comovement in financial asset prices requires strong international comovement in risk premia. The intensity of these contagion effects varies across source and recipient economies. They are uniquely strong from the United States, commensurate with the depth of its money, bond and stock markets. They are strong to emerging economies with open capital accounts, moderate to advanced economies, and weak to emerging economies with closed capital accounts.

B. Impulse Response Functions

Peak impulse response functions measure the maximum effects of selected structural shocks on endogenous variables. The estimated peak impulse responses of consumption price inflation, output, the real effective exchange rate, the ratio of the fiscal balance to nominal output, and the ratio of the current account balance to nominal output to a variety of structural shocks are plotted in Figure 22 through Figure 29. The structural shocks under consideration are foreign productivity shocks, foreign intertemporal substitution shocks, foreign monetary policy shocks, foreign credit risk premium shocks, foreign duration risk premium shocks, foreign equity risk premium shocks, foreign fiscal expenditure shocks, and foreign fiscal revenue shocks.

In response to a productivity shock which generates an increase in inflation and contraction of output in a systemic economy, the currencies of recipient economies generally depreciate in real effective terms. There tend to arise terms of trade driven increases in inflation and expansions of output in recipient economies, in spite of lower foreign demand. As a result, their fiscal and current account balances usually improve. In response to an intertemporal substitution shock which generates an increase in inflation and expansion of output in a systemic economy, there generally arise foreign demand driven increases in inflation and expansions of output in recipient economies, amplified by depreciations of their currencies in real effective terms. As a result, their fiscal and current account balances tend to improve.

In response to a monetary policy shock which generates an increase in the nominal policy interest rate in a systemic economy, the currencies of recipient economies generally depreciate in real effective terms. There tend to arise foreign demand driven decreases in inflation and contractions of output in recipient economies, mitigated by terms of trade deteriorations. As a result, their fiscal and current account balances usually deteriorate.

In response to a credit risk premium shock which generates an increase in the short term nominal market interest rate in a systemic economy, the short term nominal market interest rates of recipient economies also generally increase, reflecting international money market contagion effects. As a result, there tend to arise decreases in inflation and contractions of output in recipient economies, accompanied by deteriorations of their fiscal and current account balances. In response to a duration risk premium shock which generates an increase in the long term nominal market interest rate in a systemic economy, the long term nominal market interest rates of recipient economies also usually increase, reflecting international bond market contagion effects. As a result, there tend to arise decreases in inflation and contractions of output in recipient economies, accompanied by deteriorations of their fiscal and current account balances. In response to an equity risk premium shock which generates an increase in the price of equity in a systemic economy, the prices of equity in recipient economies also generally increase, reflecting international stock market contagion effects. As a result, there tend to arise increases in inflation and expansions of output in recipient economies, accompanied by improvements in their fiscal and current account balances.

In response to a fiscal expenditure shock which generates an improvement in the fiscal balance in a systemic economy, there generally arise foreign demand driven decreases in inflation and contractions of output in recipient economies, amplified by appreciations of their currencies in real effective terms. As a result, their fiscal and current account balances tend to deteriorate. In response to a fiscal revenue shock which generates an improvement in the fiscal balance in a systemic economy, there usually arise foreign demand driven decreases in inflation and contractions of output in recipient economies, amplified by appreciations of their currencies in real effective terms. As a result, their fiscal and current account balances tend to deteriorate.

VII. 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. To mitigate these problems while respecting monetary and fiscal policy relevant constraints, we employ a Bayesian forecasting procedure which combines restricted forecasts generated with our estimated panel unobserved components model with judgment.

A. Forecasting Procedure

Consider the linear state space model consisting of signal equations (104) and (106), and state equation (105). 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:

$$\boldsymbol{z}_{T+h|T+h-1} = \boldsymbol{G}_1 \boldsymbol{z}_{T+h-1|T+h-1}, \tag{128}$$

$$\boldsymbol{P}_{T+h|T+h-1} = \boldsymbol{G}_1 \boldsymbol{P}_{T+h-1|T+h-1} \boldsymbol{G}_1^\top + \boldsymbol{G}_2 \boldsymbol{\Sigma}_4 \boldsymbol{G}_2^\top, \tag{129}$$

$$\boldsymbol{y}_{T+h|T+h-1} = \boldsymbol{F}_1 \boldsymbol{z}_{T+h|T+h-1}, \tag{130}$$

$$\boldsymbol{Q}_{T+h|T+h-1} = \boldsymbol{F}_1 \boldsymbol{P}_{T+h|T+h-1} \boldsymbol{F}_1^\top, \tag{131}$$

$$\boldsymbol{w}_{T+h|T+h-1} = \boldsymbol{H}_{1,T+h} \boldsymbol{z}_{T+h|T+h-1}, \tag{132}$$

$$\boldsymbol{R}_{T+h|T+h-1} = \boldsymbol{H}_{1,T+h} \boldsymbol{P}_{T+h|T+h-1} \boldsymbol{H}_{1,T+h}^\top + \boldsymbol{\Sigma}_{5,T+h}. \tag{133}$$

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

$$\boldsymbol{z}_{T+h|T+h} = \boldsymbol{z}_{T+h|T+h-1} + \boldsymbol{K}_{T+h}(\boldsymbol{w}_{T+h} - \boldsymbol{w}_{T+h|T+h-1}), \tag{134}$$

$$\boldsymbol{P}_{T+h|T+h} = \boldsymbol{P}_{T+h|T+h-1} - \boldsymbol{K}_{T+h} \boldsymbol{H}_{1,T+h} \boldsymbol{P}_{T+h|T+h-1}, \tag{135}$$

$$\boldsymbol{y}_{T+h|T+h} = \boldsymbol{F}_1 \boldsymbol{z}_{T+h|T+h}, \tag{136}$$

$$\boldsymbol{Q}_{T+h|T+h} = \boldsymbol{F}_1 \boldsymbol{P}_{T+h|T+h} \boldsymbol{F}_1^\top, \tag{137}$$

where $\boldsymbol{K}_{T+h} = \boldsymbol{P}_{T+h|T+h-1} \boldsymbol{H}_{1,T+h}^\top \boldsymbol{R}_{T+h|T+h-1}^{-1}$. Given terminal forecasts $\hat{\boldsymbol{z}}_{T+H+1|T+H} = \boldsymbol{0}$ and $\hat{\boldsymbol{P}}_{T+H+1|T+H} = \boldsymbol{0}$, 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 computationally efficient Bayesian smoothing equations

$$\hat{\boldsymbol{z}}_{T+h|T+H} = \boldsymbol{J}_{T+h}^\top \hat{\boldsymbol{z}}_{T+h+1|T+H} + \boldsymbol{H}_{1,T+h}^\top \boldsymbol{R}_{T+h|T+h-1}^{-1}(\boldsymbol{w}_{T+h} - \boldsymbol{w}_{T+h|T+h-1}), \tag{138}$$

$$\boldsymbol{z}_{T+h|T+H} = \boldsymbol{z}_{T+h|T+h-1} + \boldsymbol{P}_{T+h|T+h-1} \hat{\boldsymbol{z}}_{T+h|T+H}, \tag{139}$$

$$\hat{\boldsymbol{P}}_{T+h|T+H} = \boldsymbol{J}_{T+h}^\top \hat{\boldsymbol{P}}_{T+h+1|T+H} \boldsymbol{J}_{T+h} - \boldsymbol{H}_{1,T+h}^\top \boldsymbol{R}_{T+h|T+h-1}^{-1} \boldsymbol{H}_{1,T+h}, \tag{140}$$

$$\boldsymbol{P}_{T+h|T+H} = \boldsymbol{P}_{T+h|T+h-1} + \boldsymbol{P}_{T+h|T+h-1} \hat{\boldsymbol{P}}_{T+h|T+H} \boldsymbol{P}_{T+h|T+h-1}, \tag{141}$$

$$\boldsymbol{y}_{T+h|T+H} = \boldsymbol{F}_1 \boldsymbol{z}_{T+h|T+H}, \tag{142}$$

$$\boldsymbol{Q}_{T+h|T+H} = \boldsymbol{F}_1 \boldsymbol{P}_{T+h|T+H} \boldsymbol{F}_1^\top, \tag{143}$$

where $\boldsymbol{J}_{T+h} = \boldsymbol{G}_1(\boldsymbol{I}_K - \boldsymbol{P}_{T+h|T+h-1} \boldsymbol{H}_{1,T+h}^\top \boldsymbol{R}_{T+h|T+h-1}^{-1} \boldsymbol{H}_{1,T+h})$. Under our distributional assumptions, recursive forward evaluation of equations (128) through (137), followed by recursive backward evaluation of equations (138) through (143), yields mean squared error optimal conditional forecasts.

B. Forecasting Results

We analyze the predictive accuracy of our panel unobserved components model for consumption price inflation and output growth with sequential unconditional forecasts in sample. We then generate conditional forecasts of these 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 30 through Figure 35.

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 global financial crisis. However, the model generally underpredicted the severity of this synchronized global recession, while overpredicting its disinflationary impact. While the model forecast the subsequent synchronized global recovery, it systematically underpredicted its weakness in most advanced economies.

Conditional Forecasts

We generate forecasts of inflation and output growth conditional on monetary and fiscal policy relevant constraints, and judgment concerning the paths of these variables. These combined forecasts are recursive weighted averages of restricted forecasts generated with our panel unobserved components model, and judgmental forecasts produced by the International Monetary Fund. To facilitate comparability with IMF (2013b), the restricted forecasts are generated subject to constant real effective exchange rates, and common assumptions concerning the paths of energy and nonenergy commodity prices. The weight assigned to these 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 between the restricted forecasts and the judgmental forecasts, while the restricted forecasts tend to lie near the unrestricted forecasts. These alternative forecasts generally have similar profiles, and point towards a gradual cyclical expansion in most advanced economies, accompanied by subdued output growth in many emerging economies.

Conditional Forecast Decompositions

Our conditional forecast decompositions measure the contributions of different structural shocks to revisions to the unrestricted forecasts of inflation and output growth given the deterministic restrictions imposed in generating the restricted forecasts, and to these restricted forecasts given the stochastic restrictions imposed in representing the judgmental forecasts. These conditional forecast decompositions are estimated by the difference between unconditional forecast decompositions of the combined and unrestricted forecasts, which in turn are estimated by out of sample extensions of unconditional historical decompositions.

The effects on the unrestricted forecasts of inflation and output growth of conditioning on constant real effective exchange rates and given paths for energy and nonenergy commodity prices are primarily measured by contributions from world risk premium and terms of trade shocks, respectively. The effects on the restricted forecasts of conditioning on judgment concerning the paths of inflation and output growth are primarily measured by contributions from domestic supply and demand shocks. While domestic supply shocks of variable sign tend to account for most of the persistent discrepancies between the restricted and judgmental forecasts, negative domestic demand shocks account for much in economies undergoing balance sheet deleveraging, with substantial spillovers to close trading partners.

VIII. Conclusion

This paper develops a structural macroeconometric model of the world economy, disaggregated into thirty five national economies. This panel unobserved components model encompasses an approximate linear panel dynamic stochastic general equilibrium model featuring a monetary transmission mechanism, a fiscal transmission mechanism, and extensive macrofinancial linkages, both within and across economies. A variety of monetary policy analysis, fiscal policy analysis, spillover analysis, and forecasting applications of the estimated model are demonstrated. These include accounting for business cycle fluctuations, quantifying the monetary and fiscal transmission mechanisms, and generating conditional forecasts of inflation and output growth. They are based on a Bayesian framework for conditioning on judgment in estimation and forecasting.

This panel unobserved components model consolidates much existing theoretical and empirical knowledge concerning business cycle dynamics in the world economy, provides a framework for a progressive research strategy, and suggests explanations for its own deficiencies. Many of these deficiencies trace their origins to the specifications of the markets for capital and labor inputs in the underlying panel dynamic stochastic general equilibrium model. Extending these specifications remains an objective for future research.

Appendix A. Description of the Multivariate Panel Data Set

Estimation is based on quarterly data on several macroeconomic and financial market variables observed for thirty five economies over the sample period 1999Q1 through 2012Q4. The economies under consideration are Argentina, Australia, Austria, Belgium, Brazil, Canada, China, the Czech Republic, Denmark, Finland, France, Germany, Greece, India, Indonesia, Ireland, Italy, Japan, Korea, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Russia, Saudi Arabia, South Africa, Spain, Sweden, Switzerland, Thailand, Turkey, the United Kingdom, and the United States. Where available, this data was obtained from the GDS and WEO databases compiled by the International Monetary Fund. Otherwise, it was extracted from the IFS database produced by the International Monetary Fund.

The macroeconomic variables under consideration are the price of output, the price of consumption, the quantity of output, the quantity of domestic demand, the quantity of public domestic demand, the ratio of the fiscal balance to nominal output, the ratio of the trade balance to nominal output, 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, and the quantity of public domestic demand is measured by the sum of quadratically interpolated annual real consumption and investment expenditures of the general government. The fiscal balance is measured by the quadratically interpolated annual overall fiscal balance of the general government, while the trade balance is measured by the quadratically interpolated annual trade balance for goods and services. 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 nominal policy interest rate, the short term nominal market interest rate, the long term nominal market interest rate, the price of equity, and the nominal bilateral exchange rate. The nominal policy interest rate is measured by the central bank discount rate, while the short term nominal market interest rate is measured by a three month money market rate, and the long term nominal market interest rate is measured by the ten year government bond yield. The price of equity is proxied by a broad stock price index denominated in domestic currency units, while the nominal bilateral exchange rate is measured by the domestic currency price of one United States dollar. All of these financial market variables are expressed as a period average.

Calibration is based on annual data obtained from databases compiled by the International Monetary Fund where available, and from the Bank for International Settlements or the World Bank Group otherwise. Macroeconomic great ratios are derived from the WEO and WDI databases, while financial great ratios are also derived from the EWN, BIS and IFS databases.

Bilateral trade weights are derived from the DOTS database. Portfolio weights are derived from the CPIS, BIS, and WDI databases.

Appendix B. Tables and Figures

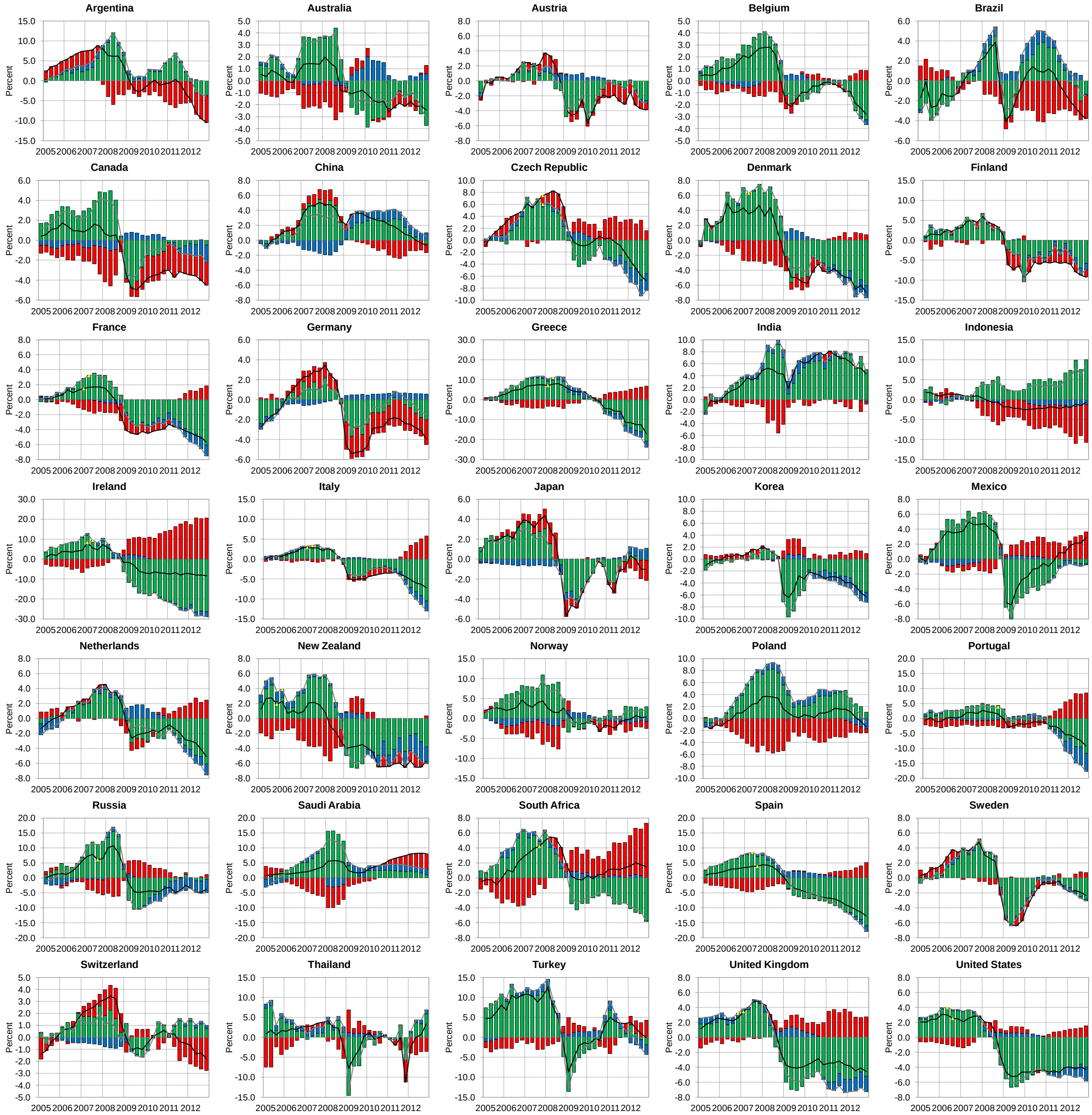
Table 1. Parameter Estimation Results

	Prior		Posterior Mode																																			
	Mean	SE	WLD	ARG	AUS	AUT	BEL	BRA	CAN	CHN	CZE	DNK	FIN	FRA	DEU	GRC	IND	IDN	IRL	ITA	JPN	KOR	MEX	NLD	NZL	NOR	POL	PRT	RUS	SAU	ZAF	ESP	SWE	CHE	THA	TUR	GBR	USA
α	0.9000	0.0900	0.9056	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
β	0.9756	0.0000	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
χ^B	0.5000	0.0500	0.5365	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
χ^S	0.5000	0.0500	0.5058	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
η	4.5000	0.4500	4.6184	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
γ^Y	1.0000	0.0000	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
γ^M	1.0000	0.0000	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
μ	0.2500	0.0250	0.2496	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
ω^Y	0.9167	0.0917	0.8815	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
ω^M	0.8333	0.0833	0.8849	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
ω_1^Y	0.3333	0.0333	0.3326	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
ω_2^Y	0.3333	0.0333	0.3432	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
ϕ^C	0.5000	0.0500	0.4987	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
ϕ_1^L	0.1000	0.0100	0.1081	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
ϕ_2^L	0.2000	0.0200	0.2094	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
ψ^M	1.5000	0.1500	1.5499	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
ρ^i	0.8500	0.0850	0.8053	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
ρ_G	0.8500	0.0850	0.8207	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
ρ_τ	0.8500	0.0850	0.8448	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
σ	3.5000	0.3500	3.6285	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
θ^Y	7.6667	0.0000	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
θ^M	7.6667	0.0000	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
ξ_0^π	1.5000	0.1500	...	...	1.4562	1.4562	1.4562	...	1.4562	...	1.4562	...	1.4562	1.4562	1.4562	1.4562	...	...	1.4562	1.4562	1.4562	...	...	1.4562	1.4562	1.4562	1.4562	1.4562	...	...	...	1.4562	1.4562	1.4562	...	...	1.4562	1.4562
ξ_1^π	1.5000	0.1500	...	1.4692	...	...	...	1.4692	...	1.4692	...	...	...	...	...	...	1.4692	1.4692	...	...	...	1.4692	1.4692	...	...	...	...	...	1.4692	...	1.4692	...	...	...	1.4692	1.4692	...	...
ξ_0^Y	0.1250	0.0125	...	...	0.1275	0.1275	0.1275	...	0.1275	...	0.1275	...	0.1275	0.1275	0.1275	0.1275	...	...	0.1275	0.1275	0.1275	...	...	0.1275	0.1275	0.1275	0.1275	0.1275	...	...	...	0.1275	0.1275	0.1275	...	...	0.1275	0.1275
ξ_1^Y	0.1250	0.0125	...	0.1170	...	...	...	0.1170	...	0.1170	...	...	...	...	...	...	0.1170	0.1170	...	...	...	0.1170	0.1170	...	...	...	...	...	0.1170	...	0.1170	...	...	...	0.1170	0.1170	...	...
ξ_1^Q	0.0625	0.0063	...	0.0646	...	...	...	0.0646	...	0.0646	...	...	...	...	...	...	0.0646	0.0646	...	...	...	0.0646	0.0646	...	...	...	...	...	0.0646	...	0.0646	...	...	...	0.0646	0.0646	...	...
ζ^G	2.5e–6	0.0000	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
ζ^τ	–2.5e–2	0.0000	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
λ_0^M	1.2719	0.1272	...	...	1.3066	1.3066	1.3066	...	1.3066	...	...	1.3066	1.3066	1.3066	1.3066	1.3066	...	...	1.3066	1.3066	1.3066	...	...	1.3066	1.3066	1.3066	...	1.3066	...	...	...	1.3066	1.3066	1.3066	...	...	1.3066	1.3066
λ_1^M	0.6359	0.0636	...	...	...	...	...	...	...	0.6230	...	...	...	...	...	...	0.6230	...	...	...	...	...	...	...	...	...	...	...	...	0.6230	...	...	...	...	...	...	...	...
λ_2^M	1.9078	0.1908	...	1.9476	...	...	...	1.9476	...	...	1.9476	...	...	...	...	...	...	1.9476	...	...	...	1.9476	1.9476	...	...	...	1.9476	...	1.9476	...	1.9476	...	...	...	1.9476	1.9476	...	...
λ_0^B	1.0801	0.1080	...	...	1.1243	1.1243	1.1243	...	1.1243	...	...	1.1243	1.1243	1.1243	1.1243	1.1243	...	...	1.1243	1.1243	1.1243	...	...	1.1243	1.1243	1.1243	...	1.1243	...	...	...	1.1243	1.1243	1.1243	...	...	1.1243	1.1243
λ_1^B	0.5401	0.0540	...	...	...	...	...	...	...	0.5454	...	...	...	...	...	...	0.5454	...	...	...	...	...	...	...	...	...	...	...	...	0.5454	...	...	...	...	...	...	...	...
λ_2^B	1.6202	0.1620	...	1.6643	...	...	...	1.6643	...	...	1.6643	...	...	...	...	...	...	1.6643	...	...	...	1.6643	1.6643	...	...	...	1.6643	...	1.6643	...	1.6643	...	...	...	1.6643	1.6643	...	...
λ_0^S	1.4447	0.1445	...	...	1.4506	1.4506	1.4506	...	1.4506	...	...	1.4506	1.4506	1.4506	1.4506	1.4506	...	...	1.4506	1.4506	1.4506	...	...	1.4506	1.4506	1.4506	...	1.4506	...	...	...	1.4506	1.4506	1.4506	...	...	1.4506	1.4506
λ_1^S	0.7223	0.0722	...	...	...	...	...	...	...	0.7227	...	...	...	...	...	...	0.7227	...	...	...	...	...	...	...	...	...	...	...	...	0.7227	...	...	...	...	...	...	...	...
λ_2^S	2.1670	0.2167	...	2.1987	...	...	...	2.1987	...	...	2.1987	...	...	...	...	...	...	2.1987	...	...	...	2.1987	2.1987	...	...	...	2.1987	...	2.1987	...	2.1987	...	...	...	2.1987	2.1987	...	...
$\rho_{\mathcal{A}}$	0.7500	0.0750	0.8470	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
ρ_{ν^C}	0.7500	0.0750	0.7323	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
ρ_{ν^X}	0.7500	0.0750	0.7224	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
ρ_{ν^M}	0.7500	0.0750	0.7734	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
$\rho_{\nu^{i,S}}$	0.7500	0.0750	0.7358	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
ρ_{ν^B}	0.7500	0.0750	0.7745	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
ρ_{ν^S}	0.7500	0.0750	0.7376	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
$\rho_{\nu^\mathcal{E}}$	0.7500	0.0750	0.7921	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
$\sigma^2_{\theta^Y{}_i}$	...	∞	...	4.6e+5	3.4e+5	3.3e+5	3.3e+5	4.0e+5	3.3e+5	3.7e+5	3.6e+5	3.4e+5	3.2e+5	3.5e+5	3.9e+5	3.2e+5	3.2e+5	3.8e+5	3.5e+5	3.5e+5	3.5e+5	3.6e+5	3.6e+5	3.4e+5	3.6e+5	3.9e+5	3.5e+5	3.3e+5	4.2e+5	4.3e+5	4.0e+5	3.5e+5	3.4e+5	3.2e+5	3.5e+5	4.2e+5	3.5e+5	4.8e+5
$\sigma^2_{\theta^M{}_i}$	...	∞	...	8.5e+4	7.0e+4	7.3e+4	7.3e+4	7.9e+4	7.2e+4	6.6e+4	7.6e+4	6.3e+4	7.4e+4	7.2e+4	7.6e+4	7.3e+4	7.1e+4	7.4e+4	7.7e+4	7.3e+4	7.5e+4	7.5e+4	7.0e+4	7.6e+4	7.0e+4	7.6e+4	7.4e+4	7.1e+4	7.8e+4	7.8e+4	7.8e+4	7.2e+4	7.2e+4	6.4e+4	7.2e+4	8.2e+4	6.5e+4	9.5e+4
$\sigma^2_{\mathcal{A},i}$	...	∞	...	1.7e+1	1.5e+1	1.7e+1	1.4e+1	1.7e+1	1.5e+1	1.6e+1	1.8e+1	1.8e+1	2.0e+1	1.5e+1	1.6e+1	1.8e+1	1.8e+1	1.9e+1	1.9e+1	1.4e+1	1.4e+1	1.7e+1	1.7e+1	1.6e+1	1.8e+1	1.9e+1	1.6e+1	1.7e+1	1.9e+1	1.7e+1	1.6e+1	1.5e+1	1.7e+1	1.5e+1	2.2e+1	2.0e+1	1.5e+1	1.5e+1
$\sigma^2_{\nu^C{}_i}$	...	∞	...	9.5e+1	7.7e+1	8.7e+1	7.6e+1	8.5e+1	7.5e+1	8.1e+1	8.9e+1	8.7e+1	9.9e+1	8.5e+1	8.8e+1	8.6e+1	9.2e+1	9.8e+1	9.3e+1	8.2e+1	7.7e+1	8.2e+1	8.0e+1	8.2e+1	8.8e+1	9.2e+1	8.4e+1	8.1e+1	9.0e+1	9.2e+1	8.5e+1	7.9e+1	8.2e+1	8.1e+1	1.1e+2	9.7e+1	7.5e+1	7.8e+1
$\sigma^2_{\nu^X{}_i}$	...	∞	...	9.4e–1	8.4e–1	7.7e–1	6.9e–1	7.9e–1	9.2e–1	7.6e–1	7.4e–1	7.8e–1	8.2e–1	6.9e–1	7.0e–1	9.5e–1	8.3e–1	9.4e–1	8.1e–1	7.3e–1	8.0e–1	8.1e–1	8.9e–1	6.6e–1	8.6e–1	9.0e–1	7.9e–1	8.0e–1	9.3e–1	1.0e+0	8.2e–1	7.1e–1	7.1e–1	7.1e–1	9.3e–1	9.8e–1	7.1e–1	6.7e–1
$\sigma^2_{\nu^M{}_i}$	...	∞	...	3.8e+0	3.2e+0	2.6e+0	2.4e+0	3.6e+0	2.7e+0	2.9e+0	2.6e+0	2.5e+0	2.9e+0	3.2e+0	3.0e+0	2.9e+0	3.2e+0	3.4e+0	2.6e+0	3.1e+0	3.2e+0	2.6e+0	2.9e+0	2.4e+0	3.0e+0	3.3e+0	2.7e+0	2.7e+0	3.6e+0	3.5e+0	3.1e+0	2.9e+0	2.6e+0	2.5e+0	2.7e+0	3.4e+0	2.5e+0	3.7e+0
$\sigma^2_{\nu^{i,P}{}_i}$	...	∞	...	1.9e+0	1.5e+0	...	...	1.6e+0	1.5e+0	1.7e+0	1.7e+0	1.8e+0	...	...	1.8e+0	...	1.6e+0	1.6e+0	...	...	1.6e+0	1.6e+0	1.6e+0	...	1.5e+0	1.7e+0	1.6e+0	...	1.7e+0	2.0e+0	1.6e+0	...	1.6e+0	1.5e+0	1.6e+0	1.7e+0	1.5e+0	1.7e+0
$\sigma^2_{\nu^{i,S}{}_i}$	...	∞	...	1.2e–1	9.1e–2	9.7e–2	9.1e–2	9.8e–2	9.1e–2	7.0e–2	9.8e–2	1.1e–1	9.9e–2	8.5e–2	9.0e–2	9.8e–2	8.1e–2	9.8e–2	1.0e–1	8.9e–2	8.7e–2	9.8e–2	9.8e–2	8.9e–2	9.1e–2	9.6e–2	9.8e–2	9.2e–2	1.0e–1	1.1e–1	9.8e–2	9.3e–2	9.1e–2	8.9e–2	9.8e–2	1.1e–1	9.0e–2	1.2e–1

	Prior		Posterior Mode																																			
	Mean	SE	WLD	ARG	AUS	AUT	BEL	BRA	CAN	CHN	CZE	DNK	FIN	FRA	DEU	GRC	IND	IDN	IRL	ITA	JPN	KOR	MEX	NLD	NZL	NOR	POL	PRT	RUS	SAU	ZAF	ESP	SWE	CHE	THA	TUR	GBR	USA
$\sigma^2_{\nu^B\ i}$	…	∞	…	2.6e–2	1.9e–2	1.9e–2	1.9e–2	2.4e–2	2.0e–2	2.7e–2	2.2e–2	1.9e–2	2.0e–2	2.2e–2	2.3e–2	2.4e–2	2.5e–2	2.5e–2	1.8e–2	2.1e–2	2.2e–2	2.4e–2	2.2e–2	2.1e–2	2.1e–2	1.8e–2	2.2e–2	2.0e–2	2.5e–2	2.5e–2	2.5e–2	2.1e–2	2.1e–2	2.1e–2	2.5e–2	2.6e–2	2.1e–2	2.7e–2
$\sigma^2_{\nu^S\ i}$	…	∞	…	1.7e+0	1.4e+0	1.6e+0	1.5e+0	1.6e+0	1.5e+0	1.8e+0	1.6e+0	1.5e+0	1.7e+0	1.4e+0	1.5e+0	1.7e+0	1.7e+0	1.6e+0	1.6e+0	1.5e+0	1.6e+0	1.6e+0	1.5e+0	1.4e+0	1.4e+0	1.6e+0	1.5e+0	1.5e+0	1.7e+0	1.8e+0	1.7e+0	1.5e+0	1.6e+0	1.4e+0	1.6e+0	1.8e+0	1.4e+0	1.4e+0
$\sigma^2_{\nu^\varepsilon\ i}$	…	∞	…	7.5e+0	7.0e+0	…	…	7.2e+0	6.9e+0	7.0e+0	7.3e+0	7.2e+0	…	…	7.2e+0	…	7.1e+0	7.2e+0	…	…	7.0e+0	7.0e+0	6.9e+0	…	7.0e+0	7.2e+0	7.2e+0	…	7.1e+0	7.3e+0	7.1e+0	…	7.0e+0	7.0e+0	6.9e+0	7.3e+0	7.0e+0	6.8e+0
$\sigma^2_{\nu^G\ i}$	…	∞	…	8.3e–2	7.0e–2	6.4e–2	6.0e–2	7.6e–2	6.8e–2	7.6e–2	8.1e–2	6.9e–2	6.5e–2	5.6e–2	5.6e–2	7.8e–2	7.1e–2	7.6e–2	7.0e–2	6.5e–2	6.1e–2	6.8e–2	6.8e–2	7.0e–2	7.5e–2	8.1e–2	6.9e–2	7.7e–2	8.4e–2	8.7e–2	6.9e–2	6.6e–2	6.4e–2	5.5e–2	6.9e–2	8.1e–2	6.5e–2	6.2e–2
$\sigma^2_{\nu^T\ i}$	…	∞	…	4.6e–1	3.8e–1	3.9e–1	3.8e–1	4.1e–1	4.2e–1	4.6e–1	4.2e–1	4.0e–1	3.8e–1	3.9e–1	4.1e–1	4.0e–1	3.8e–1	4.1e–1	4.7e–1	3.7e–1	4.2e–1	3.9e–1	4.3e–1	3.9e–1	4.0e–1	4.4e–1	3.8e–1	3.8e–1	4.7e–1	4.3e–1	4.1e–1	3.3e–1	3.8e–1	3.6e–1	4.2e–1	4.2e–1	3.8e–1	4.5e–1
$\sigma^2_{\theta^Y\ 1}$	…	∞	3.1e+4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
$\sigma^2_{\theta^Y\ 2}$	…	∞	8.7e+3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
$\sigma^2_{\bar{p}^Y\ i}$	…	∞	…	1.2e–4	4.0e–5	4.0e–6	2.1e–6	1.8e–4	1.7e–5	1.0e–4	2.4e–5	3.0e–6	3.4e–5	1.7e–5	4.4e–7	5.1e–5	2.5e–4	3.7e–4	8.6e–4	1.1e–5	2.6e–6	2.0e–5	2.3e–5	9.2e–5	1.8e–5	1.2e–4	1.2e–5	1.1e–4	3.2e–4	5.6e–4	1.8e–5	2.7e–4	1.2e–5	2.0e–5	1.5e–4	1.4e–2	9.5e–6	4.2e–5
$\sigma^2_{\bar{p}^C\ i}$	…	∞	…	1.3e–4	3.7e–6	1.8e–6	2.5e–6	4.2e–4	4.5e–6	1.5e–4	1.4e–5	6.8e–6	3.8e–5	1.8e–6	2.2e–6	1.9e–6	7.1e–4	1.6e–4	2.1e–4	2.7e–6	9.8e–6	1.4e–6	3.2e–5	8.5e–5	4.9e–6	8.8e–6	1.0e–4	3.4e–5	7.2e–4	5.1e–4	1.3e–4	3.7e–5	4.4e–6	6.8e–6	4.8e–5	1.7e–2	6.6e–5	1.1e–5
$\sigma^2_{\bar{y}\ i}$	…	∞	…	2.5e–3	1.1e–5	3.5e–5	2.4e–5	5.2e–5	3.9e–5	1.3e–4	6.6e–4	8.2e–5	1.5e–4	8.6e–5	1.3e–5	1.6e–3	2.6e–4	3.9e–5	1.1e–3	1.6e–4	4.4e–5	2.8e–5	4.7e–5	5.3e–5	2.2e–4	4.5e–5	9.0e–5	2.7e–5	7.0e–4	2.1e–4	1.7e–4	4.5e–4	5.8e–5	3.5e–5	1.1e–4	2.4e–4	2.9e–4	1.5e–4
$\sigma^2_{\bar{D}\ i}$	…	∞	…	4.3e–3	5.1e–5	1.7e–5	3.9e–5	1.9e–4	4.1e–5	8.2e–5	6.0e–4	4.8e–4	1.1e–4	1.1e–4	1.8e–5	2.1e–3	4.5e–4	7.4e–6	3.3e–3	2.0e–4	3.2e–5	6.0e–5	7.2e–5	6.4e–5	5.6e–4	2.0e–4	3.8e–4	3.7e–4	3.3e–4	7.2e–4	1.9e–4	1.2e–3	2.4e–5	2.6e–6	2.3e–4	5.2e–4	4.2e–4	2.7e–4
$\sigma^2_{\bar{i}^P\ i}$	…	∞	…	6.8e–5	4.2e–7	...	...	2.2e–6	6.6e–7	1.6e–7	8.3e–7	6.6e–7	...	...	4.4e–7	...	6.0e–7	2.6e–6	...	...	2.3e–8	1.7e–7	1.9e–5	...	1.9e–6	1.0e–6	4.8e–6	...	3.3e–5	1.9e–6	1.8e–6	...	2.0e–7	4.5e–7	5.5e–7	7.3e–5	1.1e–6	2.3e–6
$\sigma^2_{\bar{i}^S\ i}$	…	∞	…	4.0e–5	5.0e–7	6.7e–7	4.2e–7	2.2e–6	5.7e–7	5.1e–9	1.2e–6	1.1e–6	6.3e–7	4.2e–7	5.6e–7	4.3e–6	9.3e–7	2.9e–6	6.8e–7	1.4e–7	5.4e–8	4.9e–7	2.1e–5	5.0e–7	2.1e–6	1.4e–6	1.2e–5	1.9e–7	5.4e–5	2.4e–6	1.4e–6	2.4e–7	1.9e–7	5.7e–7	4.7e–7	1.0e–4	1.4e–6	1.9e–6
$\sigma^2_{\bar{i}^L\ i}$	…	∞	…	7.4e–6	2.3e–7	1.5e–7	1.3e–7	7.6e–6	2.2e–8	6.2e–8	1.1e–6	1.9e–7	1.6e–7	9.0e–8	1.2e–7	2.6e–5	4.3e–6	4.0e–6	1.1e–6	2.3e–7	8.4e–8	2.0e–6	5.2e–6	1.4e–7	1.5e–7	1.9e–7	1.2e–6	2.4e–6	7.3e–5	2.3e–6	2.1e–6	3.5e–7	6.2e–8	1.3e–7	1.2e–7	1.1e–4	1.9e–7	2.5e–7
$\sigma^2_{\bar{v}^S\ i}$	…	∞	…	1.2e–2	3.6e–3	4.4e–2	7.7e–3	1.1e–2	2.6e–3	1.1e–2	1.9e–2	3.9e–3	6.6e–3	4.2e–3	6.2e–3	4.0e–2	1.7e–2	8.7e–3	1.2e–2	6.1e–3	7.8e–3	4.9e–3	7.5e–3	3.8e–3	3.9e–3	1.1e–2	1.1e–2	1.2e–2	1.2e–2	6.5e–2	1.1e–2	1.1e–2	4.9e–3	4.4e–3	3.7e–3	3.9e–3	2.3e–3	6.7e–4
$\sigma^2_{\bar{\varepsilon}\ i}$	…	∞	…	7.8e–3	6.2e–4	...	...	1.5e–2	5.7e–4	4.8e–4	1.8e–3	1.4e–3	...	...	1.5e–3	...	6.2e–4	1.4e–4	...	...	5.9e–4	1.1e–3	7.3e–5	...	1.4e–3	7.1e–4	2.2e–3	...	1.2e–3	2.1e–8	2.2e–3	...	9.6e–4	1.9e–4	6.0e–4	3.0e–2	1.4e–3	...
$\sigma^2_{\bar{G}\ i}$	…	∞	…	1.0e–2	1.5e–5	1.4e–4	4.5e–6	2.5e–4	5.5e–5	6.6e–5	3.2e–4	3.5e–5	7.0e–5	4.4e–5	1.2e–4	4.0e–3	1.6e–3	3.7e–4	2.1e–3	3.0e–4	1.6e–4	7.8e–5	8.7e–5	8.9e–5	2.7e–4	1.4e–4	3.5e–4	2.2e–4	6.0e–4	3.7e–4	4.3e–5	8.5e–4	2.1e–5	1.7e–4	5.0e–4	8.2e–4	5.8e–4	2.1e–4
$\sigma^2_{\overline{FB}\ i}$	…	∞	…	8.9e–6	4.3e–5	6.5e–6	1.0e–5	2.4e–6	2.2e–6	1.0e–5	4.3e–5	2.1e–4	2.8e–5	1.2e–5	2.3e–5	5.8e–5	3.0e–5	7.1e–6	5.3e–4	4.7e–6	1.1e–5	9.1e–6	1.4e–6	3.8e–5	2.1e–4	9.5e–5	2.3e–5	2.1e–5	2.0e–4	8.2e–4	2.6e–6	1.4e–4	3.1e–5	1.5e–5	5.8e–5	1.7e–4	2.0e–5	3.0e–6
$\sigma^2_{\overline{TB}\ i}$	…	∞	…	1.5e–5	1.3e–5	7.2e–6	3.2e–6	1.3e–4	8.7e–7	1.9e–4	2.0e–5	2.2e–5	8.0e–6	3.5e–6	1.5e–5	9.9e–5	9.1e–6	5.8e–6	5.3e–4	4.3e–6	3.4e–7	6.1e–6	1.4e–8	1.5e–5	3.4e–5	2.8e–5	3.8e–5	5.9e–5	1.8e–5	6.2e–4	2.6e–6	1.4e–4	5.3e–6	1.5e–5	1.3e–4	2.6e–5	3.1e–6	1.5e–6
$\sigma^2_{\bar{p}^Y}$	…	∞	2.6e–3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
$\sigma^2_{\bar{p}^Y}$	…	∞	1.2e–3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

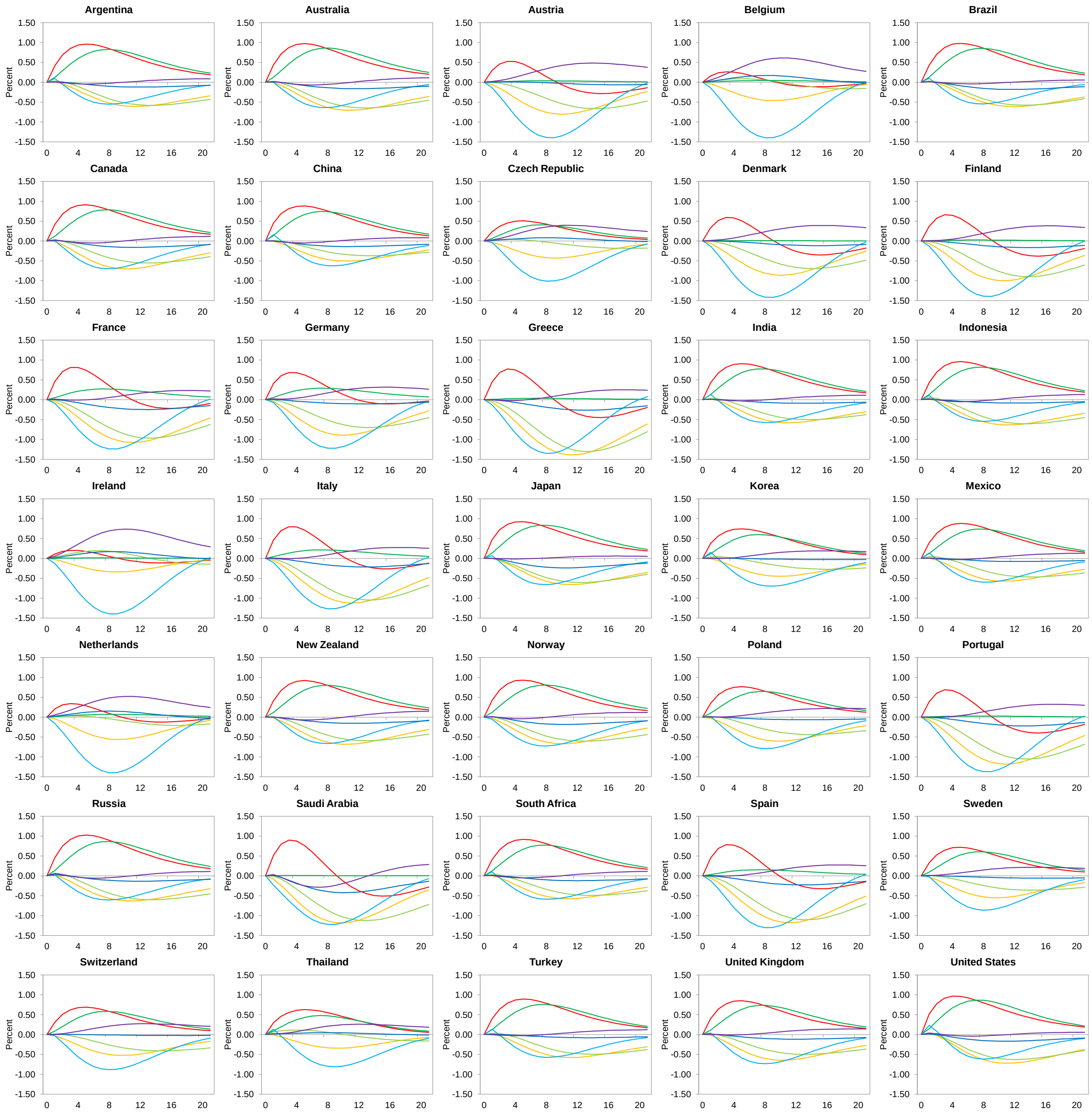
Note: All priors are normally distributed, while all posteriors are asymptotically normally distributed. All observed endogenous variables are rescaled by a factor of 100.

Figure 1. Output Gap Estimates



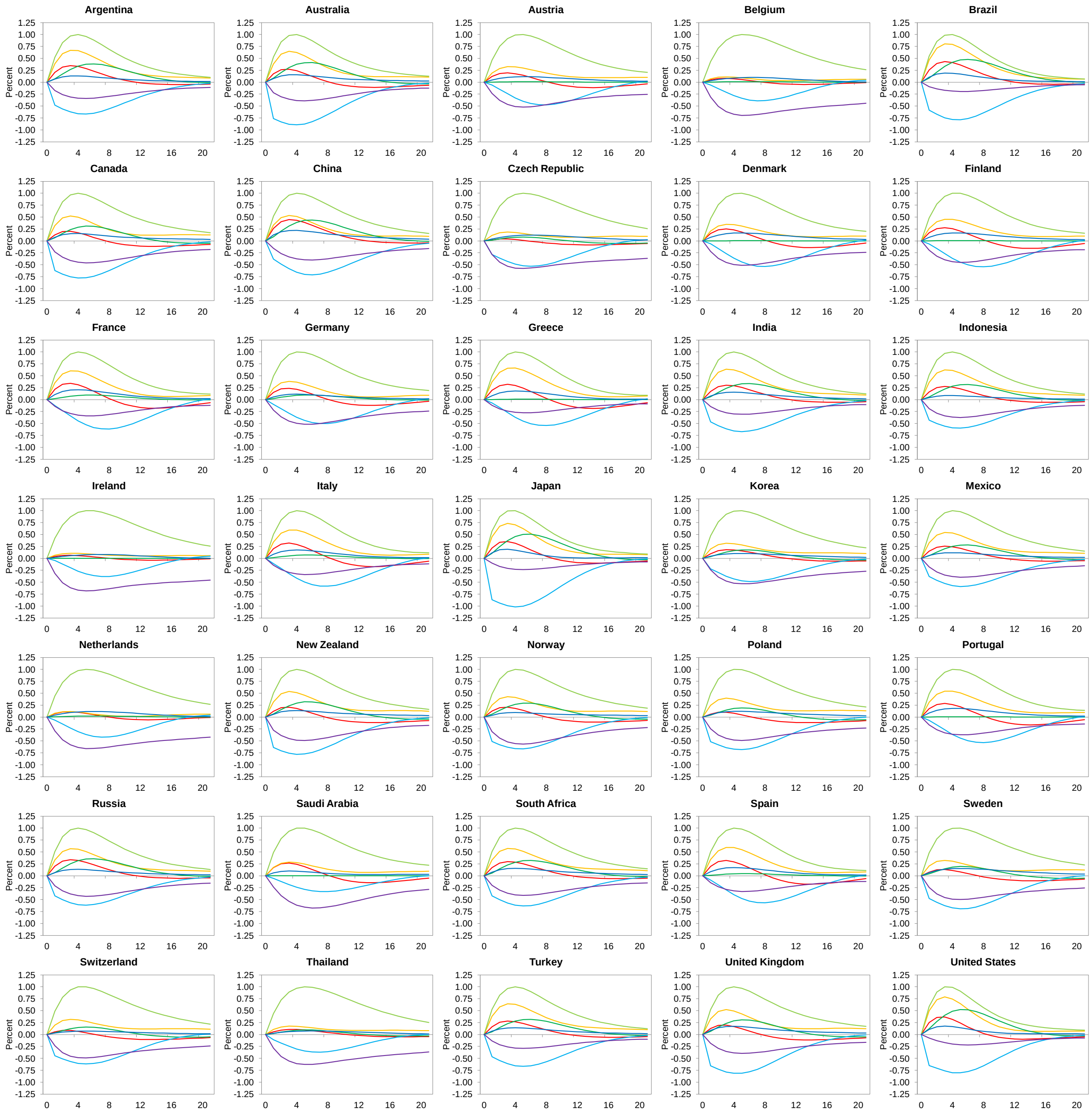
Note: Decomposes smoothed estimates of the output gap ■ into contributions from domestic demand ■ and net exports ■. Smoothed estimates of the contribution from domestic demand ■ are decomposed into contributions from private domestic demand ■ and public domestic demand ■. Structural breaks are indicated by ▲.

Figure 2. Impulse Responses to a Domestic Productivity Shock



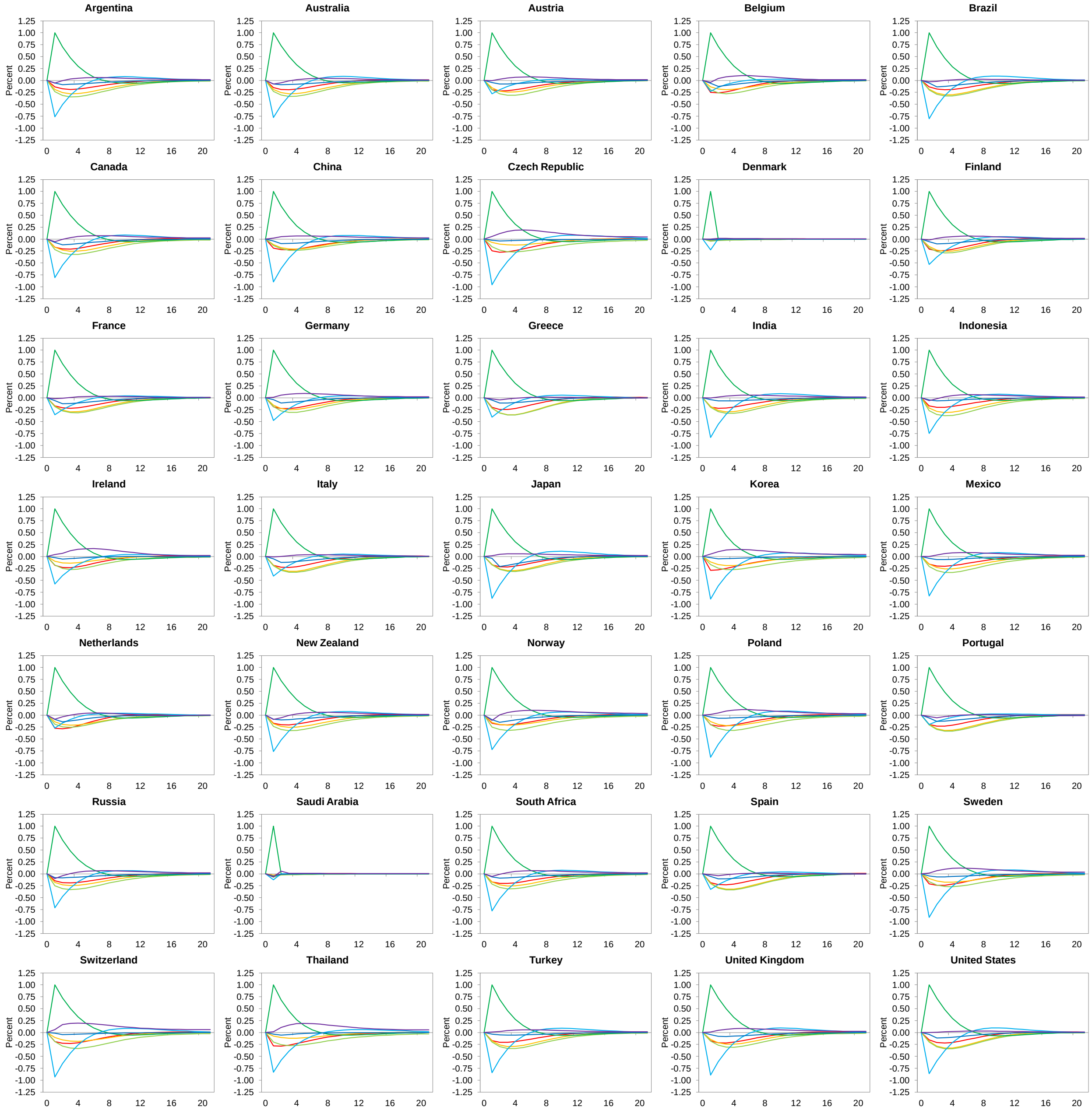
Note: Depicts the impulse responses of consumption price inflation ■, output ■, domestic demand ■, the nominal policy interest rate ■, the real effective exchange rate ■, the ratio of the fiscal balance to nominal output ■, and the ratio of the current account balance to nominal output ■ to domestic productivity shocks which raise output price inflation by one percentage point. Consumption price inflation and the nominal policy interest rate are expressed as annual percentage rates.

Figure 3. Impulse Responses to a Domestic Intertemporal Substitution Shock



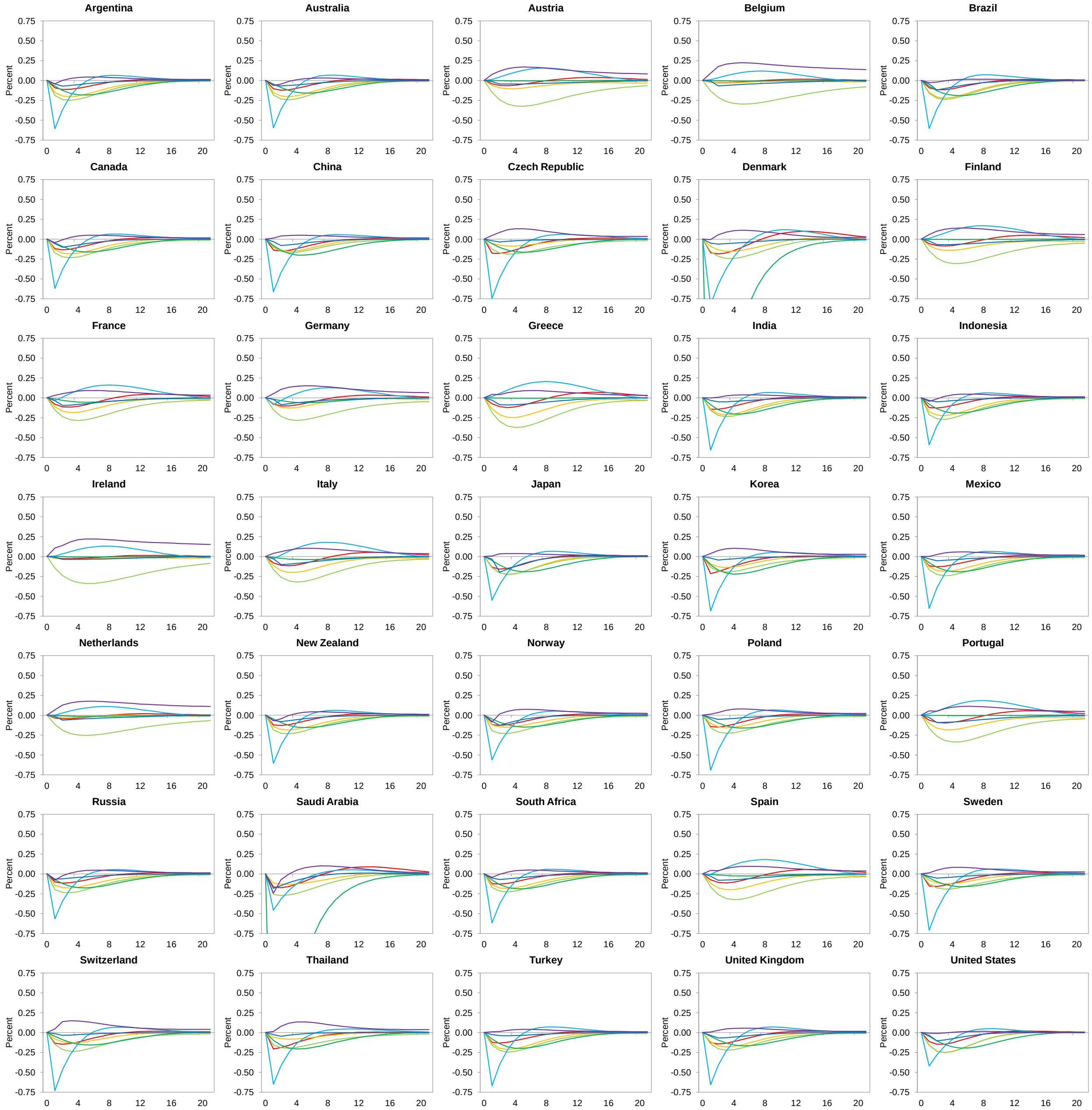
Note: Depicts the impulse responses of consumption price inflation ■, output ■, domestic demand ■, the nominal policy interest rate ■, the real effective exchange rate ■, the ratio of the fiscal balance to nominal output ■, and the ratio of the current account balance to nominal output ■ to domestic intertemporal substitution shocks which raise domestic demand by one percent. Consumption price inflation and the nominal policy interest rate are expressed as annual percentage rates.

Figure 4. Impulse Responses to a Domestic Monetary Policy Shock



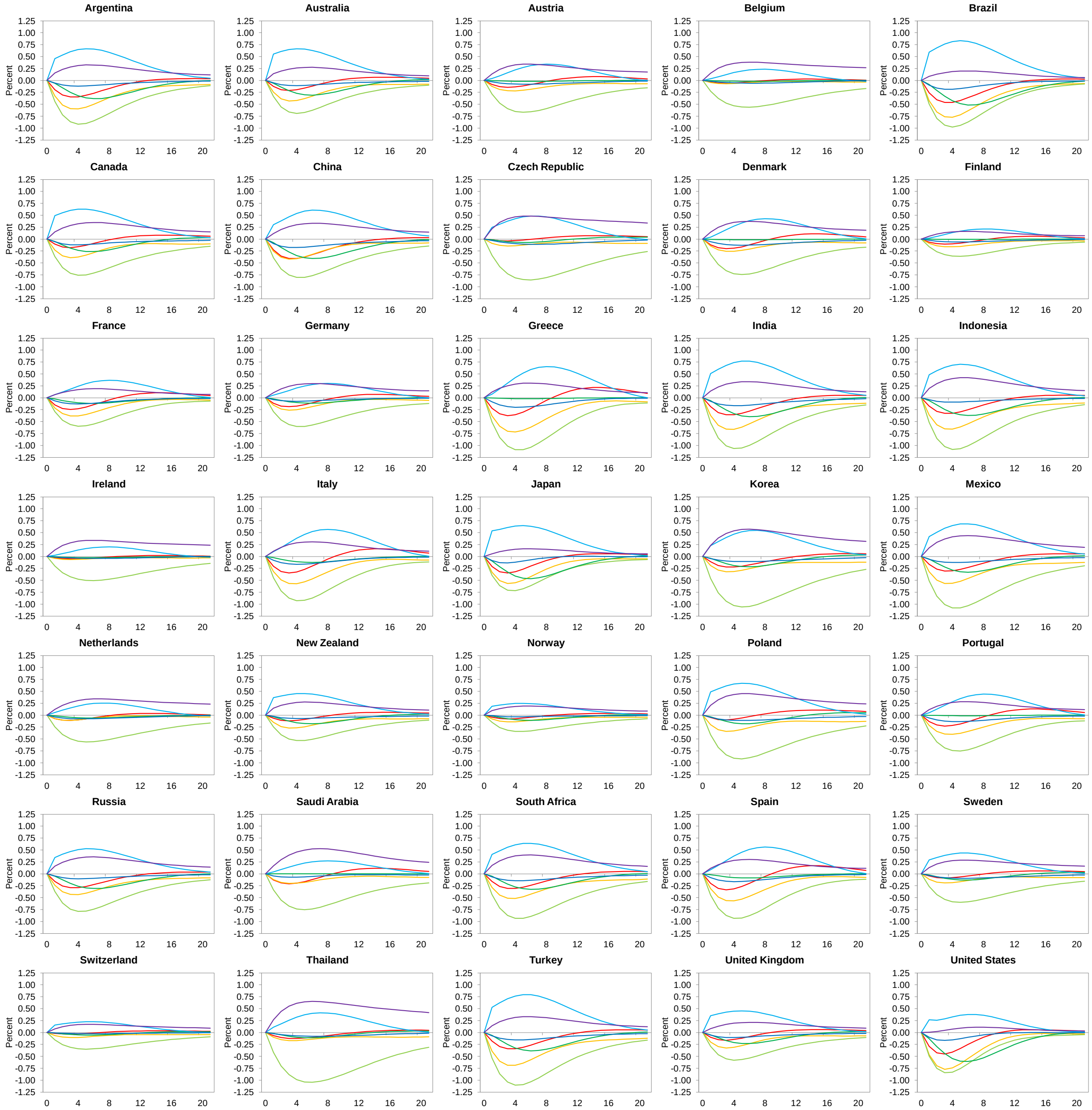
Note: Depicts the impulse responses of consumption price inflation ■, output ■, domestic demand ■, the nominal policy interest rate ■, the real effective exchange rate ■, the ratio of the fiscal balance to nominal output ■, and the ratio of the current account balance to nominal output ■ to domestic monetary policy shocks which raise the nominal policy interest rate by one percentage point. Consumption price inflation and the nominal policy interest rate are expressed as annual percentage rates.

Figure 5. Impulse Responses to a Domestic Credit Risk Premium Shock



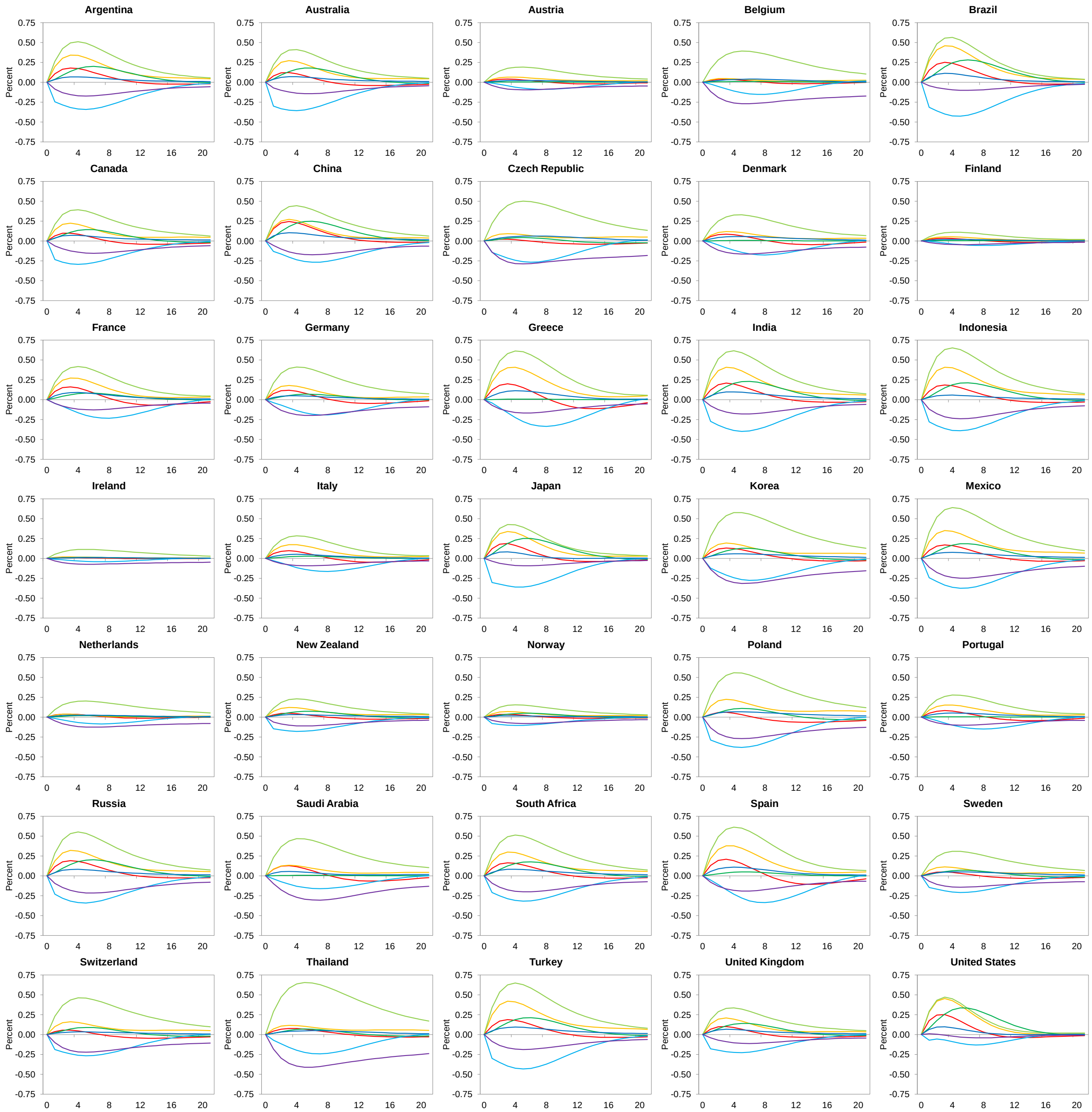
Note: Depicts the impulse responses of consumption price inflation ■, output ■, domestic demand ■, the nominal policy interest rate ■, the real effective exchange rate ■, the ratio of the fiscal balance to nominal output ■, and the ratio of the current account balance to nominal output ■ to domestic credit risk premium shocks which raise the short term nominal market interest rate by one percentage point. Consumption price inflation and the nominal policy interest rate are expressed as annual percentage rates.

Figure 6. Impulse Responses to a Domestic Duration Risk Premium Shock



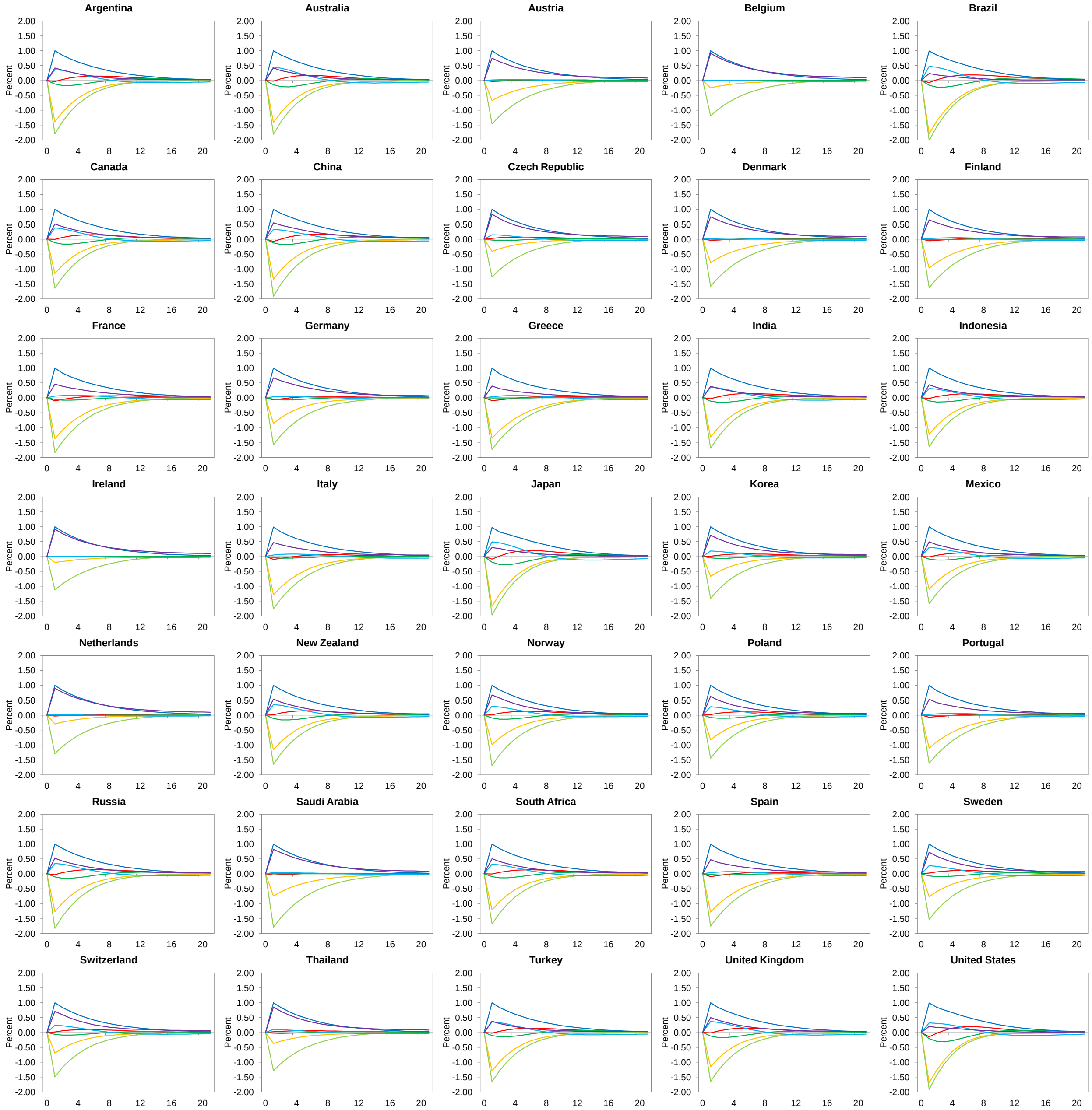
Note: Depicts the impulse responses of consumption price inflation ■, output ■, domestic demand ■, the nominal policy interest rate ■, the real effective exchange rate ■, the ratio of the fiscal balance to nominal output ■, and the ratio of the current account balance to nominal output ■ to domestic duration risk premium shocks which raise the long term nominal market interest rate by one percentage point. Consumption price inflation and the nominal policy interest rate are expressed as annual percentage rates.

Figure 7. Impulse Responses to a Domestic Equity Risk Premium Shock



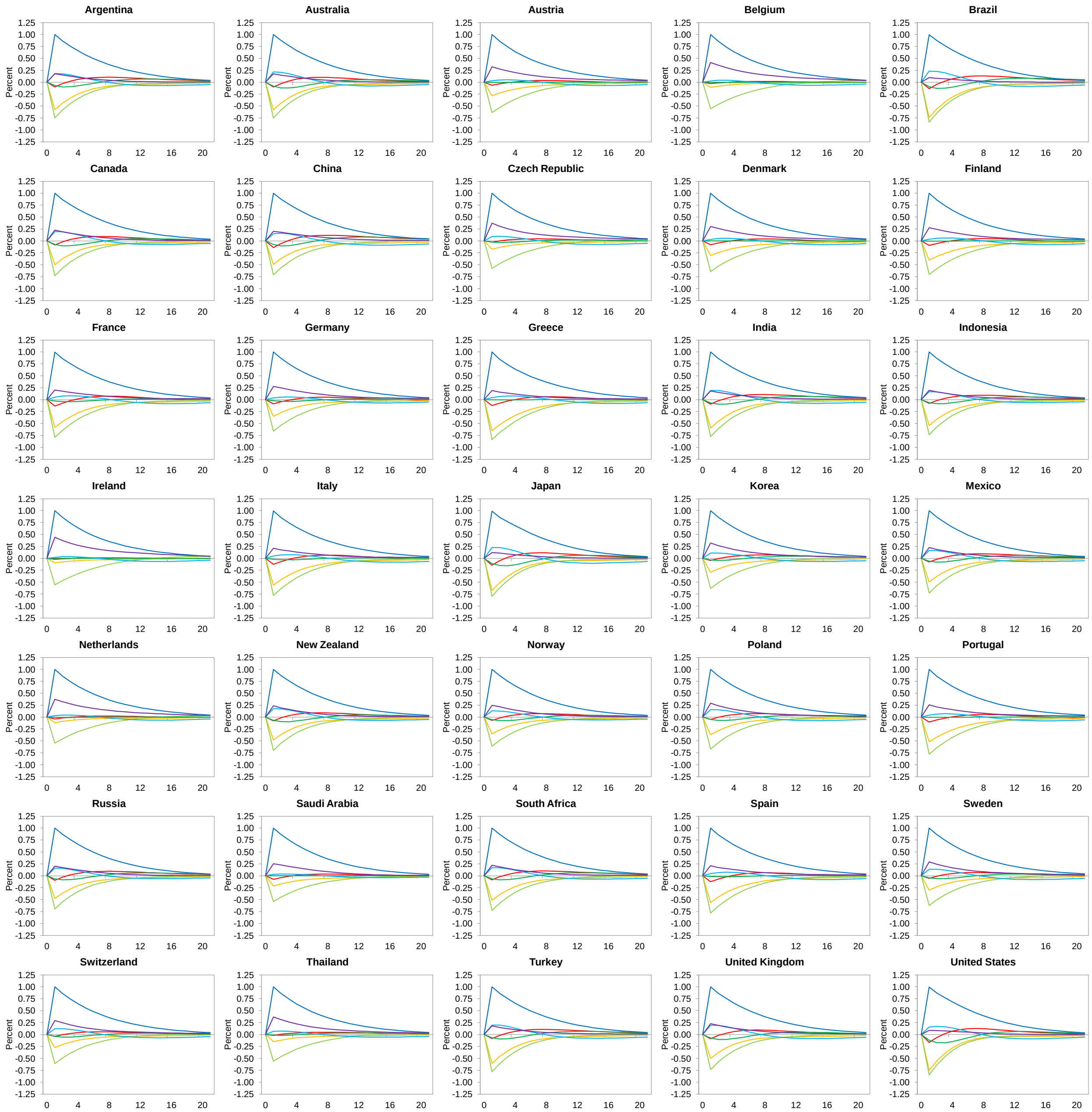
Note: Depicts the impulse responses of consumption price inflation ■, output ■, domestic demand ■, the nominal policy interest rate ■, the real effective exchange rate ■, the ratio of the fiscal balance to nominal output ■, and the ratio of the current account balance to nominal output ■ to domestic equity risk premium shocks which raise the price of equity by ten percent. Consumption price inflation and the nominal policy interest rate are expressed as annual percentage rates.

Figure 8. Impulse Responses to a Domestic Fiscal Expenditure Shock



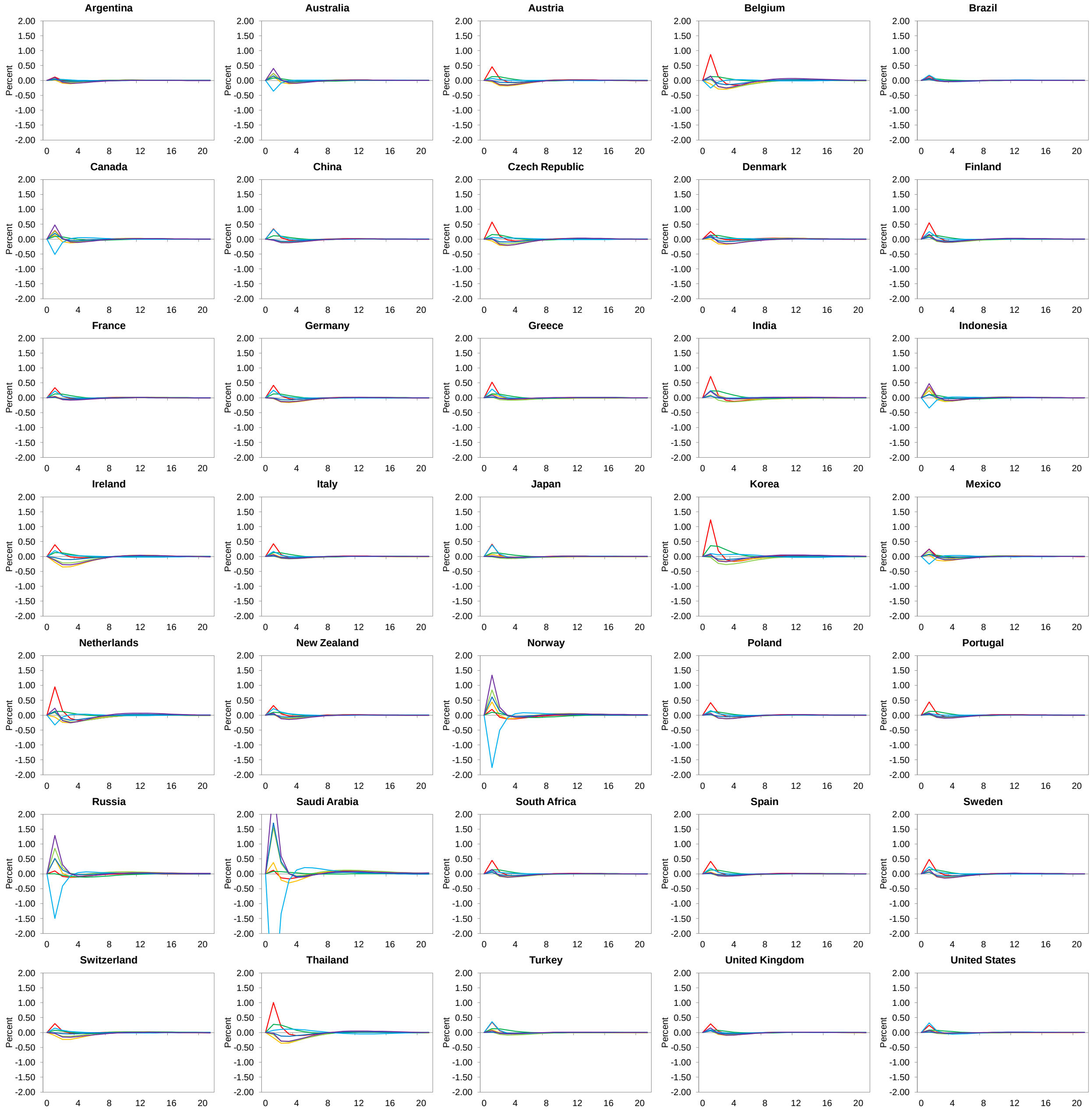
Note: Depicts the impulse responses of consumption price inflation ■, output ■, domestic demand ■, the nominal policy interest rate ■, the real effective exchange rate ■, the ratio of the fiscal balance to nominal output ■, and the ratio of the current account balance to nominal output ■ to domestic fiscal expenditure shocks which raise the ratio of the primary fiscal balance to nominal output by one percentage point. Consumption price inflation and the nominal policy interest rate are expressed as annual percentage rates.

Figure 9. Impulse Responses to a Domestic Fiscal Revenue Shock



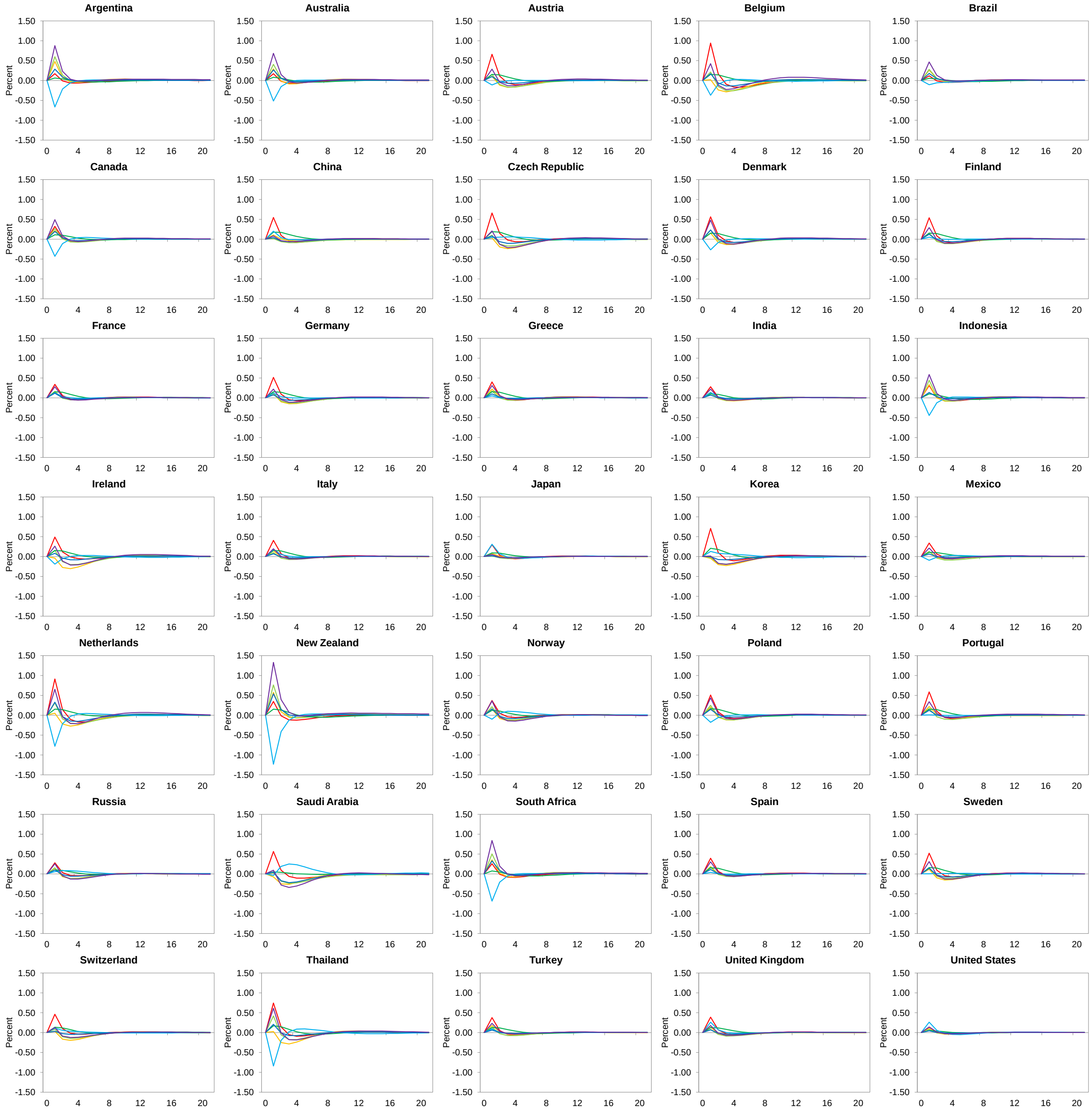
Note: Depicts the impulse responses of consumption price inflation ■, output ■, domestic demand ■, the nominal policy interest rate ■, the real effective exchange rate ■, the ratio of the fiscal balance to nominal output ■, and the ratio of the current account balance to nominal output ■ to domestic fiscal revenue shocks which raise the ratio of the primary fiscal balance to nominal output by one percentage point. Consumption price inflation and the nominal policy interest rate are expressed as annual percentage rates.

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



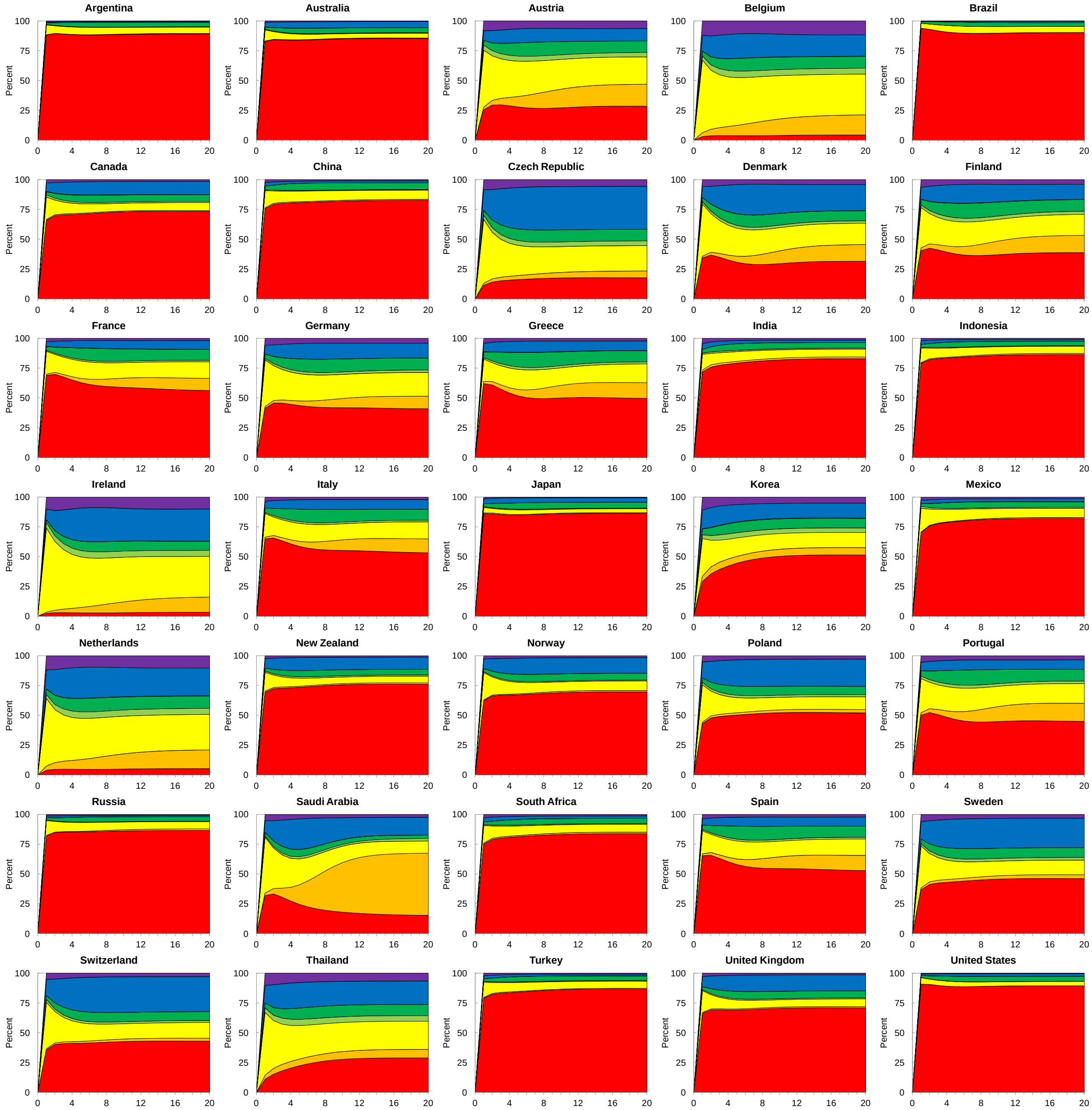
Note: Depicts the impulse responses of consumption price inflation ■, output ■, domestic demand ■, the nominal policy interest rate ■, the real effective exchange rate ■, the ratio of the fiscal balance to nominal output ■, and the ratio of the current account balance to nominal output ■ to a world energy commodity price markup shock which raises the price of energy commodities by ten percent. Consumption price inflation and the nominal policy interest rate are expressed as annual percentage rates.

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



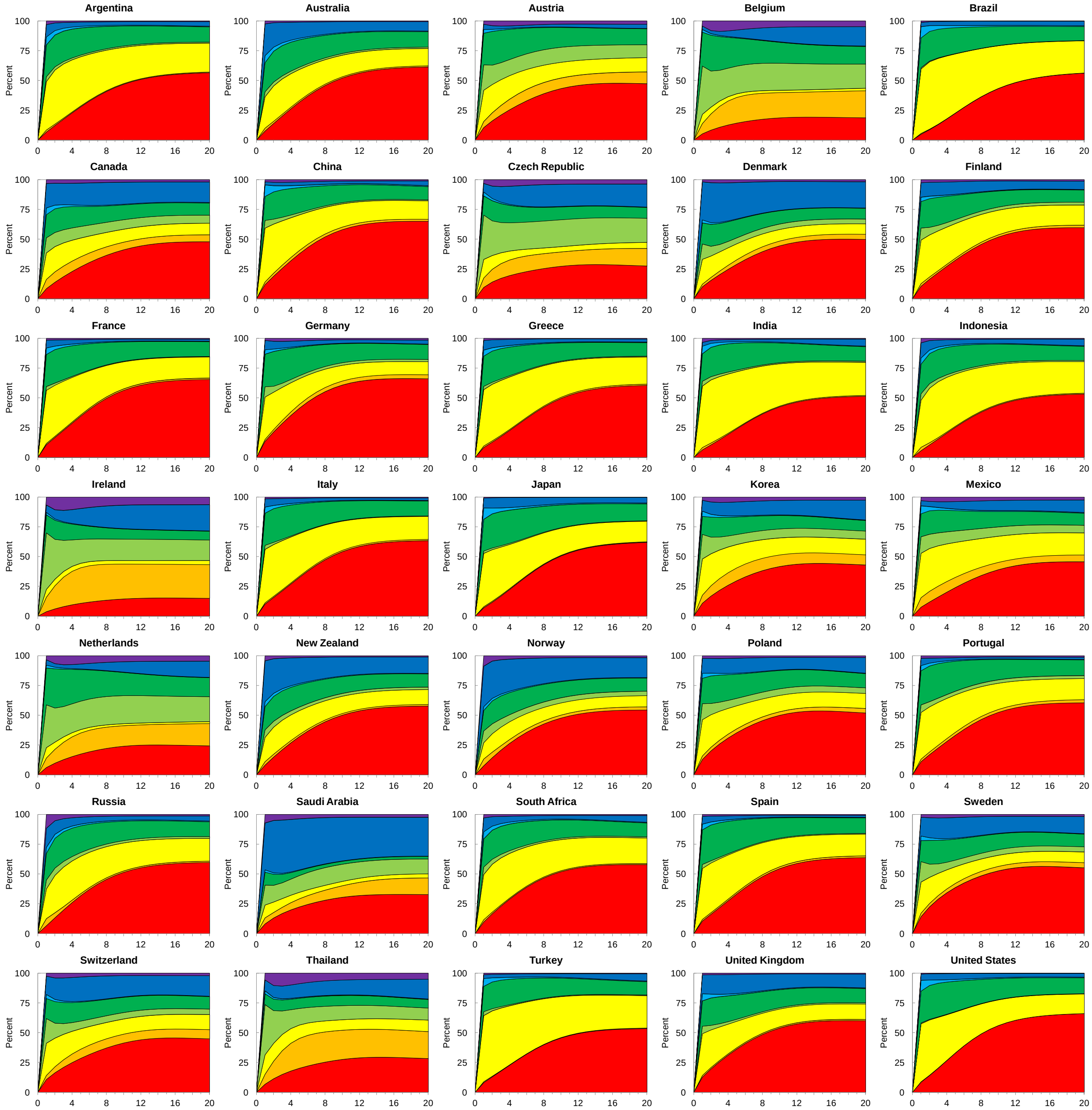
Note: Depicts the impulse responses of consumption price inflation ■, output ■, domestic demand ■, the nominal policy interest rate ■, the real effective exchange rate ■, the ratio of the fiscal balance to nominal output ■, and the ratio of the current account balance to nominal output ■ to a world nonenergy commodity price markup shock which raises the price of nonenergy commodities by ten percent. Consumption price inflation and the nominal policy interest rate are expressed as annual percentage rates.

Figure 12. Forecast Error Variance Decompositions of Consumption Price Inflation



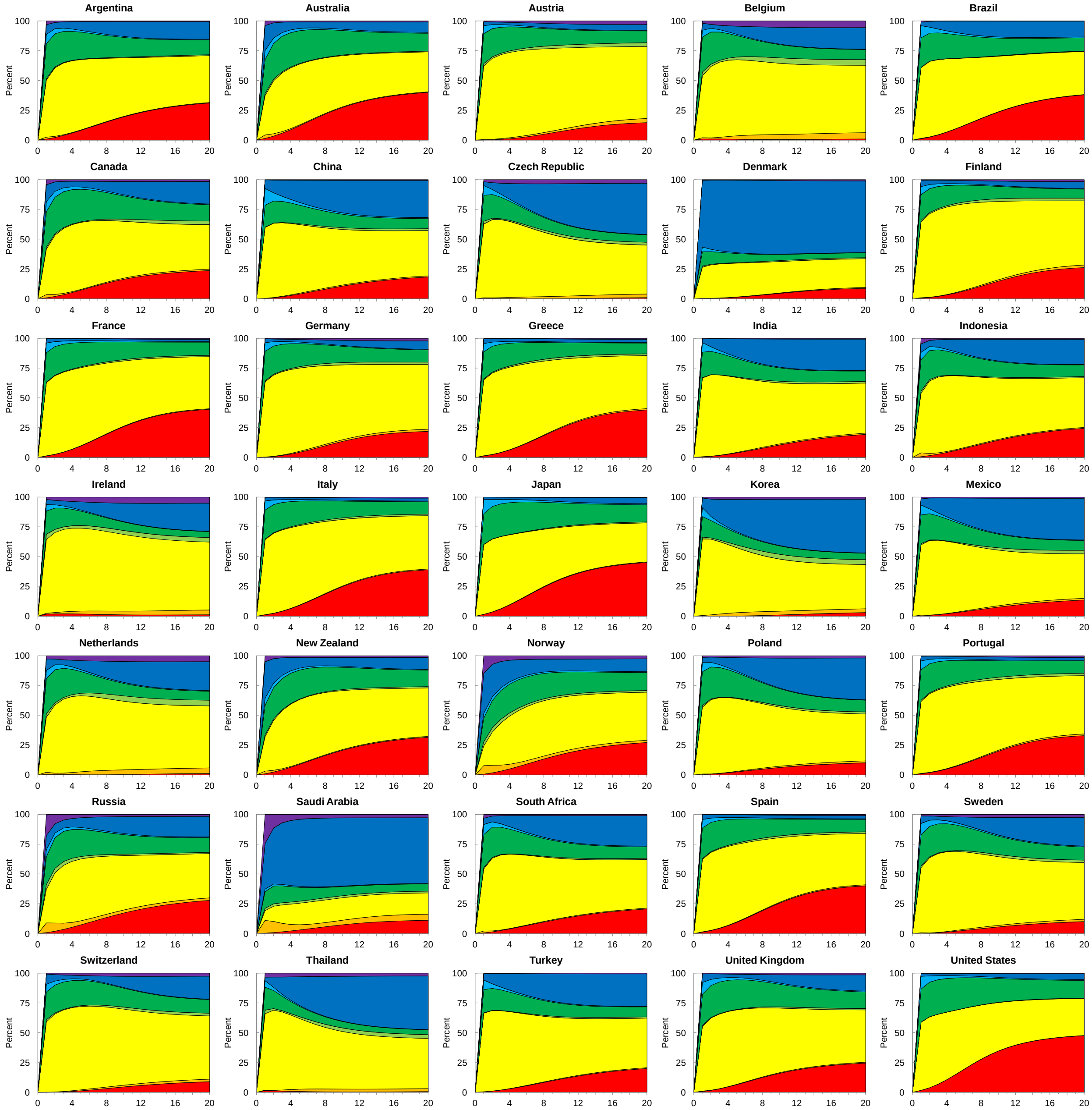
Note: Decomposes the horizon dependent forecast error variance of consumption price inflation into contributions from domestic supply ■, foreign supply ■, domestic demand ■, foreign demand ■, world monetary policy ■, world fiscal policy ■, world risk premium ■, and world terms of trade ■ shocks.

Figure 13. Forecast Error Variance Decompositions of Output



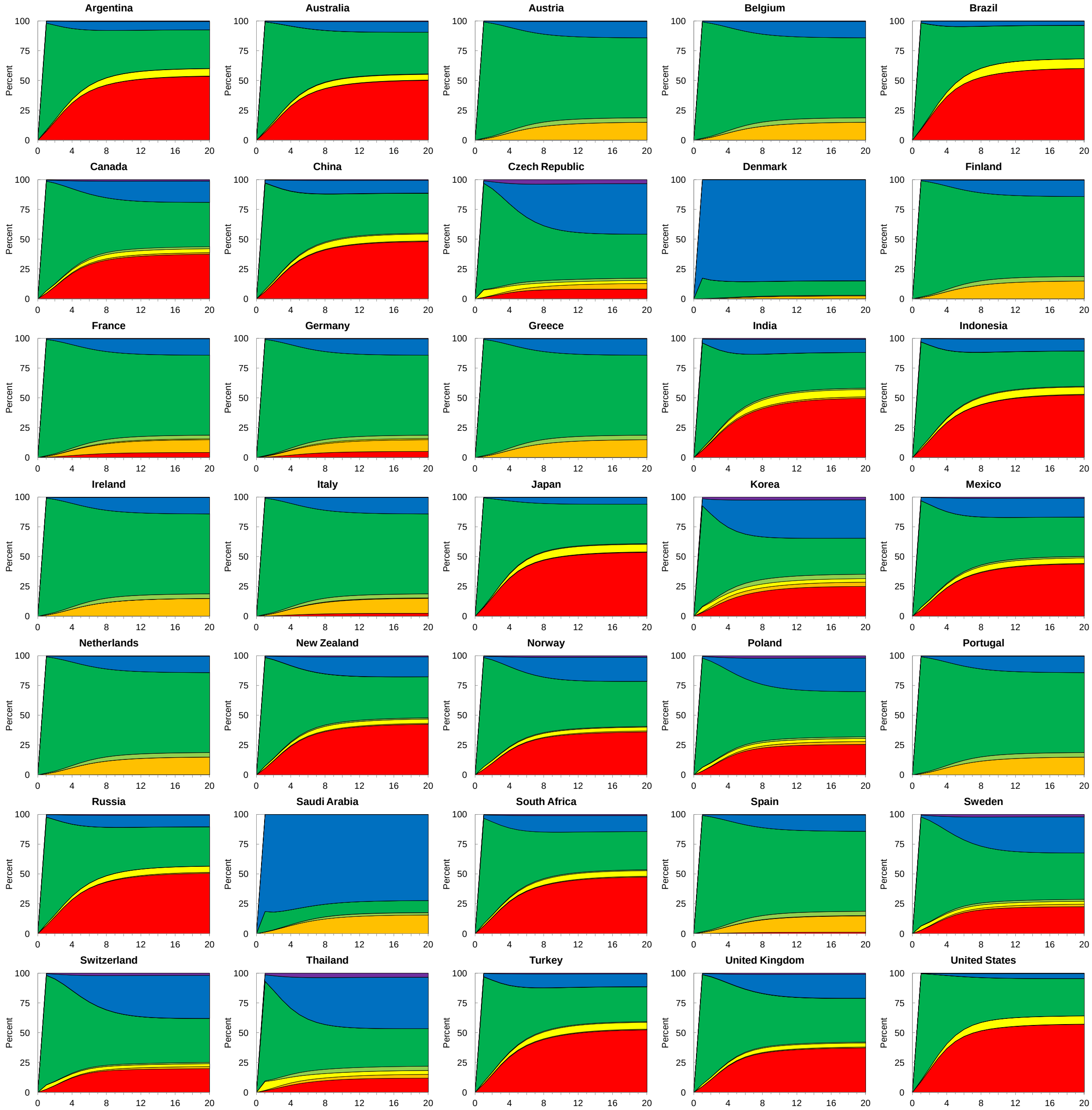
Note: Decomposes the horizon dependent forecast error variance of output into contributions from domestic supply ■, foreign supply ■, domestic demand ■, foreign demand ■, world monetary policy ■, world fiscal policy ■, world risk premium ■, and world terms of trade ■ shocks.

Figure 14. Forecast Error Variance Decompositions of Domestic Demand



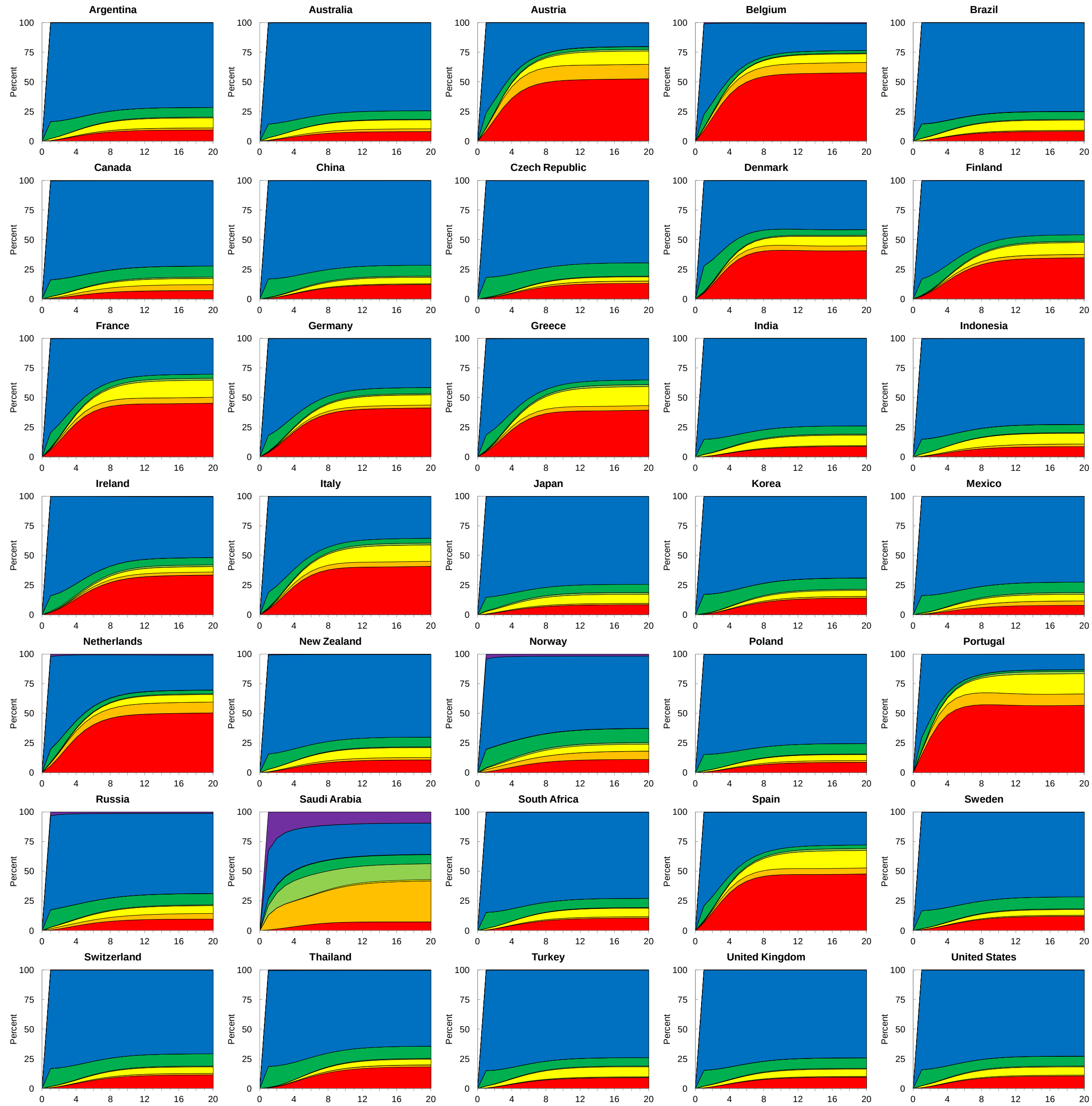
Note: Decomposes the horizon dependent forecast error variance of domestic demand into contributions from domestic supply ■, foreign supply ■, domestic demand ■, foreign demand ■, world monetary policy ■, world fiscal policy ■, world risk premium ■, and world terms of trade ■ shocks.

Figure 15. Forecast Error Variance Decompositions of the Nominal Policy Interest Rate



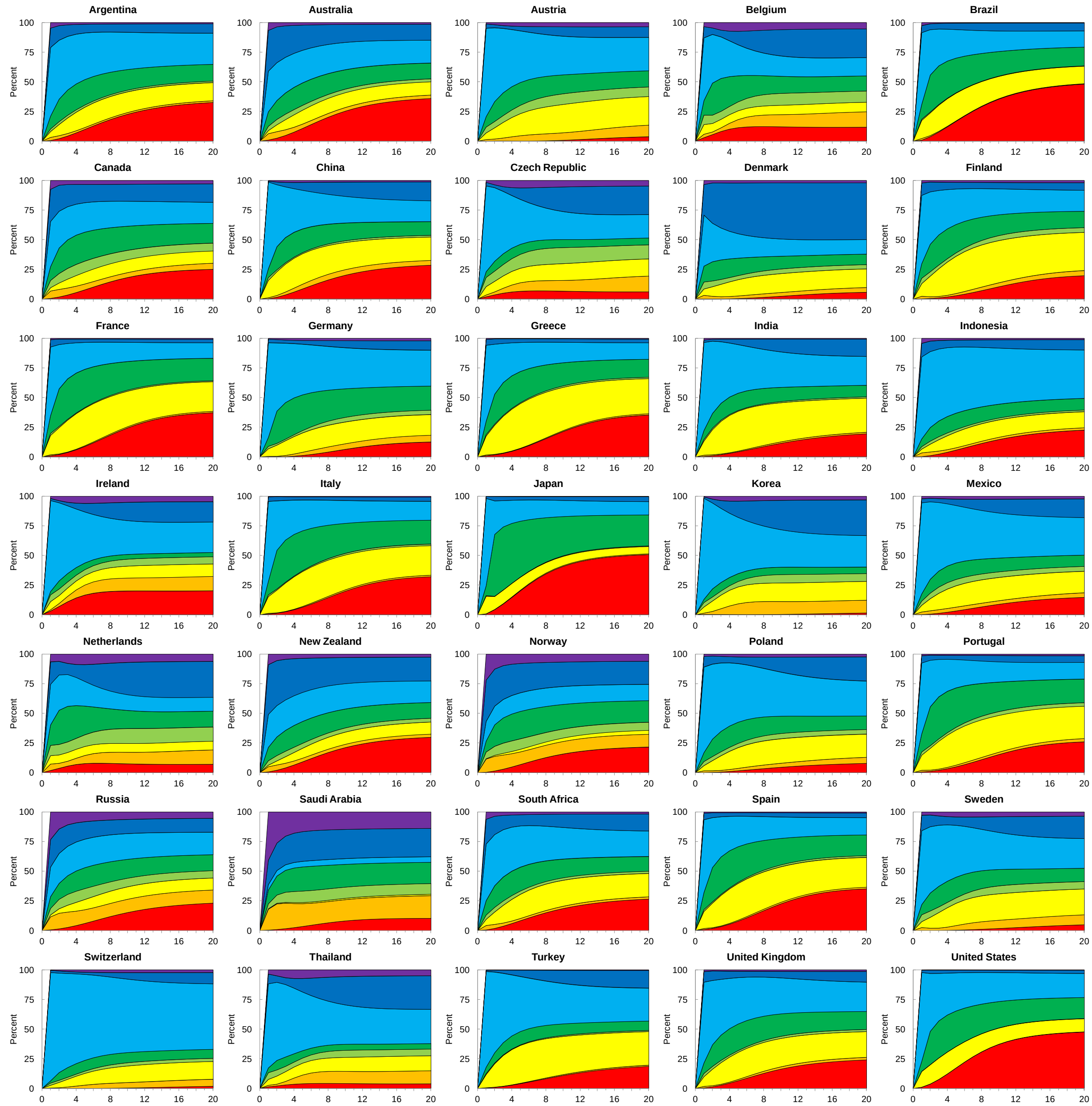
Note: Decomposes the horizon dependent forecast error variance of the nominal policy interest rate into contributions from domestic supply ■, foreign supply ■, domestic demand ■, foreign demand ■, world monetary policy ■, world fiscal policy ■, world risk premium ■, and world terms of trade ■ shocks.

Figure 16. Forecast Error Variance Decompositions of the Real Effective Exchange Rate



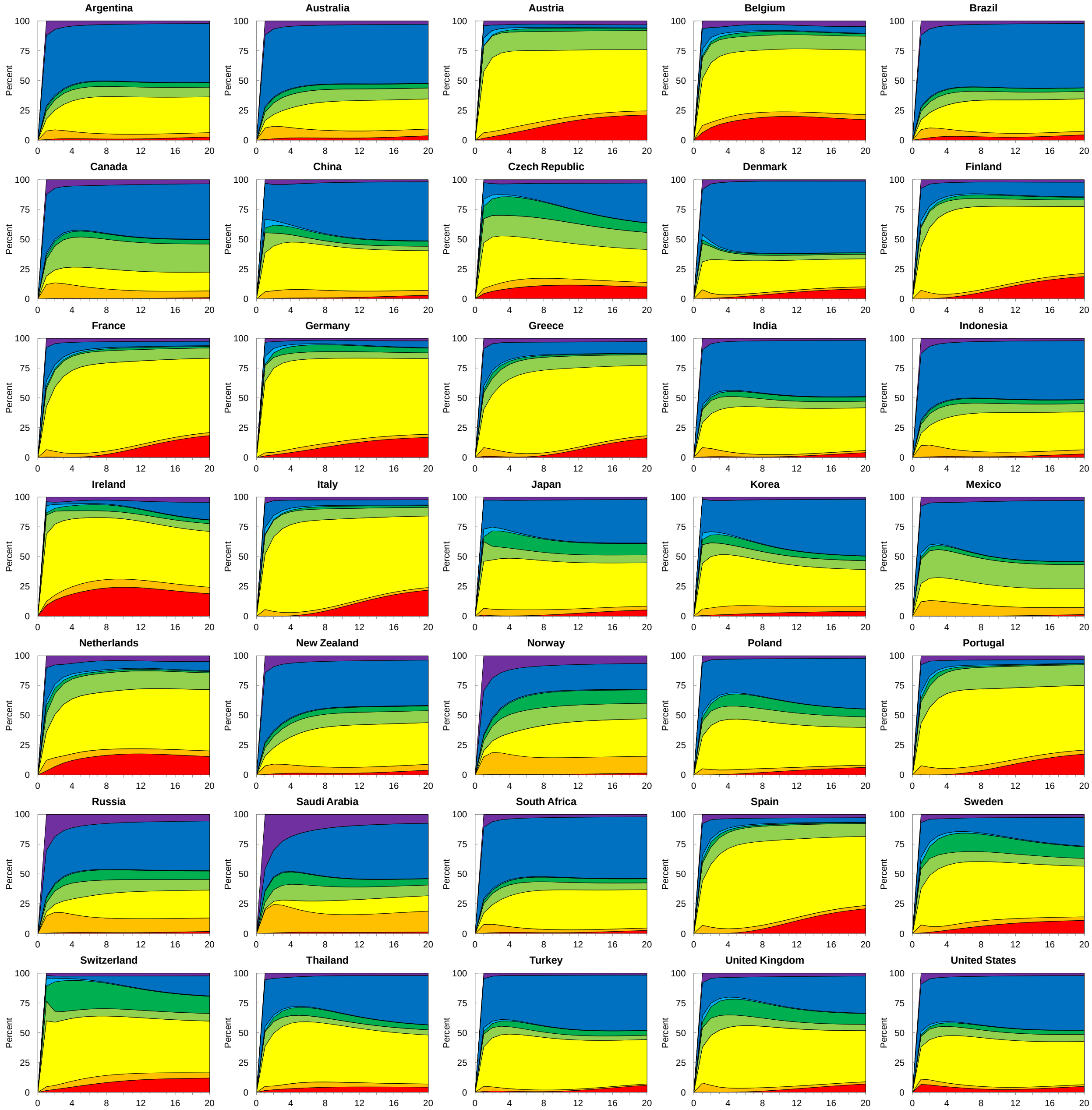
Note: Decomposes the horizon dependent forecast error variance of the real effective exchange rate into contributions from domestic supply ■, foreign supply ■, domestic demand ■, foreign demand ■, world monetary policy ■, world fiscal policy ■, world risk premium ■, and world terms of trade ■ shocks.

Figure 17. Forecast Error Variance Decompositions of the Fiscal Balance Ratio



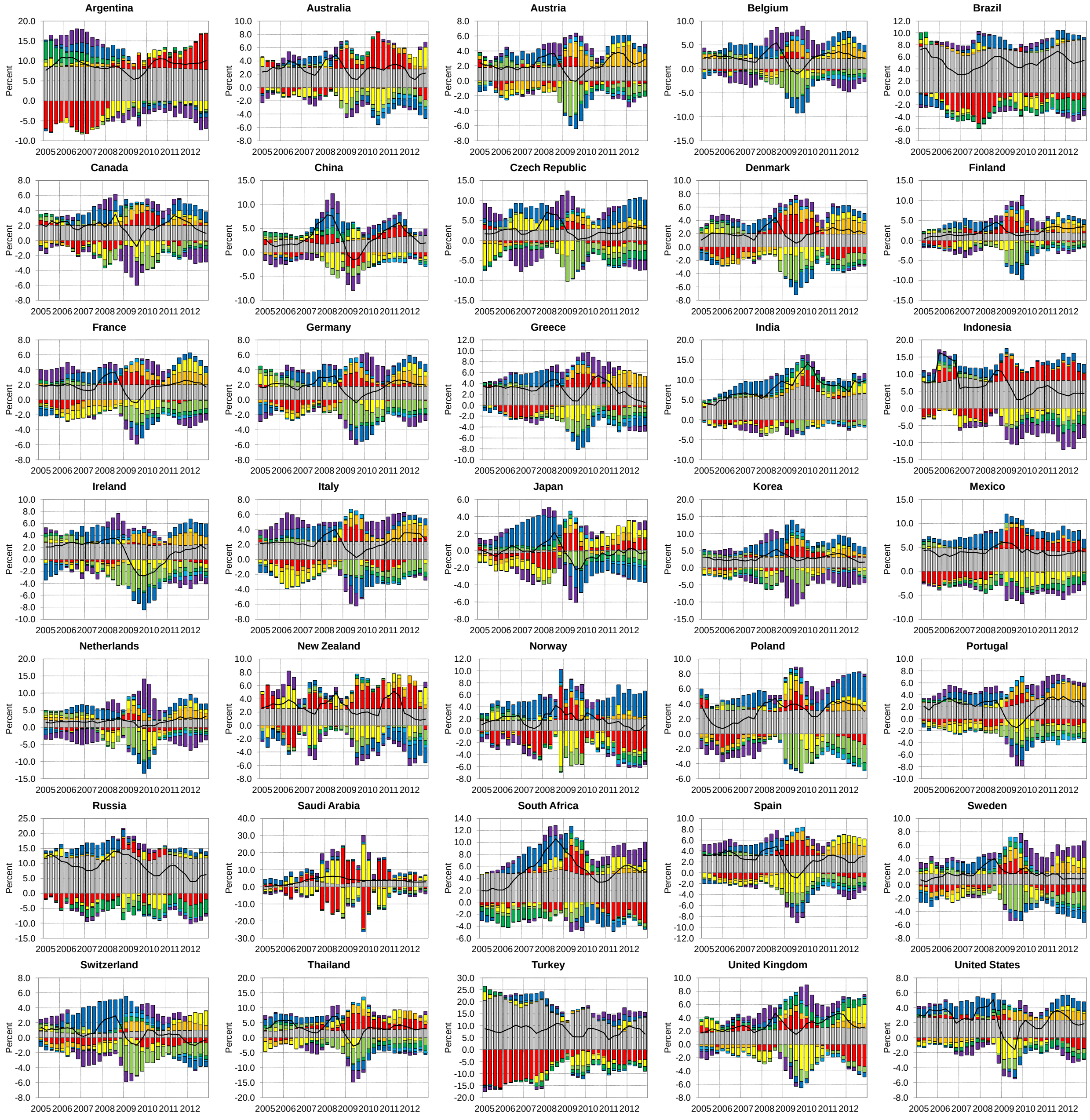
Note: Decomposes the horizon dependent forecast error variance of the ratio of the fiscal balance to nominal output into contributions from domestic supply ■, foreign supply ■, domestic demand ■, foreign demand ■, world monetary policy ■, world fiscal policy ■, world risk premium ■, and world terms of trade ■ shocks.

Figure 18. Forecast Error Variance Decompositions of the Current Account Balance Ratio



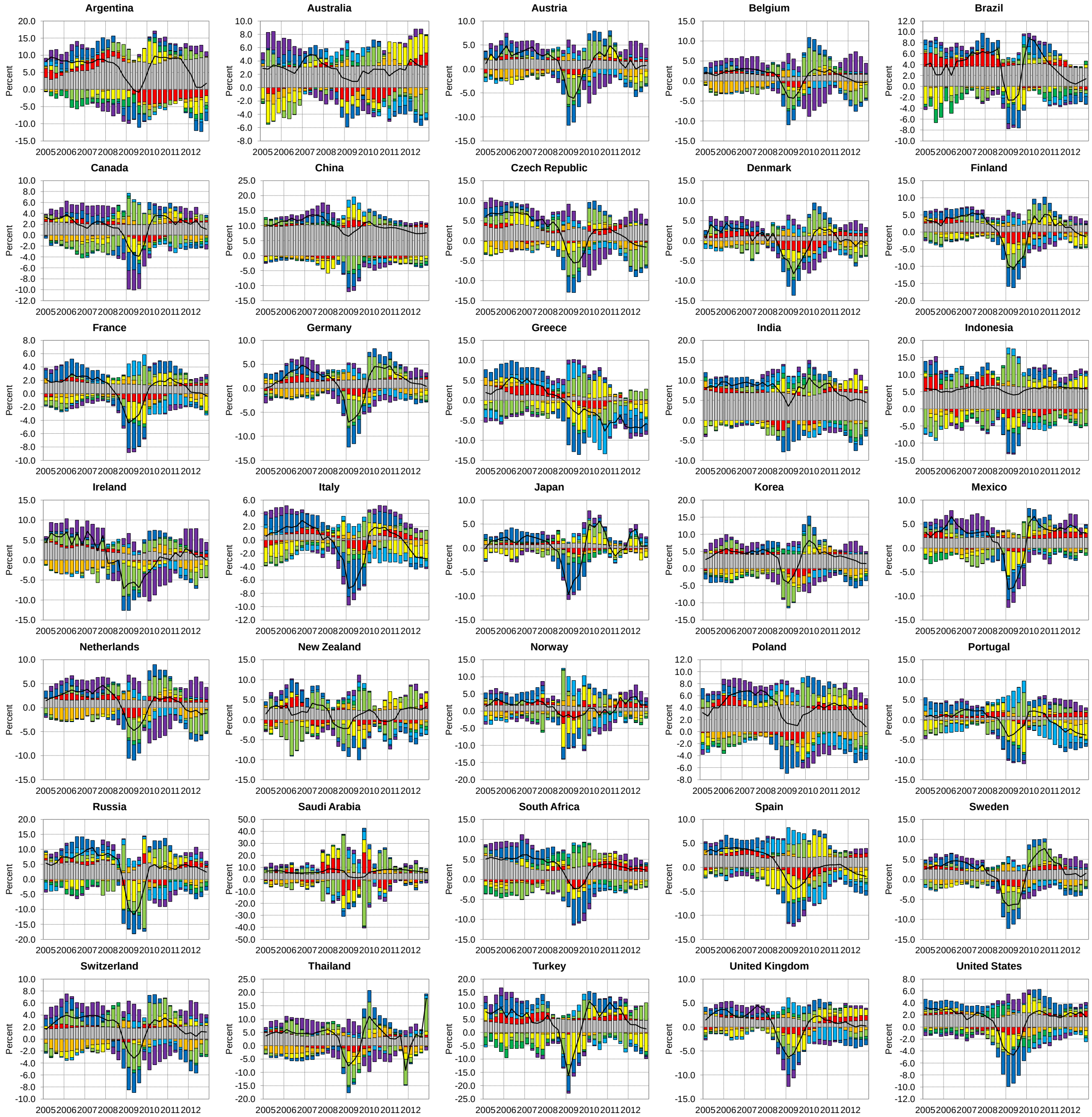
Note: Decomposes the horizon dependent forecast error variance of the ratio of the current account balance to nominal output into contributions from domestic supply ■, foreign supply ■, domestic demand ■, foreign demand ■, world monetary policy ■, world fiscal policy ■, world risk premium ■, and world terms of trade ■ shocks.

Figure 19. Historical Decompositions of Consumption Price 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 ■, world monetary policy ■, world fiscal policy ■, world risk premium ■, and world terms of trade ■ shocks.

Figure 20. Historical Decompositions of Output Growth

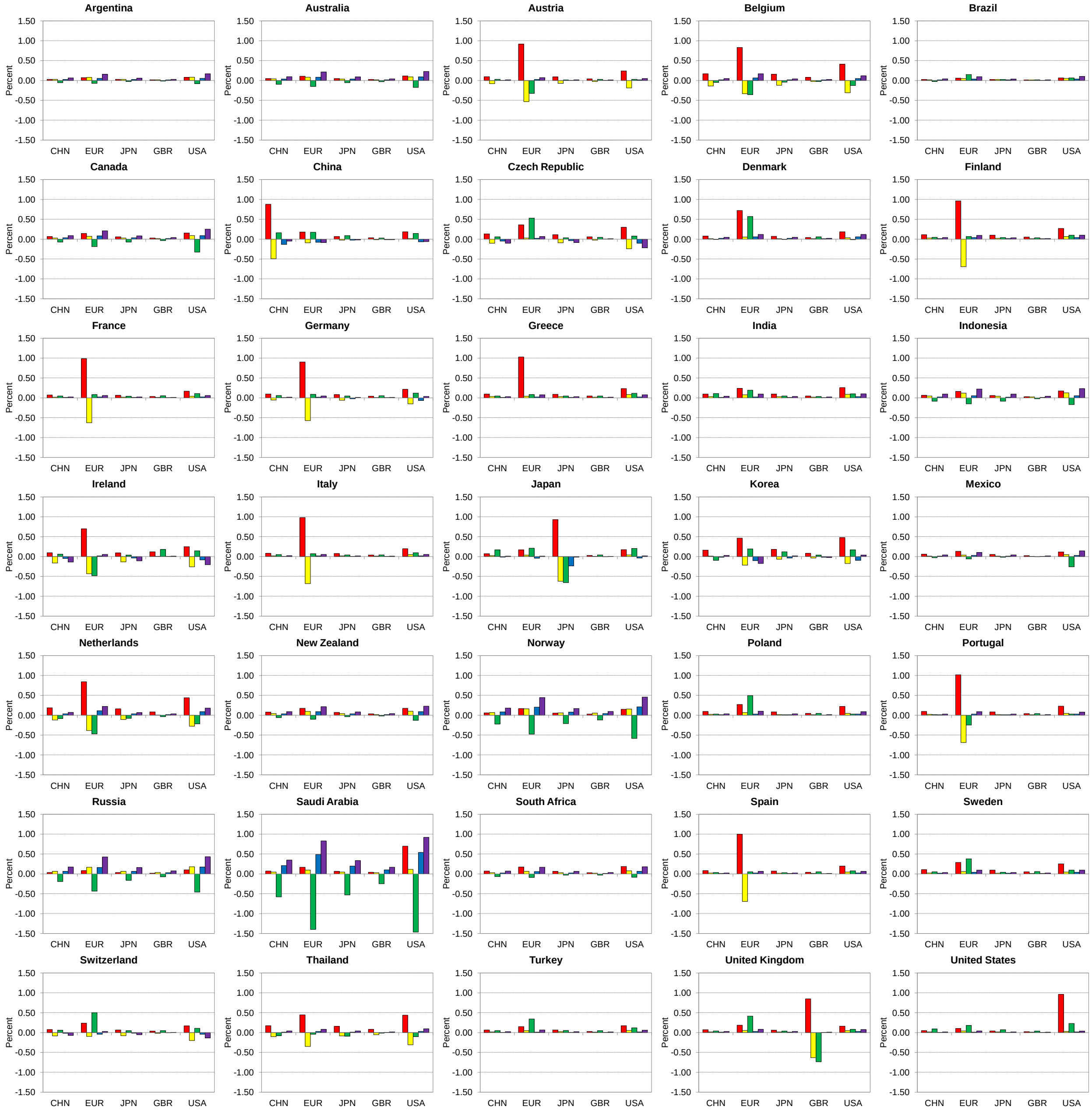


Note: Decomposes observed output growth ■ as measured by the seasonal logarithmic difference of the level of output into the sum of a trend component ■ and contributions from domestic supply ■, foreign supply ■, domestic demand ■, foreign demand ■, world monetary policy ■, world fiscal policy ■, world risk premium ■, and world terms of trade ■ shocks.

Figure 21. Simulated Conditional Betas of the Output Gap

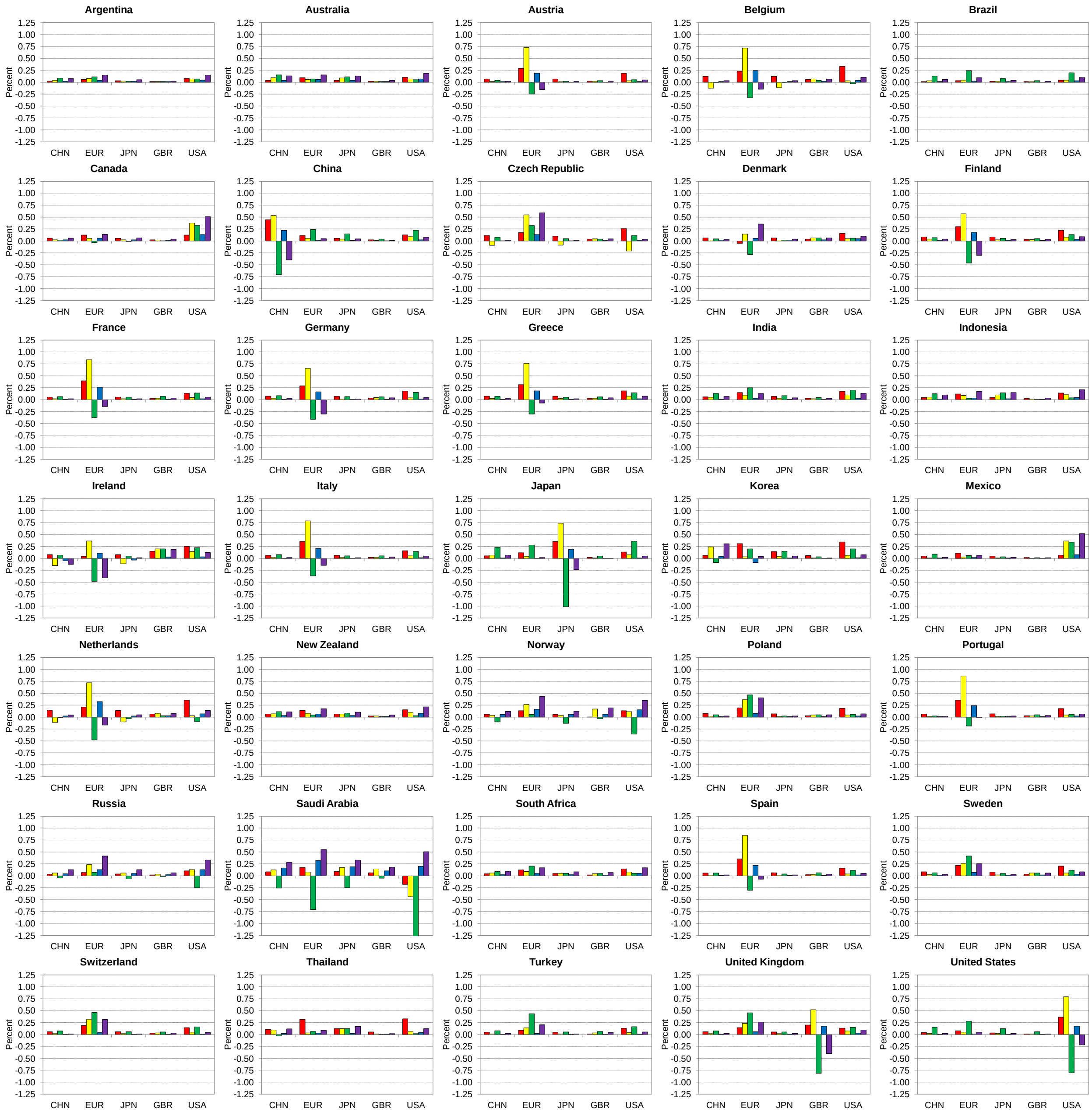
Note: Depicts the betas of the output gap with respect to the contemporaneous output gap in systemic economies conditional on all shocks ■, macroeconomic shocks ■, and financial shocks ■ in each of these systemic economies. These betas are calculated with a Monte Carlo simulation with 999 replications for $2T$ periods, discarding the first T simulated observations to eliminate dependence on initial conditions, where T denotes the observed sample size.

Figure 22. Peak Impulse Responses to Foreign Productivity Shocks



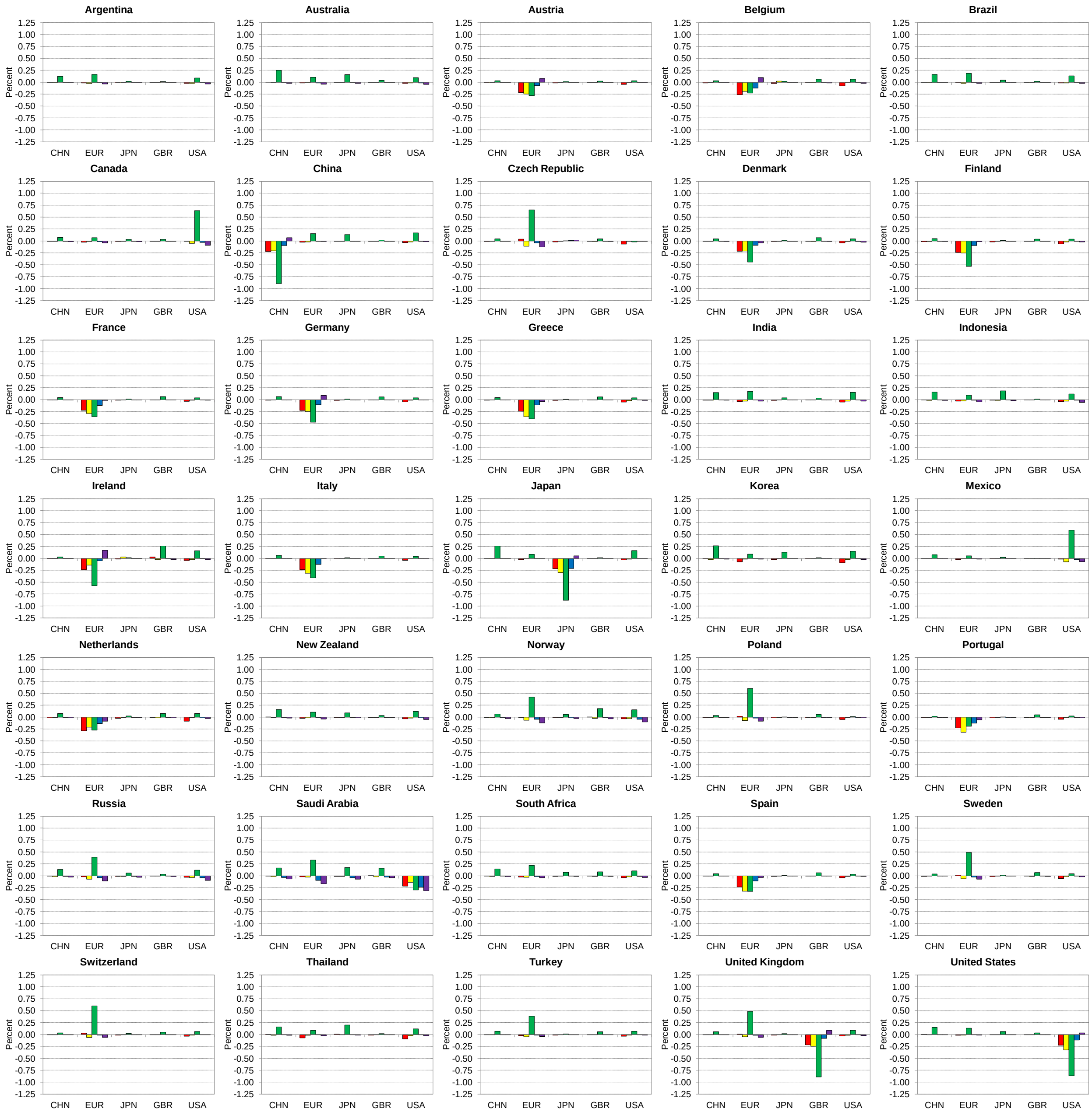
Note: Depicts the peak impulse responses of consumption price inflation ■, output ■, the real effective exchange rate ■, the ratio of the fiscal balance to nominal output ■, and the ratio of the current account balance to nominal output ■ to productivity shocks in systemic economies which raise their output price inflation by one percentage point. Consumption price inflation and the nominal policy interest rate are expressed as annual percentage rates.

Figure 23. Peak Impulse Responses to Foreign Intertemporal Substitution Shocks



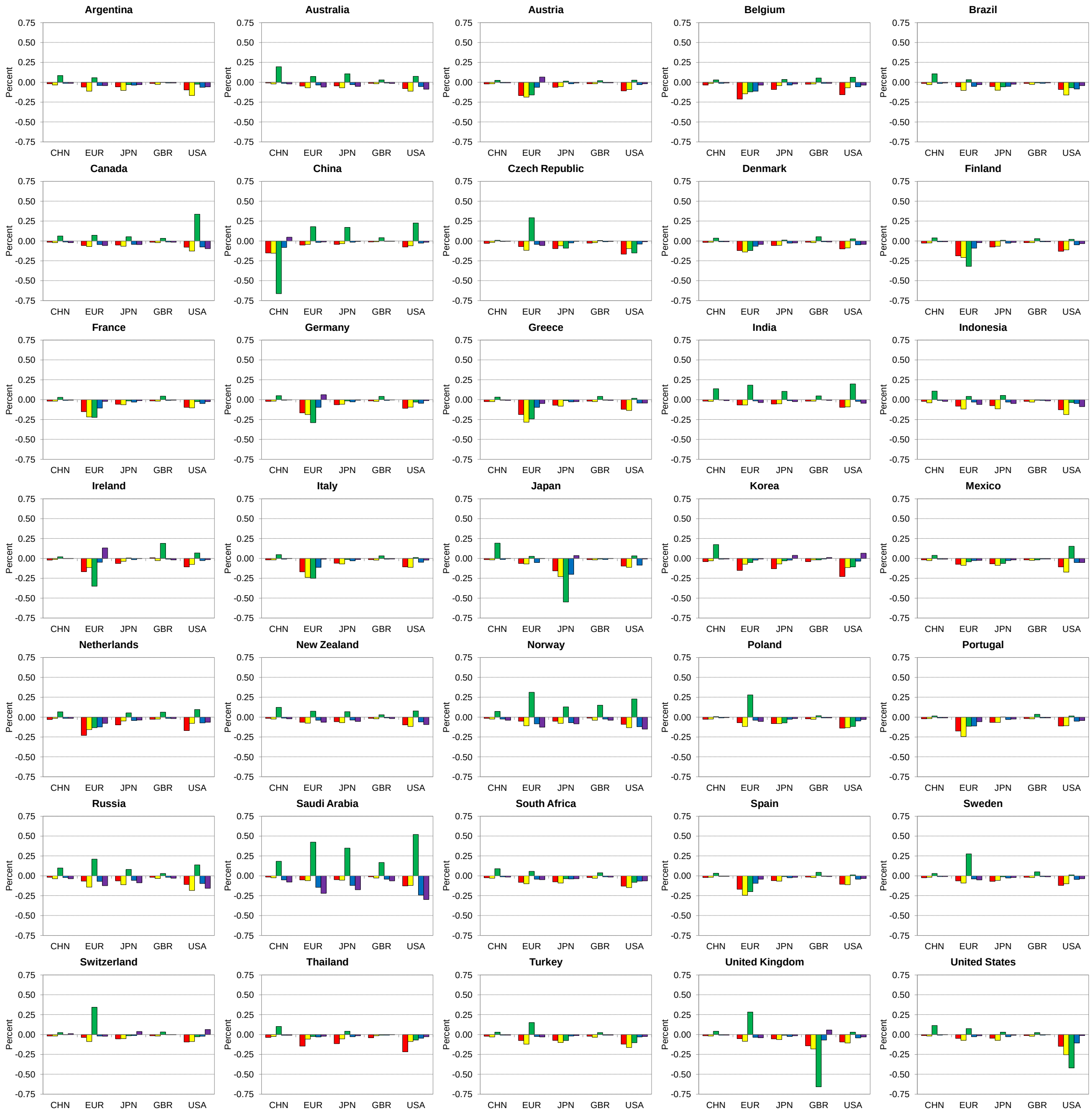
Note: Depicts the peak impulse responses of consumption price inflation, output, the real effective exchange rate, the ratio of the fiscal balance to nominal output, and the ratio of the current account balance to nominal output to intertemporal substitution shocks in systemic economies which raise their domestic demand by one percent. Consumption price inflation and the nominal policy interest rate are expressed as annual percentage rates.

Figure 24. Peak Impulse Responses to Foreign Monetary Policy Shocks



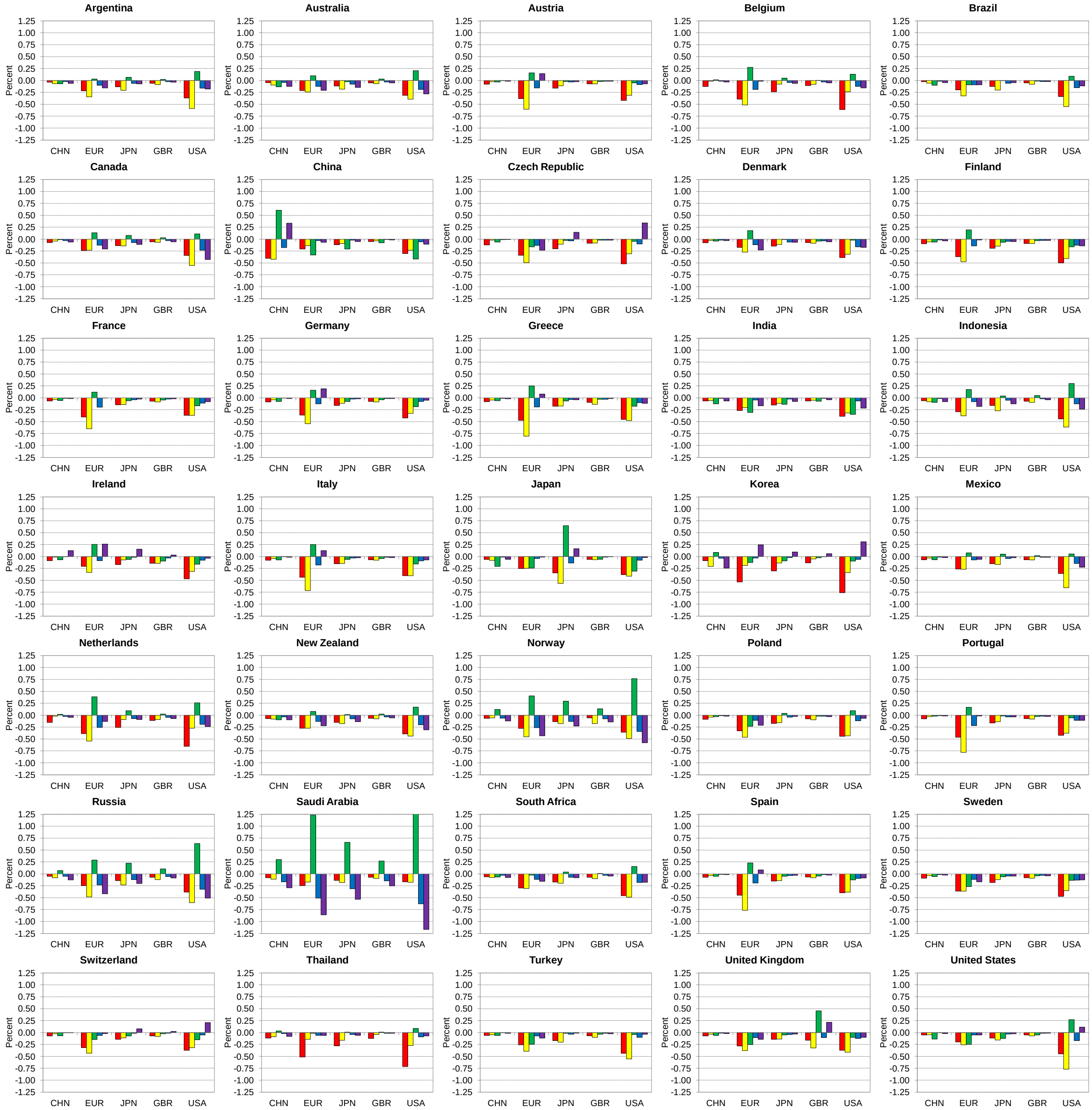
Note: Depicts the peak impulse responses of consumption price inflation ■, output ■, the real effective exchange rate ■, the ratio of the fiscal balance to nominal output ■, and the ratio of the current account balance to nominal output ■ to monetary policy shocks in systemic economies which raise their nominal policy interest rate by one percentage point. Consumption price inflation and the nominal policy interest rate are expressed as annual percentage rates.

Figure 25. Peak Impulse Responses to Foreign Credit Risk Premium Shocks



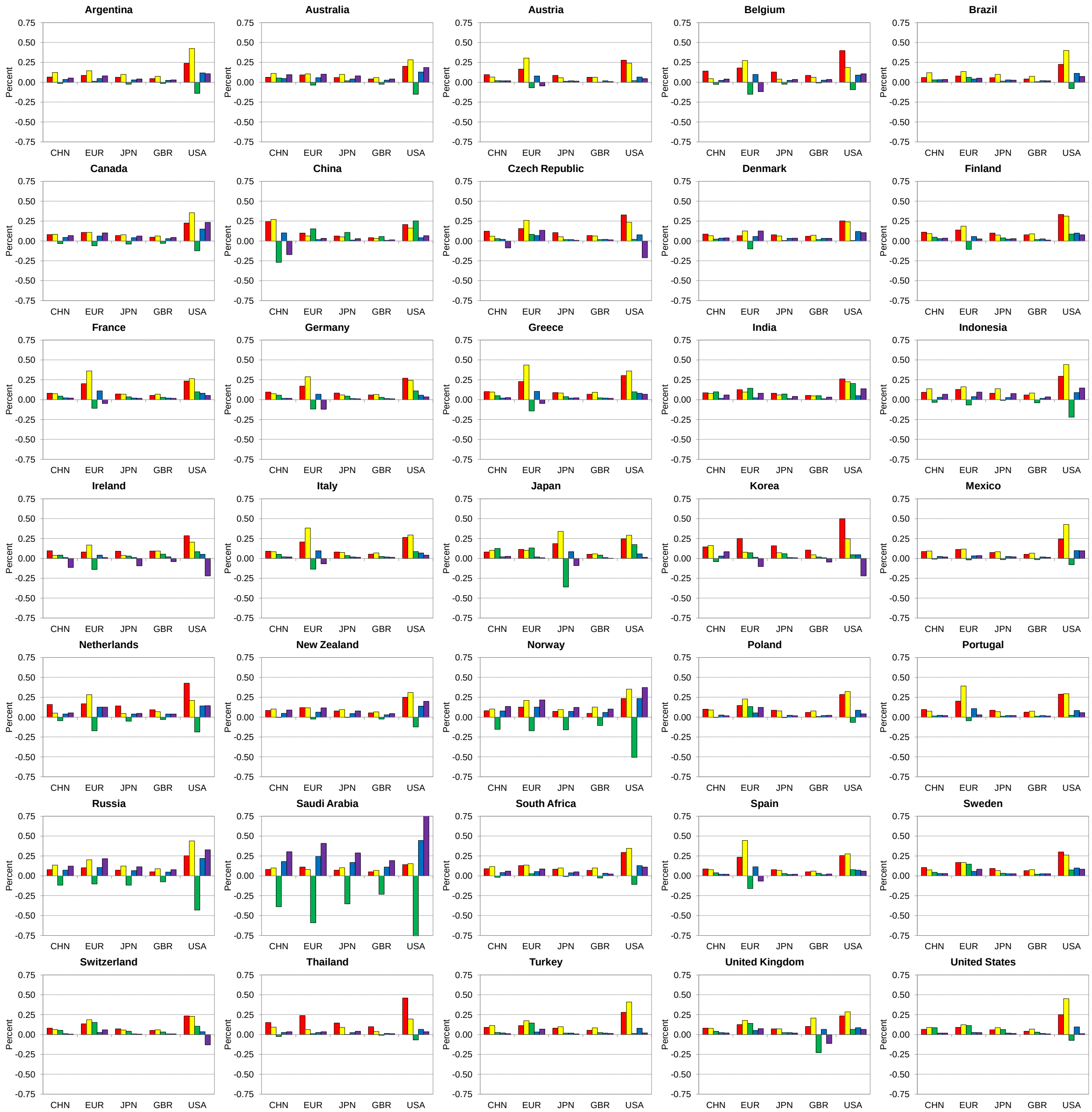
Note: Depicts the peak impulse responses of consumption price inflation ■, output ■, the real effective exchange rate ■, the ratio of the fiscal balance to nominal output ■, and the ratio of the current account balance to nominal output ■ to credit risk premium shocks in systemic economies which raise their short term nominal market interest rate by one percentage point. Consumption price inflation and the nominal policy interest rate are expressed as annual percentage rates.

Figure 26. Peak Impulse Responses to Foreign Duration Risk Premium Shocks



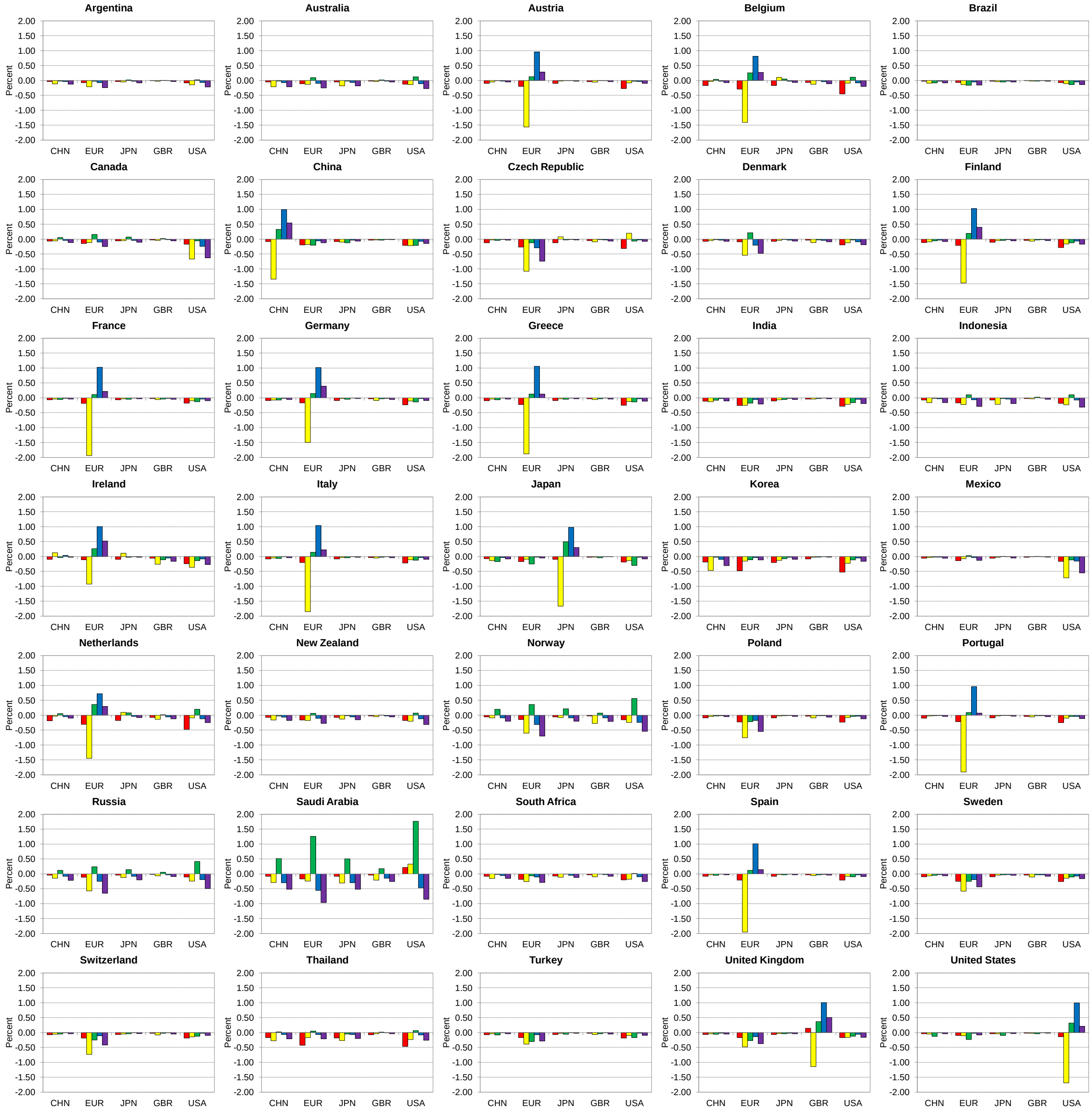
Note: Depicts the peak impulse responses of consumption price inflation ■, output ■, the real effective exchange rate ■, the ratio of the fiscal balance to nominal output ■, and the ratio of the current account balance to nominal output ■ to duration risk premium shocks in systemic economies which raise their long term nominal market interest rate by one percentage point. Consumption price inflation and the nominal policy interest rate are expressed as annual percentage rates.

Figure 27. Peak Impulse Responses to Foreign Equity Risk Premium Shocks



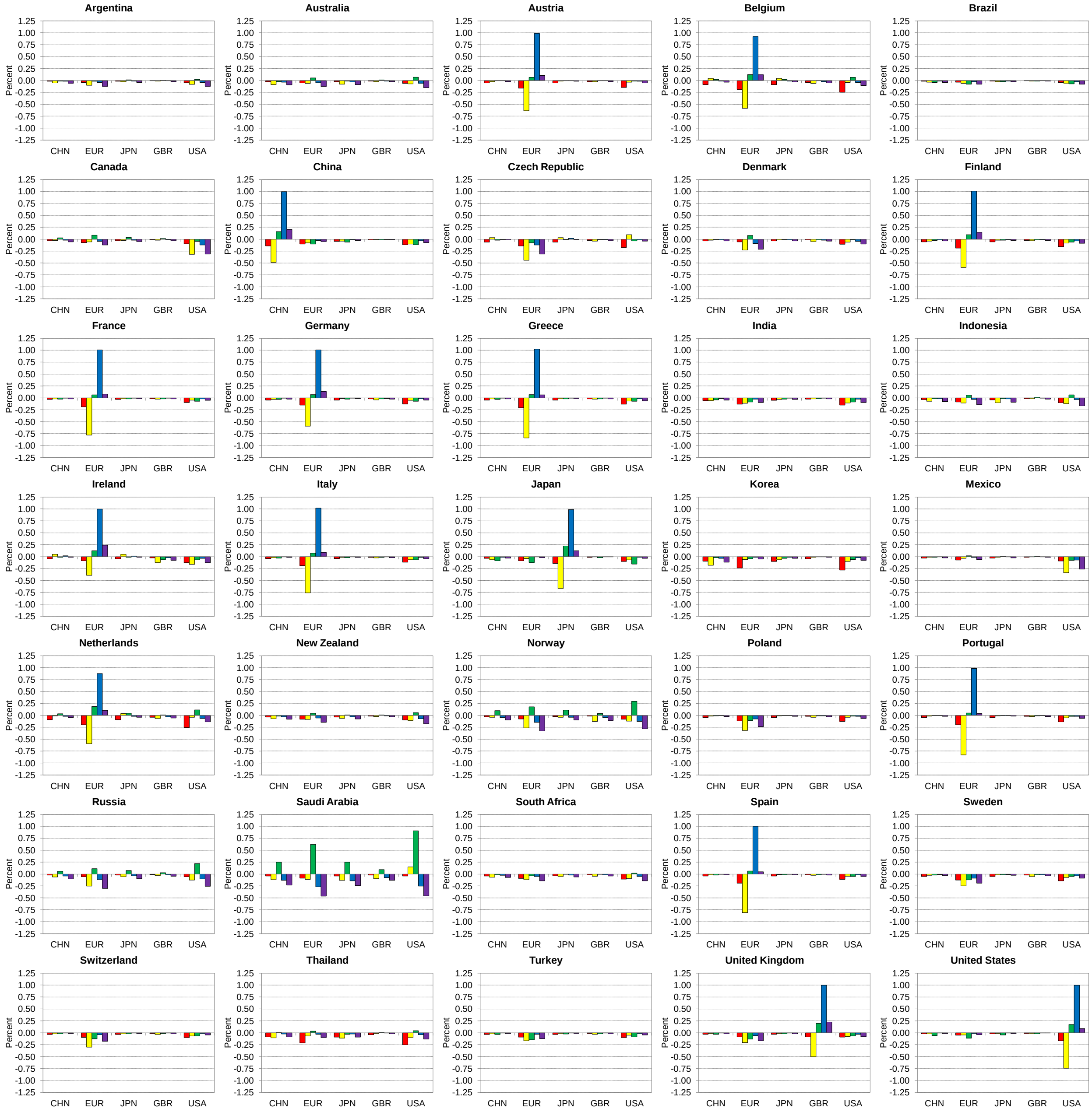
Note: Depicts the peak impulse responses of consumption price inflation ■, output ■, the real effective exchange rate ■, the ratio of the fiscal balance to nominal output ■, and the ratio of the current account balance to nominal output ■ to equity risk premium shocks in systemic economies which raise their price of equity by ten percent. Consumption price inflation and the nominal policy interest rate are expressed as annual percentage rates.

Figure 28. Peak Impulse Responses to Foreign Fiscal Expenditure Shocks



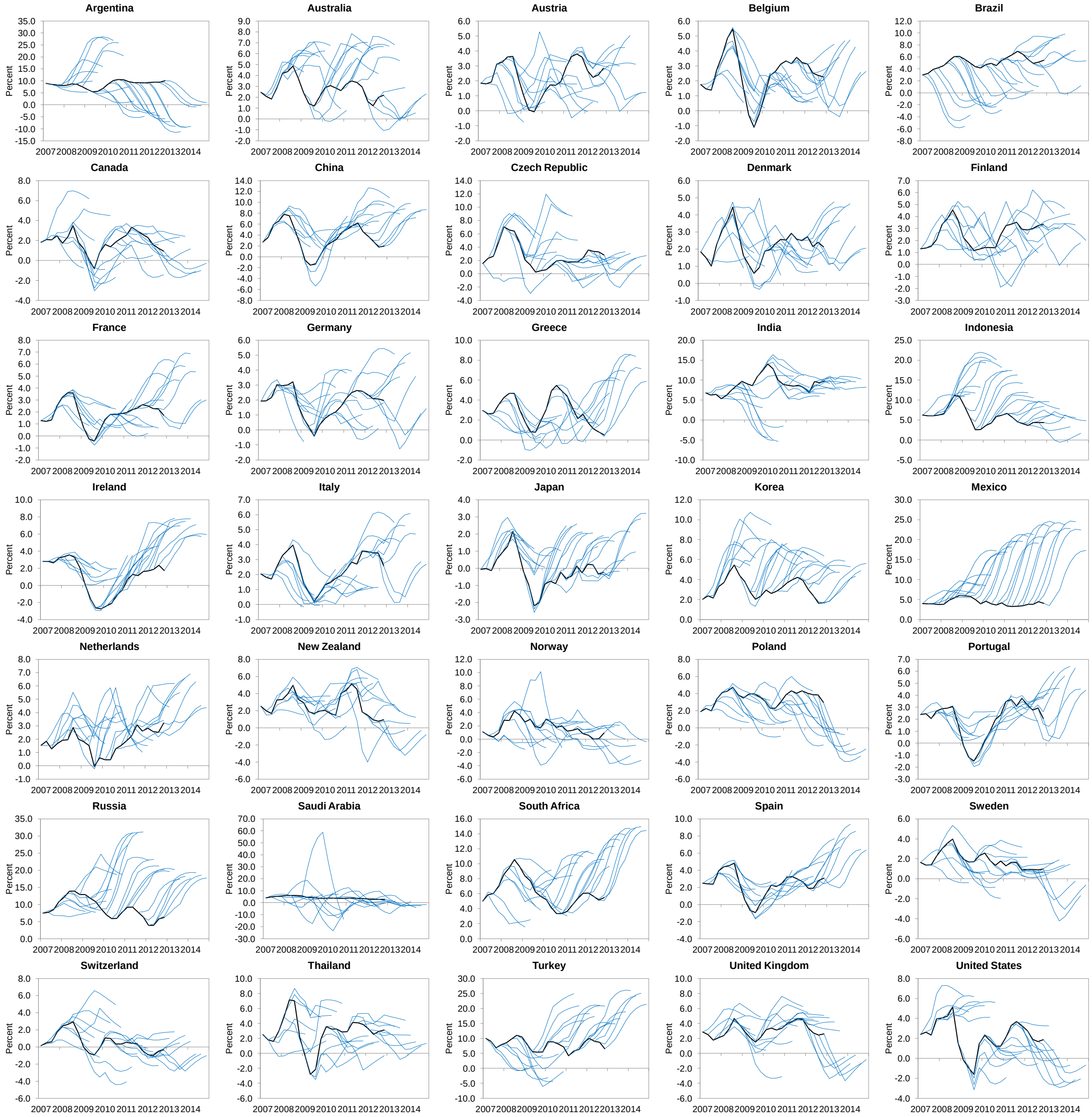
Note: Depicts the peak impulse responses of consumption price inflation ■, output ■, the real effective exchange rate ■, the ratio of the fiscal balance to nominal output ■, and the ratio of the current account balance to nominal output ■ to fiscal expenditure shocks in systemic economies which raise their ratio of the primary fiscal balance to nominal output by one percentage point. Consumption price inflation and the nominal policy interest rate are expressed as annual percentage rates.

Figure 29. Peak Impulse Responses to Foreign Fiscal Revenue Shocks



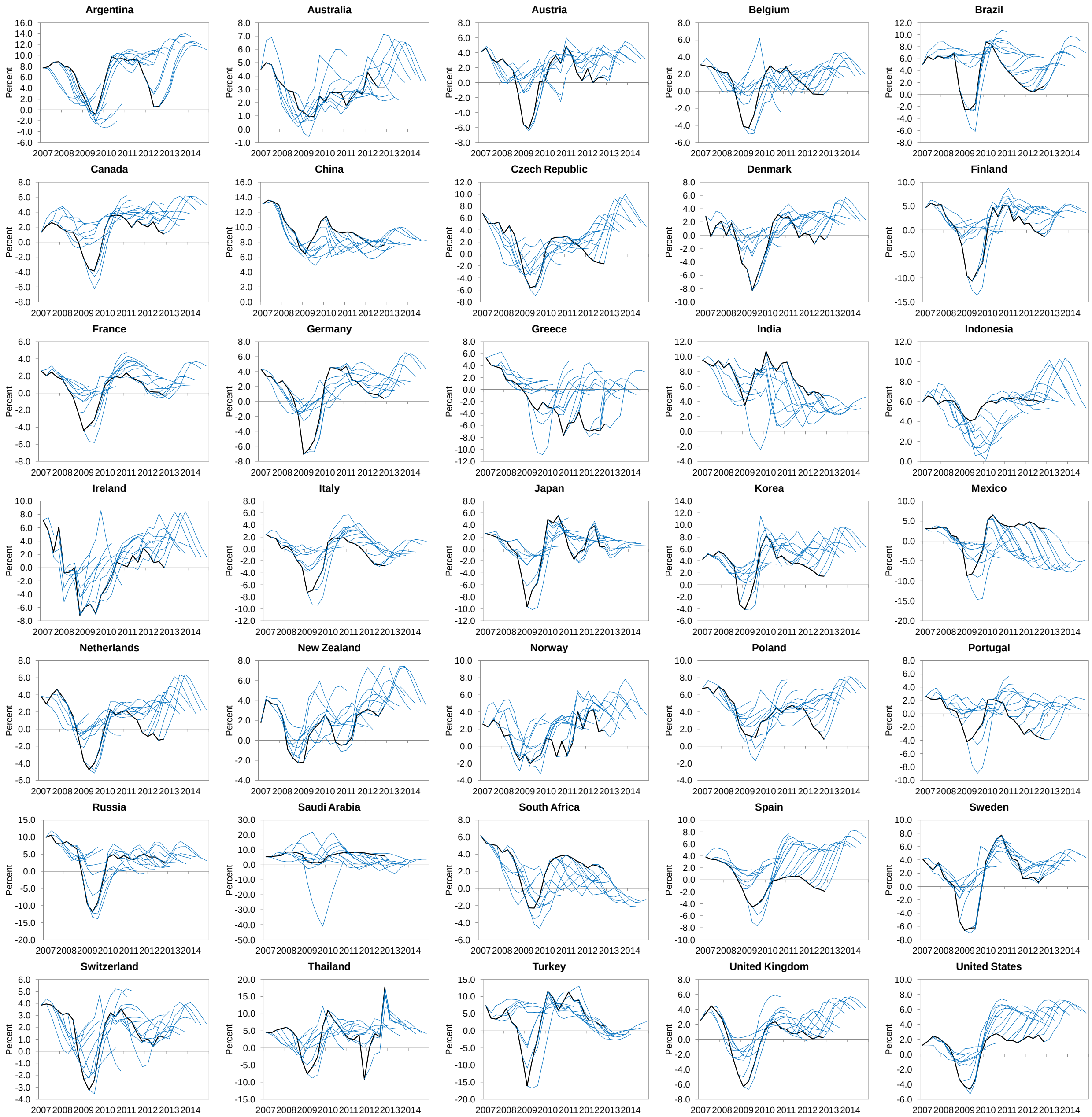
Note: Depicts the peak impulse responses of consumption price inflation ■, output ■, the real effective exchange rate ■, the ratio of the fiscal balance to nominal output ■, and the ratio of the current account balance to nominal output ■ to fiscal revenue shocks in systemic economies which raise their ratio of the primary fiscal balance to nominal output by one percentage point. Consumption price inflation and the nominal policy interest rate are expressed as annual percentage rates.

Figure 30. Sequential Unconditional Forecasts of Consumption Price Inflation



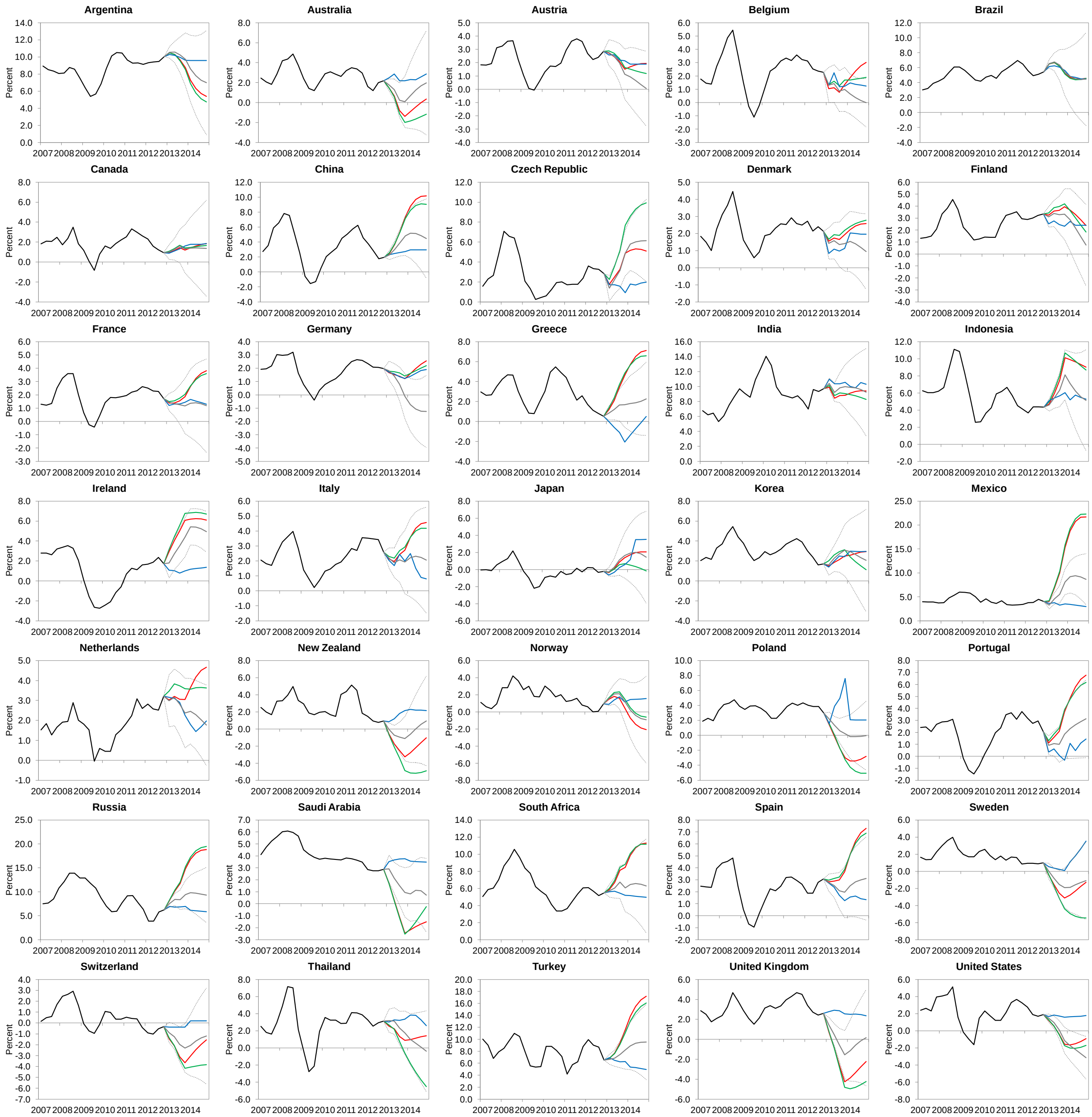
Note: Depicts observed consumption price inflation ■ as measured by the seasonal logarithmic difference of the consumption price level versus sequential unrestricted forecasts ■.

Figure 31. Sequential Unconditional Forecasts of Output Growth



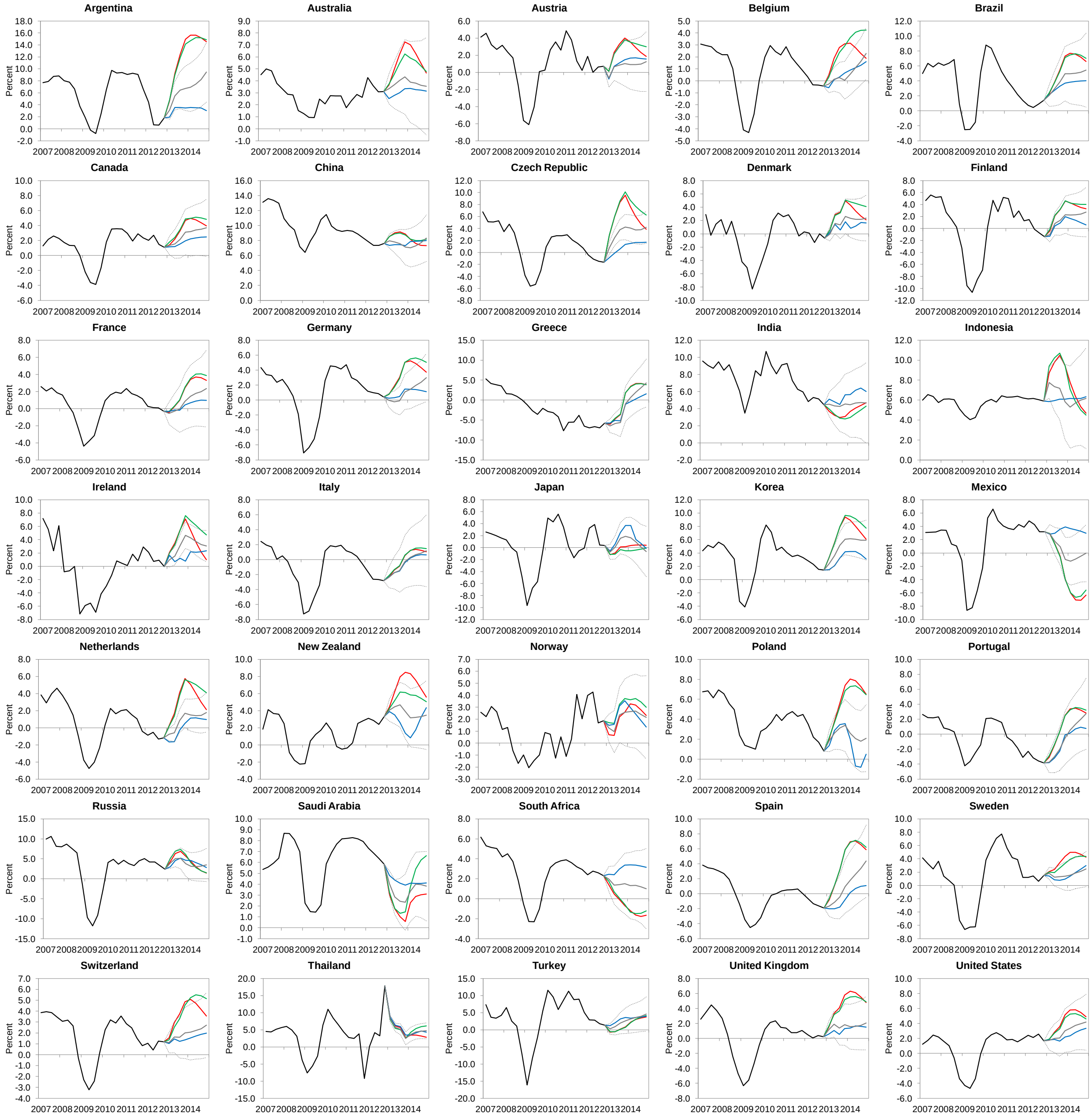
Note: Depicts observed output growth ■ as measured by the seasonal logarithmic difference of the level of output versus sequential unrestricted forecasts ■.

Figure 32. Conditional Forecasts of Consumption Price Inflation



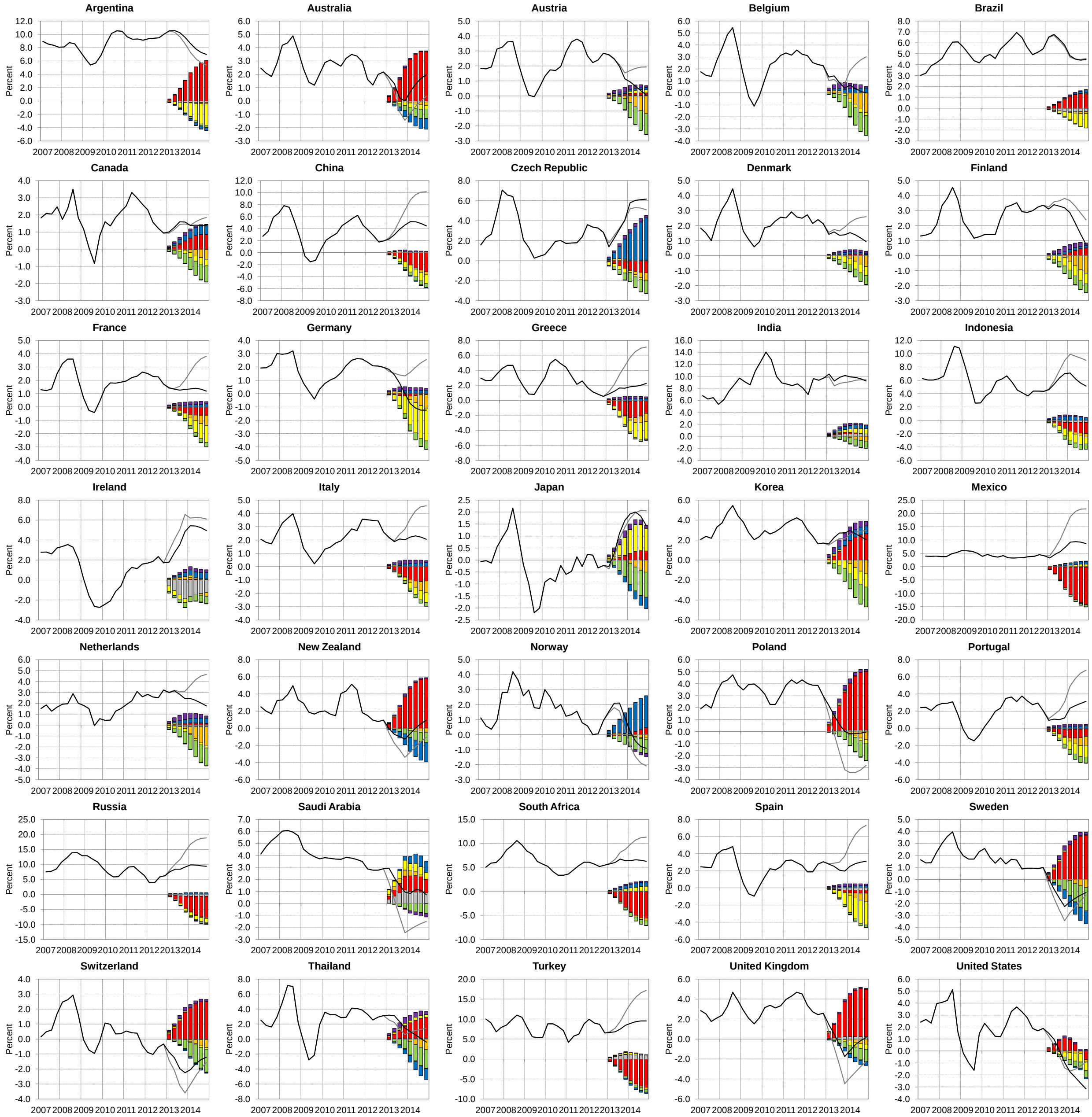
Note: Depicts observed consumption price inflation ■ as measured by the seasonal logarithmic difference of the consumption price level together with unrestricted forecasts ■, restricted forecasts ■, judgmental forecasts ■, and combined forecasts ■. Symmetric 90 percent confidence intervals represented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

Figure 33. Conditional Forecasts of Output Growth



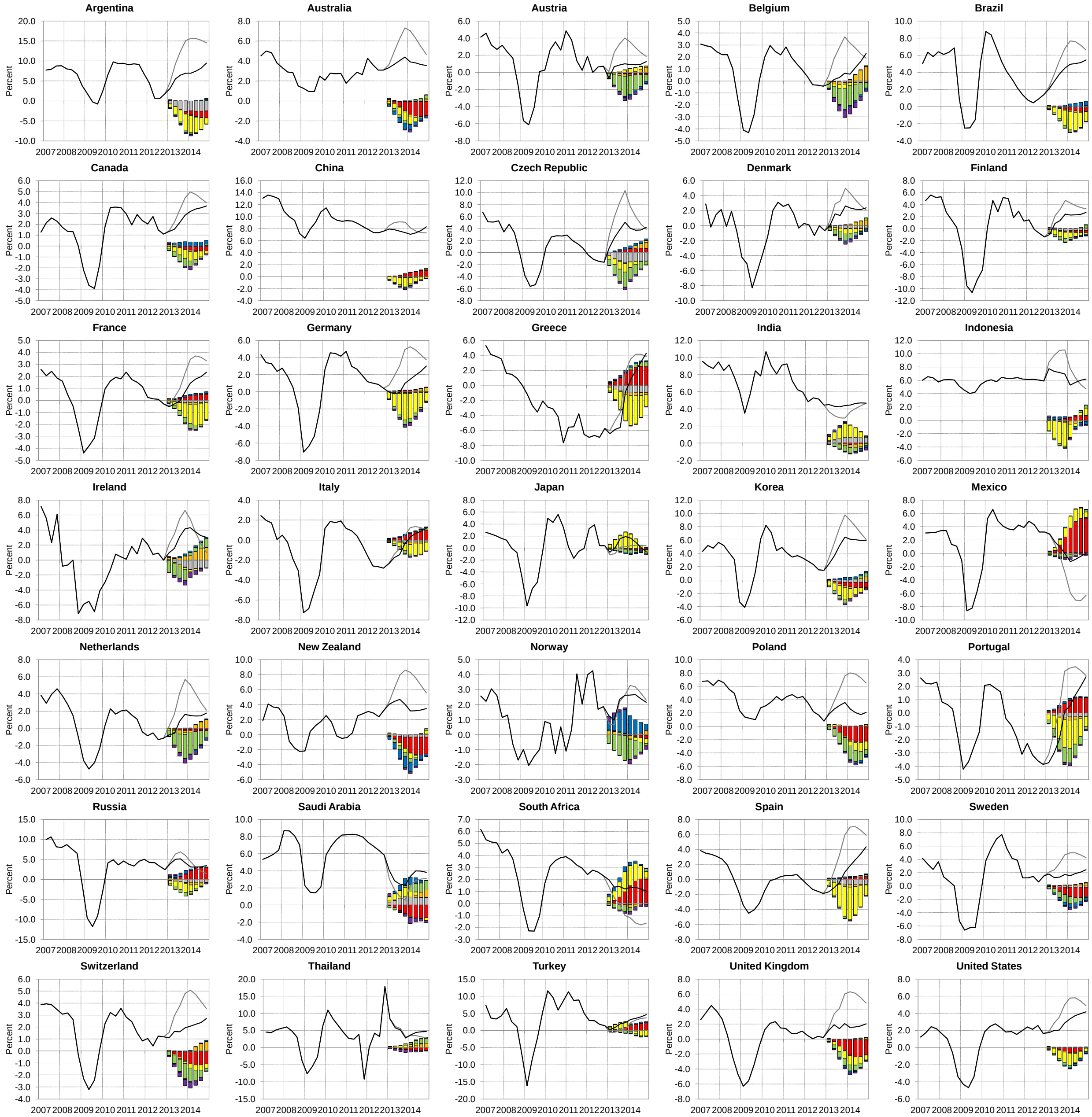
Note: Depicts observed output growth ■ as measured by the seasonal logarithmic difference of the level of output together with unrestricted forecasts ■, restricted forecasts ■, judgmental forecasts ■, and combined forecasts ■. Symmetric 90 percent confidence intervals represented by dashed lines assume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

Figure 34. Conditional Forecast Decompositions for Consumption Price Inflation



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

Figure 35. Conditional Forecast Decompositions for Output Growth



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

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