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Policy and Spillover Analysis 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 forty national economies. This panel dynamic stochastic general equilibrium model features a range of nominal and real rigidities, extensive macrofinancial linkages, and diverse spillover transmission channels. A variety of monetary policy analysis, fiscal policy analysis, spillover analysis, and forecasting applications of the estimated model are demonstrated. These include quantifying the monetary and fiscal transmission mechanisms, accounting for business cycle fluctuations, and generating relatively accurate forecasts of inflation and output growth.

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I. INTRODUCTION

Estimated dynamic stochastic general equilibrium models have recently been adopted by many monetary and fiscal authorities for policy analysis and forecasting purposes. This class of structural macroeconometric models has many variants, incorporating a range of nominal and real rigidities, and increasingly often macrofinancial linkages. 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.

Developing and estimating a dynamic stochastic general equilibrium model of the world economy, disaggregated into a large number of national economies, presents unique challenges. Adequately accounting for international business cycle comovement requires sufficient spillover transmission channels, in particular international financial linkages. Coping with the curse of dimensionality, which manifests through explosions of the numbers of variables and parameters as the number of economies increases, requires targeted parameter restrictions.

This paper develops a structural macroeconometric model of the world economy, disaggregated into forty national economies. This panel dynamic stochastic general equilibrium model features a range of nominal and real rigidities, extensive macrofinancial linkages, and diverse spillover transmission channels. Following Smets and Wouters (2003), the model features short run nominal price and wage rigidities generated by monopolistic competition, staggered reoptimization, and partial indexation in the output and labor markets. Following Christiano, Eichenbaum and Evans (2005), the resultant inertia in inflation and persistence in output is enhanced with other features such as habit persistence in consumption, adjustment costs in investment, and variable capital utilization. Households are differentiated according to whether they are credit constrained. Following Vitek (2013), credit unconstrained households allocate their financial wealth across internationally diversified short term bond, long term bond, and stock portfolios. Firms are grouped into differentiated industries. Following Vitek (2013), the commodity industries produce internationally homogeneous goods under decreasing returns to scale, while all other industries produce internationally heterogeneous goods under constant returns to scale. Following Galí (2011), the model incorporates involuntary unemployment though a reinterpretation of the labor market. Finally, following Monacelli (2005) the model accounts for short run incomplete exchange rate pass through with short run nominal price rigidities generated by monopolistic competition, staggered reoptimization, and partial indexation in the import markets. An approximate linear state space representation of the model is estimated with a Bayesian procedure, conditional on prior information concerning the common values of structural parameters across economies.

A variety of monetary policy analysis, fiscal policy analysis, spillover analysis, and forecasting applications of this estimated panel dynamic stochastic general equilibrium model of the world economy are demonstrated. These include quantifying the monetary and fiscal transmission mechanisms, accounting for business cycle fluctuations, and generating forecasts of inflation and output growth. The monetary and fiscal transmission mechanisms, as quantified with estimated impulse response functions, are broadly in line with the empirical literature, as are the drivers of business cycle fluctuations, as accounted for with estimated historical decompositions. Sequential unconditional forecasts of inflation and output growth dominate a random walk in terms of predictive accuracy by wide margins, on average across economies and horizons.

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 multivariate linear rational expectations representation of it. Estimation of the model based on an approximate linear state space representation of it 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 Theoretical Framework

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 globally 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.

In a reinterpretation of the labor market in the model of nominal wage rigidity proposed by Erceg, Henderson and Levin (2000) to incorporate involuntary unemployment along the lines of Galí (2011), each household consists of a continuum of members represented by the unit square and indexed by $(f,g) \in [0,1] \times [0,1]$. There is full risk sharing among household members, who supply indivisible differentiated intermediate labor services indexed by $f \in [0,1]$, incurring disutility from work determined by $g \in [0,1]$ if they are employed and zero otherwise. Trade specific intermediate labor services supplied by credit unconstrained and credit constrained households are perfect substitutes.

Consumption and Saving

The representative infinitely lived household has preferences defined over consumption $C_{h,i,s}$, labor supply $\{L_{h,f,i,s}\}_{f=0}^{1}$, and real financial wealth $A_{h,i,s+1}^{H}/P_{i,s}^{C}$ represented by intertemporal utility function

$$U_{h,i,t} = \mathrm{E}_t \sum_{s=t}^{\infty} \beta^{s-t} u\left(C_{h,i,s}, \{L_{h,f,i,s}\}_{f=0}^{1}, \frac{A_{h,i,s+1}^{H}}{P_{i,s}^{C}} \right), \quad (1)$$

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,

$$u\left(C_{h,i,s}, \{L_{h,f,i,s}\}_{f=0}^{1}, \frac{A_{h,i,s+1}^{H}}{P_{i,s}^{C}} \right) = \nu_{i,s}^{C} \left[\frac{1}{1-1/\sigma} \left(C_{h,i,s} - \alpha \frac{C_{i,s-1}^{Z}}{\phi^{Z}} \right)^{1-1/\sigma} - \upsilon_{i,s}^{L} \int_{0}^{1} \int_{0}^{L_{h,f,i,s}} g^{1/\eta} dg df + \frac{\nu_{i}^{A}}{1-1/\sigma} \left(\frac{A_{h,i,s+1}^{H}}{P_{i,s}^{C}} \right)^{1-1/\sigma} \right], \quad (2)$$

where $0 \leq \alpha < 1$. Endogenous preference shifter $\upsilon_{i,s}^{L}$ depends on aggregate consumption and employment according to intratemporal subutility function

$$\upsilon_{i,s}^{L} = \nu_{i,s}^{L} \left(\frac{C_{i,s}^{Z}}{\phi^{Z}} - \alpha \frac{C_{i,s-1}^{Z}}{\phi^{Z}} \right)^{-1/\sigma} (L_{i,s})^{-1/\iota}, \quad (3)$$

where $\iota > 0$. The intratemporal utility function is strictly increasing with respect to consumption if and only if serially correlated consumption demand shock $\nu_{i,s}^{C}$ satisfies $\nu_{i,s}^{C} > 0$. Given this parameter restriction, this intratemporal utility function is strictly decreasing with respect to labor supply if and only if serially correlated labor supply shock $\nu_{i,s}^{L}$ satisfies $\nu_{i,s}^{L} > 0$, and is strictly increasing with respect to real financial wealth if and only if $\nu_{i}^{A} > 0$. Given these parameter restrictions, this intratemporal utility function is strictly concave if $\sigma > 0$ and $\eta > 0$. In steady state equilibrium, ν_{i}^{A} equates the marginal rate of substitution between real financial wealth and consumption to one.

The representative household has a capitalist spirit motive for holding real financial wealth, independent of financing deferred consumption, 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 $B_{h,i,s+1}^{S,H}/P_{i,s}^{C}$, long term bond $B_{h,i,s+1}^{L,H}/P_{i,s}^{C}$ and stock $S_{h,i,s+1}^{H}/P_{i,s}^{C}$ portfolios are represented by constant elasticity of substitution intratemporal subutility function

$$\frac{A_{h,i,s+1}^{H}}{P_{i,s}^{C}} = \left[(\phi_{i,M}^{A})^{\frac{1}{\psi^{A}}} \left(\frac{B_{h,i,s+1}^{S,H}}{P_{i,s}^{C}} \right)^{\frac{\psi^{A}-1}{\psi^{A}}} + (\phi_{i,B}^{A})^{\frac{1}{\psi^{A}}} \left(\upsilon_{i,s}^{B} \frac{B_{h,i,s+1}^{L,H}}{P_{i,s}^{C}} \right)^{\frac{\psi^{A}-1}{\psi^{A}}} + (\phi_{i,S}^{A})^{\frac{1}{\psi^{A}}} \left(\upsilon_{i,s}^{S} \frac{S_{h,i,s+1}^{H}}{P_{i,s}^{C}} \right)^{\frac{\psi^{A}-1}{\psi^{A}}} \right]^{\frac{\psi^{A}}{\psi^{A}-1}}, \quad (4)$$

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

$$\frac{B_{h,i,s+1}^{S,H}}{P_{i,s}^{C}} = \left[\sum_{j=1}^{N} (\phi_{i,j}^{B})^{\frac{1}{\psi^{A}}} \left(\nu_{j,s}^{\mathcal{E}} \frac{\mathcal{E}_{i,j,s} B_{h,i,j,s+1}^{S,H}}{P_{i,s}^{C}} \right)^{\frac{\psi^{A}-1}{\psi^{A}}} \right]^{\frac{\psi^{A}}{\psi^{A}-1}}, \tag{5}$$

$$\frac{B_{h,i,s+1}^{L,H}}{P_{i,s}^{C}} = \left[\sum_{j=1}^{N} (\phi_{i,j}^{B})^{\frac{1}{\psi^{A}}} \left(\nu_{j,s}^{\mathcal{E}} \frac{\mathcal{E}_{i,j,s} B_{h,i,j,s+1}^{L,H}}{P_{i,s}^{C}} \right)^{\frac{\psi^{A}-1}{\psi^{A}}} \right]^{\frac{\psi^{A}}{\psi^{A}-1}}, \tag{6}$$

$$\frac{S_{h,i,s+1}^{H}}{P_{i,s}^{C}} = \left[\sum_{j=1}^{N} (\phi_{i,j}^{S})^{\frac{1}{\psi^{A}}} \left(\nu_{j,s}^{\mathcal{E}} \frac{\mathcal{E}_{i,j,s} S_{h,i,j,s+1}^{H}}{P_{i,s}^{C}} \right)^{\frac{\psi^{A}-1}{\psi^{A}}} \right]^{\frac{\psi^{A}}{\psi^{A}-1}}, \tag{7}$$

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

$$\frac{\mathcal{E}_{i,j,s} B_{h,i,j,s+1}^{L,H}}{P_{i,s}^{C}} = \left[\sum_{k=1}^{s} (\phi_{i,j,k,s}^{B})^{\frac{1}{\psi^{A}}} \left(\frac{\mathcal{E}_{i,j,s} V_{j,k,s}^{B} B_{h,i,j,k,s+1}^{L,H}}{P_{i,s}^{C}} \right)^{\frac{\psi^{A}-1}{\psi^{A}}} \right]^{\frac{\psi^{A}}{\psi^{A}-1}}, \tag{8}$$

$$\frac{\mathcal{E}_{i,j,s} S_{h,i,j,s+1}^{H}}{P_{i,s}^{C}} = \left[\sum_{k=1}^{M} (\phi_{i,j,k}^{S})^{\frac{1}{\psi^{A}}} \int_{0}^{1} \left(\frac{\mathcal{E}_{i,j,s} V_{j,k,l,s}^{S} S_{h,i,j,k,l,s+1}^{H}}{P_{i,s}^{C}} \right)^{\frac{\psi^{A}-1}{\psi^{A}}} dl \right]^{\frac{\psi^{A}}{\psi^{A}-1}}, \tag{9}$$

where $0 \le \phi_{i,j,k,s}^{B} \le 1$, $\sum_{k=1}^{s} \phi_{i,j,k,s}^{B} = 1$, $0 \le \phi_{i,j,k}^{S} \le 1$ and $\sum_{k=1}^{M} \phi_{i,j,k}^{S} = 1$. In the limit as $\nu_{i}^{A} \to 0$ there is no capitalist spirit 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. To cope with the curse of dimensionality, we selectively impose these parameter restrictions on optimality conditions.

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 $\{\mathcal{E}_{i,j,s}B^{S,H}_{h,i,j,s}\}^{N}_{j=1}$, long term bond $\{\mathcal{E}_{i,j,s}B^{L,H}_{h,i,j,s}\}^{N}_{j=1}$ and stock $\{\mathcal{E}_{i,j,s}S^{H}_{h,i,j,s}\}^{N}_{j=1}$ 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 $\{B^{L,H}_{h,i,j,s}\}^{N}_{j=1}$ are in turn distributed across the values of economy and vintage specific long term bonds $\{\{V^{B}_{j,k,s}B^{L,H}_{h,i,j,k,s}\}^{s-1}_{k=1}\}^{N}_{j=1}$, 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 $\{S^{H}_{h,i,j,s}\}^{N}_{j=1}$ are distributed across the values of economy, industry and firm specific shares $\{\{\{V^{S}_{j,k,l,s}S^{H}_{h,i,j,k,l,s}\}^{1}_{l=0}\}^{M}_{k=1}\}^{N}_{j=1}$, where $V^{S}_{j,k,l,s}$ denotes the local currency denominated price per share. It follows that $(1+i^{S^H}_{h,i,j,s})S^{H}_{h,i,j,s}$ $=\sum_{k=1}^{M}\int_{0}^{1}(\Pi^{S}_{j,k,l,s}+V^{S}_{j,k,l,s})S^{H}_{h,i,j,k,l,s}dl$, where $\Pi^{S}_{j,k,l,s}$ denotes the local currency denominated dividend payment per share. During period s, the representative household supplies differentiated intermediate labor services $\{L_{h,f,i,s}\}^{1}_{f=0}$, earning labor income at trade specific nominal wages $\{W_{f,i,s}\}^{1}_{f=0}$. The government levies a tax on labor income at rate $\tau_{i,s}$. These sources of wealth are summed in household dynamic budget constraint:

$$A^{H}_{h,i,s+1}=(1+i^{A^H}_{h,i,s})A^{H}_{h,i,s}+(1-\tau_{i,s})\int_{0}^{1}W_{f,i,s}L_{h,f,i,s}df-P^{C}_{i,s}C_{h,i,s}. \tag{10}$$

According to this dynamic budget constraint, at the end of period s, the representative household holds financial wealth $A^{H}_{h,i,s+1}$, which it allocates across the values of internationally diversified short term bond $B^{S,H}_{h,i,s+1}$, long term bond $B^{L,H}_{h,i,s+1}$ and stock portfolios $S^{H}_{h,i,s+1}$, that is $A^{H}_{h,i,s+1}=B^{S,H}_{h,i,s+1}+B^{L,H}_{h,i,s+1}+S^{H}_{h,i,s+1}$. 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 $\{\mathcal{E}_{i,j,s}B^{S,H}_{h,i,j,s+1}\}^{N}_{j=1}$, long term bond $\{\mathcal{E}_{i,j,s}B^{L,H}_{h,i,j,s+1}\}^{N}_{j=1}$ and stock $\{\mathcal{E}_{i,j,s}S^{H}_{h,i,j,s+1}\}^{N}_{j=1}$ portfolios subject to $B^{S,H}_{h,i,s+1}=\sum_{j=1}^{N}\mathcal{E}_{i,j,s}B^{S,H}_{h,i,j,s+1}$, $B^{L,H}_{h,i,s+1}=\sum_{j=1}^{N}\mathcal{E}_{i,j,s}B^{L,H}_{h,i,j,s+1}$ and $S^{H}_{h,i,s+1}=\sum_{j=1}^{N}\mathcal{E}_{i,j,s}S^{H}_{h,i,j,s+1}$, respectively. The local currency denominated values of economy specific long term bond portfolios $\{B^{L,H}_{h,i,j,s+1}\}^{N}_{j=1}$ are in turn allocated across the local currency denominated values of economy and vintage specific long term bonds $\{\{V^{B}_{j,k,s}B^{L,H}_{h,i,j,k,s+1}\}^{s}_{k=1}\}^{N}_{j=1}$ subject to $B^{L,H}_{h,i,j,s+1}=\sum_{k=1}^{s}V^{B}_{j,k,s}B^{L,H}_{h,i,j,k,s+1}$. In parallel, the local currency denominated values of economy specific stock portfolios $\{S^{H}_{h,i,j,s+1}\}^{N}_{j=1}$ 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 force participation $\{\{N_{h,f,i,s}\}_{f=0}^{1}\}_{s=t}^{\infty}$, 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 (10) 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 $T\rightarrow\infty$. In equilibrium, abstracting from the capitalist spirit motive the solutions to this utility maximization problem satisfy intertemporal optimality condition

$$\mathrm{E}_t\frac{\beta u_C(h,i,t+1)}{u_C(h,i,t)}\frac{P_{i,t}^{C}}{P_{i,t+1}^{C}}(1+i_{h,i,t+1}^{A^H})=1, \tag{11}$$

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

$$-\frac{u_{L_f}(h,f,i,t)}{u_C(h,i,t)}=(1-\tau_{i,t})\frac{W_{f,i,t}}{P_{i,t}^{C}}, \tag{12}$$

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

$$\begin{aligned}&\phi_{i,M}^{A}\sum_{j=1}^{N}\phi_{i,j}^{B}\left\{1+\mathrm{E}_t\frac{\beta u_C(h,i,t+1)}{u_C(h,i,t)}\frac{u_C(h,i,t)}{u_A(h,i,t)}\frac{P_{i,t}^{C}}{P_{i,t+1}^{C}}\left[(1+i_{h,i,t+1}^{A^H})-(1+i_{j,t}^{S})\frac{\mathcal{E}_{i,j,t+1}}{\mathcal{E}_{i,j,t}}\right]\right\}^{1-\psi^A}\\&+\phi_{i,B}^{A}\sum_{j=1}^{N}\phi_{i,j}^{B}\sum_{k=1}^{t}\phi_{i,j,k,t}^{B}\left\{1+\mathrm{E}_t\frac{\beta u_C(h,i,t+1)}{u_C(h,i,t)}\frac{u_C(h,i,t)}{u_A(h,i,t)}\frac{P_{i,t}^{C}}{P_{i,t+1}^{C}}\left[(1+i_{h,i,t+1}^{A^H})-\frac{i_{j,k}^{L}+V_{j,k,t+1}^{B}}{V_{j,k,t}^{B}}\frac{\mathcal{E}_{i,j,t+1}}{\mathcal{E}_{i,j,t}}\right]\right\}^{1-\psi^A}\\&+\phi_{i,S}^{A}\sum_{j=1}^{N}\phi_{i,j}^{S}\sum_{k=1}^{M}\phi_{i,j,k}^{S}\int_{0}^{1}\left\{1+\mathrm{E}_t\frac{\beta u_C(h,i,t+1)}{u_C(h,i,t)}\frac{u_C(h,i,t)}{u_A(h,i,t)}\frac{P_{i,t}^{C}}{P_{i,t+1}^{C}}\left[(1+i_{h,i,t+1}^{A^H})-\frac{\Pi_{j,k,l,t+1}^{S}+V_{j,k,l,t+1}^{S}}{V_{j,k,l,t}^{S}}\frac{\mathcal{E}_{i,j,t+1}}{\mathcal{E}_{i,j,t}}\right]\right\}^{1-\psi^A}dl=1,\end{aligned} \tag{13}$$

which relates it to the expected present values of the gross real 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

$$\mathrm{E}_t\frac{\beta u_C(h,i,t+1)}{u_C(h,i,t)}\frac{P_{i,t}^{C}}{P_{i,t+1}^{C}}\left[(1+i_{i,t}^{S})-(1+i_{j,t}^{S})\frac{\mathcal{E}_{i,j,t+1}}{\mathcal{E}_{i,j,t}}\right]=-\frac{u_A(h,i,t)}{u_C(h,i,t)}(\nu_{i,t}^{\mathcal{E}}-\nu_{j,t}^{\mathcal{E}}), \tag{14}$$

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

$$\mathrm{E}_t \frac{\beta u_C(h,i,t+1)}{u_C(h,i,t)} \frac{P_{i,t}^C}{P_{i,t+1}^C} \left[(1+i_{i,t}^S) - \frac{i_{i,k}^L + V_{i,k,t+1}^B}{V_{i,k,t}^B} \right] = -\frac{u_A(h,i,t)}{u_C(h,i,t)} \nu_{i,t}^{\mathcal{E}} (1-\upsilon_{i,t}^B), \tag{15}$$

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

$$\mathrm{E}_t \frac{\beta u_C(h,i,t+1)}{u_C(h,i,t)} \frac{P_{i,t}^C}{P_{i,t+1}^C} \left[(1+i_{i,t}^S) - \frac{\Pi_{i,k,l,t+1}^S + V_{i,k,l,t+1}^S}{V_{i,k,l,t}^S} \right] = -\frac{u_A(h,i,t)}{u_C(h,i,t)} \nu_{i,t}^{\mathcal{E}} (1-\upsilon_{i,t}^S), \tag{16}$$

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 force participation $\{\{N_{h,f,i,s}\}_{f=0}^{1}\}_{s=t}^{\infty}$ to maximize intertemporal utility function (1) subject to dynamic budget constraint (10), and the applicable restrictions on financial asset holdings. In equilibrium, the solutions to this utility maximization problem satisfy household static budget constraint

$$P_{i,t}^C C_{h,i,t} = \Pi_{i,t}^S + (1-\tau_{i,t}) \int_0^1 W_{f,i,t} L_{h,f,i,t} df, \tag{17}$$

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

$$-\frac{u_{L_f}(h,f,i,t)}{u_C(h,i,t)} = (1-\tau_{i,t}) \frac{W_{f,i,t}}{P_{i,t}^C}, \tag{18}$$

which equates the marginal rate of substitution between leisure and consumption for the marginal trade specific labor force participant to the corresponding 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.

Labor Supply

The unemployment rate $u_{i,t}^L$ measures the share of the labor force $N_{i,t}$ in unemployment $U_{i,t}$, that is $u_{i,t}^L = \frac{U_{i,t}}{N_{i,t}}$, where unemployment equals the labor force less employment $L_{i,t}$, that is $U_{i,t} = N_{i,t} - L_{i,t}$. The labor force satisfies $N_{i,t} = \int_0^1 N_{f,i,t} df$.

There exist a large number of perfectly competitive firms which combine differentiated intermediate labor services $L_{f,i,t}$ supplied by trade unions of workers to produce final labor service $L_{i,t}$ according to constant elasticity of substitution production function

$$L_{i,t} = \left[\int_0^1 (L_{f,i,t})^{\frac{\theta_{i,t}^L - 1}{\theta_{i,t}^L}} df \right]^{\frac{\theta_{i,t}^L}{\theta_{i,t}^L - 1}}, \tag{19}$$

where serially uncorrelated wage markup shock $\theta_{i,t}^L$ satisfies $\theta_{i,t}^L > 1$ with $\theta_i^L = \theta^L$. The representative final labor service firm maximizes profits derived from production of the final labor service with respect to inputs of intermediate labor services, implying demand functions:

$$L_{f,i,t} = \left(\frac{W_{f,i,t}}{W_{i,t}} \right)^{-\theta_{i,t}^L} L_{i,t}. \tag{20}$$

Since the production function exhibits constant returns to scale, in equilibrium the representative final labor service firm generates zero profit, implying aggregate wage index:

$$W_{i,t} = \left[\int_0^1 (W_{f,i,t})^{1-\theta_{i,t}^L} df \right]^{\frac{1}{1-\theta_{i,t}^L}}. \tag{21}$$

As the wage elasticity of demand for intermediate labor services $\theta_{i,t}^L$ increases, they become closer substitutes, and individual trade unions have less market power.

In an extension of the model of nominal wage rigidity proposed by Erceg, Henderson and Levin (2000) along the lines of Smets and Wouters (2003), each period a randomly selected fraction $1-\omega^L$ of trade unions adjust their wage optimally. The remaining fraction ω^L of trade unions adjust their wage to account for past consumption price inflation according to partial indexation rule

$$W_{f,i,t} = \left(\frac{P_{i,t-1}^C}{P_{i,t-2}^C} \right)^{\gamma^L} \left(\frac{\bar{P}_{i,t-1}^C}{\bar{P}_{i,t-2}^C} \right)^{1-\gamma^L} W_{f,i,t-1}, \tag{22}$$

where $0 \le \gamma^L \le 1$. Under this specification, although trade unions adjust their wage every period, they infrequently do so optimally, and the interval between optimal wage adjustments is a random variable.

If the representative trade union can adjust its wage optimally in period t, then it does so to maximize intertemporal utility function (1) subject to dynamic budget constraint (10), intermediate labor service demand function (20), and the assumed form of nominal wage rigidity. Since all trade unions that adjust their wage optimally in period t solve an identical utility maximization problem, in equilibrium they all choose a common wage $W_{i,t}^*$ given by necessary first order condition:

$$\frac{W_{i,t}^*}{W_{i,t}} = -\frac{\mathrm{E}_t \sum_{s=t}^{\infty} (\omega^L)^{s-t} \frac{\beta^{s-t} u_C(h,i,s)}{u_C(h,i,t)} \theta_{i,s}^L \frac{u_{L_f}(h,f,i,s)}{u_C(h,i,s)} \left[\left(\frac{P_{i,t-1}^C}{P_{i,s-1}^C} \right)^{\gamma^L} \left(\frac{\bar{P}_{i,t-1}^C}{\bar{P}_{i,s-1}^C} \right)^{1-\gamma^L} \frac{W_{i,s}}{W_{i,t}} \right]^{\theta_{i,s}^L} \left(\frac{W_{i,t}^*}{W_{i,t}} \right)^{-\theta_{i,s}^L} L_{h,i,s}}{\mathrm{E}_t \sum_{s=t}^{\infty} (\omega^L)^{s-t} \frac{\beta^{s-t} u_C(h,i,s)}{u_C(h,i,t)} (\theta_{i,s}^L - 1)(1-\tau_{i,s}) \frac{W_{i,s}}{P_{i,s}^C} \left[\left(\frac{P_{i,t-1}^C}{P_{i,s-1}^C} \right)^{\gamma^L} \left(\frac{\bar{P}_{i,t-1}^C}{\bar{P}_{i,s-1}^C} \right)^{1-\gamma^L} \frac{W_{i,s}}{W_{i,t}} \right]^{\theta_{i,s}^L - 1} \left(\frac{W_{i,t}^*}{W_{i,t}} \right)^{-\theta_{i,s}^L} L_{h,i,s}}. \quad (23)$$

This necessary first order condition equates the expected present value of the marginal utility of consumption gained from labor supply to the expected present value of the marginal utility cost incurred from leisure foregone. Aggregate wage index (21) equals an average of the wage set by the fraction $1-\omega^L$ of trade unions that adjust their wage optimally in period t, and the average of the wages set by the remaining fraction ω^L of trade unions that adjust their wage according to partial indexation rule (22):

$$W_{i,t} = \left\{ (1-\omega^L)(W_{i,t}^*)^{1-\theta_{i,t}^L} + \omega^L \left[\left(\frac{P_{i,t-1}^C}{P_{i,t-2}^C} \right)^{\gamma^L} \left(\frac{\bar{P}_{i,t-1}^C}{\bar{P}_{i,t-2}^C} \right)^{1-\gamma^L} W_{i,t-1} \right]^{1-\theta_{i,t}^L} \right\}^{\frac{1}{1-\theta_{i,t}^L}}. \quad (24)$$

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

B. The Production Sector

The production sector consists of a finite set of industries indexed by $k \in \{1,\ldots,M\}$, of which the first M^* produce nonrenewable commodities. In particular, the energy commodity industry labeled $k=1$ and the nonenergy commodity industry labeled $k=2$ produce internationally homogeneous goods for foreign absorption under decreasing returns to scale, while all other industries produce internationally heterogeneous goods for domestic and foreign absorption 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 fixed proportions production function

$$Y_{i,t} = \min\left\{\frac{Y_{i,k,t}}{\phi_{i,k}^{Y}}\right\}_{k=1}^{M}, \tag{25}$$

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:

$$Y_{i,k,t} = \phi_{i,k}^{Y} Y_{i,t}. \tag{26}$$

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:

$$P_{i,t}^{Y} = \sum_{k=1}^{M} \phi_{i,k}^{Y} P_{i,k,t}^{Y}. \tag{27}$$

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

$$Y_{i,k,t} = \left[\int_{0}^{1} (Y_{i,k,l,t})^{\frac{\theta_{i,k,t}^{Y}-1}{\theta_{i,k,t}^{Y}}} dl\right]^{\frac{\theta_{i,k,t}^{Y}}{\theta_{i,k,t}^{Y}-1}}, \tag{28}$$

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 $1 \le k \le M*$ 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:

$$Y_{i,k,l,t} = \left(\frac{P_{i,k,l,t}^{Y}}{P_{i,k,t}^{Y}}\right)^{-\theta_{i,k,t}^{Y}} Y_{i,k,t}. \tag{29}$$

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:

$$P_{i,k,t}^{Y} = \left[\int_{0}^{1} (P_{i,k,l,t}^{Y})^{1-\theta_{i,k,t}^{Y}} dl\right]^{\frac{1}{1-\theta_{i,k,t}^{Y}}}. \tag{30}$$

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

Labor Demand and Investment

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. Entry into and exit from the monopolistically competitive industry specific intermediate output good sectors is prohibited.

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

$$\Pi^S_{i,k,l,t} + V^S_{i,k,l,t} = \mathrm{E}_t \sum_{s=t}^{\infty} \frac{\beta^{s-t}\lambda_{i,s}}{\lambda_{i,t}} \Pi^S_{i,k,l,s}, \tag{31}$$

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 net profits $\Pi^S_{i,k,l,s}$, defined as after tax earnings less investment expenditures,

$$\Pi^S_{i,k,l,s} = (1-\tau_{i,s})(P^Y_{i,k,l,s}Y_{i,k,l,s} - W_{i,s}L_{i,k,l,s} - \Phi_{i,k,l,s}) - P^I_{i,s}I_{i,k,l,s}, \tag{32}$$

where $Y_{i,k,l,s} = \mathcal{F}(u^K_{i,k,l,s}K_{i,k,s}, \mathcal{A}_{i,s}L_{i,k,l,s})$. 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 final labor service $L_{i,k,l,s}$, and other variable costs $\Phi_{i,k,l,s}$. The government levies a tax on earnings at rate $\tau_{i,s}$.

The representative industry specific intermediate output good firm utilizes capital $K_{i,k,s}$ at rate $u^K_{i,k,l,s}$ and rents final labor service $L_{i,k,l,s}$ to produce industry specific differentiated intermediate output good $Y_{i,k,l,s}$ according to production function

$$\mathcal{F}(u^K_{i,k,l,s}K_{i,k,s}, \mathcal{A}_{i,s}L_{i,k,l,s}) = (u^K_{i,k,l,s}K_{i,k,s})^{\phi^K_k}(\mathcal{A}_{i,s}L_{i,k,l,s})^{\phi^L_k}, \tag{33}$$

where serially correlated productivity shock $\mathcal{A}_{i,s}$ satisfies $\mathcal{A}_{i,s} > 0$, while $\phi^K_k = (1-\phi^F_k)\phi^K$ and $\phi^L_k = (1-\phi^F_k)\phi^L$ with $\phi^K + \phi^L = 1$ and $\phi^F_k > 0$ for $1 \le k \le M^*$ and $\phi^F_k = 0$ otherwise.

In utilizing capital to produce output, the representative industry specific intermediate output good firm incurs a cost $\mathcal{G}(u^K_{i,k,l,s}, K_{i,k,s})$ denominated in terms of capital,

$$\Phi_{i,k,l,s} = P^I_{i,s}\mathcal{G}(u^K_{i,k,l,s}, K_{i,k,s}) + F^Y_{i,k,s}, \tag{34}$$

where industry specific fixed cost $F_{i,k,s}^{Y}$ ensures that $\Phi_{i,k,s} = 0$. Following Christiano, Eichenbaum and Evans (2005), this capital utilization cost is increasing in the capital utilization rate at an increasing rate,

$$\mathcal{G}(u_{i,k,l,s}^{K}, K_{i,k,s}) = \mu^{K}\left[e^{\kappa(u_{i,k,l,s}^{K}-1)} - 1\right]K_{i,k,s}, \tag{35}$$

where $\mu^{K} > 0$ and $\kappa > 0$. In steady state equilibrium, the capital utilization rate equals one, and the cost of utilizing capital equals zero.

Capital is industry specific but not firm specific, and the representative industry specific intermediate output good firm enters period s with access to previously accumulated capital stock $K_{i,k,s}$, which subsequently evolves according to accumulation function

$$K_{i,k,s+1} = (1-\delta)K_{i,k,s} + \mathcal{H}(I_{i,k,s}, I_{i,k,s-1}), \tag{36}$$

where $0 \le \delta \le 1$. Following Christiano, Eichenbaum and Evans (2005), effective investment function $\mathcal{H}(I_{i,k,s}, I_{i,k,s-1})$ incorporates convex adjustment costs,

$$\mathcal{H}(I_{i,k,s}, I_{i,k,s-1}) = \nu_{i,s}^{I}\left[1 - \frac{\chi^{F}}{2}\left(\frac{I_{i,k,s}}{I_{i,k,s-1}} - 1\right)^{2}\right]I_{i,k,s}, \tag{37}$$

where serially correlated investment demand shock $\nu_{i,s}^{I}$ satisfies $\nu_{i,s}^{I} > 0$, while $\chi^{F} > 0$. In steady state equilibrium, these adjustment costs equal zero, and effective investment equals actual investment.

In period t, the representative industry specific intermediate output good firm chooses state contingent sequences for employment $\{L_{i,k,l,s}\}_{s=t}^{\infty}$, the capital utilization rate $\{u_{i,k,l,s}^{K}\}_{s=t}^{\infty}$, investment $\{I_{i,k,l,s}\}_{s=t}^{\infty}$, and the capital stock $\{K_{i,k,l,s+1}\}_{s=t}^{\infty}$ to maximize pre-dividend stock market value (31) subject to production function (33), capital accumulation function (36), and terminal nonnegativity constraint $K_{i,k,l,T+1} \ge 0$ for $T \to \infty$. We consider a symmetric equilibrium under which $I_{i,k,l,s} = I_{i,k,s}$ and $K_{i,k,l,s+1} = K_{i,k,s+1}$, where $I_{i,k,s} = \int_0^1 I_{i,k,l,s}dl$ and $K_{i,k,s+1} = \int_0^1 K_{i,k,l,s+1}dl$. In equilibrium, demand for the final labor service satisfies necessary first order condition

$$\mathcal{F}_{\mathcal{A}L}(u_{i,k,l,t}^{K}K_{i,k,t}, \mathcal{A}_{i,t}L_{i,k,l,t})\Psi_{i,k,l,t} = (1-\tau_{i,t})\frac{W_{i,t}}{P_{i,k,t}^{Y}\mathcal{A}_{i,t}}, \tag{38}$$

where $P_{i,k,s}^{Y}\Psi_{i,k,l,s}$ denotes the Lagrange multiplier associated with the period s production technology constraint. This necessary first order condition equates real marginal cost $\Psi_{i,k,l,t}$ to the ratio of the after tax industry specific real wage to the marginal product of labor. In equilibrium, the capital utilization rate satisfies necessary first order condition

$$\mathcal{F}_{u^{K}K}(u_{i,k,l,t}^{K}K_{i,k,t}, \mathcal{A}_{i,t}L_{i,k,l,t})\frac{P_{i,k,t}^{Y}\Psi_{i,k,l,t}}{P_{i,t}^{I}} = (1-\tau_{i,t})\frac{\mathcal{G}_{u^{K}}(u_{i,k,l,t}^{K}, K_{i,k,t})}{K_{i,k,t}}, \tag{39}$$

which equates the marginal revenue product of utilized capital to its marginal cost. In equilibrium, demand for the final investment good satisfies necessary first order condition

$$Q_{i,k,l,t}\mathcal{H}_1(I_{i,k,t}, I_{i,k,t-1}) + \mathrm{E}_t \frac{\beta\lambda_{i,t+1}}{\lambda_{i,t}} Q_{i,k,l,t+1}\mathcal{H}_2(I_{i,k,t+1}, I_{i,k,t}) = P_{i,t}^I, \tag{40}$$

which equates the expected present value of an additional unit of investment to its price, where $Q_{i,k,l,s}$ denotes the Lagrange multiplier associated with the period s capital accumulation function. In equilibrium, this shadow price of capital satisfies necessary first order condition

$$Q_{i,k,l,t} = \mathrm{E}_t \frac{\beta\lambda_{i,t+1}}{\lambda_{i,t}} \left\{ P_{i,t+1}^I \left[u_{i,k,l,t+1}^K \mathcal{F}_{u^K K}(u_{i,k,l,t+1}^K K_{i,k,t+1}, \mathcal{A}_{i,t+1} L_{i,k,l,t+1}) \frac{P_{i,k,t+1}^Y \Psi_{i,k,l,t+1}}{P_{i,t+1}^I} - (1-\tau_{i,t+1})\mathcal{G}_K(u_{i,k,l,t+1}^K, K_{i,k,t+1}) \right] + (1-\delta) Q_{i,k,l,t+1} \right\}, \tag{41}$$

which equates it to the expected present value of the sum of the future marginal revenue product of capital net of its marginal utilization cost, and the future shadow price of capital net of depreciation. Provided that the pre-dividend stock market value is bounded and strictly concave, together with other necessary first order conditions, and a transversality condition derived from the necessary complementary slackness condition associated with the terminal nonnegativity constraint, these necessary first order conditions are sufficient for the unique value maximizing state contingent sequence of industry specific intermediate output good firm allocations.

Output Supply

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 $1-\omega_k^Y$ of industry specific intermediate output good firms adjust their price optimally, where $0 \le \omega_k^Y < 1$ with $\omega_k^Y = \omega^Y$ for $k > M^*$. The remaining fraction ω_k^Y of intermediate output good firms adjust their price to account for past industry specific output price inflation according to partial indexation rule

$$P_{i,k,l,t}^Y = \left(\frac{P_{i,k,t-1}^Y}{P_{i,k,t-2}^Y} \right)^{\gamma_k^Y} \left(\frac{\bar{P}_{i,k,t-1}^Y}{\bar{P}_{i,k,t-2}^Y} \right)^{1-\gamma_k^Y} P_{i,k,l,t-1}^Y, \tag{42}$$

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, optimal price adjustment opportunities arrive randomly, 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 (31) subject to production function (33), industry specific intermediate output good demand function (29), 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:

$$\frac{P_{i,k,t}^{Y,*}}{P_{i,k,t}^{Y}}=\frac{\mathrm{E}_t\sum_{s=t}^{\infty}(\omega_k^Y)^{s-t}\frac{\beta^{s-t}\lambda_{i,s}}{\lambda_{i,t}}\theta_{i,k,s}^{Y}\Psi_{i,k,l,s}\left[\left(\frac{P_{i,k,t-1}^{Y}}{P_{i,k,s-1}^{Y}}\right)^{\gamma_k^Y}\left(\frac{\bar{P}_{i,k,t-1}^{Y}}{\bar{P}_{i,k,s-1}^{Y}}\right)^{1-\gamma_k^Y}\frac{P_{i,k,s}^{Y}}{P_{i,k,t}^{Y}}\right]^{\theta_{i,k,s}^{Y}}\left(\frac{P_{i,k,t}^{Y,*}}{P_{i,k,t}^{Y}}\right)^{-\theta_{i,k,s}^{Y}}P_{i,k,s}^{Y}Y_{i,k,s}}{\mathrm{E}_t\sum_{s=t}^{\infty}(\omega_k^Y)^{s-t}\frac{\beta^{s-t}\lambda_{i,s}}{\lambda_{i,t}}(\theta_{i,k,s}^{Y}-1)(1-\tau_{i,s})\left[\left(\frac{P_{i,k,t-1}^{Y}}{P_{i,k,s-1}^{Y}}\right)^{\gamma_k^Y}\left(\frac{\bar{P}_{i,k,t-1}^{Y}}{\bar{P}_{i,k,s-1}^{Y}}\right)^{1-\gamma_k^Y}\frac{P_{i,k,s}^{Y}}{P_{i,k,t}^{Y}}\right]^{\theta_{i,k,s}^{Y}-1}\left(\frac{P_{i,k,t}^{Y,*}}{P_{i,k,t}^{Y}}\right)^{-\theta_{i,k,s}^{Y}}P_{i,k,s}^{Y}Y_{i,k,s}}. \quad (43)$$

This necessary first order condition equates the expected present value of the after tax marginal revenue gained from output supply to the expected present value of the marginal cost incurred from production. Aggregate output price index (30) 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 (42):

$$P_{i,k,t}^{Y}=\left\{(1-\omega_k^Y)(P_{i,k,t}^{Y,*})^{1-\theta_{i,k,t}^{Y}}+\omega_k^Y\left[\left(\frac{P_{i,k,t-1}^{Y}}{P_{i,k,t-2}^{Y}}\right)^{\gamma_k^Y}\left(\frac{\bar{P}_{i,k,t-1}^{Y}}{\bar{P}_{i,k,t-2}^{Y}}\right)^{1-\gamma_k^Y}P_{i,k,t-1}^{Y}\right]^{1-\theta_{i,k,t}^{Y}}\right\}^{\frac{1}{1-\theta_{i,k,t}^{Y}}}. \quad (44)$$

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,

$$\mathcal{E}_{i,t}=\prod_{j=1}^{N}(\mathcal{E}_{i,j,t})^{w_{i,j}^T},\ \mathcal{Q}_{i,t}=\prod_{j=1}^{N}(\mathcal{Q}_{i,j,t})^{w_{i,j}^T}, \quad (45)$$

where the real bilateral exchange rate $\mathcal{Q}_{i,j,t}$ satisfies $\mathcal{Q}_{i,j,t}=\frac{\mathcal{E}_{i,j,t}P_{j,t}^{Y}}{P_{i,t}^{Y}}$, and bilateral trade weight $w_{i,j}^T$ satisfies $w_{i,i}^T=0$, $0\le w_{i,j}^T\le 1$ and $\sum_{j=1}^{N}w_{i,j}^T=1$. Furthermore, the terms of trade $\mathcal{T}_{i,t}$ equals the ratio of the internal terms of trade to the external terms of trade,

$$\mathcal{T}_{i,t}=\frac{\mathcal{T}_{i,t}^{X}}{\mathcal{T}_{i,t}^{M}},\ \mathcal{T}_{i,t}^{X}=\frac{P_{i,t}^{X}}{P_{i,t}},\ \mathcal{T}_{i,t}^{M}=\frac{P_{i,t}^{M}}{P_{i,t}}, \quad (46)$$

where the internal terms of trade $\mathcal{T}_{i,t}^{X}$ measures the relative price of exports, and the external terms of trade $\mathcal{T}_{i,t}^{M}$ 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 $\mathcal{E}_{i*,i,t}P_{i,k,t}^{Y}=P_{k,t}^{Y}$ for $1\le k\le M*$, which implies that

$$P_{k,t}^{Y} = \sum_{i=1}^{N} w_i^Y \mathcal{E}_{i*,i,t} P_{i,k,t}^{Y}, \tag{47}$$

where $P_{k,t}^{Y}$ denotes the quotation currency denominated price of energy or nonenergy commodities, and world output weight w_i^Y satisfies $0 < w_i^Y < 1$ and $\sum_{i=1}^{N} w_i^Y = 1$.

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 fixed proportions production function

$$X_{i,t} = \min\left\{ \frac{X_{i,k,t}}{\phi_{i,k}^{X}} \right\}_{k=1}^{M}, \tag{48}$$

where $X_{i,k,t} = Y_{i,k,t}$ for $1 \le k \le M*$, while $0 \le \phi_{i,k}^{X} \le 1$ and $\sum_{k=1}^{M} \phi_{i,k}^{X} = 1$. 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:

$$X_{i,k,t} = \phi_{i,k}^{X} X_{i,t}. \tag{49}$$

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:

$$P_{i,t}^{X} = \sum_{k=1}^{M} \phi_{i,k}^{X} P_{i,k,t}^{Y}. \tag{50}$$

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 $Z_{i,t}^{h} \in \{C_{i,t}^{h}, I_{i,t}^{h}, G_{i,t}^{h}\}$ with the final import good $Z_{i,t}^{f} \in \{C_{i,t}^{f}, I_{i,t}^{f}, G_{i,t}^{f}\}$ to produce final private consumption, private investment or public consumption good $Z_{i,t} \in \{C_{i,t}, I_{i,t}, G_{i,t}\}$ according to constant elasticity of substitution production function

$$Z_{i,t} = \left[(\phi_{i,Y}^{D})^{\frac{1}{\psi^M}} (Z_{i,t}^{h})^{\frac{\psi^M - 1}{\psi^M}} + (\phi_{i,M}^{D})^{\frac{1}{\psi^M}} (\nu_{i,t}^{M} Z_{i,t}^{f})^{\frac{\psi^M - 1}{\psi^M}} \right]^{\frac{\psi^M}{\psi^M - 1}}, \tag{51}$$

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 absorption good firm maximizes profits derived from production of the final private consumption, private investment or public consumption good, with respect to inputs of the final noncommodity output and import goods, implying demand functions:

$$Z_{i,t}^{h} = \phi_{i,Y}^{D} \left(\frac{P_{i,t}}{P_{i,t}^{Z}} \right)^{-\psi^{M}} Z_{i,t},\ Z_{i,t}^{f} = \phi_{i,M}^{D} \left(\frac{1}{\nu_{i}^{M}} \frac{P_{i,t}^{M}}{P_{i,t}^{Z}} \right)^{-\psi^{M}} \frac{Z_{i,t}}{\nu_{i,t}^{M}}. \tag{52}$$

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

$$P_{i,t}^{Z} = \left[\phi_{i,Y}^{D} (P_{i,t})^{1-\psi^{M}} + \phi_{i,M}^{D} \left(\frac{P_{i,t}^{M}}{\nu_{i}^{M}} \right)^{1-\psi^{M}} \right]^{\frac{1}{1-\psi^{M}}}. \tag{53}$$

Combination of this aggregate private consumption, private investment or public consumption price index with final noncommodity output and import good demand functions (52) yields:

$$Z_{i,t}^{h} = \phi_{i,Y}^{D} \left[\phi_{i,Y}^{D} + \phi_{i,M}^{D} \left(\frac{\mathcal{T}_{i,t}^{M}}{\nu_{i}^{M}} \right)^{1-\psi^{M}} \right]^{\frac{\psi^{M}}{1-\psi^{M}}} Z_{i,t},\ Z_{i,t}^{f} = \phi_{i,M}^{D} \left[\phi_{i,M}^{D} + \phi_{i,Y}^{D} \left(\frac{\mathcal{T}_{i,t}^{M}}{\nu_{i}^{M}} \right)^{\psi^{M}-1} \right]^{\frac{\psi^{M}}{1-\psi^{M}}} \frac{Z_{i,t}}{\nu_{i,t}^{M}}. \tag{54}$$

These demand functions for the final noncommodity output and import goods are directly proportional to final private consumption, private investment or public consumption good demand, with a proportionality coefficient that varies with the external terms of trade. The derivation of these results selectively abstracts from import demand shocks.

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 fixed proportions production function

$$M_{i,t} = \min \left\{ \nu_{j,t}^{X} \frac{M_{i,j,t}}{\phi_{i,j}^{M}} \right\}_{j=1}^{N}, \tag{55}$$

where serially correlated export demand shock $\nu_{i,t}^{X}$ satisfies $\nu_{i,t}^{X} > 0$, while $\phi_{i,i}^{M} = 0$, $0 \leq \phi_{i,j}^{M} \leq 1$ 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:

$$M_{i,j,t} = \phi_{i,j}^{M} \frac{M_{i,t}}{\nu_{j,t}^{X}}. \tag{56}$$

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:

$$P_{i,t}^{M} = \sum_{j=1}^{N} \phi_{i,j}^{M} \frac{P_{i,j,t}^{M}}{\nu_{j}^{X}}. \tag{57}$$

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. The derivation of these results selectively abstracts from export demand shocks.

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

$$M_{i,j,t} = \left[\int_0^1 (M_{i,j,l,t})^{\frac{\theta_{i,t}^M - 1}{\theta_{i,t}^M}} dl \right]^{\frac{\theta_{i,t}^M}{\theta_{i,t}^M - 1}}, \tag{58}$$

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:

$$M_{i,j,l,t} = \left(\frac{P_{i,j,l,t}^M}{P_{i,j,t}^M} \right)^{-\theta_{i,t}^M} M_{i,j,t}. \tag{59}$$

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:

$$P_{i,j,t}^M = \left[\int_0^1 (P_{i,j,l,t}^M)^{1-\theta_{i,t}^M} dl \right]^{\frac{1}{1-\theta_{i,t}^M}}. \tag{60}$$

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. Entry into and exit from the monopolistically competitive economy specific intermediate import good sectors is prohibited.

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 capitalist spirit motive equals the expected present value of current and future dividend payments:

$$\Pi^M_{i,j,l,t} + V^M_{i,j,l,t} = \mathrm{E}_t \sum_{s=t}^{\infty} \frac{\beta^{s-t} \lambda_{i,s}}{\lambda_{i,t}} \Pi^M_{i,j,l,s}. \tag{61}$$

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 $\Pi^M_{i,j,l,s}$, defined as earnings less economy specific fixed cost $F^M_{i,j,s}$:

$$\Pi^M_{i,j,l,s} = P^M_{i,j,l,s} M_{i,j,l,s} - \mathcal{E}_{i,j,s} P^X_{j,s} M_{i,j,l,s} - F^M_{i,j,s}. \tag{62}$$

Earnings are defined as revenues derived from sales of economy specific differentiated intermediate import good $M_{i,j,l,s}$ at price $P^M_{i,j,l,s}$ 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. Fixed cost $F^M_{i,j,s}$ ensures that $\Pi^M_{i,j,s} = 0$.

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 $0 \leq \omega^M < 1$. 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

$$P^M_{i,j,l,t} = \left[\left(\frac{P^M_{i,j,t-1}}{P^M_{i,j,t-2}} \right)^{1-\mu^M_i} \prod_{k=1}^{M^*} \left(\frac{\mathcal{E}_{i,i^*,t} P^Y_{k,t}}{\mathcal{E}_{i,i^*,t-1} P^Y_{k,t-1}} \right)^{\mu^M_{i,k}} \right]^{\gamma^M} \left[\left(\frac{\bar{P}^M_{i,j,t-1}}{\bar{P}^M_{i,j,t-2}} \right)^{1-\mu^M_i} \prod_{k=1}^{M^*} \left(\frac{\bar{\mathcal{E}}_{i,i^*,t} \bar{P}^Y_{k,t}}{\bar{\mathcal{E}}_{i,i^*,t-1} \bar{P}^Y_{k,t-1}} \right)^{\mu^M_{i,k}} \right]^{1-\gamma^M} P^M_{i,j,l,t-1}, \tag{63}$$

where $0 \leq \gamma^M \leq 1$, while $\mu^M_i = \sum_{k=1}^{M^*} \mu^M_{i,k}$ with $\mu^M_{i,k} = \mu^M \frac{\bar{M}_{i,k,t}}{\bar{M}_{i,t}}$ and $\mu^M \geq 0$. 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 (61) subject to economy specific intermediate import good demand function (59), 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 $P^{M,*}_{i,j,t}$ given by necessary first order condition:

$$\frac{P^{M,*}_{i,j,t}}{P^M_{i,j,t}} = \frac{\mathrm{E}_t \sum_{s=t}^{\infty} (\omega^M)^{s-t} \frac{\beta^{s-t}\lambda_{i,s}}{\lambda_{i,t}} \theta^M_{i,s} \frac{\mathcal{E}_{i,j,s} P^X_{j,s}}{P^M_{i,j,s}} \left\{ \left[\left(\frac{P^M_{i,j,t-1}}{P^M_{i,j,s-1}} \right)^{1-\mu^M_i} \prod_{k=1}^{M^*} \left(\frac{\mathcal{E}_{i,i^*,t} P^Y_{k,t}}{\mathcal{E}_{i,i^*,s} P^Y_{k,s}} \right)^{\mu^M_{i,k}} \right]^{\gamma^M} \left[\left(\frac{\bar{P}^M_{i,j,t-1}}{\bar{P}^M_{i,j,s-1}} \right)^{1-\mu^M_i} \prod_{k=1}^{M^*} \left(\frac{\bar{\mathcal{E}}_{i,i^*,t} \bar{P}^Y_{k,t}}{\bar{\mathcal{E}}_{i,i^*,s} \bar{P}^Y_{k,s}} \right)^{\mu^M_{i,k}} \right]^{1-\gamma^M} \frac{P^M_{i,j,s}}{P^M_{i,j,t}} \right\}^{\theta^M_{i,s}} \left(\frac{P^{M,*}_{i,j,t}}{P^M_{i,j,t}} \right)^{-\theta^M_{i,s}} P^M_{i,j,s} M_{i,j,s}}{\mathrm{E}_t \sum_{s=t}^{\infty} (\omega^M)^{s-t} \frac{\beta^{s-t}\lambda_{i,s}}{\lambda_{i,t}} (\theta^M_{i,s} - 1) \left\{ \left[\left(\frac{P^M_{i,j,t-1}}{P^M_{i,j,s-1}} \right)^{1-\mu^M_i} \prod_{k=1}^{M^*} \left(\frac{\mathcal{E}_{i,i^*,t} P^Y_{k,t}}{\mathcal{E}_{i,i^*,s} P^Y_{k,s}} \right)^{\mu^M_{i,k}} \right]^{\gamma^M} \left[\left(\frac{\bar{P}^M_{i,j,t-1}}{\bar{P}^M_{i,j,s-1}} \right)^{1-\mu^M_i} \prod_{k=1}^{M^*} \left(\frac{\bar{\mathcal{E}}_{i,i^*,t} \bar{P}^Y_{k,t}}{\bar{\mathcal{E}}_{i,i^*,s} \bar{P}^Y_{k,s}} \right)^{\mu^M_{i,k}} \right]^{1-\gamma^M} \frac{P^M_{i,j,s}}{P^M_{i,j,t}} \right\}^{\theta^M_{i,s}-1} \left(\frac{P^{M,*}_{i,j,t}}{P^M_{i,j,t}} \right)^{-\theta^M_{i,s}} P^M_{i,j,s} M_{i,j,s}}. \tag{64}$$

This necessary first order condition equates the expected present value of the marginal revenue gained from import supply to the expected present value of the marginal cost incurred from production. Aggregate import price index (60) 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 (63):

$$P_{i,j,t}^{M} = \left\{ (1-\omega^M)(P_{i,j,t}^{M,*})^{1-\theta_{i,t}^M} + \omega^M \left\{ \left[\left(\frac{P_{i,j,t-1}^M}{P_{i,j,t-2}^M} \right)^{1-\mu_i^M} \prod_{k=1}^{M*} \left(\frac{\mathcal{E}_{i,i*,t} P_{k,t}^Y}{\mathcal{E}_{i,i*,t-1} P_{k,t-1}^Y} \right)^{\mu_{i,k}^M} \right]^{\gamma^M} \left[\left(\frac{\bar{P}_{i,j,t-1}^M}{\bar{P}_{i,j,t-2}^M} \right)^{1-\mu_i^M} \prod_{k=1}^{M*} \left(\frac{\bar{\mathcal{E}}_{i,i*,t} \bar{P}_{k,t}^Y}{\bar{\mathcal{E}}_{i,i*,t-1} \bar{P}_{k,t-1}^Y} \right)^{\mu_{i,k}^M} \right]^{1-\gamma^M} P_{i,j,t-1}^M \right\}^{1-\theta_{i,t}^M} \right\}^{\frac{1}{1-\theta_{i,t}^M}}. \quad (65)$$

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

$$\begin{aligned} i_{i,t}^P - \bar{i}_{i,t}^P = \rho_j^i (i_{i,t-1}^P - \bar{i}_{i,t-1}^P) + (1-\rho_j^i) \Big[\xi_j^\pi (\pi_{i,t}^C - \bar{\pi}_{i,t}^C) + \xi_j^Y (\ln Y_{i,t} - \ln \bar{Y}_{i,t}) + \xi_j^Q (\ln Q_{i,t} - \ln \bar{Q}_{i,t}) \\ + \xi_j^i (i_{k,t}^P - \bar{i}_{k,t}^P) + \xi_j^{\mathcal{E}} (\ln \mathcal{E}_{i,k,t} - \ln \bar{\mathcal{E}}_{i,k,t}) \Big] + \nu_{i,t}^{i^P}, \end{aligned} \quad (66)$$

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 instead tracks the contemporaneous deviation of the nominal policy interest rate for the economy that issues the anchor currency from its steady state equilibrium value one for one with $\xi_j^i = 1$, while responding to any contemporaneous deviation of the corresponding nominal bilateral exchange rate from its target value one for one 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 $v_{i,t}^{i^P}$.

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

$$\frac{G_{i,t}}{\bar{Y}_{i,t}} - \frac{\bar{G}_{i,t}}{\bar{Y}_{i,t}} = \rho_G \left(\frac{G_{i,t-1}}{\bar{Y}_{i,t-1}} - \frac{\bar{G}_{i,t-1}}{\bar{Y}_{i,t-1}} \right) + (1-\rho_G)\zeta^G \left(\frac{A_{i,t+1}^G}{P_{i,t}^Y Y_{i,t}} - \frac{\bar{A}_{i,t+1}^G}{\bar{P}_{i,t}^Y \bar{Y}_{i,t}} \right) + v_{i,t}^G, \tag{67}$$

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 public 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 $v_{i,t}^G$.

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

$$\tau_{i,t} - \bar{\tau}_{i,t} = \rho_\tau (\tau_{i,t-1} - \bar{\tau}_{i,t-1}) + (1-\rho_\tau)\zeta^\tau \left(\frac{A_{i,t+1}^G}{P_{i,t}^Y Y_{i,t}} - \frac{\bar{A}_{i,t+1}^G}{\bar{P}_{i,t}^Y \bar{Y}_{i,t}} \right) + v_{i,t}^T, \tag{68}$$

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 $v_{i,t}^T$.

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

$$i_{i,t}^{S} = i_{i,t}^{P} + \zeta^{i} \frac{A_{i,t+1}}{P_{i,t}^{Y} Y_{i,t}} + \upsilon_{i,t}^{i^S}, \tag{69}$$

where $\zeta^{i} < 0$. As specified, the spread between the yield to maturity on short term bonds and the nominal policy interest rate is decreasing in the contemporaneous ratio of national financial wealth to nominal output. For economies belonging to a currency block, the ratio of national financial wealth to nominal output is expressed as an output weighted average across block members. 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:

$$A_{i,t+1}^{G} = (1+i_{i,t}^{A^G})A_{i,t}^{G} + \int_0^1 \tau_{i,t} \int_0^1 W_{f,i,t} L_{h,f,i,t} \, df \, dh + \sum_{k=1}^{M} \int_0^1 \tau_{i,t} (P_{i,k,l,t}^{Y} Y_{i,k,l,t} - W_{i,t} L_{i,k,l,t}) dl - P_{i,t}^{G} G_{i,t}. \tag{70}$$

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, firms and the government,

$$X_{i,t} = Y_{i,t} - C_{i,t}^{h} - I_{i,t}^{h} - G_{i,t}^{h}, \tag{71}$$

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, firms and the government:

$$M_{i,t} = C_{i,t}^{f} + I_{i,t}^{f} + G_{i,t}^{f}. \tag{72}$$

In equilibrium, combination of these final output and import good market clearing conditions yields output expenditure decomposition,

$$P_{i,t}^{Y} Y_{i,t} = P_{i,t}^{C} C_{i,t} + P_{i,t}^{I} I_{i,t} + P_{i,t}^{G} G_{i,t} + P_{i,t}^{X} X_{i,t} - P_{i,t}^{M} M_{i,t}, \tag{73}$$

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

Let $A_{i,t+1}$ denote the net foreign asset position, which equals the sum of the financial wealth of households $A_{i,t+1}^{H}$, firms $A_{i,t+1}^{F}$ and the government $A_{i,t+1}^{G}$,

$$A_{i,t+1} = A_{i,t+1}^{H} + A_{i,t+1}^{F} + A_{i,t+1}^{G}, \tag{74}$$

where $A_{i,t+1}^{F} = -V_{i,t}^{S}$. Imposing equilibrium conditions on government dynamic budget constraint (70) 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 $PB_{i,t} = \tau_{i,t} P_{i,t}^{Y} Y_{i,t} - P_{i,t}^{G} G_{i,t}$,

$$FB_{i,t} = \left[\frac{B_{i,i}^{S,G}}{A_{i}^{G}} i_{i,t-1}^{S} + \frac{B_{i,i}^{L,G}}{A_{i}^{G}} i_{i,t-1}^{L,E} \right] A_{i,t}^{G} + PB_{i,t}, \tag{75}$$

where effective long term nominal market interest rate $i_{i,t}^{L,E}$ satisfies $i_{i,t}^{L,E} = \chi^{G} i_{i,t-1}^{L,E} + (1-\chi^{G}) i_{i,t}^{L}$ with $0 \leq \chi^{G} < 1$. The derivation of this result abstracts from capital gains on long term bond holdings, and imposes restrictions $V_{i,k-1,t-1}^{B} B_{i,i,k-1,t}^{L,G} = \chi^{G} V_{i,k,t-1}^{B} B_{i,i,k,t}^{L,G}$, $B_{i,i,t}^{S,G} / A_{i,t}^{G} = B_{i,i}^{S,G} / A_{i}^{G}$ and $B_{i,i,t}^{L,G} / A_{i,t}^{G} = B_{i,i}^{L,G} / A_{i}^{G}$. Imposing equilibrium conditions on household dynamic budget constraint (10), and combining it with government dynamic budget constraint (75), net profit definition (32), and output expenditure decomposition (73), reveals that the increase in net foreign assets equals national saving less investment expenditures, or equivalently that the current account balance $CA_{i,t} = \mathcal{E}_{i*,i,t} A_{i,t+1} - \mathcal{E}_{i*,i,t-1} A_{i,t}$ equals the sum of net international investment income and the trade balance $TB_{i,t} = \mathcal{E}_{i*,i,t} P_{i,t}^{X} X_{i,t} - \mathcal{E}_{i*,i,t} P_{i,t}^{M} M_{i,t}$,

$$CA_{i,t} = \left\{ \sum_{j=1}^{N} w_{j}^{M} \left[(1 + i_{j,t-1}^{S}) \frac{\mathcal{E}_{i*,j,t}}{\mathcal{E}_{i*,j,t-1}} - 1 \right] \right\} \mathcal{E}_{i*,i,t-1} A_{i,t} + TB_{i,t}, \tag{76}$$

where world money market capitalization weight w_{i}^{M} satisfies $0 < w_{i}^{M} < 1$ and $\sum_{i=1}^{N} w_{i}^{M} = 1$. The derivation of this result abstracts from foreign long term bond and stock holdings, and imposes restriction $\frac{\mathcal{E}_{i,j,t-1} B_{i,j,t}^{S}}{A_{i,t}} = w_{j}^{M}$.

III. THE EMPIRICAL FRAMEWORK

Estimation, inference and forecasting are based on a linear state space representation of an approximate multivariate linear rational expectations representation of this panel dynamic stochastic general equilibrium model of the world economy. This multivariate linear rational expectations representation is derived by linearizing the equilibrium conditions of this panel dynamic stochastic general equilibrium model around its stationary deterministic steady state equilibrium, and consolidating them by substituting out intermediate variables assuming small capital utilization costs. Unless stated otherwise, this steady state equilibrium abstracts from long run balanced growth, and features zero inflation and net financial asset holdings.[2]

In what follows, $\hat{x}_{i,t}$ denotes the deviation of variable $x_{i,t}$ from its steady state equilibrium value, while $\mathrm{E}_t\, x_{i,t+s}$ denotes the rational expectation of variable $x_{i,t+s}$ conditional on information available in period t. 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 $Z = T$. Furthermore, 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. Endogenous Variables

Output price inflation $\hat{\pi}_{i,t}^{Y}$ depends on a linear combination of its past and expected future values driven by the contemporaneous labor income share, output, and the internal terms of trade according to output price Phillips curve:

$$\begin{aligned}\hat{\pi}_{i,t}^{Y} = {} & \frac{\gamma^{Y}}{1+\gamma^{Y}\beta}\hat{\pi}_{i,t-1}^{Y} + \frac{\beta}{1+\gamma^{Y}\beta}\mathrm{E}_t\hat{\pi}_{i,t+1}^{Y} + \frac{(1-\omega^{Y})(1-\omega^{Y}\beta)}{\omega^{Y}(1+\gamma^{Y}\beta)}\left\{\ln\frac{\hat{W}_{i,t}\hat{L}_{i,t}}{\hat{P}_{i,t}^{Y}\hat{Y}_{i,t}}\right. \\ & \left. + \left[1-\left(1-\frac{X_i}{Y_i}\sum_{k=1}^{M^*}\frac{X_{i,k}}{X_i}\phi_k^{F}\right)^{-1}\right]\ln\hat{Y}_{i,t} + \frac{X_i}{Y_i}\ln\hat{\mathcal{T}}_{i,t}^{X} - \frac{1}{\theta^{Y}-1}\ln\hat{\theta}_{i,t}^{Y}\right\} + \frac{X_i}{Y_i}\mathcal{P}_1(L)\Delta\ln\hat{\mathcal{T}}_{i,t}^{X}.\end{aligned} \tag{77}$$

Output price inflation also depends on contemporaneous, past and expected future changes in 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 and commodity export intensities.

Consumption price inflation $\hat{\pi}_{i,t}^{C}$ depends on a linear combination of its past and expected future values driven by the contemporaneous labor income share, output, and the internal terms of trade according to consumption price Phillips curve:

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

$$\hat{\pi}_{i,t}^{C}=\frac{\gamma^{Y}}{1+\gamma^{Y}\beta}\hat{\pi}_{i,t-1}^{C}+\frac{\beta}{1+\gamma^{Y}\beta}\mathrm{E}_{t}\hat{\pi}_{i,t+1}^{C}+\frac{(1-\omega^{Y})(1-\omega^{Y}\beta)}{\omega^{Y}(1+\gamma^{Y}\beta)}\left\{\ln\frac{\hat{W}_{i,t}\hat{L}_{i,t}}{\hat{P}_{i,t}^{Y}\hat{Y}_{i,t}}\right.$$
$$\left.+\left[1-\left(1-\frac{X_i}{Y_i}\sum_{k=1}^{M*}\frac{X_{i,k}}{X_i}\phi_k^F\right)^{-1}\right]\ln\hat{Y}_{i,t}+\frac{X_i}{Y_i}\ln\hat{\mathcal{T}}_{i,t}^{X}-\frac{1}{\theta^{Y}-1}\ln\hat{\theta}_{i,t}^{Y}\right\}+\frac{M_i}{Y_i}\mathcal{P}_1(L)\Delta\ln\hat{\mathcal{T}}_{i,t}^{M}. \tag{78}$$

Consumption price inflation also depends on contemporaneous, past and expected future changes in the external terms of trade. The response coefficients of this relationship vary across economies with their trade openness and commodity export intensities.

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

$$\ln\hat{Y}_{i,t}=\frac{\alpha}{1+\alpha}\ln\hat{Y}_{i,t-1}+\frac{1}{1+\alpha}\mathrm{E}_t\ln\hat{Y}_{i,t+1}-\left(1-\frac{X_i}{Y_i}\right)\left\{(1-\phi^C)\frac{C_i}{Y_i}\sigma\frac{1-\alpha}{1+\alpha}\mathrm{E}_t\left(\hat{r}_{i,t+1}^{A^H}-\ln\frac{\hat{v}_{i,t}^{C}}{\hat{v}_{i,t+1}^{C}}\right)\right.$$
$$\left.-\phi^C\mathcal{P}_2(L)\left[\frac{\Pi_i^S}{P_i^YY_i}\ln\frac{\hat{\Pi}_{i,t}^S}{\hat{P}_{i,t}^C}+(1-\tau_i)\frac{W_iL_i}{P_i^YY_i}\left(\ln\frac{\hat{W}_{i,t}\hat{L}_{i,t}}{\hat{P}_{i,t}^C}-\frac{1}{1-\tau_i}\hat{\tau}_{i,t}\right)\right]-\mathcal{P}_2(L)\left(\frac{I_i}{Y_i}\ln\hat{I}_{i,t}+\frac{G_i}{Y_i}\ln\hat{G}_{i,t}\right)\right\} \tag{79}$$
$$+\frac{X_i}{Y_i}\mathcal{P}_2(L)\sum_{j=1}^{N}w_{i,j}^X\left\{\ln\frac{\hat{v}_{i,t}^M\hat{D}_{j,t}}{\hat{v}_{i,t}^X\hat{v}_{j,t}^M}-\psi^M\left[\left(1-\frac{M_j}{Y_j}\right)\ln\hat{\mathcal{T}}_{j,t}^M-\left(1-\frac{M_i}{Y_i}\right)\ln\hat{\mathcal{T}}_{i,t}^M\right]\right\}.$$

Reflecting the existence of credit constraints, output also depends on contemporaneous, past and expected future real profit and disposable labor income. In addition, output depends on contemporaneous, past, and expected future investment and public domestic demand. Finally, reflecting the existence of international trade linkages, output depends on contemporaneous, past and expected future 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 composition of their domestic demand, the size of their government, their labor income share, their trade openness, and their trade pattern.

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

$$\ln\hat{D}_{i,t}=\frac{\alpha}{1+\alpha}\ln\hat{D}_{i,t-1}+\frac{1}{1+\alpha}\mathrm{E}_t\ln\hat{D}_{i,t+1}-(1-\phi^C)\frac{C_i}{Y_i}\sigma\frac{1-\alpha}{1+\alpha}\mathrm{E}_t\left(\hat{r}_{i,t+1}^{A^H}-\ln\frac{\hat{v}_{i,t}^{C}}{\hat{v}_{i,t+1}^{C}}\right)$$
$$+\phi^C\mathcal{P}_2(L)\left[\frac{\Pi_i^S}{P_i^YY_i}\ln\frac{\hat{\Pi}_{i,t}^S}{\hat{P}_{i,t}^C}+(1-\tau_i)\frac{W_iL_i}{P_i^YY_i}\left(\ln\frac{\hat{W}_{i,t}\hat{L}_{i,t}}{\hat{P}_{i,t}^C}-\frac{1}{1-\tau_i}\hat{\tau}_{i,t}\right)\right]+\mathcal{P}_2(L)\left(\frac{I_i}{Y_i}\ln\hat{I}_{i,t}+\frac{G_i}{Y_i}\ln\hat{G}_{i,t}\right). \tag{80}$$

Reflecting the existence of credit constraints, domestic demand also depends on contemporaneous, past and expected future real profit and disposable labor income. Finally, domestic demand depends on contemporaneous, past, and expected future investment and public domestic demand. The response coefficients of this relationship vary across economies with the composition of their domestic demand, the size of their government, and their labor income share.

Consumption $\ln \hat{C}_{i,t}$ depends on a weighted average of its past and expected future values driven by the contemporaneous real ex ante portfolio return according to consumption demand relationship:

$$\ln \hat{C}_{i,t} = \frac{\alpha}{1+\alpha} \ln \hat{C}_{i,t-1} + \frac{1}{1+\alpha} \mathrm{E}_t \ln \hat{C}_{i,t+1} - (1-\phi^C)\sigma \frac{1-\alpha}{1+\alpha} \mathrm{E}_t \left(\hat{r}^{A^H}_{i,t+1} - \ln \frac{\hat{v}^C_{i,t}}{\hat{v}^C_{i,t+1}} \right)$$
$$+ \phi^C \left(\frac{C_i}{Y_i} \right)^{-1} \mathcal{P}_2(L) \left[\frac{\Pi^S_i}{P^Y_i Y_i} \ln \frac{\hat{\Pi}^S_{i,t}}{\hat{P}^C_{i,t}} + (1-\tau_i) \frac{W_i L_i}{P^Y_i Y_i} \left(\ln \frac{\hat{W}_{i,t} \hat{L}_{i,t}}{\hat{P}^C_{i,t}} - \frac{1}{1-\tau_i} \hat{\tau}_{i,t} \right) \right]. \quad (81)$$

Reflecting the existence of credit constraints, consumption also depends on contemporaneous, past and expected future real profit and disposable labor income, where polynomial in the lag operator $\mathcal{P}_2(L) = 1 - \frac{\alpha}{1+\alpha} L - \frac{1}{1+\alpha} \mathrm{E}_t L^{-1}$. The response coefficients of this relationship vary across economies with their consumption intensity, the size of their government, and their labor income share.

Investment $\ln \hat{I}_{i,t}$ depends on a weighted average of its past and expected future values driven by the contemporaneous relative shadow price of capital according to investment demand relationship:

$$\ln \hat{I}_{i,t} = \frac{1}{1+\beta} \ln \hat{I}_{i,t-1} + \frac{\beta}{1+\beta} \mathrm{E}_t \ln \hat{I}_{i,t+1} + \frac{1}{\chi^F (1+\beta)} \ln \left(\hat{v}^I_{i,t} \frac{\hat{Q}_{i,t}}{\hat{P}^C_{i,t}} \right). \quad (82)$$

The relative shadow price of capital $\ln \frac{\hat{Q}_{i,t}}{\hat{P}^C_{i,t}}$ depends on its expected future value, as well as the contemporaneous real ex ante portfolio return, according to investment Euler equation:

$$\ln \frac{\hat{Q}_{i,t}}{\hat{P}^C_{i,t}} = \mathrm{E}_t \left[\beta(1-\delta) \ln \frac{\hat{Q}_{i,t+1}}{\hat{P}^C_{i,t+1}} - \hat{r}^{A^H}_{i,t+1} + (1-\beta(1-\delta)) \left(\kappa \ln \hat{u}^K_{i,t+1} - \frac{1}{1-\tau_i} \hat{\tau}_{i,t+1} \right) \right]. \quad (83)$$

The relative shadow price of capital also depends on the expected future capital utilization and output tax rates. The capital utilization rate $\ln \hat{u}^K_{i,t}$ depends on the contemporaneous real wage according to capital utilization relationship:

$$\ln \hat{u}^K_{i,t} = \frac{1}{\kappa} \left(\ln \frac{\hat{W}_{i,t}}{\hat{P}^C_{i,t}} - \ln \frac{\hat{u}^K_{i,t} \hat{K}_{i,t}}{\hat{L}_{i,t}} \right). \quad (84)$$

The capital utilization rate also depends on the contemporaneous deviation of utilized capital from employment. The capital stock $\ln \hat{K}_{i,t+1}$ satisfies $\ln \hat{K}_{i,t+1} = (1-\delta) \ln \hat{K}_{i,t} + \delta \ln(\hat{v}^I_{i,t} \hat{I}_{i,t})$.

Exports $\ln \hat{X}_{i,t}$ depend on contemporaneous export weighted foreign demand, as well as the export weighted average foreign external terms of trade, according to export demand relationship:

$$\ln \hat{X}_{i,t} = \sum_{j=1}^{N} w_{i,j}^{X} \left[\ln \frac{\hat{D}_{j,t}}{\hat{v}_{i,t}^{X} \hat{v}_{j,t}^{M}} - \psi^{M} \left(1 - \frac{M_j}{Y_j} \right) \ln \hat{\mathcal{T}}_{j,t}^{M} \right]. \tag{85}$$

The response coefficients of this relationship vary across economies with their trade pattern and the trade openness of their trading partners.

Imports $\ln \hat{M}_{i,t}$ depend on contemporaneous domestic demand, as well as the domestic external terms of trade, according to import demand relationship:

$$\ln \hat{M}_{i,t} = \ln \frac{\hat{D}_{i,t}}{\hat{v}_{i,t}^{M}} - \psi^{M} \left(1 - \frac{M_i}{Y_i} \right) \ln \hat{\mathcal{T}}_{i,t}^{M}. \tag{86}$$

The response coefficients of this relationship vary across economies with their trade openness.

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

$$\mathrm{E}_t \hat{i}_{i,t+1}^{A^H} = \hat{i}_{i,t}^{S} - \chi^{H} \left[\frac{B_i^{L,H}}{A_i^{H}} \sum_{j=1}^{N} w_{i.j}^{B} \left(\ln \hat{\upsilon}_{j,t}^{B} - \frac{B_i^{H}}{B_i^{L,H}} \ln \frac{\hat{v}_{i,t}^{\mathcal{E}}}{\hat{v}_{j,t}^{\mathcal{E}}} \right) + \frac{S_i^{H}}{A_i^{H}} \sum_{j=1}^{N} w_{i,j}^{S} \left(\ln \hat{\upsilon}_{j,t}^{S} - \ln \frac{\hat{v}_{i,t}^{\mathcal{E}}}{\hat{v}_{j,t}^{\mathcal{E}}} \right) \right]. \tag{87}$$

Reflecting the existence of internal and external macrofinancial linkages, 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 parameter χ^{H} is theoretically predicted to equal one, and satisfies $\chi^{H} > 0$. The response coefficients of this relationship vary across economies with their domestic and foreign financial exposures. The real ex ante portfolio return $\mathrm{E}_t \hat{r}_{i,t+1}^{A^H}$ satisfies $\mathrm{E}_t \hat{r}_{i,t+1}^{A^H} = \mathrm{E}_t \hat{i}_{i,t+1}^{A^H} - \mathrm{E}_t \hat{\pi}_{i,t+1}^{C}$.

The nominal policy interest rate $\hat{i}_{i,t}^{P}$ depends on a weighted average of its past and desired values according to monetary policy rule:

$$\hat{i}_{i,t}^{P} = \rho_j^{i} \hat{i}_{i,t-1}^{P} + (1-\rho_j^{i})(\xi_j^{\pi} \hat{\pi}_{i,t}^{C} + \xi_j^{Y} \ln \hat{Y}_{i,t} + \xi_j^{Q} \ln \hat{\mathcal{Q}}_{i,t} + \xi_j^{i} \hat{i}_{k,t}^{P} + \xi_j^{\mathcal{E}} \ln \hat{\mathcal{E}}_{i,k,t}) + \hat{v}_{i,t}^{i^P}. \tag{88}$$

Under a flexible inflation targeting regime $j = 0$, and the desired nominal policy interest rate responds to contemporaneous consumption price inflation and output. Under a managed exchange rate regime $j = 1$, and it also responds to the contemporaneous real effective exchange rate. Under a fixed exchange rate regime $j = 2$, and the nominal policy interest rate instead tracks the contemporaneous nominal policy interest rate for the economy that issues the anchor currency one for one, while responding to the contemporaneous corresponding nominal bilateral exchange rate one for one. 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 real policy interest rate $\hat{r}_{i,t}^{P}$ satisfies $\hat{r}_{i,t}^{P} = \hat{i}_{i,t}^{P} - \mathrm{E}_t \hat{\pi}_{i,t+1}^{C}$.

The short term nominal market interest rate $\hat{i}^S_{i,t}$ depends on the contemporaneous nominal policy interest rate and the net foreign asset ratio according to money market relationship,

$$\hat{i}^S_{i,t} = \hat{i}^P_{i,t} + \zeta^i \frac{\hat{A}_{i,t+1}}{P^Y_{i,t} Y_{i,t}} + \hat{\upsilon}^{i^S}_{i,t}, \tag{89}$$

where credit risk premium shock $\hat{\upsilon}^{i^S}_{i,t} = \lambda^M_k \sum_{j=1}^N w^M_j \hat{\nu}^{i^S}_{j,t} + (1-\lambda^M_k w^M_i)\hat{\nu}^{i^S}_{i,t}$. The intensity of international money market contagion varies across economies, with $k = 0$ for advanced economies, $k = 1$ for internationally financially integrated emerging economies, and $k = 2$ for internationally financially unintegrated emerging economies. For economies belonging to a currency block, the ratio of national financial wealth to nominal output is expressed as an output weighted average across block members. 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 long term nominal market interest rate $\hat{i}^L_{i,t}$ depends on a weighted average of its expected future value and the contemporaneous short term nominal market interest rate according to bond market relationship,

$$\hat{i}^L_{i,t} = \beta \mathrm{E}_t \hat{i}^L_{i,t+1} + (1-\beta)(\hat{i}^S_{i,t} - \ln \hat{\upsilon}^B_{i,t}), \tag{90}$$

where duration risk premium shock $\ln \hat{\upsilon}^B_{i,t} = \lambda^B_k \sum_{j=1}^N w^B_j \ln \hat{\nu}^B_{j,t} + (1-\lambda^B_k w^B_i) \ln \hat{\nu}^B_{i,t}$. The intensity of international bond market contagion varies across economies, with $k = 0$ for advanced economies, $k = 1$ for internationally financially integrated emerging economies, and $k = 2$ for internationally financially unintegrated emerging economies. The long term real market interest rate $\hat{r}^L_{i,t}$ satisfies the same bond market relationship, driven by the contemporaneous short term real market interest rate.

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

$$\ln \hat{V}^S_{i,t} = \beta \mathrm{E}_t \ln \hat{V}^S_{i,t+1} + (1-\beta)\mathrm{E}_t \ln \hat{\Pi}^S_{i,t+1} - (\hat{i}^S_{i,t} - \ln \hat{\upsilon}^S_{i,t}), \tag{91}$$

where equity risk premium shock $\ln \hat{\upsilon}^S_{i,t} = \lambda^S_k \sum_{j=1}^N w^S_j \ln \hat{\nu}^S_{j,t} + (1-\lambda^S_k w^S_i) \ln \hat{\nu}^S_{i,t}$. The intensity of international stock market contagion varies across economies, with $k = 0$ for advanced economies, $k = 1$ for internationally financially integrated emerging economies, and $k = 2$ for internationally financially unintegrated emerging economies.

Real profits $\ln \frac{\hat{\Pi}^S_{i,t}}{\hat{P}^Y_{i,t}}$ depends on contemporaneous output, the labor income share and the output tax rate, as well as the deviation of investment from output and the terms of trade, according to profit function:

$$\ln \frac{\hat{\Pi}^S_{i,t}}{\hat{P}^Y_{i,t}} = \ln \hat{Y}_{i,t} - \left(\frac{\Pi^S_i}{P^Y_i Y_i}\right)^{-1} \left[(1-\tau_i)\frac{W_i L_i}{P^Y_i Y_i} \ln \frac{\hat{W}_{i,t}\hat{L}_{i,t}}{\hat{P}^Y_{i,t}\hat{Y}_{i,t}} + \left(1 - \frac{W_i L_i}{P^Y_i Y_i}\right)\hat{\tau}_{i,t} + \frac{I_i}{Y_i}\left(\ln \frac{\hat{I}_{i,t}}{\hat{Y}_{i,t}} - \frac{X_i}{Y_i} \ln \frac{\hat{\mathcal{T}}^X_{i,t}}{\hat{\mathcal{T}}^M_{i,t}}\right)\right]. \tag{92}$$

The response coefficients of this relationship vary across economies with the size of their government, their labor income share, their investment intensity, and their trade openness.

The real wage $\ln \frac{\hat{W}_{i,t}}{\hat{P}^C_{i,t}}$ depends on a weighted average of its past and expected future values driven by the contemporaneous unemployment rate according to wage Phillips curve:

$$\ln \frac{\hat{W}_{i,t}}{\hat{P}^C_{i,t}} = \frac{1}{1+\beta} \ln \frac{\hat{W}_{i,t-1}}{\hat{P}^C_{i,t-1}} + \frac{\beta}{1+\beta} \mathrm{E}_t \ln \frac{\hat{W}_{i,t+1}}{\hat{P}^C_{i,t+1}} - \frac{(1-\omega^L)(1-\omega^L\beta)}{\omega^L(1+\beta)} \left(\frac{1}{\eta} \hat{u}^L_{i,t} + \frac{1}{\theta^L - 1} \ln \hat{\theta}^L_{i,t} \right) - \frac{1+\gamma^L\beta}{1+\beta} \mathcal{P}_3(L) \hat{\pi}^C_{i,t}. \tag{93}$$

The real wage also depends on contemporaneous, past and expected future consumption price inflation, where polynomial in the lag operator $\mathcal{P}_3(L) = 1 - \frac{\gamma^L}{1+\gamma^L\beta} L - \frac{\beta}{1+\gamma^L\beta} \mathrm{E}_t L^{-1}$. The unemployment rate $\hat{u}^L_{i,t}$ satisfies $\hat{u}^L_{i,t} = \ln \hat{N}_{i,t} - \ln \hat{L}_{i,t}$.

The labor force $\ln \hat{N}_{i,t}$ depends on contemporaneous employment and the after tax real wage according to labor supply relationship:

$$\ln \hat{N}_{i,t} = \frac{\eta}{\iota} \ln \hat{L}_{i,t} + \eta \left[\ln \frac{\hat{W}_{i,t}}{\hat{P}^C_{i,t}} - \frac{1}{1-\tau_i} \hat{\tau}_{i,t} - \ln \hat{v}^L_{i,t} \right]. \tag{94}$$

Employment $\ln \hat{L}_{i,t}$ depends on contemporaneous output and the utilized capital stock according to production function:

$$\ln \hat{Y}_{i,t} = \left(1 - \frac{X_i}{Y_i} \sum_{k=1}^{M^*} \frac{X_{i,k}}{X_i} \phi^F_k - \frac{\theta^Y}{\theta^Y - 1} \frac{W_i L_i}{P^Y_i Y_i} \right) \ln(\hat{u}^K_{i,t} \hat{K}_{i,t}) + \frac{\theta^Y}{\theta^Y - 1} \frac{W_i L_i}{P^Y_i Y_i} \ln(\hat{\mathcal{A}}_{i,t} \hat{L}_{i,t}). \tag{95}$$

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

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

$$\ln \hat{\mathcal{E}}_{i,i*,t} = \mathrm{E}_t \ln \hat{\mathcal{E}}_{i,i*,t+1} - \left[(\hat{i}^S_{i,t} - \hat{i}^S_{i*,t}) + \ln \frac{\hat{v}^{\mathcal{E}}_{i,t}}{\hat{v}^{\mathcal{E}}_{i*,t}} \right]. \tag{96}$$

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 real bilateral exchange rate $\ln \hat{\mathcal{Q}}_{i,i*,t}$ satisfies $\ln \hat{\mathcal{Q}}_{i,i*,t} = \ln \hat{\mathcal{E}}_{i,i*,t} + \ln \hat{P}^Y_{i*,t} - \ln \hat{P}^Y_{i,t}$.[3]

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

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

$$\ln \hat{\mathcal{T}}_{i,t}^{X} = \left(1 - \frac{X_i}{Y_i}\sum_{k=1}^{M*}\frac{X_{i,k}}{X_i}\right)^{-1}\sum_{k=1}^{M*}\frac{X_{i,k}}{X_i}\ln\frac{\hat{\mathcal{E}}_{i,i*,t}\hat{P}_{k,t}^{Y}}{\hat{P}_{i,t}^{Y}}. \tag{97}$$

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

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

$$\begin{aligned}\Delta \ln \hat{\mathcal{T}}_{i,t}^{M} &= \frac{\gamma^{M}(1-\mu_i^{M})}{1+\gamma^{M}\beta(1-\mu_i^{M})}\Delta\ln\hat{\mathcal{T}}_{i,t-1}^{M} + \frac{\beta}{1+\gamma^{M}\beta(1-\mu_i^{M})}\mathrm{E}_t\Delta\ln\hat{\mathcal{T}}_{i,t+1}^{M} \\ &\quad + \frac{(1-\omega^{M})(1-\omega^{M}\beta)}{\omega^{M}(1+\gamma^{M}\beta(1-\mu_i^{M}))}\left\{\sum_{j=1}^{N} w_{i,j}^{M}\left[\ln\frac{\hat{\mathcal{Q}}_{i,j,t}}{\hat{\mathcal{T}}_{i,t}^{M}} + \frac{X_i}{Y_i}\ln\hat{\mathcal{T}}_{i,t}^{X} + \left(1-\frac{X_j}{Y_j}\right)\ln\hat{\mathcal{T}}_{j,t}^{X}\right] - \frac{1}{\theta^{M}-1}\ln\hat{\theta}_{i,t}^{M}\right\} \\ &\quad - \mathcal{P}_4(L)\left(\hat{\pi}_{i,t}^{Y} - \frac{X_i}{Y_i}\Delta\ln\hat{\mathcal{T}}_{i,t}^{X}\right) + \frac{\gamma^{M}(1+\beta)}{1+\gamma^{M}\beta(1-\mu_i^{M})}\sum_{k=1}^{M*}\mu_{i,k}^{M}\mathcal{P}_5(L)\ln(\hat{\mathcal{E}}_{i,i*,t}\hat{P}_{k,t}^{Y}).\end{aligned} \tag{98}$$

The change in the external terms of trade also depends on the contemporaneous domestic and import weighted average foreign internal terms of trade. In addition, the change in the external terms of trade depends on contemporaneous, past and expected future output price inflation and the change in the internal terms of trade, where polynomial in the lag operator $\mathcal{P}_4(L) = 1 - \frac{\gamma^{M}(1-\mu_i^{M})}{1+\gamma^{M}\beta(1-\mu_i^{M})}L - \frac{\beta}{1+\gamma^{M}\beta(1-\mu_i^{M})}\mathrm{E}_t L^{-1}$. Finally, the change in the external terms of trade depends on the contemporaneous, past and expected future domestic currency denominated prices of energy and nonenergy commodities. The response coefficients of this relationship vary across economies with their trade openness, their trade pattern, and their commodity import intensities.

Public domestic demand $\ln \hat{G}_{i,t}$ depends on a weighted average of its past and desired values according to fiscal expenditure rule:

$$\ln\hat{G}_{i,t} = \rho_G \ln\hat{G}_{i,t-1} + (1-\rho_G)\zeta^{G}\left(\frac{G_i}{Y_i}\right)^{-1}\frac{\hat{A}_{i,t+1}^{G}}{P_{i,t}^{Y}Y_{i,t}} + \left(\frac{G_i}{Y_i}\right)^{-1}\hat{\nu}_{i,t}^{G}. \tag{99}$$

Desired public domestic demand responds to the contemporaneous net government asset ratio. The response coefficients of this relationship vary across economies with the size of their government.

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

$$\hat{\tau}_{i,t} = \rho_\tau \hat{\tau}_{i,t-1} + (1-\rho_\tau)\zeta^\tau \frac{\hat{A}^G_{i,t+1}}{P^Y_{i,t} Y_{i,t}} + \hat{v}^T_{i,t}. \tag{100}$$

The desired output tax rate responds to the contemporaneous net government asset ratio.

The fiscal balance ratio $\frac{FB_{i,t}}{P^Y_{i,t}Y_{i,t}}$ depends on a weighted average of the past short term nominal market interest rate and the effective long term nominal market interest rate, as well as the past net government asset ratio, and the contemporaneous growth rate of nominal output and the primary fiscal balance ratio, according to government dynamic budget constraint:

$$\frac{FB_{i,t}}{P^Y_{i,t}Y_{i,t}} = \frac{1}{\beta}\frac{1}{1+g}\left[\frac{A^G_i}{P^Y_i Y_i}\left(\frac{B^{S,G}_{i,i}}{A^G_i}\hat{i}^S_{i,t-1} + \frac{B^{L,G}_{i,i}}{A^G_i}\hat{i}^{L,E}_{i,t-1}\right) + (1-\beta)\left(\frac{\hat{A}^G_{i,t}}{P^Y_{i,t-1}Y_{i,t-1}} - \frac{A^G_i}{P^Y_i Y_i}\ln\frac{\hat{P}^Y_{i,t}\hat{Y}_{i,t}}{\hat{P}^Y_{i,t-1}\hat{Y}_{i,t-1}}\right)\right] + \frac{PB_{i,t}}{P^Y_{i,t}Y_{i,t}}. \tag{101}$$

In addition, the primary fiscal balance ratio $\frac{PB_{i,t}}{P^Y_{i,t}Y_{i,t}}$ depends on the contemporaneous output tax rate and the deviation of public domestic demand from output, as well as the terms of trade, according to:

$$\frac{PB_{i,t}}{P^Y_{i,t}Y_{i,t}} = \hat{\tau}_{i,t} - \frac{G_i}{Y_i}\left(\ln\frac{\hat{G}_{i,t}}{\hat{Y}_{i,t}} - \frac{X_i}{Y_i}\ln\frac{\hat{\mathcal{T}}^X_{i,t}}{\hat{\mathcal{T}}^M_{i,t}}\right). \tag{102}$$

Furthermore, the net government asset ratio $\frac{\hat{A}^G_{i,t+1}}{P^Y_{i,t}Y_{i,t}}$ depends on its past value, as well as the contemporaneous growth rate of nominal output and the fiscal balance ratio, according to:

$$\frac{\hat{A}^G_{i,t+1}}{P^Y_{i,t}Y_{i,t}} = \frac{1}{1+g}\left(\frac{\hat{A}^G_{i,t}}{P^Y_{i,t-1}Y_{i,t-1}} - \frac{A^G_i}{P^Y_i Y_i}\ln\frac{\hat{P}^Y_{i,t}\hat{Y}_{i,t}}{\hat{P}^Y_{i,t-1}\hat{Y}_{i,t-1}}\right) + \frac{FB_{i,t}}{P^Y_{i,t}Y_{i,t}}. \tag{103}$$

Finally, the effective long term nominal market interest rate $\hat{i}^{L,E}_{i,t}$ depends on a weighted average of its past value and the contemporaneous long term nominal market interest rate according to $\hat{i}^{L,E}_{i,t} = \chi^G \hat{i}^{L,E}_{i,t-1} + (1-\chi^G)\hat{i}^L_{i,t}$. 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 current account balance ratio $\frac{CA_{i,t}}{\mathcal{E}_{i*,i,t}P^Y_{i,t}Y_{i,t}}$ depends on the contemporaneous quotation currency denominated world money market portfolio return, as well as the past net foreign asset ratio, and the contemporaneous growth rate of world nominal output and the trade balance ratio, according to national dynamic budget constraint:

$$\frac{CA_{i,t}}{\mathcal{E}_{i*,i,t}P^Y_{i,t}Y_{i,t}} = \frac{1}{\beta}\frac{1}{1+g}\left[\frac{A_i}{P^Y_i Y_i}\sum_{j=1}^N w^M_j\left(\hat{i}^S_{j,t-1} + \ln\frac{\hat{\mathcal{E}}_{i*,j,t}}{\hat{\mathcal{E}}_{i*,j,t-1}}\right) + (1-\beta)\left(\frac{\hat{A}_{i,t}}{P^Y_{i,t-1}Y_{i,t-1}} - \frac{A_i}{P^Y_i Y_i}\ln\frac{\hat{P}^Y_t\hat{Y}_t}{\hat{P}^Y_{t-1}\hat{Y}_{t-1}}\right)\right] + \frac{TB_{i,t}}{\mathcal{E}_{i*,i,t}P^Y_{i,t}Y_{i,t}}. \tag{104}$$

Furthermore, the trade balance ratio $\frac{TB_{i,t}}{\mathcal{E}_{i*,i,t}P^Y_{i,t}Y_{i,t}}$ depends on the contemporaneous deviation of exports from imports and the terms of trade according to:

$$\frac{TB_{i,t}}{\mathcal{E}_{i*,i,t}P^Y_{i,t}Y_{i,t}} = \frac{X_i}{Y_i}\ln\frac{\hat{\mathcal{T}}^X_{i,t}\hat{X}_{i,t}}{\hat{\mathcal{T}}^M_{i,t}\hat{M}_{i,t}}. \tag{105}$$

Finally, the net foreign asset ratio $\frac{\hat{A}_{i,t+1}}{P^Y_{i,t}Y_{i,t}}$ depends on its past value, as well as the contemporaneous growth rate of world nominal output and the current account balance ratio, according to:

$$\frac{\hat{A}_{i,t+1}}{P^Y_{i,t}Y_{i,t}} = \frac{1}{1+g}\left(\frac{\hat{A}_{i,t}}{P^Y_{i,t-1}Y_{i,t-1}} - \frac{A_i}{P^Y_i Y_i}\ln\frac{\hat{P}^Y_t\hat{Y}_t}{\hat{P}^Y_{t-1}\hat{Y}_{t-1}}\right) + \frac{CA_{i,t}}{\mathcal{E}_{i*,i,t}P^Y_{i,t}Y_{i,t}}. \tag{106}$$

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 price of commodities $\ln\hat{P}^Y_{k,t}$ depends on a weighted average of its past and expected future values driven by the contemporaneous world output weighted average labor income share, output, and the relative domestic currency denominated price of commodities according to commodity price Phillips curve:

$$\begin{aligned}\ln\hat{P}^Y_{k,t} &= \frac{1}{1+\beta}\ln\hat{P}^Y_{k,t-1} + \frac{\beta}{1+\beta}\mathrm{E}_t\ln\hat{P}^Y_{k,t+1} + \frac{(1-\omega^Y_k)(1-\omega^Y_k\beta)}{\omega^Y_k(1+\beta)}\sum_{i=1}^{N} w^Y_i\left\{\ln\frac{\hat{W}_{i,t}\hat{L}_{i,t}}{\hat{P}^Y_{i,t}\hat{Y}_{i,t}}\right.\\ &\left.+\left[\frac{1}{1-\phi^F_k} - \left(1-\frac{X_i}{Y_i}\sum_{k=1}^{M*}\frac{X_{i,k}}{X_i}\phi^F_k\right)^{-1}\right]\ln\hat{Y}_{i,t} - \ln\frac{\hat{\mathcal{E}}_{i,i*,t}\hat{P}^Y_{k,t}}{\hat{P}^Y_{i,t}} - \frac{1}{\theta^Y-1}\ln\hat{\theta}^Y_{k,t}\right\} - \sum_{i=1}^{N} w^Y_i\mathcal{P}_5(L)\ln\hat{\mathcal{E}}_{i,i*,t}.\end{aligned} \tag{107}$$

The price of commodities also depends on the contemporaneous, past and expected future world output weighted average nominal bilateral exchange rate, where polynomial in the lag operator $\mathcal{P}_5(L) = 1 - \frac{1}{1+\beta}L - \frac{\beta}{1+\beta}\mathrm{E}_t L^{-1}$. 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. Exogenous Variables

The productivity $\ln\hat{\mathcal{A}}_{i,t}$, labor supply $\ln\hat{\nu}^L_{i,t}$, consumption demand $\ln\hat{\nu}^C_{i,t}$, investment demand $\ln\hat{\nu}^I_{i,t}$, export demand $\ln\hat{\nu}^X_{i,t}$, and import demand $\ln\hat{\nu}^M_{i,t}$ shocks follow stationary first order autoregressive processes:

$$\ln\hat{\mathcal{A}}_{i,t} = \rho_{\mathcal{A}}\ln\hat{\mathcal{A}}_{i,t-1} + \varepsilon^{\mathcal{A}}_{i,t},\ \varepsilon^{\mathcal{A}}_{i,t} \sim \text{iid } \mathcal{N}(0,\sigma^2_{\mathcal{A},i}), \tag{108}$$

$$\ln\hat{\nu}^L_{i,t} = \rho_{\nu^L}\ln\hat{\nu}^L_{i,t-1} + \varepsilon^{\nu^L}_{i,t},\ \varepsilon^{\nu^L}_{i,t} \sim \text{iid } \mathcal{N}(0,\sigma^2_{\nu^L,i}), \tag{109}$$

$$\ln\hat{\nu}^C_{i,t} = \rho_{\nu^C}\ln\hat{\nu}^C_{i,t-1} + \varepsilon^{\nu^C}_{i,t},\ \varepsilon^{\nu^C}_{i,t} \sim \text{iid } \mathcal{N}(0,\sigma^2_{\nu^C,i}), \tag{110}$$

$$\ln\hat{\nu}^I_{i,t} = \rho_{\nu^I}\ln\hat{\nu}^I_{i,t-1} + \varepsilon^{\nu^I}_{i,t},\ \varepsilon^{\nu^I}_{i,t} \sim \text{iid } \mathcal{N}(0,\sigma^2_{\nu^I,i}), \tag{111}$$

$$\ln\hat{\nu}^X_{i,t} = \rho_{\nu^X}\ln\hat{\nu}^X_{i,t-1} + \varepsilon^{\nu^X}_{i,t},\ \varepsilon^{\nu^X}_{i,t} \sim \text{iid } \mathcal{N}(0,\sigma^2_{\nu^X,i}), \tag{112}$$

$$\ln\hat{\nu}^M_{i,t} = \rho_{\nu^M}\ln\hat{\nu}^M_{i,t-1} + \varepsilon^{\nu^M}_{i,t},\ \varepsilon^{\nu^M}_{i,t} \sim \text{iid } \mathcal{N}(0,\sigma^2_{\nu^M,i}). \tag{113}$$

In addition, the credit risk premium $\hat{\nu}_{i,t}^{i^S}$, duration risk premium $\ln\hat{\nu}_{i,t}^{B}$, equity risk premium $\ln\hat{\nu}_{i,t}^{S}$, and currency risk premium $\ln\hat{\nu}_{i,t}^{\mathcal{E}}$ shocks follow stationary first order autoregressive processes:

$$\hat{\nu}_{i,t}^{i^S} = \rho_{\nu^{i,S}}\hat{\nu}_{i,t-1}^{i^S} + \varepsilon_{i,t}^{\nu^{i,S}},\ \varepsilon_{i,t}^{\nu^{i,S}} \sim \text{iid } \mathcal{N}(0,\sigma_{\nu^{i,S},i}^2), \tag{114}$$

$$\ln\hat{\nu}_{i,t}^{B} = \rho_{\nu^B}\ln\hat{\nu}_{i,t-1}^{B} + \varepsilon_{i,t}^{\nu^B},\ \varepsilon_{i,t}^{\nu^B} \sim \text{iid } \mathcal{N}(0,\sigma_{\nu^B,i}^2), \tag{115}$$

$$\ln\hat{\nu}_{i,t}^{S} = \rho_{\nu^S}\ln\hat{\nu}_{i,t-1}^{S} + \varepsilon_{i,t}^{\nu^S},\ \varepsilon_{i,t}^{\nu^S} \sim \text{iid } \mathcal{N}(0,\sigma_{\nu^S,i}^2), \tag{116}$$

$$\ln\hat{\nu}_{i,t}^{\mathcal{E}} = \rho_{\nu^{\mathcal{E}}}\ln\hat{\nu}_{i,t-1}^{\mathcal{E}} + \varepsilon_{i,t}^{\nu^{\mathcal{E}}},\ \varepsilon_{i,t}^{\nu^{\mathcal{E}}} \sim \text{iid } \mathcal{N}(0,\sigma_{\nu^{\mathcal{E}},i}^2). \tag{117}$$

Furthermore, the output price markup $\ln\hat{\theta}_{i,t}^{Y}$, import price markup $\ln\hat{\theta}_{i,t}^{M}$, wage markup $\ln\hat{\theta}_{i,t}^{L}$, and commodity price markup $\ln\hat{\theta}_{k,t}^{Y}$ shocks follow white noise processes:

$$\ln\hat{\theta}_{i,t}^{Y} = \varepsilon_{i,t}^{\theta^Y},\ \varepsilon_{i,t}^{\theta^Y} \sim \text{iid } \mathcal{N}(0,\sigma_{\theta^Y,i}^2), \tag{118}$$

$$\ln\hat{\theta}_{i,t}^{M} = \varepsilon_{i,t}^{\theta^M},\ \varepsilon_{i,t}^{\theta^M} \sim \text{iid } \mathcal{N}(0,\sigma_{\theta^M,i}^2), \tag{119}$$

$$\ln\hat{\theta}_{i,t}^{L} = \varepsilon_{i,t}^{\theta^L},\ \varepsilon_{i,t}^{\theta^L} \sim \text{iid } \mathcal{N}(0,\sigma_{\theta^L,i}^2), \tag{120}$$

$$\ln\hat{\theta}_{k,t}^{Y} = \varepsilon_{k,t}^{\theta^Y},\ \varepsilon_{k,t}^{\theta^Y} \sim \text{iid } \mathcal{N}(0,\sigma_{\theta^Y,k}^2). \tag{121}$$

Finally, the monetary policy $\hat{\nu}_{i,t}^{i^P}$, fiscal expenditure $\hat{\nu}_{i,t}^{G}$, and fiscal revenue $\hat{\nu}_{i,t}^{T}$ shocks follow white noise processes:

$$\hat{\nu}_{i,t}^{i^P} = \varepsilon_{i,t}^{\nu^{i,P}},\ \varepsilon_{i,t}^{\nu^{i,P}} \sim \text{iid } \mathcal{N}(0,\sigma_{\nu^{i,P},i}^2), \tag{122}$$

$$\hat{\nu}_{i,t}^{G} = \varepsilon_{i,t}^{\nu^G},\ \varepsilon_{i,t}^{\nu^G} \sim \text{iid } \mathcal{N}(0,\sigma_{\nu^G,i}^2), \tag{123}$$

$$\hat{\nu}_{i,t}^{T} = \varepsilon_{i,t}^{\nu^T},\ \varepsilon_{i,t}^{\nu^T} \sim \text{iid } \mathcal{N}(0,\sigma_{\nu^T,i}^2). \tag{124}$$

As an identifying restriction, all innovations are assumed to be independent, which combined with our distributional assumptions implies multivariate normality.

IV. Estimation

The traditional econometric interpretation of an approximate linear state space representation of this panel dynamic stochastic general equilibrium 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. 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

Observed macroeconomic and financial market variables exhibit business cycle fluctuations around diverse trend paths, which may or may not feature long run growth. To allow for the absence of long run growth in estimating the cyclical components of all of the observed endogenous variables under consideration, we generalize the filter described in Hodrick and Prescott (1997) by parameterizing the difference order associated with the penalty term determining the smoothness of the trend component, and quantify the uncertainty surrounding the resultant estimates.

Cyclical Components

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

$$S(\{\bar{y}_t\}_{t=1}^T) = \sum_{t=1}^{T}(y_t - \bar{y}_t)^2 + \lambda \sum_{t=d+1}^{T}(\Delta^d \bar{y}_t)^2, \tag{125}$$

where smoothing parameter $\lambda \geq 0$. This minimization problem strikes a balance between minimizing the sum of squares of the cyclical component and the sum of squares of the ordinary difference of order d of the trend component, where d is a positive integer. Using matrix notation, this objective function may be expressed as

$$S(\bar{\boldsymbol{y}}) = (\boldsymbol{y} - \bar{\boldsymbol{y}})^\top(\boldsymbol{y} - \bar{\boldsymbol{y}}) + \lambda(\boldsymbol{\Delta}^d \bar{\boldsymbol{y}})^\top(\boldsymbol{\Delta}^d \bar{\boldsymbol{y}}), \tag{126}$$

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

$$\bar{\boldsymbol{y}}_{|T} = \left[\boldsymbol{I}_T + \lambda(\boldsymbol{\Delta}^d)^\top(\boldsymbol{\Delta}^d)\right]^{-1}\boldsymbol{y}. \tag{127}$$

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 $d = 2$, and to that used in Lucas (1980) for $d = 1$.

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

$$\text{Var}(\bar{\boldsymbol{y}}_{|T}) = \left[\boldsymbol{I}_T + \lambda(\boldsymbol{\Delta}^d)^\top(\boldsymbol{\Delta}^d)\right]^{-1}\left[\sigma_C^2 \boldsymbol{I}_T + \lambda^2\sigma_T^2(\boldsymbol{\Delta}^d)^\top(\boldsymbol{\Delta}^d)\right]\left[\boldsymbol{I}_T + \lambda(\boldsymbol{\Delta}^d)^\top(\boldsymbol{\Delta}^d)\right]^{-1}, \tag{128}$$

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

following Schlicht (2005). Substituting sample moments for their population counterparts, we propose mean squared error matrix estimator

$$\mathrm{Var}(\bar{\boldsymbol{y}}_{|T}) = \left[\boldsymbol{I}_T + \lambda(\boldsymbol{\Delta}^d)^\intercal(\boldsymbol{\Delta}^d)\right]^{-1}\left[\hat{\sigma}_C^2\boldsymbol{I}_T + \lambda^2\hat{\sigma}_T^2(\boldsymbol{\Delta}^d)^\intercal(\boldsymbol{\Delta}^d)\right]\left[\boldsymbol{I}_T + \lambda(\boldsymbol{\Delta}^d)^\intercal(\boldsymbol{\Delta}^d)\right]^{-1}, \tag{129}$$

where $\hat{\sigma}_C^2 = \frac{1}{T}\sum_{t=1}^{T}(\hat{y}_t)^2$ and $\hat{\sigma}_T^2 = \frac{1}{T-d}\sum_{t=d+1}^{T}(\Delta^d\bar{y}_t)^2$. As λ increases, the estimated trend component becomes smoother, converging to a deterministic polynomial of degree $d-1$ in the limit as $\lambda \to \infty$. We therefore recommend choosing the minimum value of d for which $\{\Delta^{d-1}y_t\}_{t=d}^T$ does not exhibit long run growth.

Parameters

Let $\{\hat{\boldsymbol{x}}_t\}_{t=1}^T$ denote a vector stochastic process consisting of the cyclical components of $N_{\boldsymbol{x}}$ nonpredetermined endogenous variables, of which $N_{\boldsymbol{y}}$ are observed. This vector stochastic process satisfies second order stochastic linear difference equation

$$\boldsymbol{A}_0\hat{\boldsymbol{x}}_t = \boldsymbol{A}_1\hat{\boldsymbol{x}}_{t-1} + \boldsymbol{A}_2\mathrm{E}_t\hat{\boldsymbol{x}}_{t+1} + \boldsymbol{A}_3\hat{\boldsymbol{v}}_t, \tag{130}$$

where vector stochastic process $\{\hat{\boldsymbol{v}}_t\}_{t=1}^T$ consists of the cyclical components of $N_{\boldsymbol{v}}$ exogenous variables. This vector stochastic process satisfies stationary first order stochastic linear difference equation

$$\hat{\boldsymbol{v}}_t = \boldsymbol{B}_1\hat{\boldsymbol{v}}_{t-1} + \boldsymbol{\varepsilon}_t, \tag{131}$$

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

$$\hat{\boldsymbol{x}}_t = \boldsymbol{C}_1\hat{\boldsymbol{x}}_{t-1} + \boldsymbol{C}_2\hat{\boldsymbol{v}}_t. \tag{132}$$

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

Let $\{\hat{\boldsymbol{y}}_t\}_{t=1}^T$ denote a vector stochastic process consisting of the estimated cyclical components of $N_{\boldsymbol{y}}$ observed nonpredetermined endogenous variables. Also, let $\{\boldsymbol{z}_t\}_{t=1}^T$ denote a vector stochastic process consisting of the cyclical components of $N_{\boldsymbol{x}}$ nonpredetermined endogenous variables and $N_{\boldsymbol{v}}$ exogenous variables. Given unique stationary solution (132), these vector stochastic processes have linear state space representation

$$\hat{\boldsymbol{y}}_t = \boldsymbol{F}_1\boldsymbol{z}_t, \tag{133}$$

$$\boldsymbol{z}_t = \boldsymbol{G}_1\boldsymbol{z}_{t-1} + \boldsymbol{G}_2\boldsymbol{\varepsilon}_t, \tag{134}$$

where $\boldsymbol{z}_0 \sim \mathcal{N}(\boldsymbol{z}_{0|0}, \boldsymbol{P}_{0|0})$. The initial state vector is assumed to be independent from the state innovation vector, 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:

$$\boldsymbol{z}_{t|t-1} = \boldsymbol{G}_1 \boldsymbol{z}_{t-1|t-1}, \tag{135}$$

$$\boldsymbol{P}_{t|t-1} = \boldsymbol{G}_1 \boldsymbol{P}_{t-1|t-1} \boldsymbol{G}_1^{\top} + \boldsymbol{G}_2 \boldsymbol{\Sigma}_1 \boldsymbol{G}_2^{\top}, \tag{136}$$

$$\hat{\boldsymbol{y}}_{t|t-1} = \boldsymbol{F}_1 \boldsymbol{z}_{t|t-1}, \tag{137}$$

$$\boldsymbol{Q}_{t|t-1} = \boldsymbol{F}_1 \boldsymbol{P}_{t|t-1} \boldsymbol{F}_1^{\top}. \tag{138}$$

Given these predictions, and a multivariate normally distributed state innovation vector, estimates conditional on information available at time t satisfy Bayesian updating equations

$$\boldsymbol{z}_{t|t} = \boldsymbol{z}_{t|t-1} + \boldsymbol{K}_t (\hat{\boldsymbol{y}}_t - \hat{\boldsymbol{y}}_{t|t-1}), \tag{139}$$

$$\boldsymbol{P}_{t|t} = \boldsymbol{P}_{t|t-1} - \boldsymbol{K}_t \boldsymbol{F}_1 \boldsymbol{P}_{t|t-1}, \tag{140}$$

where $\boldsymbol{K}_t = \boldsymbol{P}_{t|t-1} \boldsymbol{F}_1^{\top} \boldsymbol{Q}_{t|t-1}^{-1}$. Given terminal conditions $\hat{\boldsymbol{z}}_{T+1|T} = \boldsymbol{0}$ and $\hat{\boldsymbol{P}}_{T+1|T} = \boldsymbol{0}$, estimates conditional on information available at time T satisfy computationally efficient Bayesian smoothing equations

$$\hat{\boldsymbol{z}}_{t|T} = \boldsymbol{J}_t^{\top} \hat{\boldsymbol{z}}_{t+1|T} + \boldsymbol{F}_1^{\top} \boldsymbol{Q}_{t|t-1}^{-1} (\hat{\boldsymbol{y}}_t - \hat{\boldsymbol{y}}_{t|t-1}), \tag{141}$$

$$\boldsymbol{z}_{t|T} = \boldsymbol{z}_{t|t-1} + \boldsymbol{P}_{t|t-1} \hat{\boldsymbol{z}}_{t|T}, \tag{142}$$

$$\hat{\boldsymbol{P}}_{t|T} = \boldsymbol{J}_t^{\top} \hat{\boldsymbol{P}}_{t+1|T} \boldsymbol{J}_t - \boldsymbol{F}_1^{\top} \boldsymbol{Q}_{t|t-1}^{-1} \boldsymbol{F}_1, \tag{143}$$

$$\boldsymbol{P}_{t|T} = \boldsymbol{P}_{t|t-1} + \boldsymbol{P}_{t|t-1} \hat{\boldsymbol{P}}_{t|T} \boldsymbol{P}_{t|t-1}, \tag{144}$$

where $\boldsymbol{J}_t = \boldsymbol{G}_1 (\boldsymbol{I}_K - \boldsymbol{P}_{t|t-1} \boldsymbol{F}_1^{\top} \boldsymbol{Q}_{t|t-1}^{-1} \boldsymbol{F}_1)$. Under our distributional assumptions, recursive forward evaluation of equations (135) through (140), followed by recursive backward evaluation of equations (141) through (144), 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:

$$f(\boldsymbol{\theta} \mid \{\hat{\boldsymbol{y}}_t\}_{t=1}^T) \propto f(\{\hat{\boldsymbol{y}}_t\}_{t=1}^T \mid \boldsymbol{\theta}) f(\boldsymbol{\theta}). \tag{145}$$

Given a multivariate normally distributed state innovation vector, conditional density function $f(\{\hat{\boldsymbol{y}}_t\}_{t=1}^T \mid \boldsymbol{\theta})$ satisfies:

$$f(\{\hat{\boldsymbol{y}}_t\}_{t=1}^T \mid \boldsymbol{\theta}) = \prod_{t=1}^{T} (2\pi)^{-\frac{N_y}{2}} \mid \boldsymbol{Q}_{t|t-1} \mid^{-\frac{1}{2}} \exp\left\{ -\frac{1}{2} (\hat{\boldsymbol{y}}_t - \hat{\boldsymbol{y}}_{t|t-1})^{\top} \boldsymbol{Q}_{t|t-1}^{-1} (\hat{\boldsymbol{y}}_t - \hat{\boldsymbol{y}}_{t|t-1}) \right\}. \tag{146}$$

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

$$f(\boldsymbol{\theta}) = (2\pi)^{-\frac{K}{2}} |\boldsymbol{\Omega}|^{-\frac{1}{2}} \exp\left\{-\frac{1}{2}(\boldsymbol{\theta}-\boldsymbol{\theta}_1)^{\mathsf{T}} \boldsymbol{\Omega}^{-1}(\boldsymbol{\theta}-\boldsymbol{\theta}_1)\right\}. \tag{147}$$

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

$$\sqrt{T}(\hat{\boldsymbol{\theta}}_T - \boldsymbol{\theta}_0) \xrightarrow{d} \mathcal{N}(\mathbf{0}, -\boldsymbol{\mathcal{H}}_0^{-1}), \tag{148}$$

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:

$$\hat{\boldsymbol{\mathcal{H}}}_T = -\frac{1}{T}\sum_{t=1}^{T}\left[\nabla_{\theta}\hat{\boldsymbol{y}}_{t|t-1}^{\mathsf{T}}\boldsymbol{Q}_{t|t-1}^{-1}\nabla_{\theta}\hat{\boldsymbol{y}}_{t|t-1} + \frac{1}{2}\nabla_{\theta}\boldsymbol{Q}_{t|t-1}^{\mathsf{T}}(\boldsymbol{Q}_{t|t-1}^{-1}\otimes\boldsymbol{Q}_{t|t-1}^{-1})\nabla_{\theta}\boldsymbol{Q}_{t|t-1}\right] - \frac{1}{T}\boldsymbol{\Omega}^{-1}. \tag{149}$$

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

B. Estimation Results

Estimation of the parameters of the approximate linear state space representation of our panel dynamic stochastic general equilibrium model is based on the estimated cyclical components of a total of 621 endogenous variables observed for forty economies over the sample period 1999Q1 through 2013Q4. The advanced and emerging economies under consideration are Argentina, Australia, Austria, Belgium, Brazil, Canada, Chile, China, Colombia, the Czech Republic, Denmark, Finland, France, Germany, Greece, India, Indonesia, Ireland, Israel, Italy, Japan, Korea, Malaysia, Mexico, the Netherlands, New Zealand, Norway, the Philippines, 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 private consumption, the quantity of exports, the quantity of imports, 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 wage, the unemployment rate, employment, the nominal bilateral exchange rate, the quantity of public domestic demand, the fiscal balance ratio, and the prices of nonrenewable energy and nonenergy commodities. For a detailed description of this multivariate panel data set, refer to Appendix A.

Cyclical Components

Our panel dynamic stochastic general equilibrium model is designed to explain both high and low frequency cyclical variation in its observed endogenous variables. High frequency cyclical variation is captured by deviations of these endogenous variables from their flexible price and wage equilibrium components, while low frequency cyclical variation is accounted for by deviations of these flexible price and wage equilibrium components from steady state equilibrium values.

We estimate the cyclical components of all of the observed endogenous variables under consideration with our generalization of the filter described in Hodrick and Prescott (1997). For the price of output, the price of consumption, the quantity of output, the quantity of private consumption, the quantity of exports, the quantity of imports, the price of equity, the nominal wage, employment, the nominal bilateral exchange rate, the quantity of public domestic demand, and the prices of energy and nonenergy commodities, we set $d = 2$ and $\lambda = 16,000$. For the nominal policy interest rate, the short term nominal market interest rate, the long term nominal market interest rate, the unemployment rate, and the fiscal balance ratio, we set $d = 1$ and $\lambda = 400$.

Parameters

The set of parameters associated with our panel dynamic stochastic general equilibrium model is partitioned into two subsets. Structural parameters are either estimated conditional on informative independent priors or are calibrated, while innovation variances are estimated conditional on diffuse 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, Chile, the Czech Republic, the Euro Area, Israel, Japan, Mexico, New Zealand, Norway, Poland, Sweden, the United Kingdom and the United States, by a managed exchange rate regime in Argentina, Brazil, China, Colombia, India, Indonesia, Korea, Malaysia, the Philippines, Russia, South Africa, Switzerland, Thailand and Turkey, and by a fixed exchange rate regime in Denmark and Saudi Arabia, consistent with IMF (2012). The internationally financially integrated emerging economies are Argentina, Brazil, Colombia, India, Indonesia, Mexico, the Philippines, Poland, Russia, South Africa, Thailand and Turkey, while the internationally financially unintegrated emerging economies are Chile, China, Malaysia 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 2011. All weights are normalized to sum to one across economies, where applicable.

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 a global maximum, starting values for structural parameters are generated with a customized implementation of the differential evolution algorithm proposed by Storn and Price (1997). Structural parameter estimation results pertaining to the sample period 1999Q3 through 2013Q4 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 approximate linear state space representation of our panel dynamic stochastic general equilibrium 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.

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 dynamic stochastic general equilibrium 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, private consumption, private investment, the nominal policy interest rate, the real effective exchange rate, the unemployment rate, the fiscal balance ratio, and the current account balance ratio to a variety of structural shocks are plotted in Figure 1 through Figure 12 of Appendix B. The structural shocks under consideration are domestic productivity, domestic labor supply, domestic consumption demand, domestic investment demand, domestic monetary policy, domestic credit risk premium, domestic duration risk premium, domestic equity risk premium, domestic fiscal expenditure, domestic fiscal revenue, and world energy and 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 usually deteriorates due to the fall in output and rise in debt service costs, whereas the current account balance tends to improve reflecting the rise in the terms of trade. In response to a domestic labor supply shock which generates a persistent increase in the labor force, there arises a persistent hump shaped expansion of output, accompanied by a persistent hump shaped decrease in inflation. Facing a monetary policy tradeoff, the central bank generally cuts the nominal policy interest rate to stimulate inflation, and the currency depreciates in real effective terms. The fiscal balance typically improves due to the rise in output and fall in debt service costs, whereas the current account balance tends to deteriorate reflecting the fall in the terms of trade.

In response to a domestic consumption demand shock which generates a persistent hump shaped increase in consumption, there arises a persistent hump shaped expansion of output, generally accompanied by a persistent hump shaped increase in inflation. Not facing a monetary policy tradeoff, the central bank usually raises the nominal policy interest rate to stabilize inflation and output, which tends to crowd out investment and appreciate the currency in real effective terms. The fiscal balance improves due to the rise in output in spite of higher debt service costs, whereas the current account balance deteriorates commensurate with the larger rise in domestic demand. In response to a domestic investment demand shock which generates a persistent hump shaped increase in investment, there arises a persistent hump shaped expansion of output, generally accompanied by a persistent hump shaped increase in inflation. Not facing a monetary policy tradeoff, the central bank typically raises the nominal policy interest rate to stabilize inflation and output, crowding out consumption and appreciating the currency in real effective terms. The fiscal balance improves due to the rise in output in spite of higher debt service costs, whereas 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 0.2 percent across economies within a range of 0.1 to 0.3 percent, while the median peak decrease in inflation is 0.1 percentage points within a range of 0.1 to 0.2 percentage points, and the median peak increase in the unemployment rate is 0.1 percentage points within a range of 0.0 to 0.1 percentage points. The fiscal balance deteriorates due to the fall in output and rise in debt service costs, whereas the current account balance generally 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 perhaps 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 0.3 percent across economies, within a range of 0.0 to 0.4 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 and rise in debt service costs, whereas the current account balance usually 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, generally 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 0.3 percent across economies, within a range of 0.0 to 0.6 percent. The central bank typically cuts 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 and rise in debt service costs, whereas 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, generally 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 0.1 percent across economies, within a range of 0.0 to 0.3 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 in spite of higher debt service costs, whereas 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, accompanied by a persistent hump shaped 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 1.0 percent within a range of 0.1 to 1.6 percent, and generally decreases across economies with their trade openness. The central bank usually cuts the nominal policy interest rate to stabilize inflation and output, crowding in investment and depreciating the currency 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, 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 0.4 percent within a range of 0.0 to 0.6 percent, and generally decreases across economies with their trade openness. The central bank typically cuts the nominal policy interest rate to stabilize inflation and output, which tends to crowd in investment and depreciate the currency 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 consumption 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 usually improve, reflecting the rise in the terms of trade. In contrast, for net importers of energy or nonenergy commodities, the currency typically depreciates in real effective terms, inducing a terms of trade driven contraction of consumption 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, reflecting the fall in the terms of trade.

B. Forecast Error Variance Decompositions

Forecast error variance decompositions measure the contributions of disjoint 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, private consumption, private investment, the nominal policy interest rate, the real effective exchange rate, the unemployment rate, the fiscal balance ratio, and the current account balance ratio are plotted in Figure 13 through Figure 21. The sets of structural shocks under consideration are domestic supply, foreign supply, domestic demand, foreign demand, world monetary policy, domestic fiscal policy, foreign fiscal policy, domestic risk premium, foreign risk premium, and world terms of trade shocks.

Our estimated forecast error variance decompositions indicate that unpredictable variation in inflation is primarily driven by supply and terms of trade shocks, and to a lesser extent demand and monetary policy shocks, at all horizons. The contribution of domestic relative to foreign demand shocks is generally decreasing across economies with their trade openness and increasing with their monetary policy autonomy. In contrast, estimated forecast error variance decompositions attribute most unpredictable variation in output to demand shocks, followed by supply and monetary policy shocks, at all frequencies. The contribution of domestic relative to foreign demand shocks is usually decreasing across economies with their trade openness. Estimated forecast error variance decompositions of consumption and investment reveal similar patterns, except that domestic demand shocks are larger contributors to unpredictable variation at all horizons, while foreign demand shocks are smaller contributors. In addition, fiscal policy shocks are typically significant contributors to unpredictable consumption fluctuations at short horizons, while risk premium and terms of trade shocks tend to be significant contributors to unpredictable investment fluctuations at all horizons.

Estimated forecast error variance decompositions indicate that unpredictable variation in the nominal policy interest rate is primarily driven by supply and monetary policy shocks at all horizons. In addition, demand and terms of trade shocks are major contributors to unpredictable fluctuations at long horizons, where the contribution of domestic relative to foreign demand 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 supply and demand shocks, and to a lesser extent monetary policy and risk premium shocks, at all frequencies. The contribution of domestic relative to foreign risk premium shocks is usually increasing across economies with their monetary policy autonomy. Estimated forecast error variance decompositions of the unemployment rate attribute most unpredictable variation to supply and demand shocks, and to a lesser extent monetary policy and terms of trade shocks, at all horizons. The contribution of domestic relative to foreign demand shocks is typically decreasing across economies with their trade openness.

Our estimated forecast error variance decompositions indicate 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 all horizons. The contribution of monetary policy shocks is generally increasing across economies with their net government debt positions. In addition, terms of trade shocks are usually significant contributors to unpredictable fluctuations for major net commodity exporters. Estimated forecast error variance decompositions of the current account balance attribute most unpredictable variation to demand shocks at all frequencies, together with monetary policy and risk premium shocks for economies with high net foreign asset or debt positions. In addition, terms of trade shocks are typically significant contributors to unpredictable fluctuations for major net commodity exporters and importers.

C. Historical Decompositions

Historical decompositions measure the time varying contributions of disjoint sets of structural shocks to the realizations of endogenous variables. The estimated historical decompositions of consumption price inflation, output growth, and the unemployment rate are plotted in Figure 22 through Figure 24. The sets of structural shocks under consideration are domestic supply, foreign supply, domestic demand, foreign demand, world monetary policy, domestic fiscal policy, foreign fiscal policy, domestic risk premium, foreign risk premium, and world terms of trade shocks.

Our estimated historical decompositions of inflation attribute deviations from trend rates primarily to economy specific combinations of supply and demand shocks, together with terms of trade shocks. The contribution of domestic relative to foreign demand shocks has generally been decreasing across economies with their trade openness and increasing with their monetary policy autonomy. Trend inflation rates have typically stabilized at relatively low levels in advanced economies, particularly those with well established flexible inflation targeting regimes such as Australia, Canada, the Czech Republic, Israel, Korea, New Zealand, Norway, Sweden, and the United Kingdom. Estimated historical decompositions of output growth attribute business cycle dynamics around relatively stable trend growth rates primarily to economy specific combinations of demand shocks, and to a lesser extent supply 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 generally been amplified by risk premium shocks and mitigated by fiscal policy shocks. Trend output growth rates have typically stabilized at relatively low levels in advanced economies, and at relatively high levels in emerging economies. Estimated historical decompositions of the unemployment rate attribute deviations from trend rates primarily to economy specific combinations of supply and demand shocks. The contribution of domestic relative to foreign demand shocks has generally been decreasing across economies with their trade openness.

During the build up to the global financial crisis, positive demand shocks contributed to a synchronized global expansion, amplified by risk premium shocks. This synchronized global expansion was reflected in a synchronized global rise in inflation, generally amplified by world terms of trade shocks. During the global financial crisis, negative demand shocks, amplified and accelerated by risk premium shocks, generated a synchronized global recession. This synchronized global recession was mitigated by countercyclical unsystematic monetary or fiscal policy interventions. It was reflected in a synchronized global fall in inflation and rise in the unemployment rate, the former typically amplified by terms of trade shocks. Since the global financial crisis, positive demand shocks, generally amplified by risk premium shocks, have contributed to a synchronized global recovery. In the Euro Area periphery, this recovery was derailed by risk premium shocks, which necessitated procyclical unsystematic fiscal policy interventions.

VI. Spillover Analysis

Within the framework of our estimated panel dynamic stochastic general equilibrium 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 (2013). The macroeconomic shocks under consideration are productivity, labor supply, consumption demand, investment demand, monetary policy, fiscal expenditure, and fiscal revenue shocks. The financial shocks under consideration are credit risk premium, duration risk premium, 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 output with respect to contemporaneous output in systemic economies, conditional on macroeconomic or financial shocks in each of these systemic economies, are plotted in Figure 25. 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 dynamic stochastic general equilibrium 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 dynamic stochastic general equilibrium 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 are typically concentrated among geographically close trading partners, which tend to 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 dynamic stochastic general equilibrium model. The pattern of international business cycle comovement driven by financial shocks transcends bilateral portfolio investment relationships, which are typically 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 tend to be 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 internationally financially integrated emerging economies, moderate to advanced economies, and weak to internationally financially unintegrated emerging economies.

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 fiscal balance ratio, and the current account balance ratio to a variety of structural shocks are plotted in Figure 26 through Figure 35. The structural shocks under consideration are foreign productivity, foreign labor supply, foreign consumption demand, foreign investment demand, foreign monetary policy, foreign credit risk premium, foreign duration risk premium, foreign equity risk premium, foreign fiscal expenditure, 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 usually 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 tend to improve. In response to a labor supply shock which generates a decrease in inflation and expansion of output in a systemic economy, the currencies of recipient economies generally appreciate in real effective terms. There typically arise terms of trade driven decreases in inflation and contractions of output in recipient economies, in spite of higher foreign demand. As a result, their fiscal and current account balances tend to deteriorate.

In response to a consumption demand 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 usually improve. In response to an investment demand shock which generally generates an increase in inflation and expansion of output in a systemic economy, there typically 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 usually 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 tend to 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 usually 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 generally increase, reflecting international bond market contagion effects. As a result, there typically 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 usually 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. As a result, their fiscal and current account balances usually deteriorate. In response to a fiscal revenue 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. As a result, their fiscal and current account balances typically deteriorate.

VII. Forecasting

We analyze the predictive accuracy of our estimated panel dynamic stochastic general equilibrium model of the world economy for consumption price inflation and output growth with sequential unconditional forecasts in sample. The results of this forecast performance evaluation exercise are plotted in Figure 36 through Figure 38.

We measure the dynamic forecasting performance of our estimated panel dynamic stochastic general equilibrium model relative to that of a driftless random walk for variable $\hat{x}_{i,t}$ over a holdout sample of size R at horizons $h \in \{1, \ldots, H\}$ on the basis of the logarithm of the U statistic due to Theil (1966), which equals the ratio of root mean squared prediction errors:

$$\ln U_{i,h} = \ln \frac{\sqrt{\frac{1}{R-h}\sum_{s=1}^{R-h}(\hat{x}_{i,T-R+h+s} - \hat{x}_{i,T-R+h+s|T-R+s})^2}}{\sqrt{\frac{1}{R-h}\sum_{s=1}^{R-h}(\hat{x}_{i,T-R+h+s} - \hat{x}_{i,T-R+s})^2}}. \tag{150}$$

If $\ln U_{i,h} < 0$ then the estimated model dominates a random walk in terms of predictive accuracy for economy i at horizon h over the holdout sample under consideration, and vice versa. We set $R = 9S$ and $H = 2S$, where $S = 4$ denotes the seasonal frequency.

We find that our estimated panel dynamic stochastic general equilibrium model generally dominates a random walk in terms of predictive accuracy for inflation and output growth. Indeed, over the holdout sample under consideration, the root mean squared prediction error is 39 percent lower for inflation and 33 percent lower for output growth, on average across economies and horizons. This marginal predictive power is typically increasing with respect to the forecast horizon.

Visual inspection of our sequential unconditional forecasts of inflation and output growth indicates that our estimated panel dynamic stochastic general equilibrium model is capable of predicting business cycle turning points. Indeed, these sequential unconditional forecasts 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 underpredicted its weakness in most advanced economies.

VIII. CONCLUSION

This paper develops a structural macroeconometric model of the world economy, disaggregated into forty national economies. This panel dynamic stochastic general equilibrium model features a range of nominal and real rigidities, extensive macrofinancial linkages, and diverse spillover transmission channels. A variety of monetary policy analysis, fiscal policy analysis, spillover analysis, and forecasting applications of the estimated model are demonstrated. These include quantifying the monetary and fiscal transmission mechanisms with impulse response functions, accounting for business cycle fluctuations with historical decompositions, and generating relatively accurate sequential unconditional forecasts of inflation and output growth.

This estimated panel dynamic stochastic general equilibrium 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. It features financial intermediation via a variety of globally integrated capital markets, but not in parallel by commercial banks subject to financial frictions and regulatory constraints. The associated macrofinancial linkages have the potential to amplify and propagate business cycle fluctuations, both domestically and abroad. Adding them to the model remains an objective for future research.

Appendix A. Description of the Data Set

Estimation is based on quarterly data on a variety of macroeconomic and financial market variables observed for forty economies over the sample period 1999Q1 through 2013Q4. The economies under consideration are Argentina, Australia, Austria, Belgium, Brazil, Canada, Chile, China, Colombia, the Czech Republic, Denmark, Finland, France, Germany, Greece, India, Indonesia, Ireland, Israel, Italy, Japan, Korea, Malaysia, Mexico, the Netherlands, New Zealand, Norway, the Philippines, 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 private consumption, the quantity of exports, the quantity of imports, the nominal wage, the unemployment rate, employment, the quantity of public domestic demand, the fiscal balance ratio, and the prices of nonrenewable 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 private consumption is measured by seasonally adjusted real private consumption expenditures. The quantity of exports is measured by seasonally adjusted real export revenues, while the quantity of imports is measured by seasonally adjusted real import expenditures. The nominal wage is derived from the quadratically interpolated annual labor income share, while the unemployment rate is measured by the seasonally adjusted share of total unemployment in the total labor force, and employment is measured by quadratically interpolated annual total employment. The quantity of public domestic demand is measured by the sum of quadratically interpolated annual real consumption and investment expenditures of the general government, while the fiscal balance is measured by the quadratically interpolated annual overall fiscal balance of the general government. 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 IFS and BIS 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

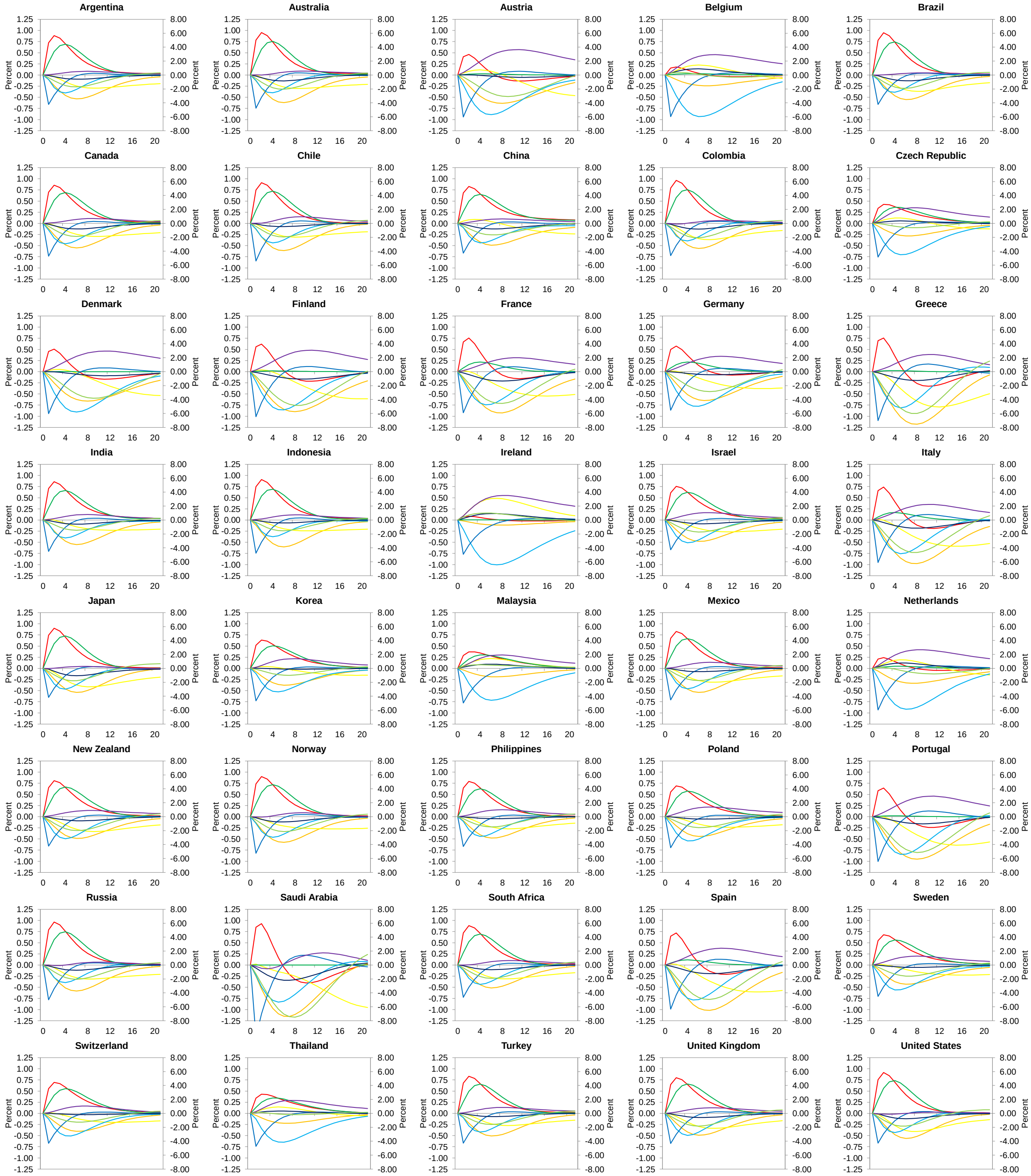
Table 1. Structural Parameter Estimation Results

Parameter	Prior Mean	Prior Standard Deviation	Posterior Mode
α	0.9000	0.0900	0.9216
β	0.9756	0.0000	...
χ^{H}	0.2000	0.0200	0.1962
χ^{F}	1.7500	0.1750	1.7347
χ^{G}	0.9639	0.0000	...
δ	0.0250	0.0000	...
η	0.0500	0.0050	0.0523
γ^{Y}	0.5000	0.0500	0.4506
γ^{M}	0.5000	0.0500	0.4882
γ^{L}	0.5000	0.0500	0.5160
ι	0.0800	0.0080	0.0779
κ	0.5000	0.0500	0.4976
μ^{M}	0.2500	0.0250	0.2544
ω^{Y}	0.8750	0.0875	0.8645
ω^{M}	0.8750	0.0875	0.8337
ω^{L}	0.8750	0.0875	0.9066
ω_1^{Y}	0.3333	0.0333	0.3437
ω_2^{Y}	0.3333	0.0333	0.3385
ϕ^{C}	0.4500	0.0450	0.4653
ϕ_1^{F}	0.9000	0.0900	0.9168
ϕ_2^{F}	0.8000	0.0800	0.8117
ψ^{M}	1.5000	0.1500	1.5604
ρ^{i}	0.7500	0.0750	0.7233
ρ_{G}	0.7500	0.0750	0.7411
ρ_{τ}	0.7500	0.0750	0.7587
σ	5.0000	0.5000	5.2537
θ^{Y}	7.6667	0.0000	...
θ^{M}	7.6667	0.0000	...
θ^{L}	7.6667	0.0000	...
ξ_0^{π}	1.5000	0.1500	1.5047
ξ_1^{π}	1.5000	0.1500	1.4849
ξ_0^{Y}	0.1250	0.0125	0.1275
ξ_1^{Y}	0.1250	0.0125	0.1252
ξ_1^{Q}	0.0250	0.0025	0.0239
ζ^{i}	−0.0000	0.0000	...
ζ^{G}	0.0013	0.0000	...
ζ^{τ}	−0.0375	0.0000	...
λ_0^{M}	1.0984	0.1098	1.1140
λ_1^{M}	1.6475	0.1648	1.5770
λ_2^{M}	0.5492	0.0549	0.5309
λ_0^{B}	1.0984	0.1098	1.0967
λ_1^{B}	1.6475	0.1648	1.6422
λ_2^{B}	0.5492	0.0549	0.5591
λ_0^{S}	1.3901	0.1390	1.3796
λ_1^{S}	2.0851	0.2085	2.1074
λ_2^{S}	0.6950	0.0695	0.7326
ρ_{A}	0.7500	0.0750	0.7901
$\rho_{v,C}$	0.7500	0.0750	0.7868
$\rho_{v,I}$	0.7500	0.0750	0.7554

Parameter	Prior Mean	Prior Standard Deviation	Posterior Mode
$\rho_{v,X}$	0.7500	0.0750	0.7523
$\rho_{v,M}$	0.7500	0.0750	0.7561
$\rho_{v,i,S}$	0.7500	0.0750	0.7372
$\rho_{v,B}$	0.7500	0.0750	0.8237
$\rho_{v,S}$	0.7500	0.0750	0.7783
$\rho_{v,\varepsilon}$	0.7500	0.0750	0.7745
$\rho_{v,L}$	0.7500	0.0750	0.7436

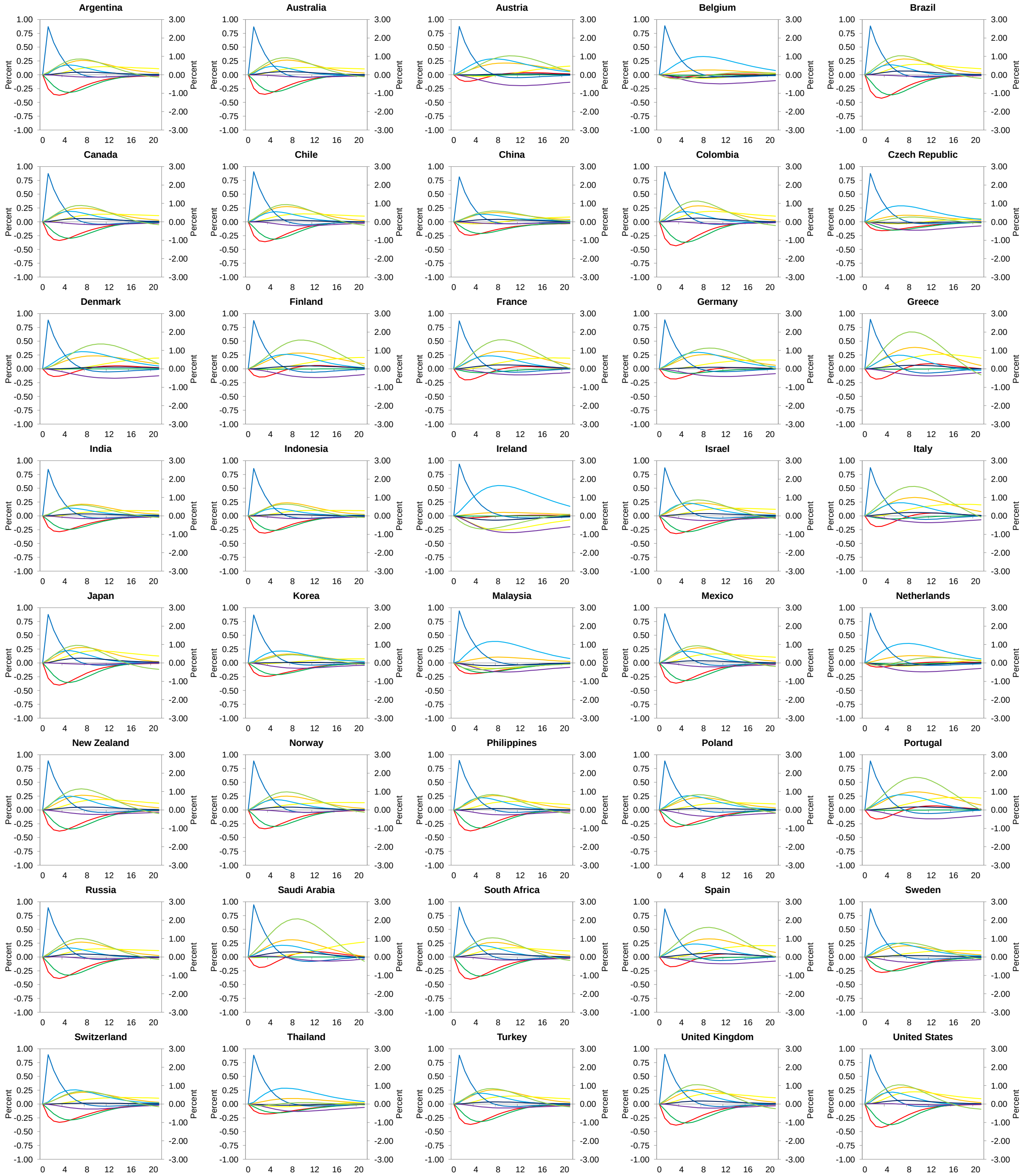
Note: All priors are normally distributed, while all posteriors are asymptotically normally distributed.

Figure 1. Impulse Responses to a Domestic Productivity Shock



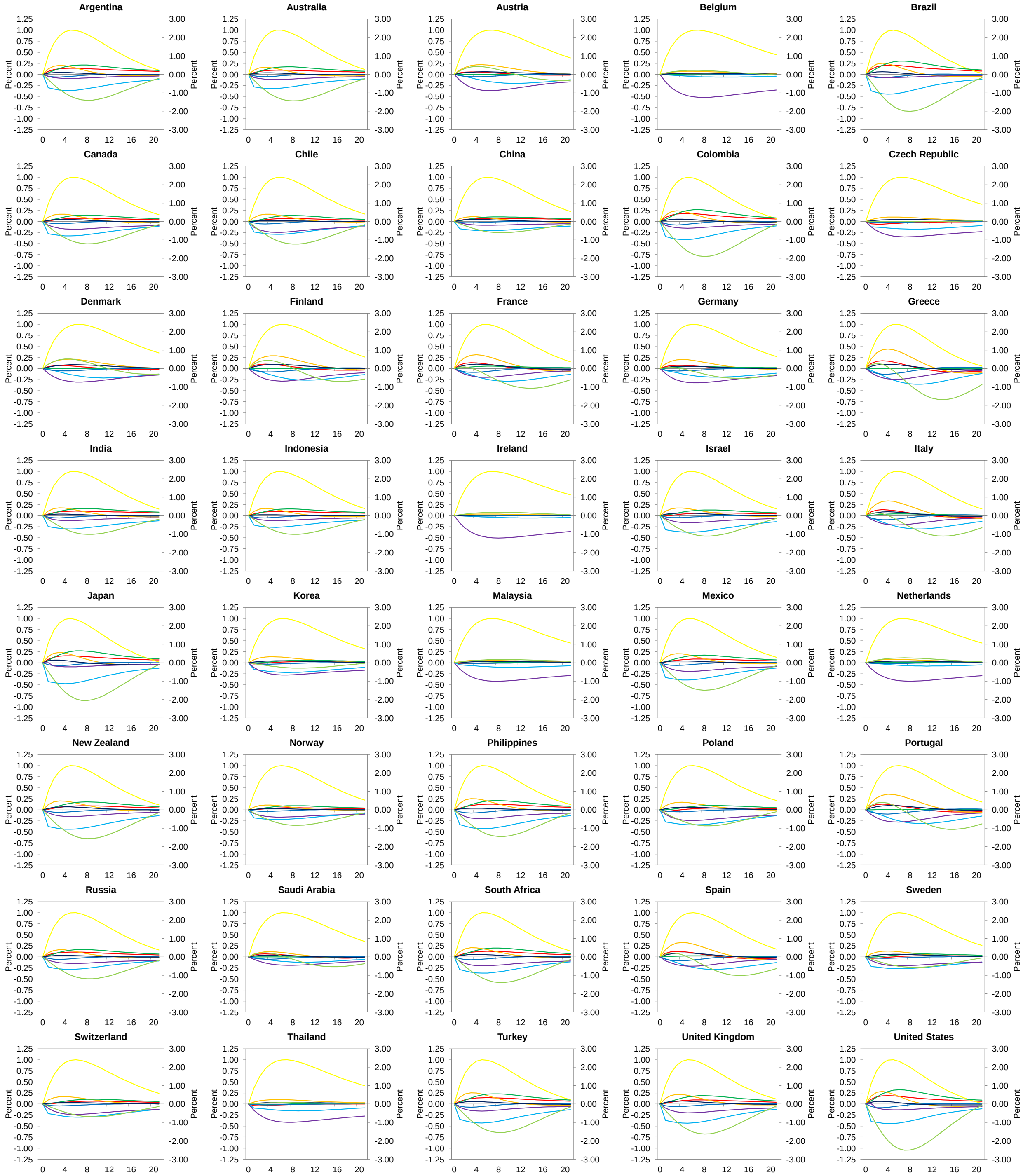
Note: Depicts the impulse responses of consumption price inflation ■ (lhs), output ■ (lhs), private consumption ■ (lhs), private investment ■ (rhs), the nominal policy interest rate ■ (lhs), the real effective exchange rate ■ (lhs), the unemployment rate ■ (lhs), the fiscal balance ratio ■ (lhs), and the current account balance ratio ■ (lhs) to domestic productivity shocks which raise output price inflation by one percentage point. Results are annualized where applicable.

Figure 2. Impulse Responses to a Domestic Labor Supply Shock



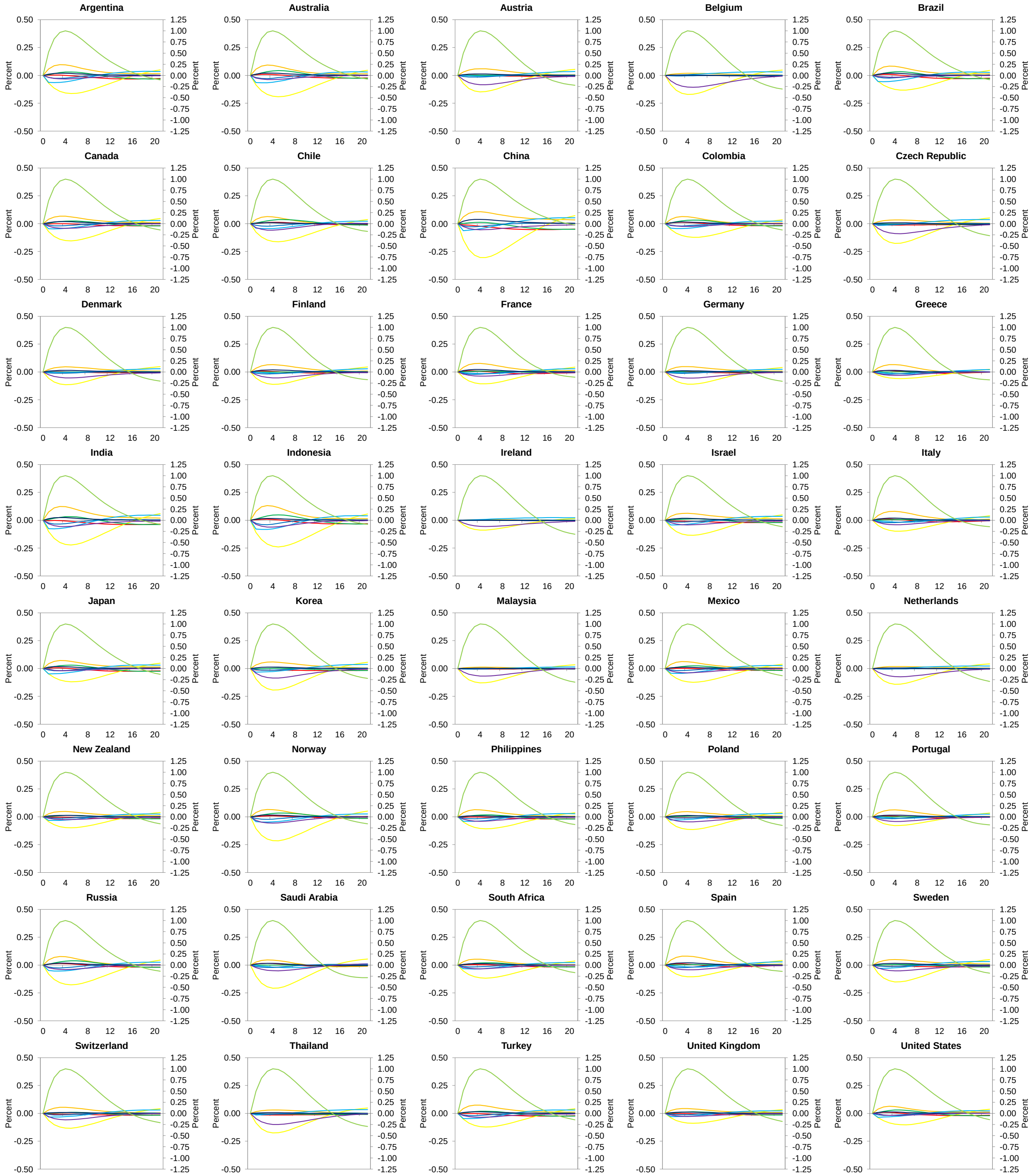
Note: Depicts the impulse responses of consumption price inflation ■ (lhs), output ■ (lhs), private consumption ■ (lhs), private investment ■ (rhs), the nominal policy interest rate ■ (lhs), the real effective exchange rate ■ (lhs), the unemployment rate ■ (lhs), the fiscal balance ratio ■ (lhs), and the current account balance ratio ■ (lhs) to domestic labor supply shocks which raise the labor force by one percent. Results are annualized where applicable.

Figure 3. Impulse Responses to a Domestic Consumption Demand Shock



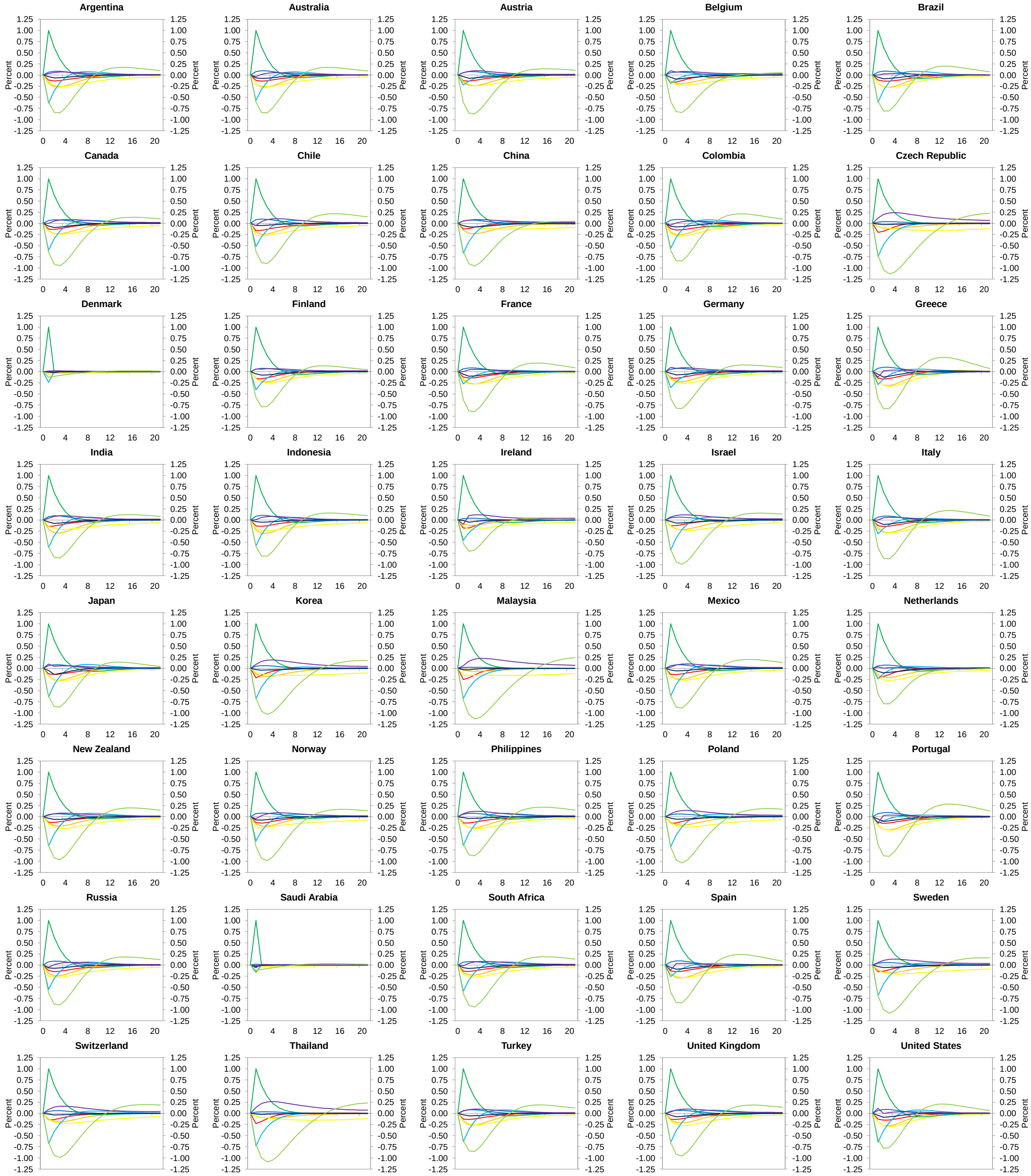
Note: Depicts the impulse responses of consumption price inflation ■ (lhs), output ■ (lhs), private consumption ■ (lhs), private investment ■ (rhs), the nominal policy interest rate ■ (lhs), the real effective exchange rate ■ (lhs), the unemployment rate ■ (lhs), the fiscal balance ratio ■ (lhs), and the current account balance ratio ■ (lhs) to domestic consumption demand shocks which raise private consumption by one percent. Results are annualized where applicable.

Figure 4. Impulse Responses to a Domestic Investment Demand Shock



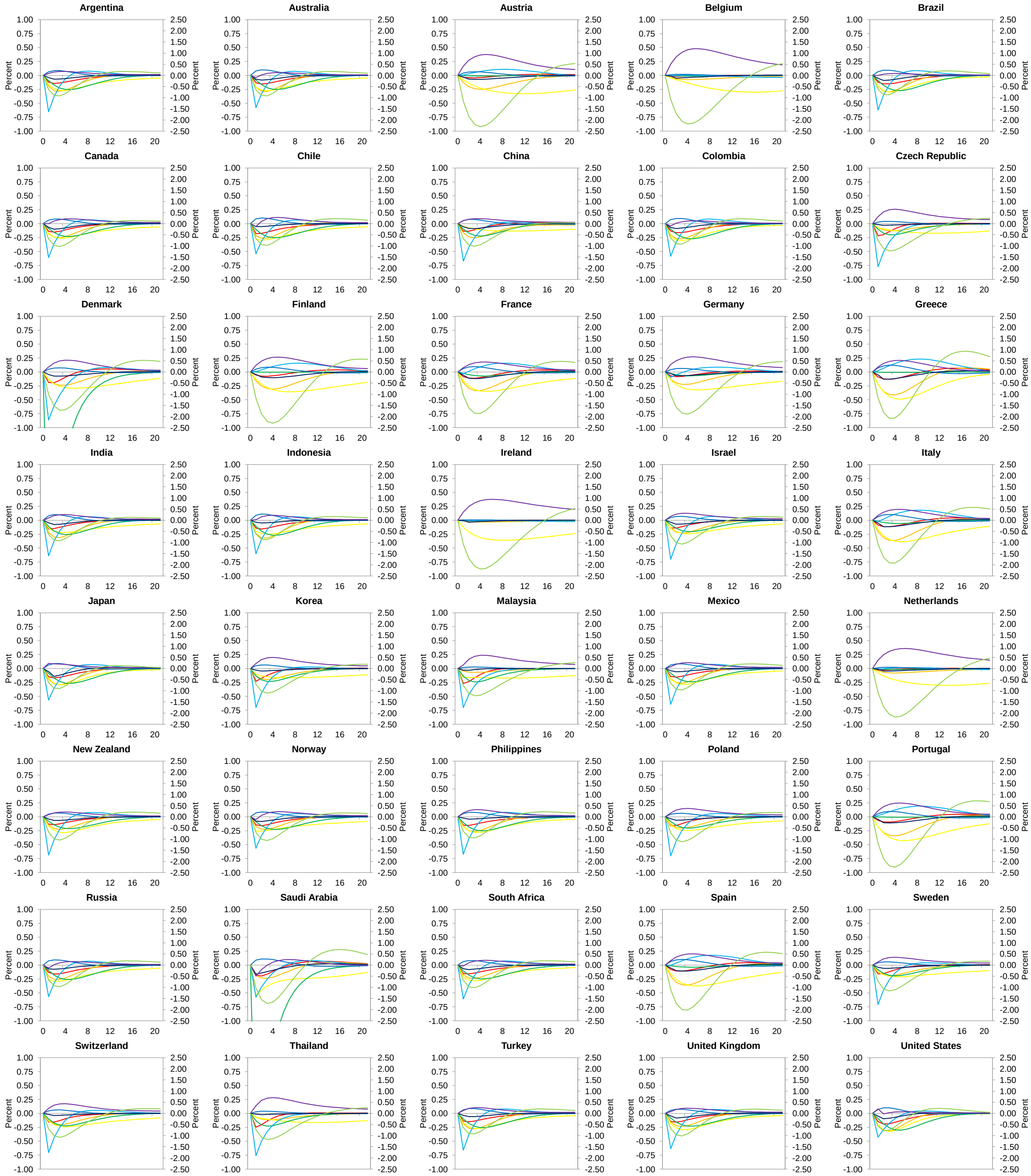
Note: Depicts the impulse responses of consumption price inflation ■ (lhs), output ■ (lhs), private consumption ■ (lhs), private investment ■ (rhs), the nominal policy interest rate ■ (lhs), the real effective exchange rate ■ (lhs), the unemployment rate ■ (lhs), the fiscal balance ratio ■ (lhs), and the current account balance ratio ■ (lhs) to domestic investment demand shocks which raise private investment by one percent. Results are annualized where applicable.

Figure 5. Impulse Responses to a Domestic Monetary Policy Shock



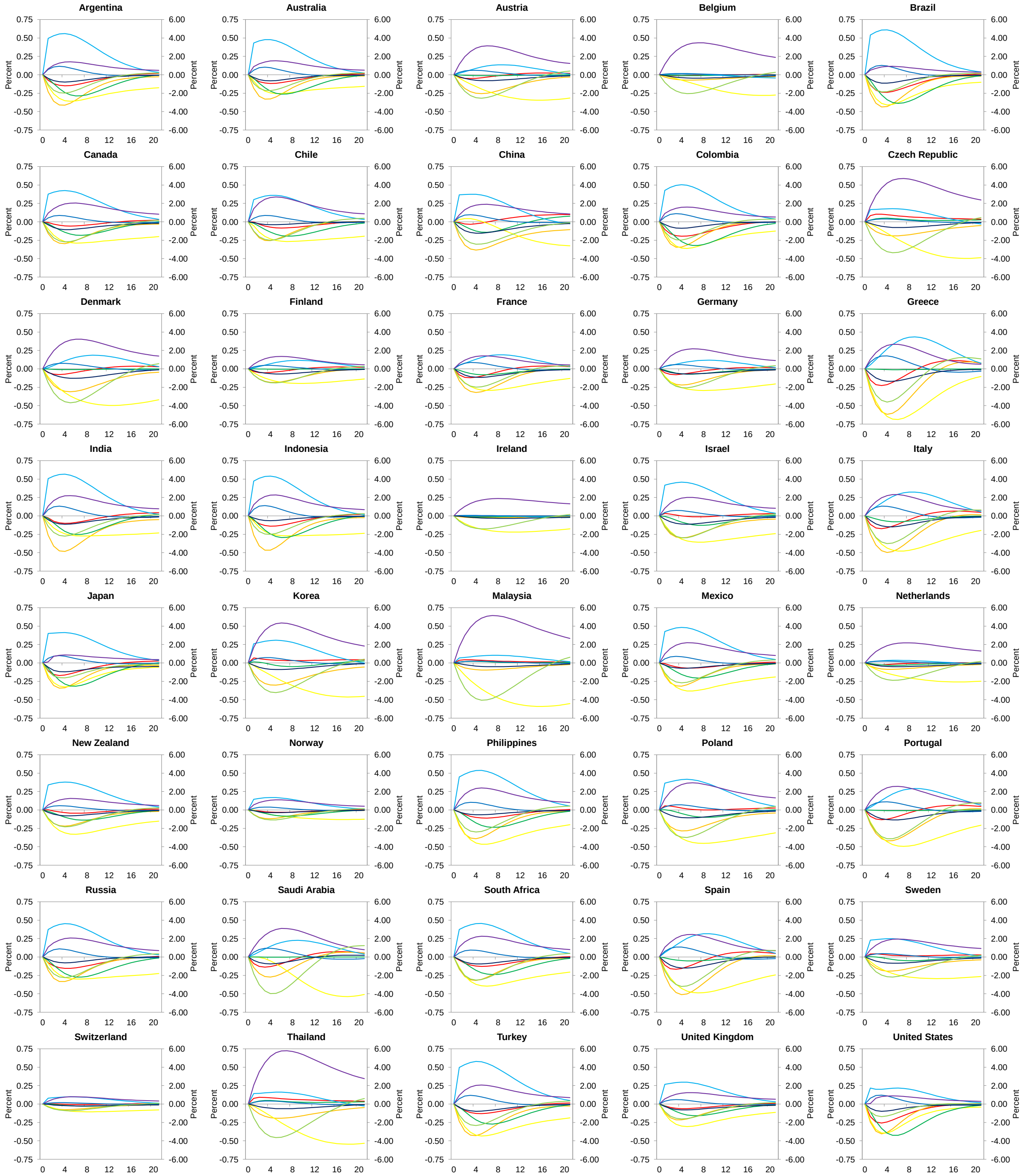
Note: Depicts the impulse responses of consumption price inflation ■ (lhs), output ■ (lhs), private consumption ■ (lhs), private investment ■ (rhs), the nominal policy interest rate ■ (lhs), the real effective exchange rate ■ (lhs), the unemployment rate ■ (lhs), the fiscal balance ratio ■ (lhs), and the current account balance ratio ■ (lhs) to domestic monetary policy shocks which raise the nominal policy interest rate by one percentage point. Results are annualized where applicable.

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



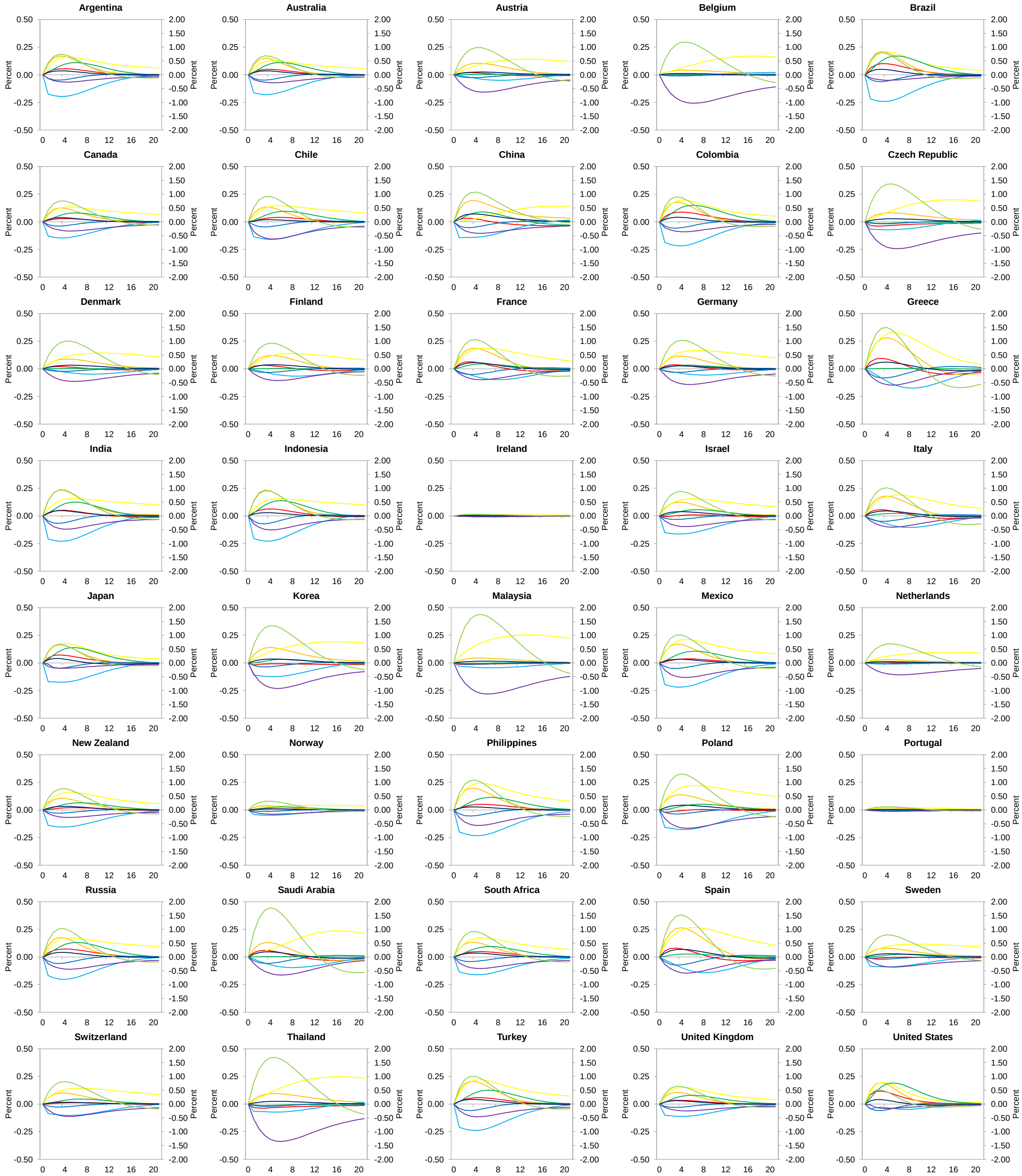
Note: Depicts the impulse responses of consumption price inflation ■ (lhs), output ■ (lhs), private consumption ■ (lhs), private investment ■ (rhs), the nominal policy interest rate ■ (lhs), the real effective exchange rate ■ (lhs), the unemployment rate ■ (lhs), the fiscal balance ratio ■ (lhs), and the current account balance ratio ■ (lhs) to domestic credit risk premium shocks which raise the short term nominal market interest rate by one percentage point. Results are annualized where applicable.

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



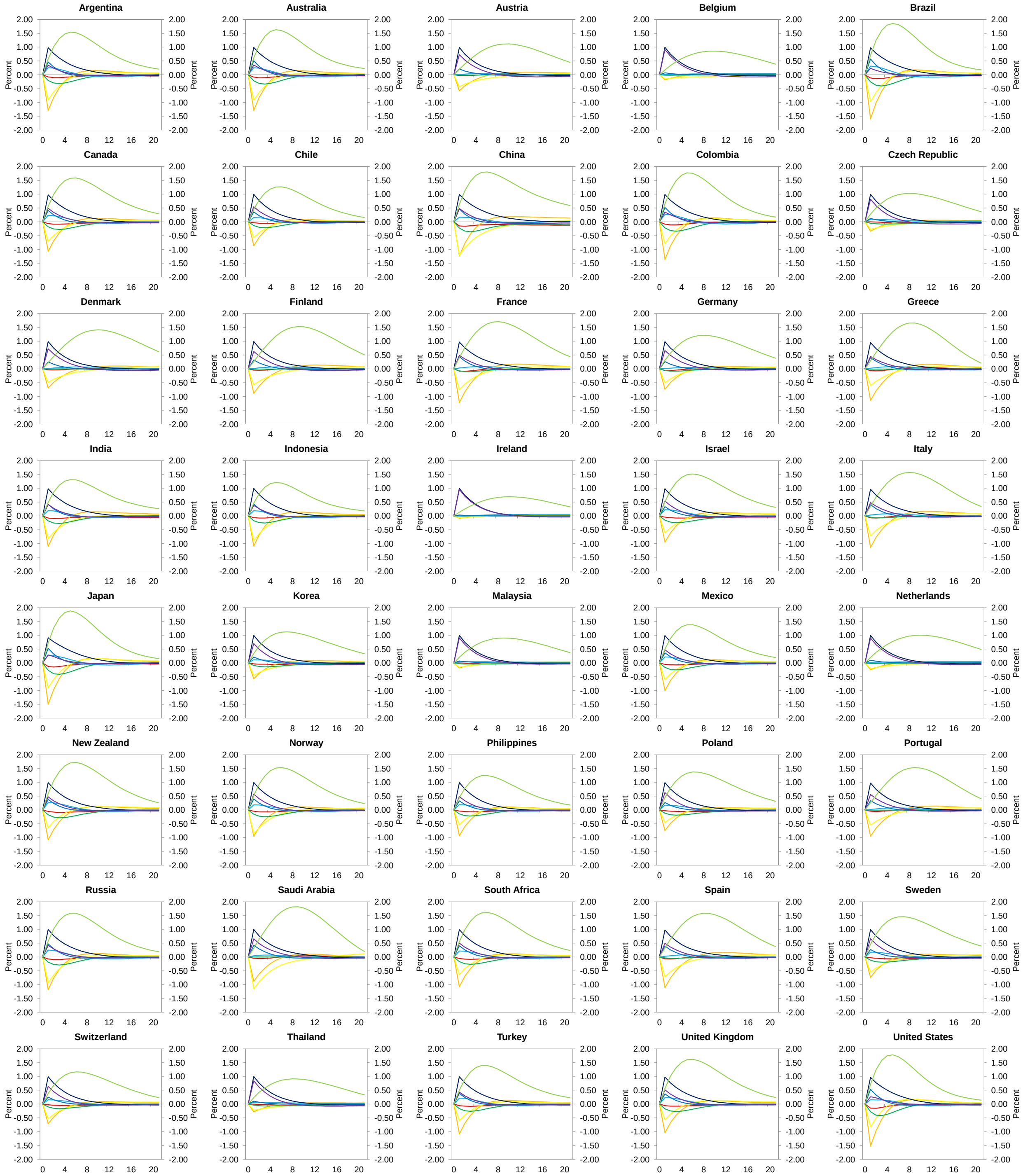
Note: Depicts the impulse responses of consumption price inflation ■ (lhs), output ■ (lhs), private consumption ■ (lhs), private investment ■ (rhs), the nominal policy interest rate ■ (lhs), the real effective exchange rate ■ (lhs), the unemployment rate ■ (lhs), the fiscal balance ratio ■ (lhs), and the current account balance ratio ■ (lhs) to domestic duration risk premium shocks which raise the long term nominal market interest rate by one percentage point. Results are annualized where applicable.

Figure 8. Impulse Responses to a Domestic Equity Risk Premium Shock



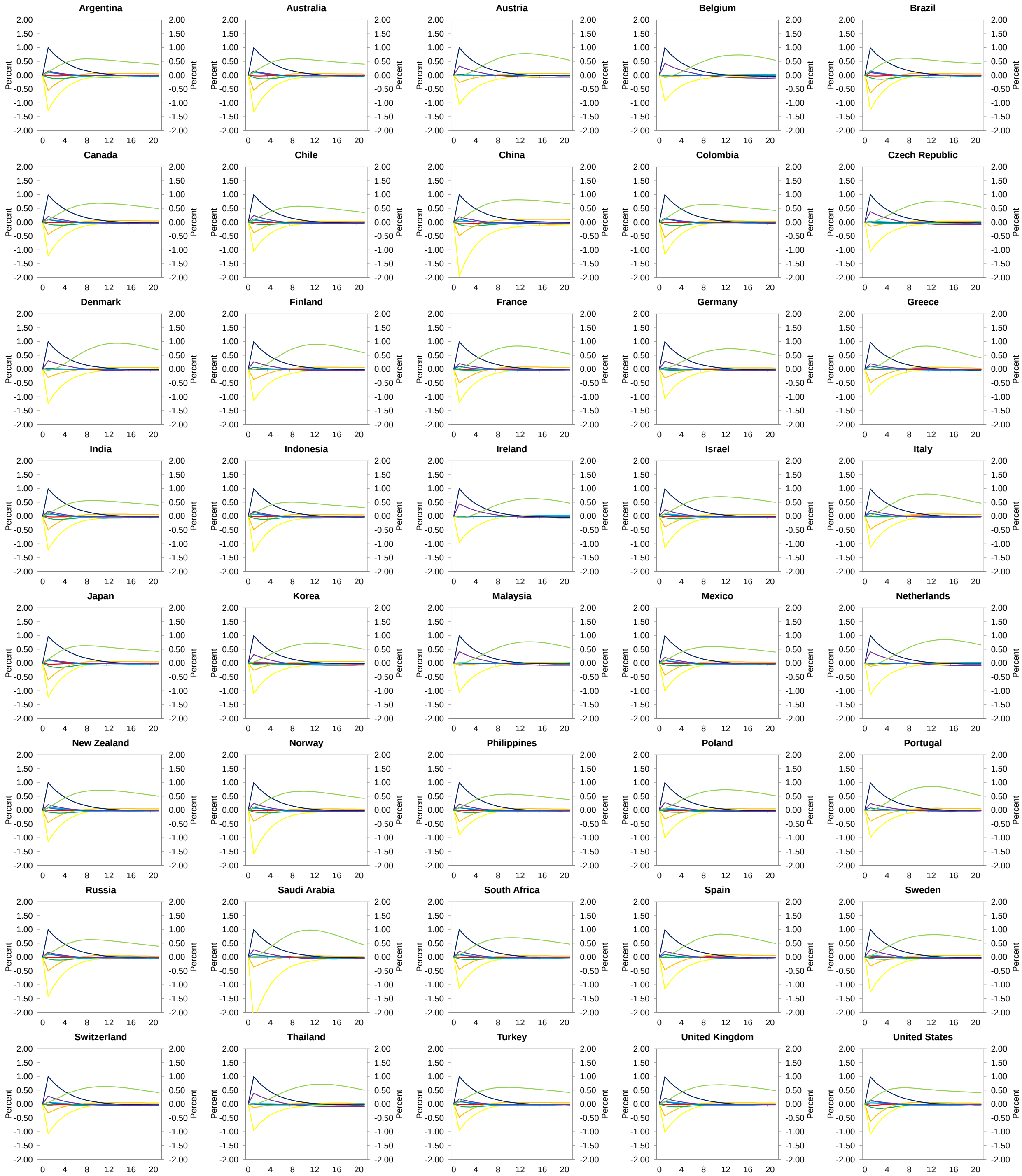
Note: Depicts the impulse responses of consumption price inflation ■ (lhs), output ■ (lhs), private consumption ■ (lhs), private investment ■ (rhs), the nominal policy interest rate ■ (lhs), the real effective exchange rate ■ (lhs), the unemployment rate ■ (lhs), the fiscal balance ratio ■ (lhs), and the current account balance ratio ■ (lhs) to domestic equity risk premium shocks which raise the price of equity by ten percent. Results are annualized where applicable.

Figure 9. Impulse Responses to a Domestic Fiscal Expenditure Shock



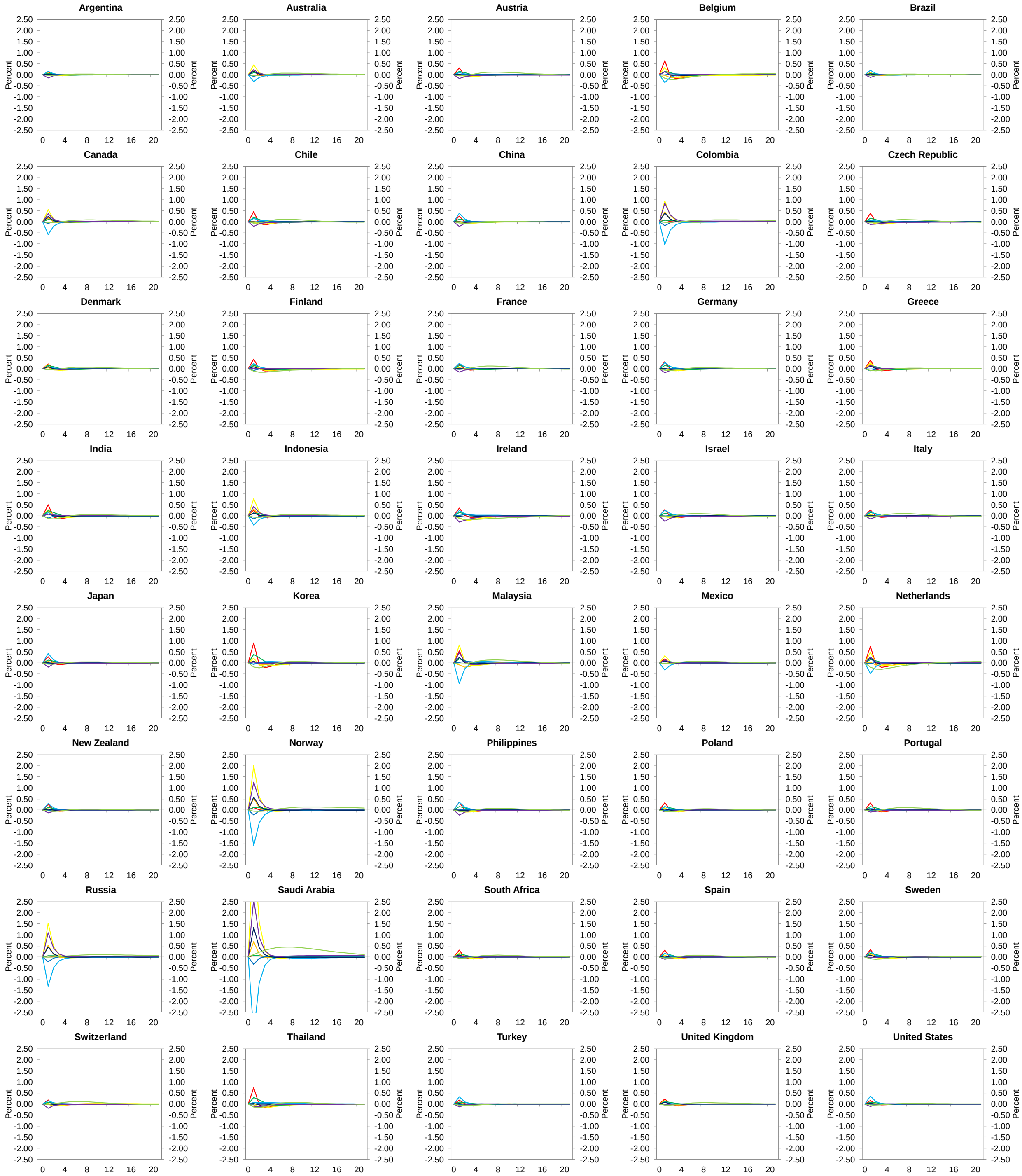
Note: Depicts the impulse responses of consumption price inflation ■ (lhs), output ■ (lhs), private consumption ■ (lhs), private investment ■ (rhs), the nominal policy interest rate ■ (lhs), the real effective exchange rate ■ (lhs), the unemployment rate ■ (lhs), the fiscal balance ratio ■ (lhs), and the current account balance ratio ■ (lhs) to domestic fiscal expenditure shocks which raise the primary fiscal balance ratio by one percentage point. Results are annualized where applicable.

Figure 10. Impulse Responses to a Domestic Fiscal Revenue Shock



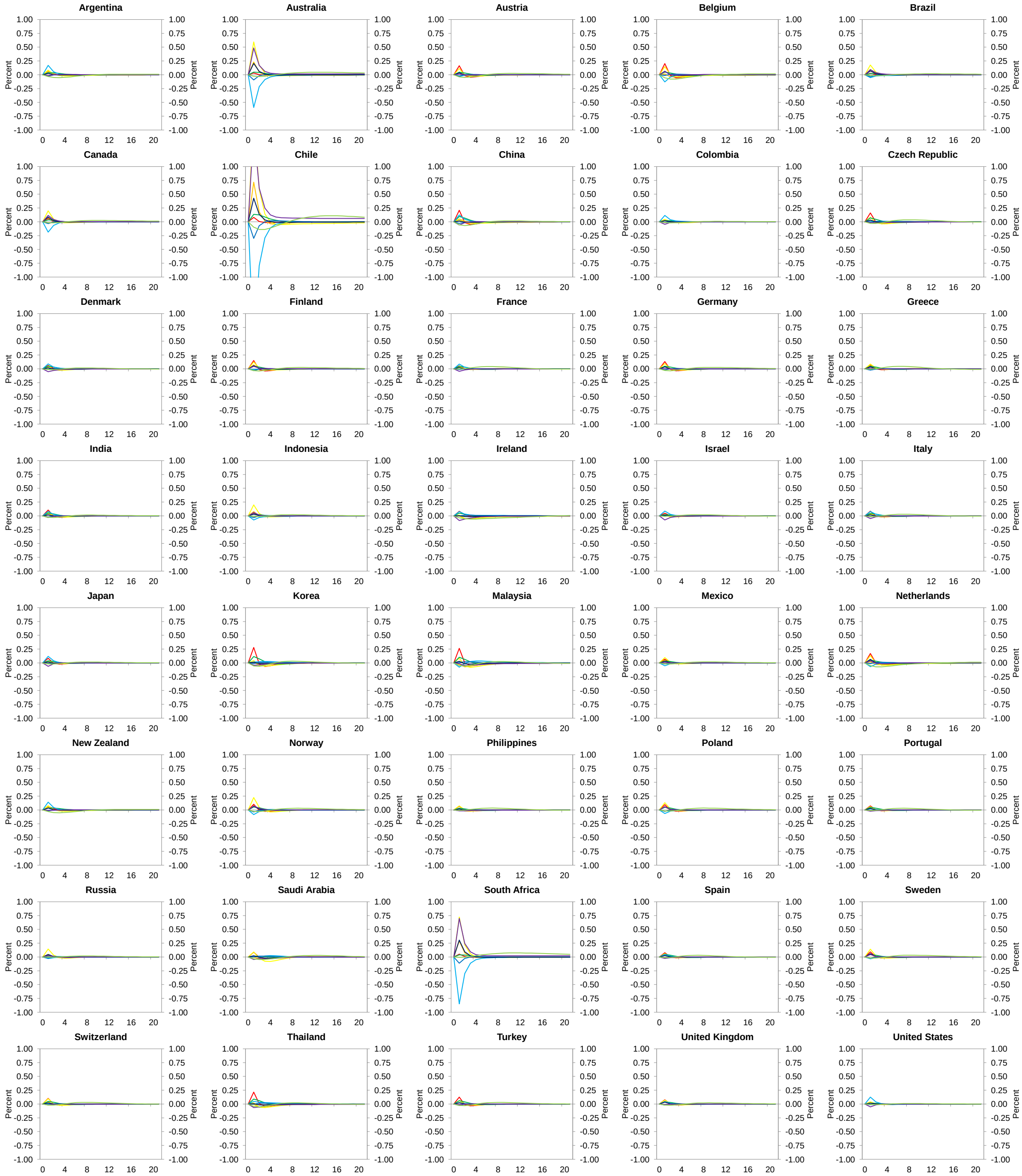
Note: Depicts the impulse responses of consumption price inflation ■ (lhs), output ■ (lhs), private consumption ■ (lhs), private investment ■ (rhs), the nominal policy interest rate ■ (lhs), the real effective exchange rate ■ (lhs), the unemployment rate ■ (lhs), the fiscal balance ratio ■ (lhs), and the current account balance ratio ■ (lhs) to domestic fiscal revenue shocks which raise the primary fiscal balance ratio by one percentage point. Results are annualized where applicable.

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



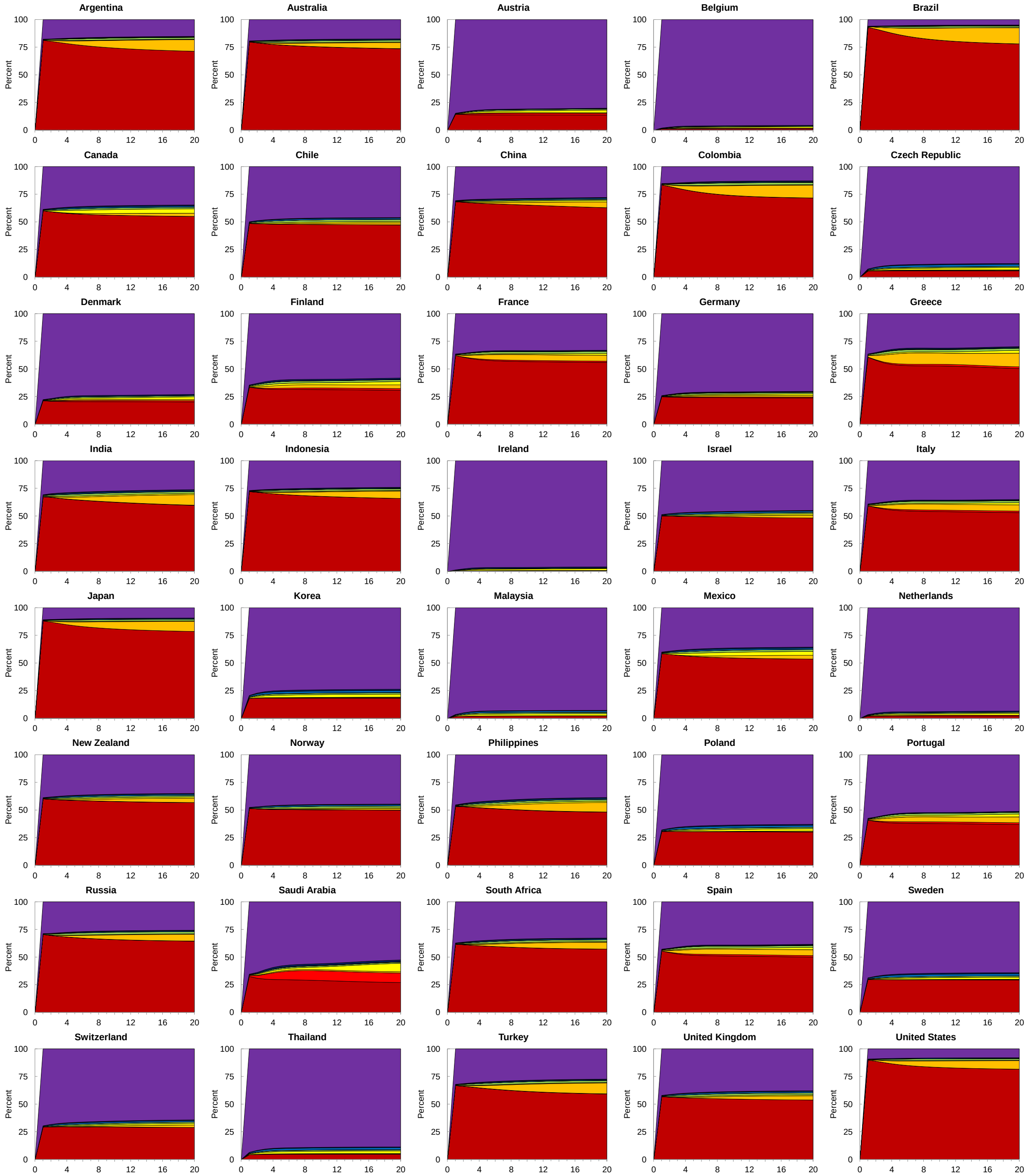
Note: Depicts the impulse responses of consumption price inflation ■ (lhs), output ■ (lhs), private consumption ■ (lhs), private investment ■ (rhs), the nominal policy interest rate ■ (lhs), the real effective exchange rate ■ (lhs), the unemployment rate ■ (lhs), the fiscal balance ratio ■ (lhs), and the current account balance ratio ■ (lhs) to a world energy commodity price markup shock which raises the price of energy commodities by ten percent. Results are annualized where applicable.

Figure 12. Impulse Responses to a World Nonenergy Commodity Price Markup Shock



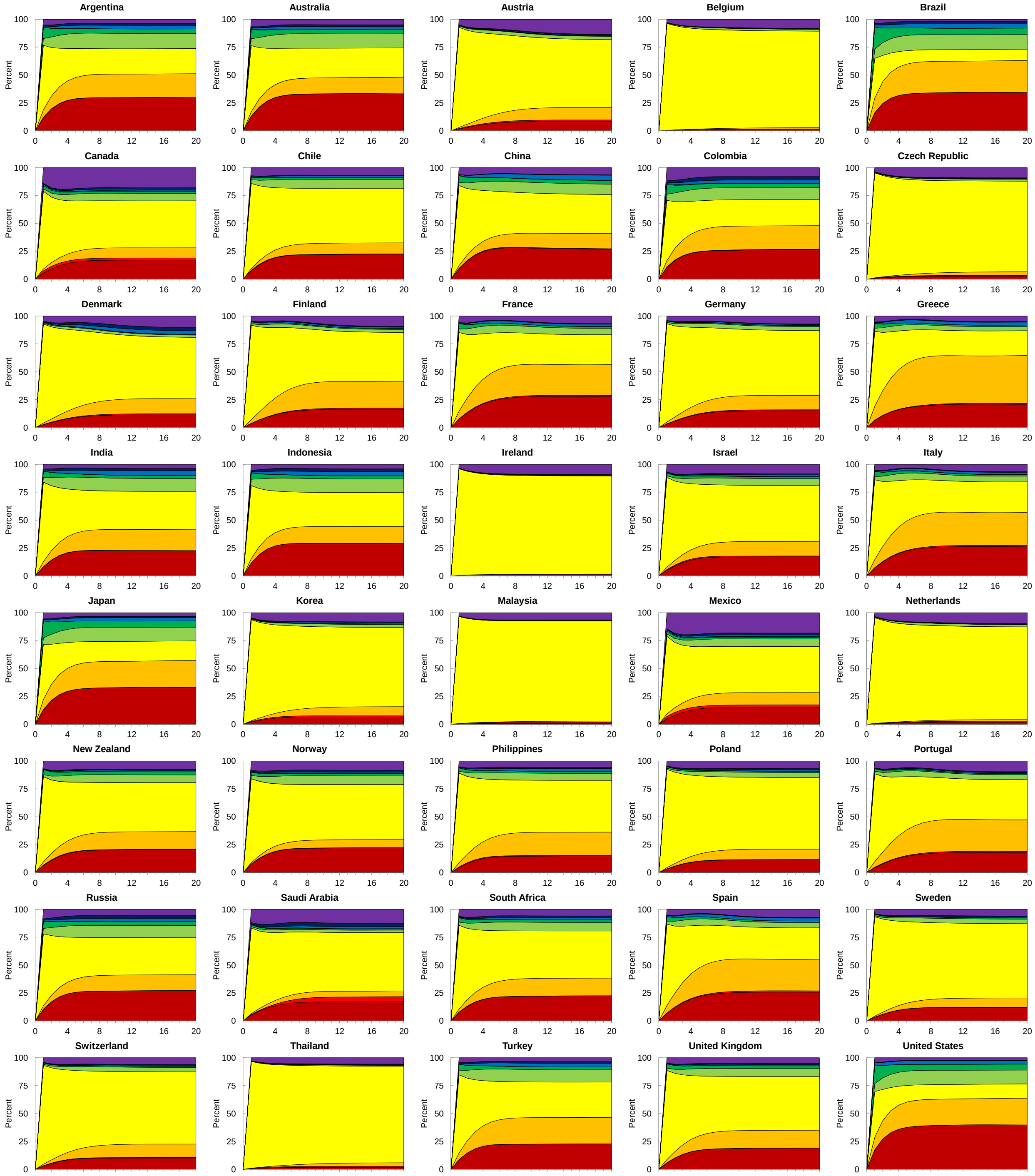
Note: Depicts the impulse responses of consumption price inflation ■ (lhs), output ■ (lhs), private consumption ■ (lhs), private investment ■ (rhs), the nominal policy interest rate ■ (lhs), the real effective exchange rate ■ (lhs), the unemployment rate ■ (lhs), the fiscal balance ratio ■ (lhs), and the current account balance ratio ■ (lhs) to a world nonenergy commodity price markup shock which raises the price of nonenergy commodities by ten percent. Results are annualized where applicable.

Figure 13. Forecast Error Variance Decompositions of Consumption Price Inflation



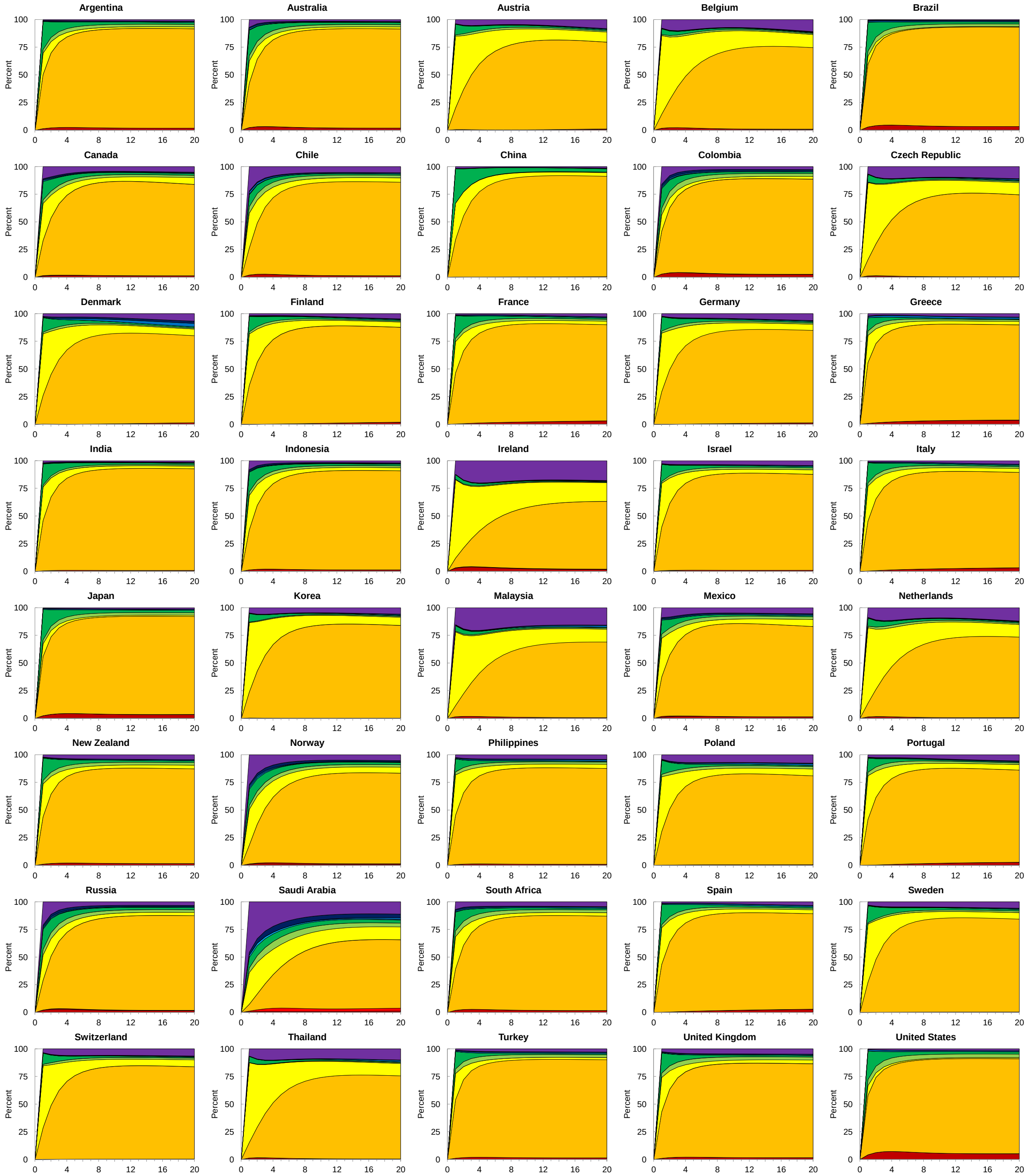
Note: Decomposes the horizon dependent forecast error variance of consumption price inflation into contributions from domestic supply ■, foreign supply ■, domestic demand ■, foreign demand ■, world monetary policy ■, domestic fiscal policy ■, foreign fiscal policy ■, domestic risk premium ■, foreign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

Figure 14. Forecast Error Variance Decompositions of Output



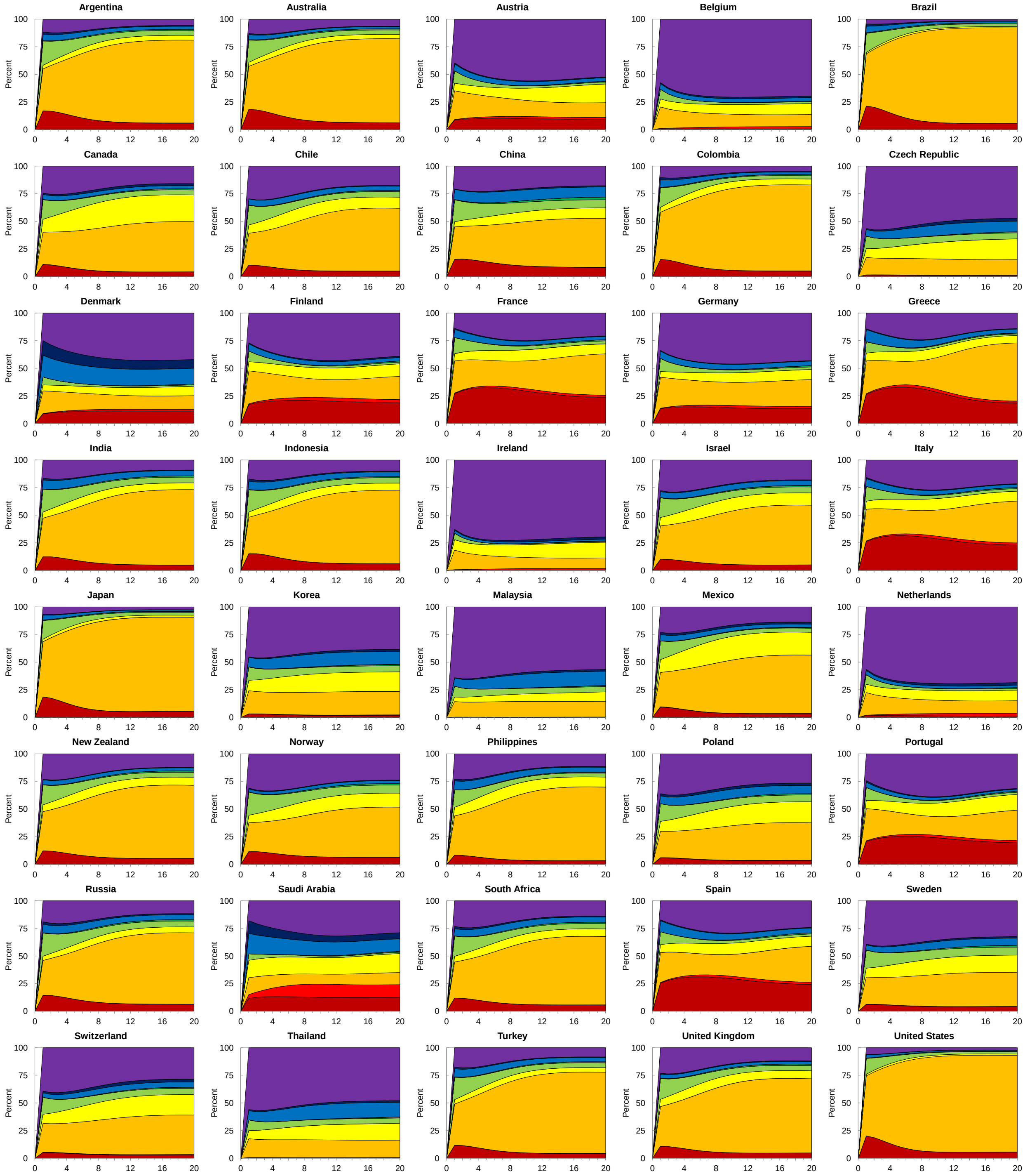
Note: Decomposes the horizon dependent forecast error variance of output into contributions from domestic supply ■, foreign supply ■, domestic demand ■, foreign demand ■, world monetary policy ■, domestic fiscal policy ■, foreign fiscal policy ■, domestic risk premium ■, foreign risk premium ■, and world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

Figure 15. Forecast Error Variance Decompositions of Private Consumption



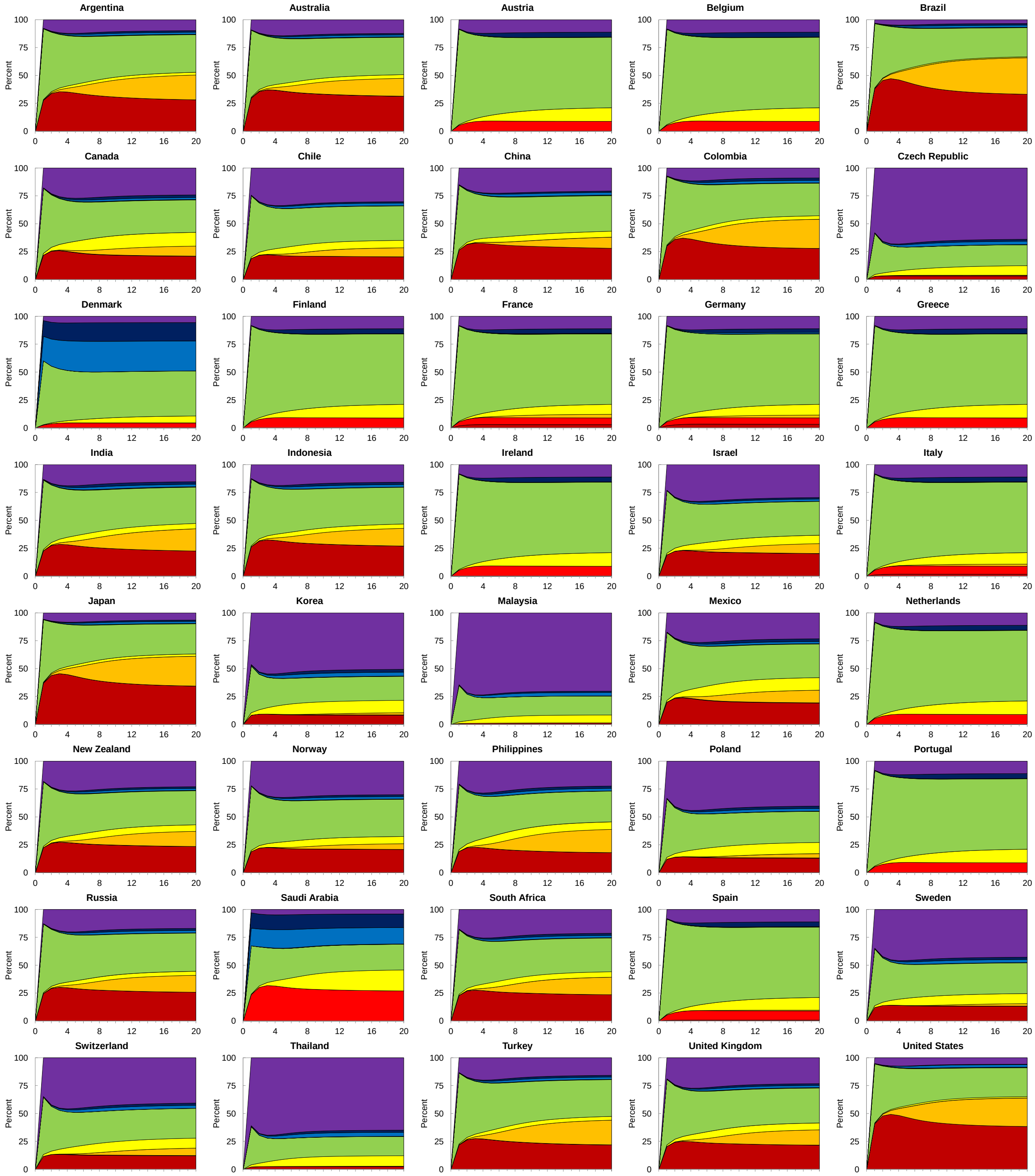
Note: Decomposes the horizon dependent forecast error variance of private consumption into contributions from domestic supply ■, foreign supply ■, domestic demand ■, foreign demand ■, world monetary policy ■, domestic fiscal policy ■, foreign fiscal policy ■, domestic risk premium ■, foreign risk premium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

Figure 16. Forecast Error Variance Decompositions of Private Investment



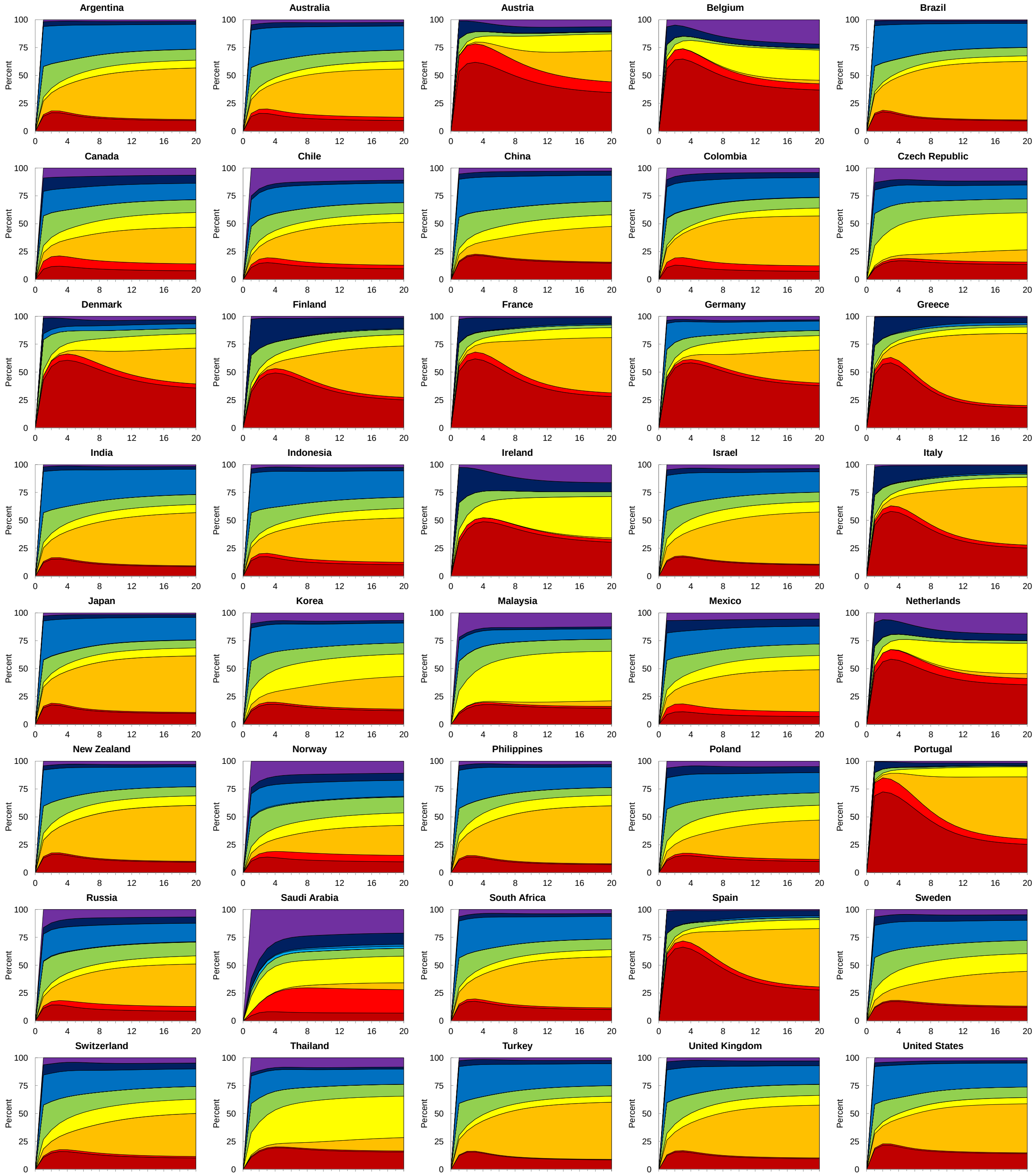
Note: Decomposes the horizon dependent forecast error variance of private investment into contributions from domestic supply ■, foreign supply ■, domestic demand ■, foreign demand ■, world monetary policy ■, domestic fiscal policy ■, foreign fiscal policy ■, domestic risk premium ■, foreign risk premium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

Figure 17. Forecast Error Variance Decompositions of the Nominal Policy Interest Rate



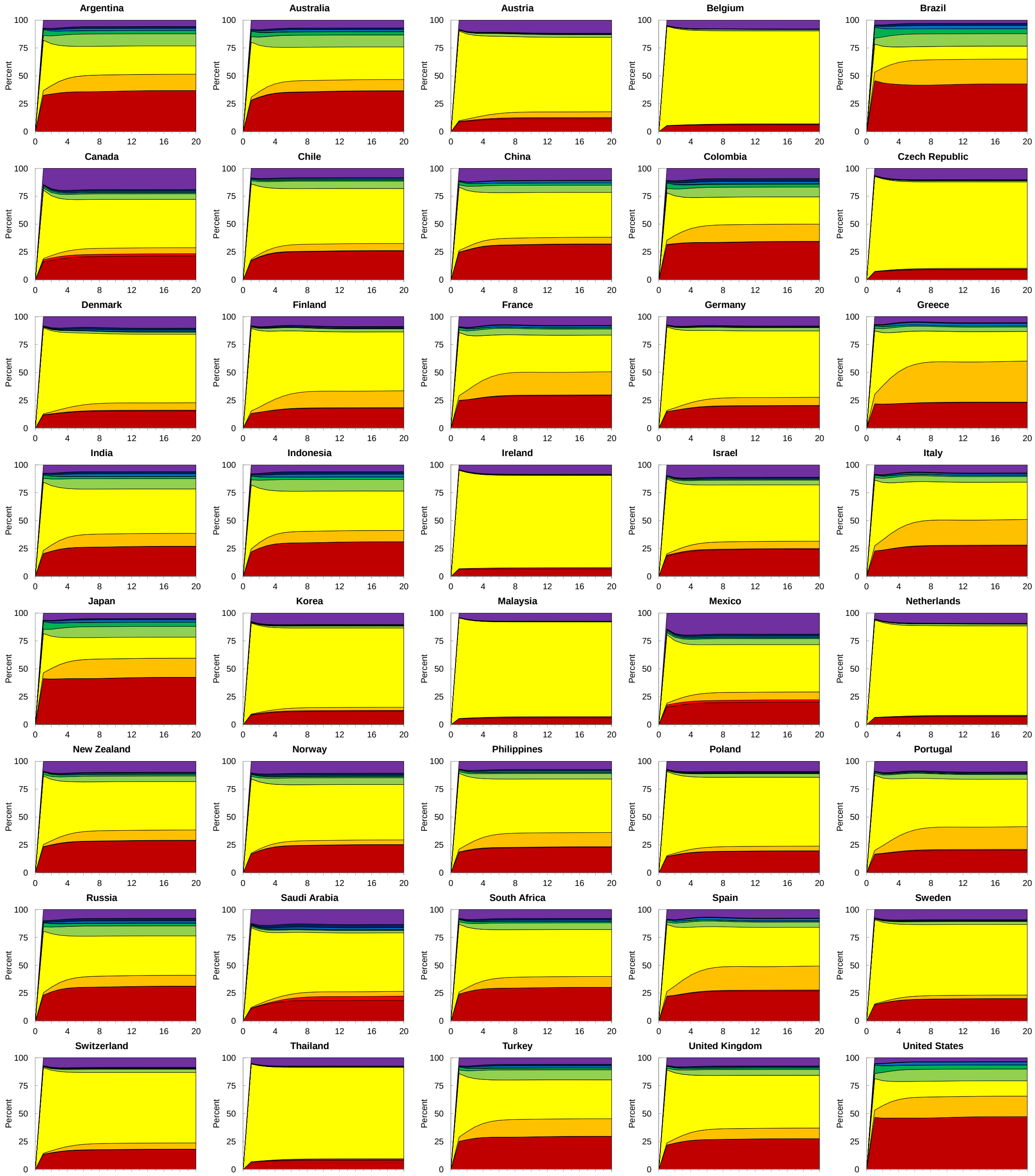
Note: Decomposes the horizon dependent forecast error variance of the nominal policy interest rate into contributions from domestic supply ■, foreign supply ■, domestic demand ■, foreign demand ■, world monetary policy ■, domestic fiscal policy ■, foreign fiscal policy ■, domestic risk premium ■, foreign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

Figure 18. Forecast Error Variance Decompositions of the Real Effective Exchange Rate



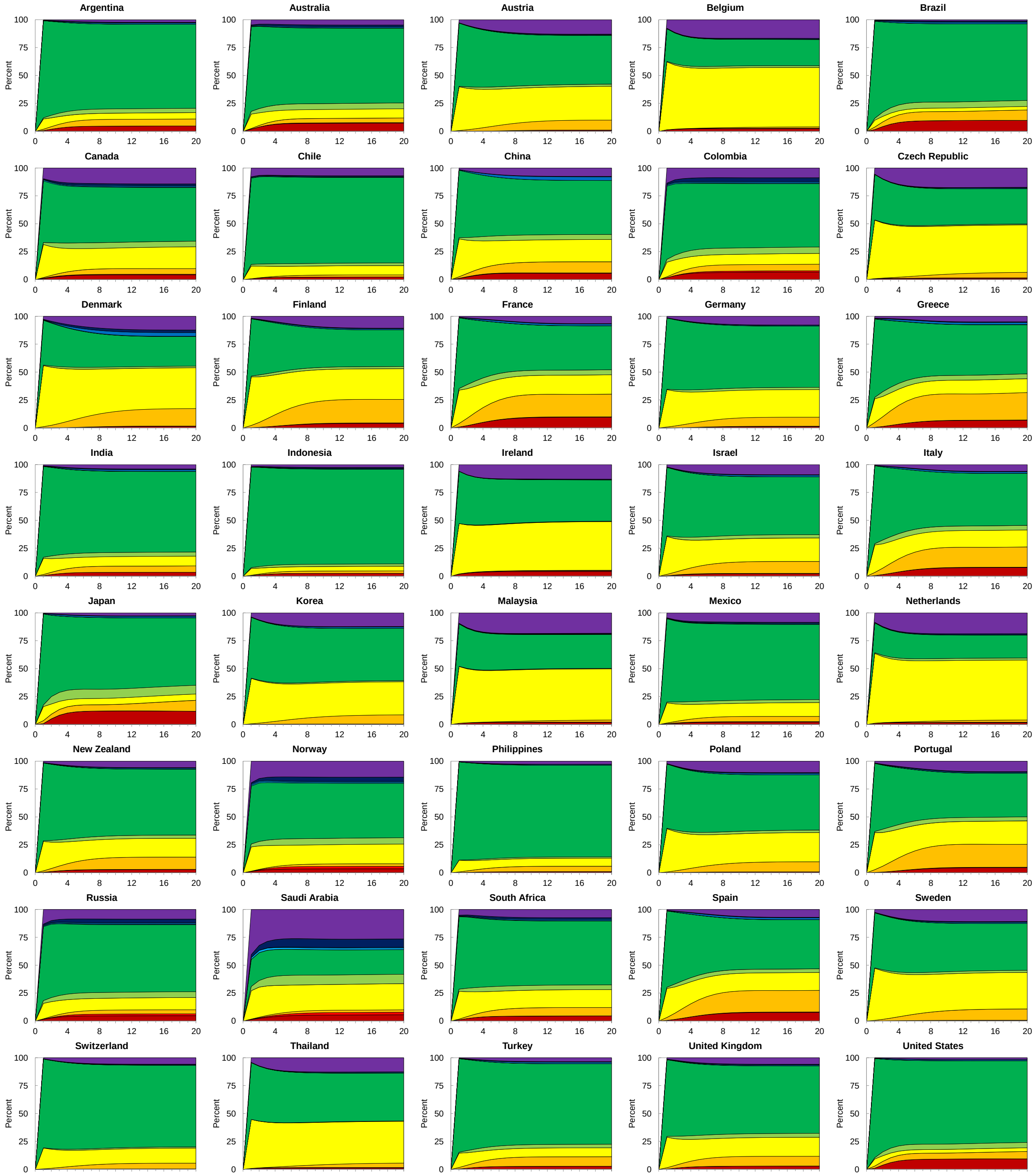
Note: Decomposes the horizon dependent forecast error variance of the real effective exchange rate into contributions from domestic supply ■, foreign supply ■, domestic demand ■, foreign demand ■, world monetary policy ■, domestic fiscal policy ■, foreign fiscal policy ■, domestic risk premium ■, foreign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

Figure 19. Forecast Error Variance Decompositions of the Unemployment Rate



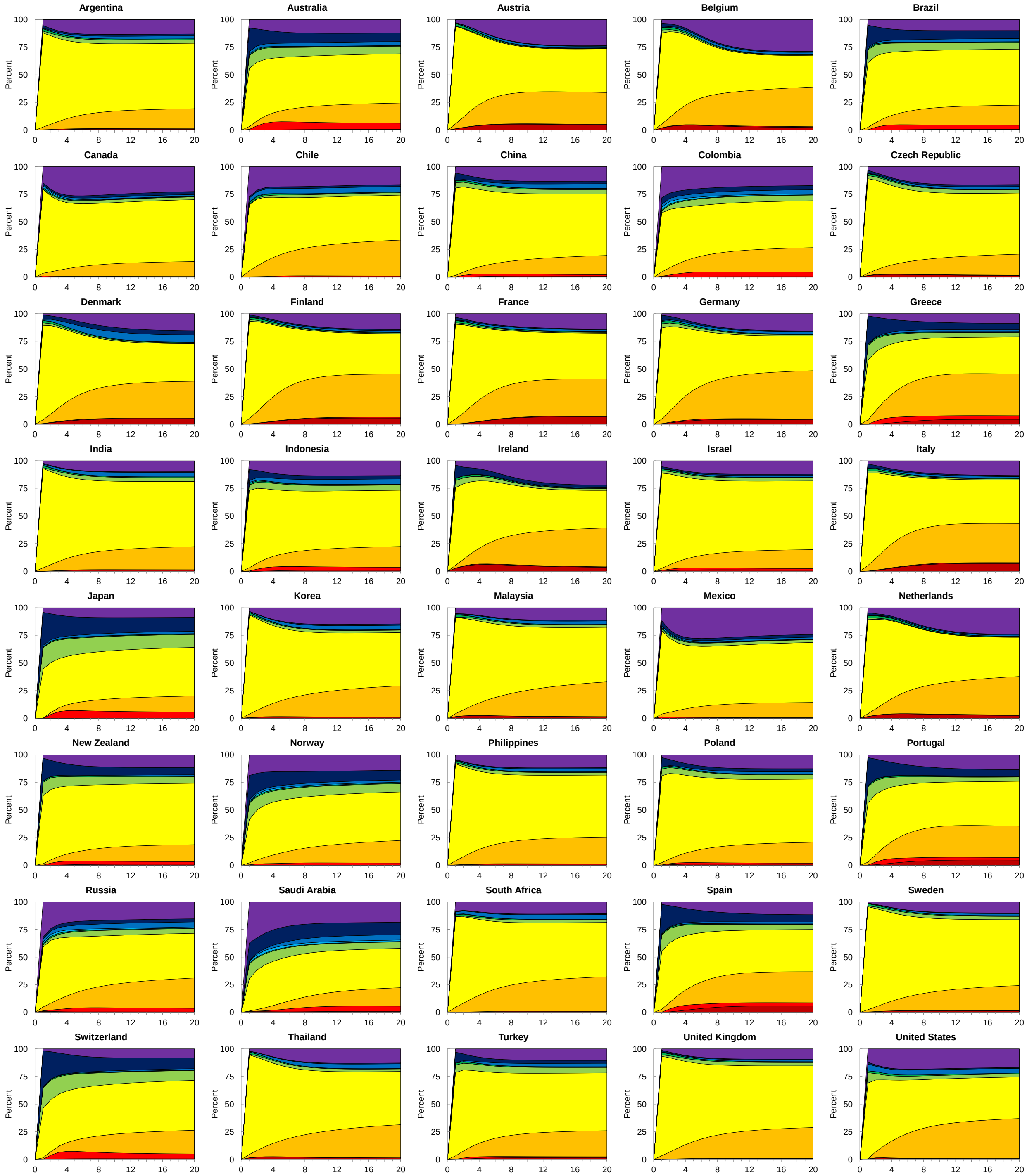
Note: Decomposes the horizon dependent forecast error variance of the unemployment rate into contributions from domestic supply ■, foreign supply ■, domestic demand ■, foreign demand ■, world monetary policy ■, domestic fiscal policy ■, foreign fiscal policy ■, domestic risk premium ■, foreign risk premium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

Figure 20. Forecast Error Variance Decompositions of the Fiscal Balance Ratio



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

Figure 21. Forecast Error Variance Decompositions of the Current Account Balance Ratio

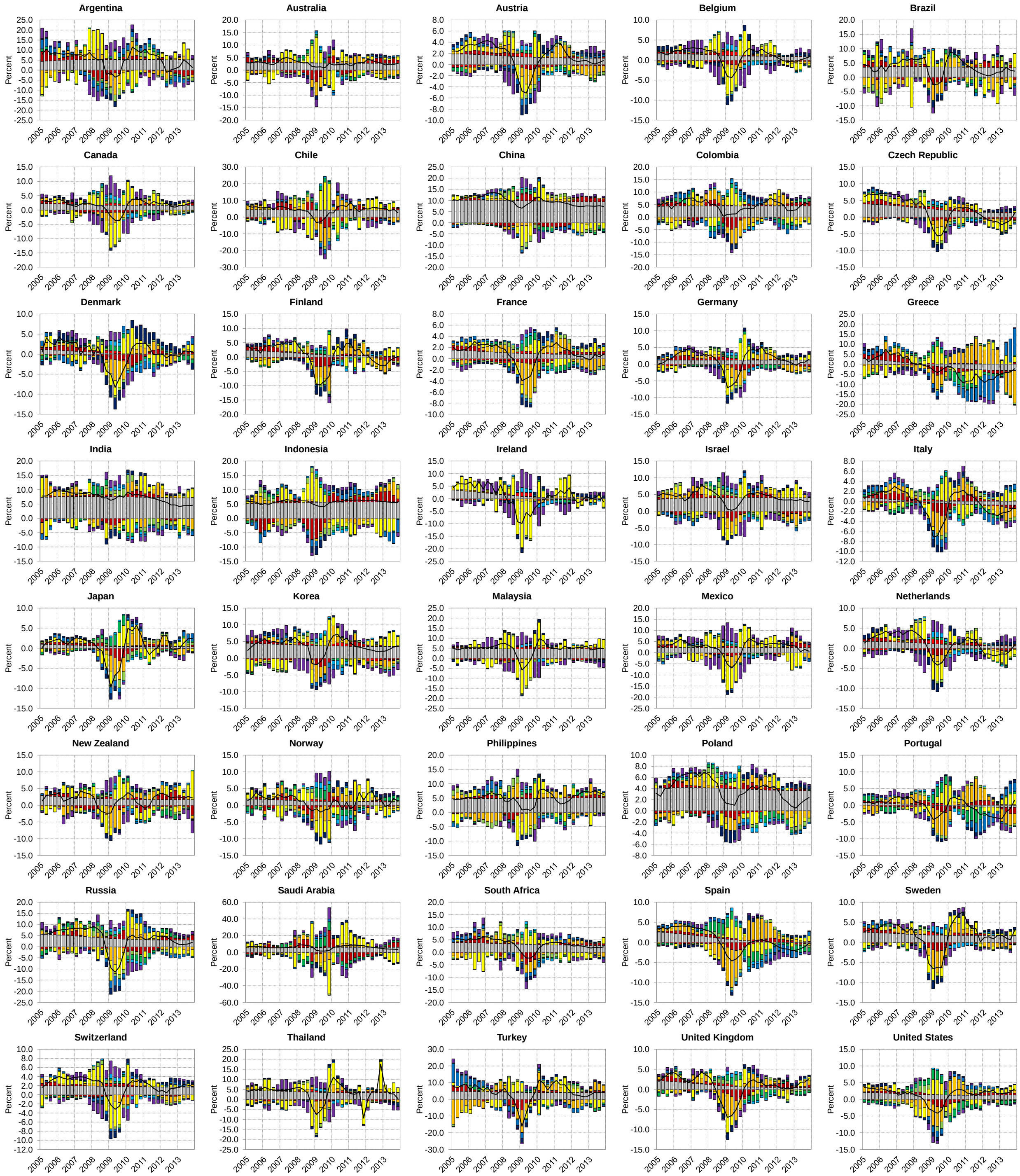


Note: Decomposes the horizon dependent forecast error variance of the current account balance ratio into contributions from domestic supply ■, foreign supply ■, domestic demand ■, foreign demand ■, world monetary policy ■, domestic fiscal policy ■, foreign fiscal policy ■, domestic risk premium ■, foreign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

Figure 22. Historical Decompositions of Consumption Price Inflation

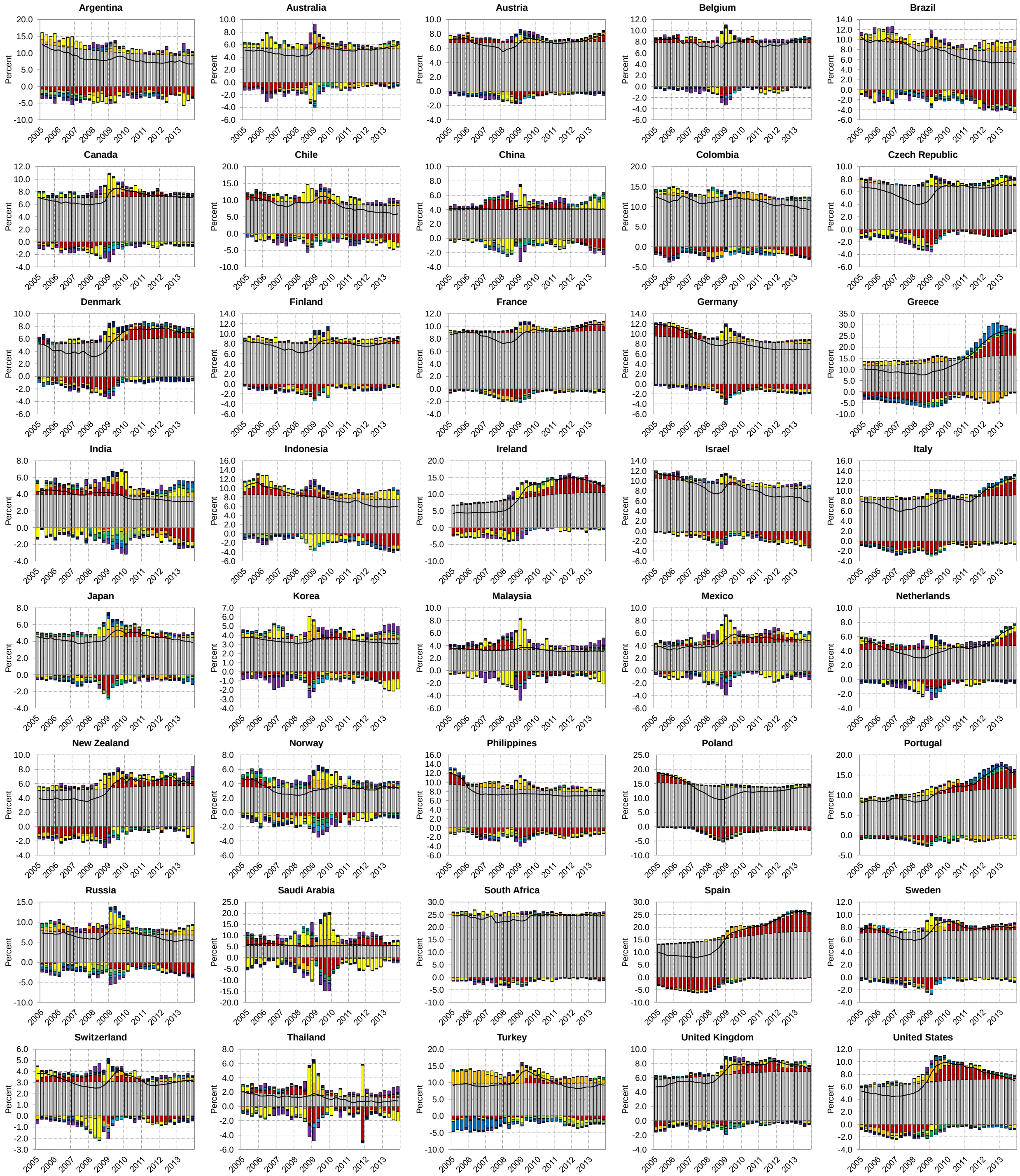
Note: Decomposes observed consumption price inflation ■ as measured by the seasonal logarithmic difference of the price of consumption into the sum of a trend component ■ and contributions from domestic supply ■, foreign supply ■, domestic demand ■, foreign demand ■, world monetary policy ■, domestic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

Figure 23. Historical Decompositions of Output Growth



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

Figure 24. Historical Decompositions of the Unemployment Rate

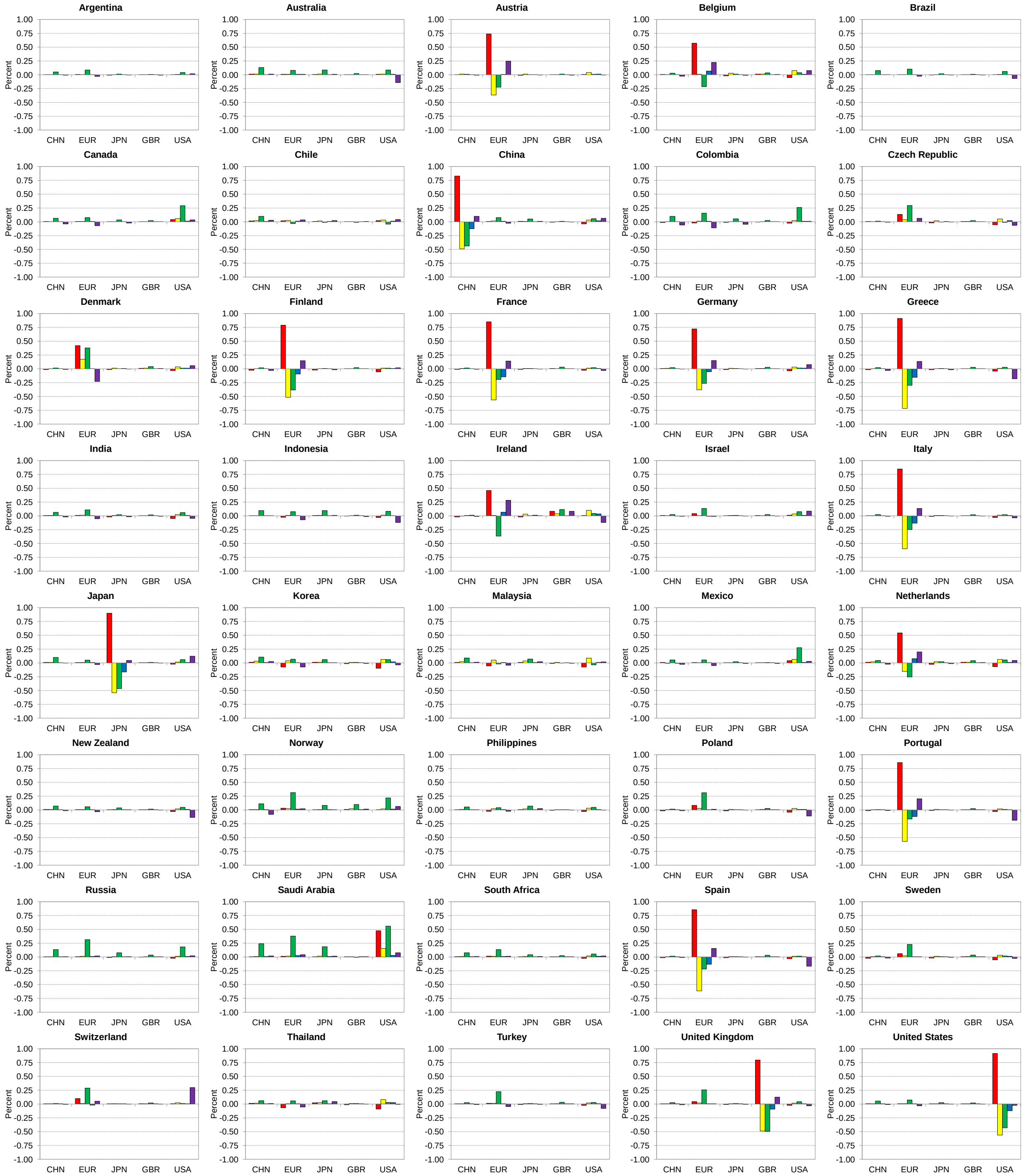


Note: Decomposes the observed unemployment rate ■ into the sum of a trend component ■ and contributions from domestic supply ■, foreign supply ■, domestic demand ■, foreign demand ■, world monetary policy ■, domestic fiscal policy ■, foreign fiscal policy ■, domestic risk premium ■, foreign risk premium ■, and world terms of trade ■ shocks.

Figure 25. Simulated Conditional Betas of Output

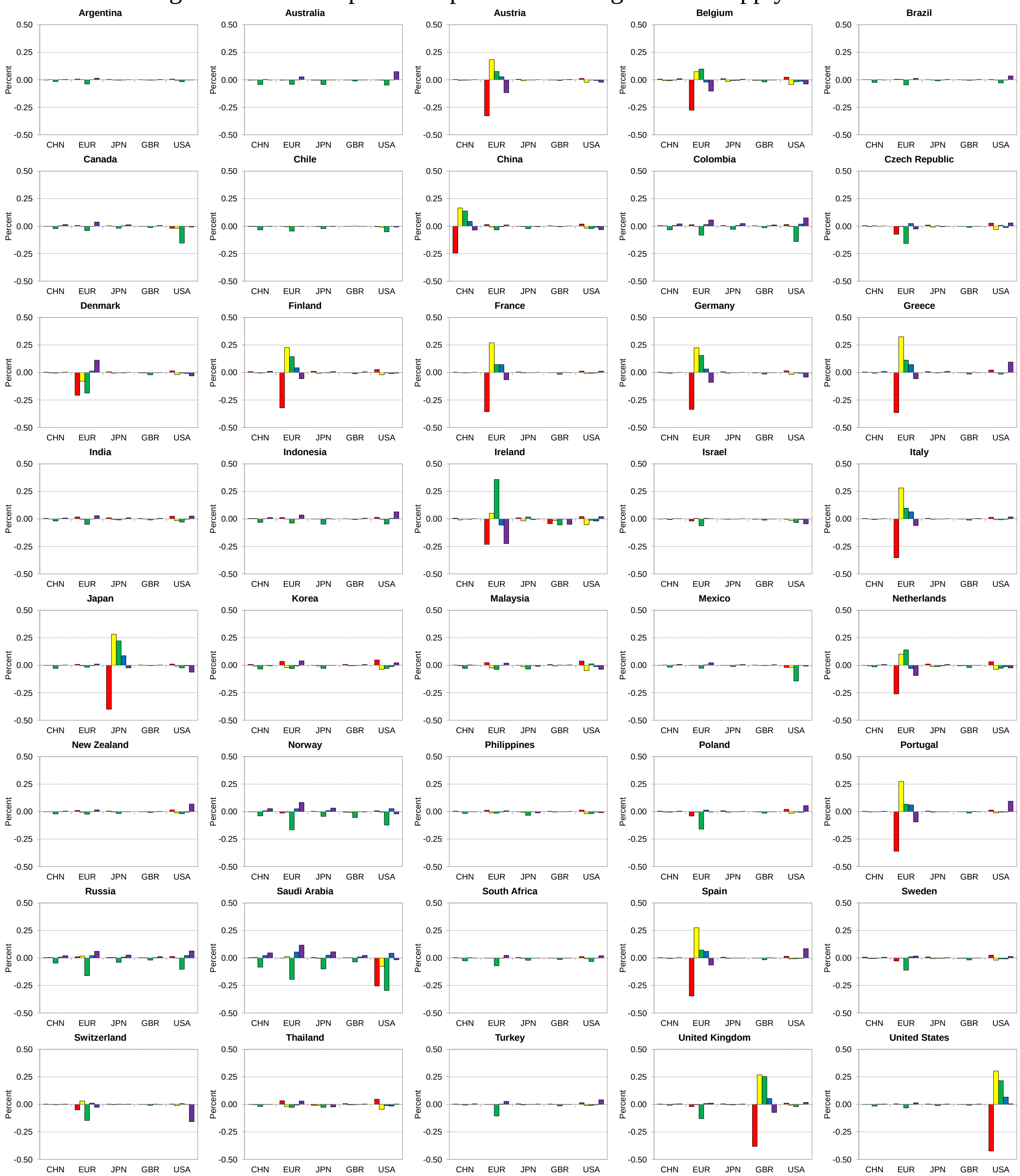
Note: Depicts the betas of output with respect to contemporaneous output in systemic economies conditional on all shocks ■, macroeconomic shocks ■, and financial shocks ■ in each of these systemic economies. These betas are calculated with a Monte Carlo simulation with 999 replications for $2T$ periods,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

Figure 26. Peak Impulse Responses to Foreign Productivity Shocks



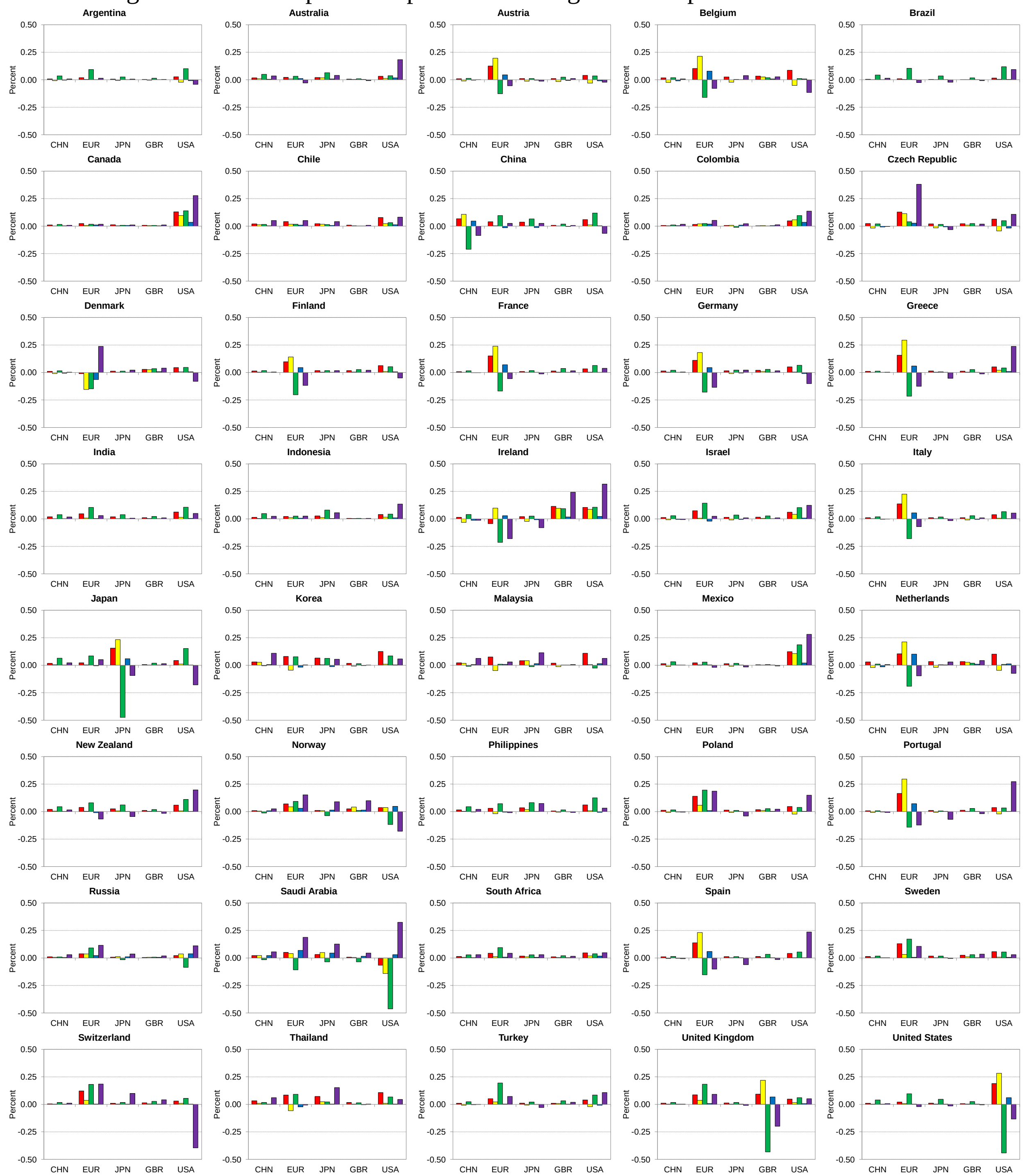
Note: Depicts the peak impulse responses of consumption price inflation ■, output ■, the real effective exchange rate ■, the fiscal balance ratio ■, and the current account balance ratio ■ to productivity shocks in systemic economies which raise their output price inflation by one percentage point. Results are annualized where applicable.

Figure 27. Peak Impulse Responses to Foreign Labor Supply Shocks



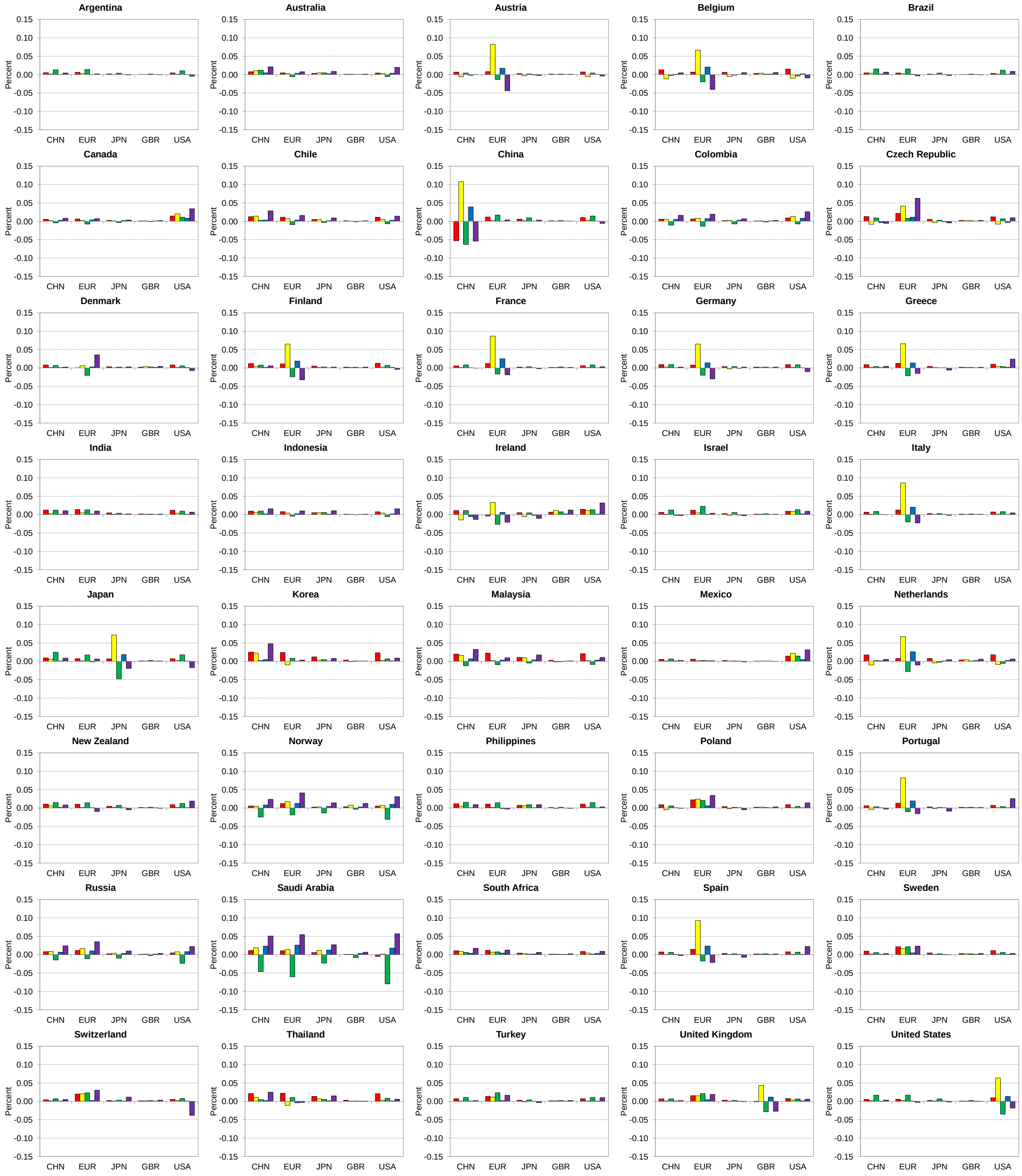
Note: Depicts the peak impulse responses of consumption price inflation ■, output ■, the real effective exchange rate ■, the fiscal balance ratio ■, and the current account balance ratio ■ to labor supply shocks in systemic economies which raise their labor force by one percent. Results are annualized where applicable.

Figure 28. Peak Impulse Responses to Foreign Consumption Demand Shocks



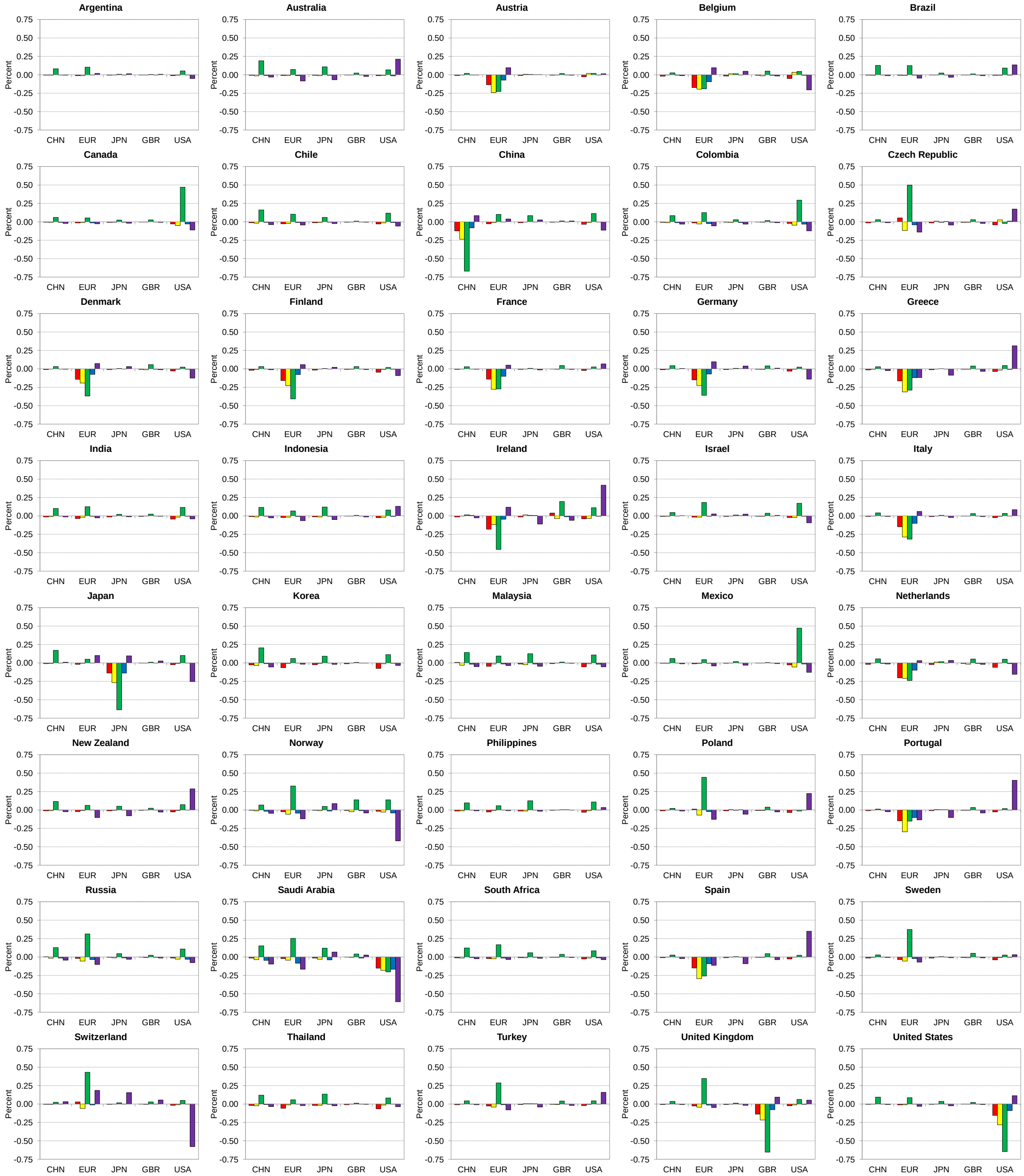
Note: Depicts the peak impulse responses of consumption price inflation ■, output ■, the real effective exchange rate ■, the fiscal balance ratio ■, and the current account balance ratio ■ to consumption demand shocks in systemic economies which raise their private consumption by one percent. Results are annualized where applicable.

Figure 29. Peak Impulse Responses to Foreign Investment Demand Shocks



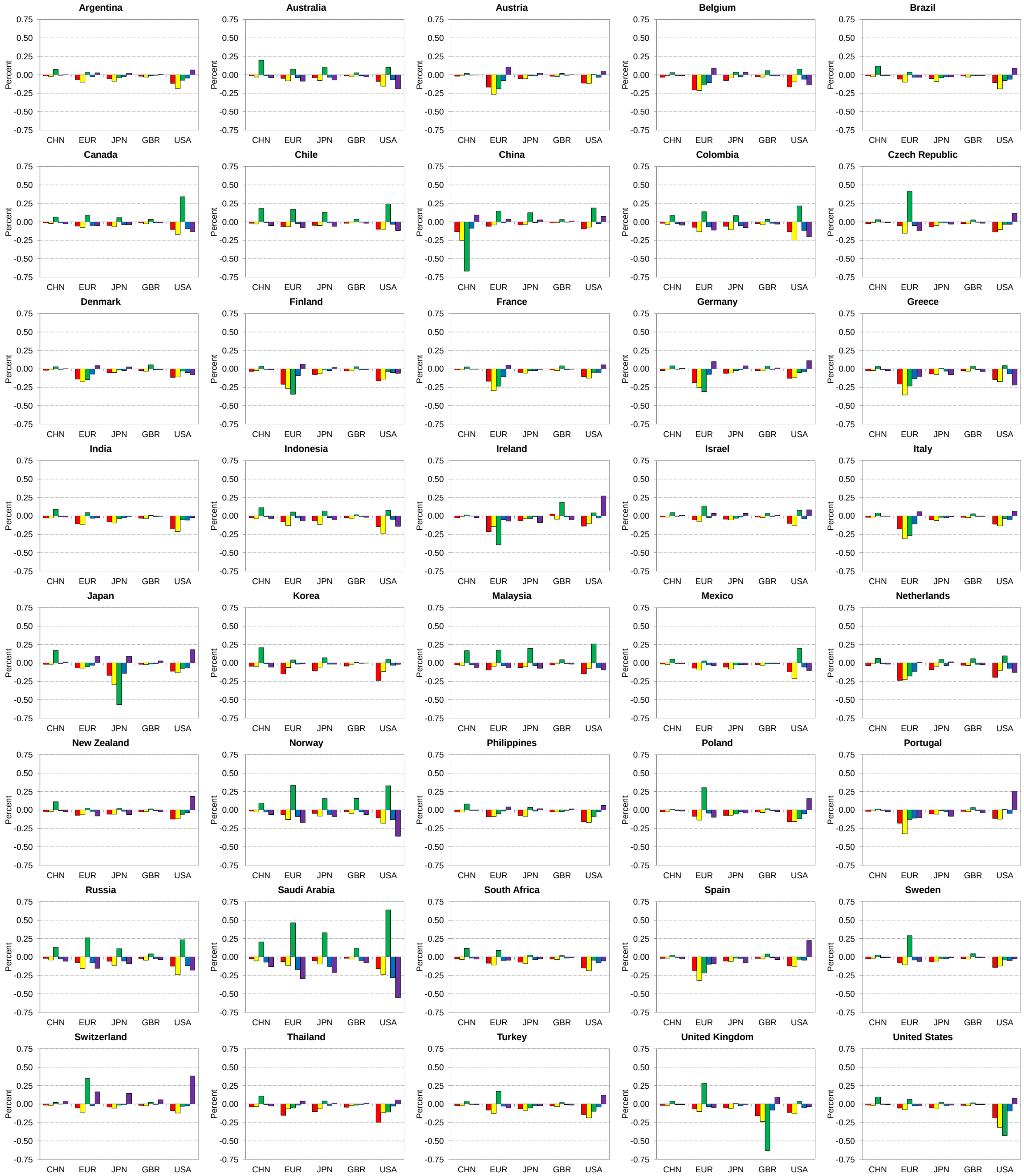
Note: Depicts the peak impulse responses of consumption price inflation ■, output ■, the real effective exchange rate ■, the fiscal balance ratio ■, and the current account balance ratio ■ to investment demand shocks in systemic economies which raise their private investment by one percent. Results are annualized where applicable.

Figure 30. Peak Impulse Responses to Foreign Monetary Policy Shocks



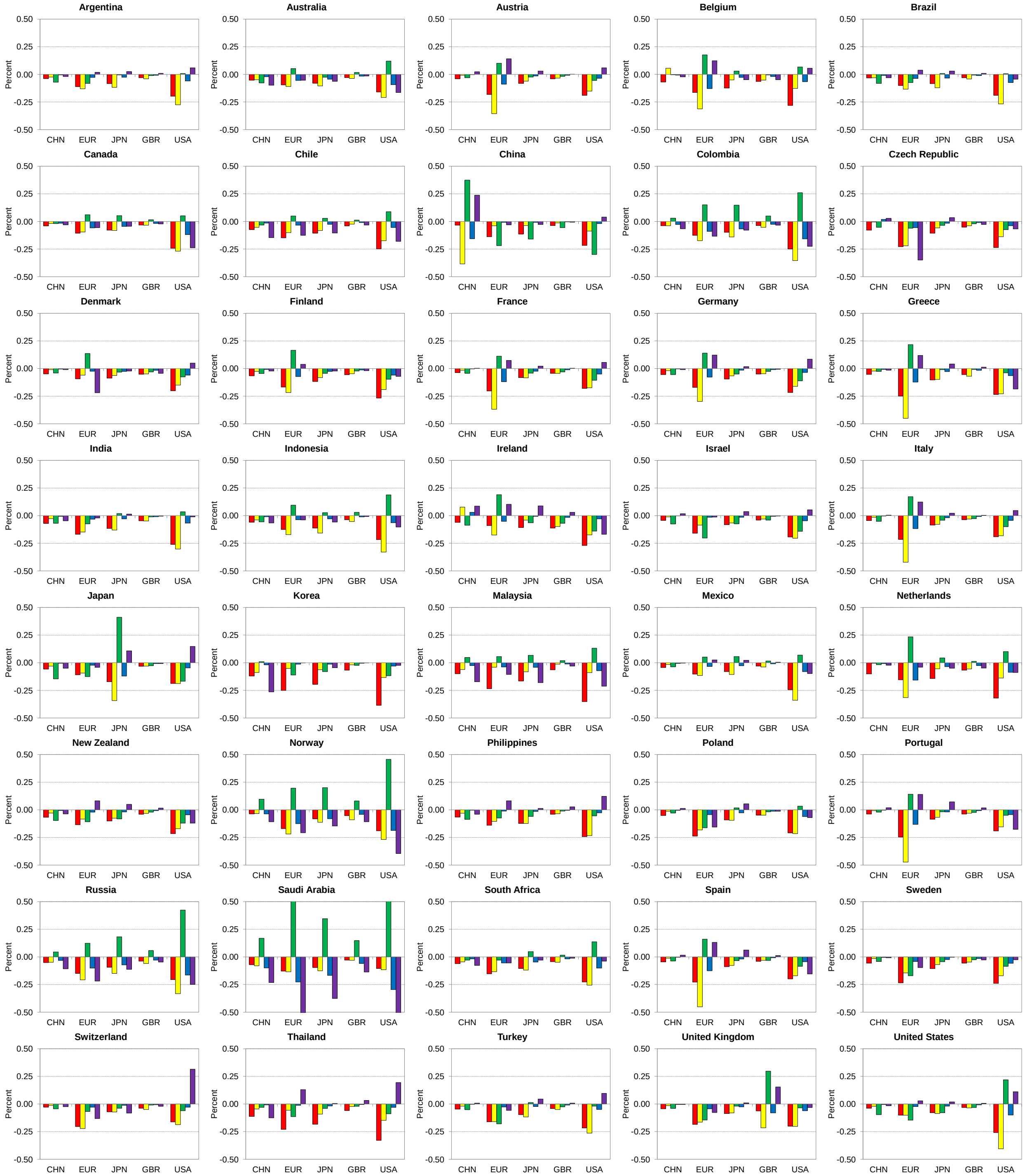
Note: Depicts the peak impulse responses of consumption price inflation ■, output ■, the real effective exchange rate ■, the fiscal balance ratio ■, and the current account balance ratio ■ to monetary policy shocks in systemic economies which raise their nominal policy interest rate by one percentage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

Figure 31. Peak Impulse Responses to Foreign Credit Risk Premium Shocks



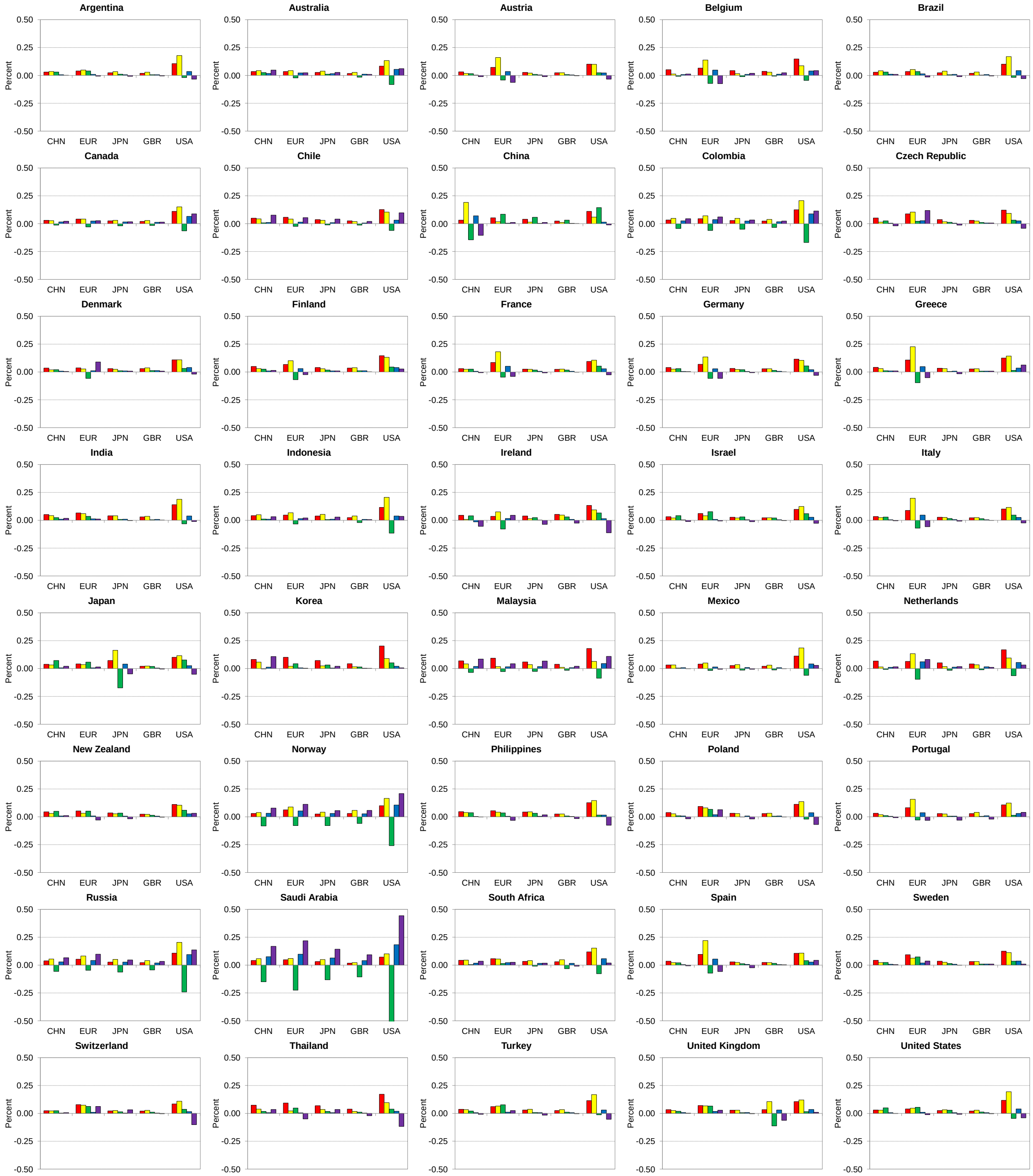
Note: Depicts the peak impulse responses of consumption price inflation ■, output ■, the real effective exchange rate ■, the fiscal balance ratio ■, and the current account balance ratio ■ to credit risk premium shocks in systemic economies which raise their short term nominal market interest rate by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

Figure 32. Peak Impulse Responses to Foreign Duration Risk Premium Shocks



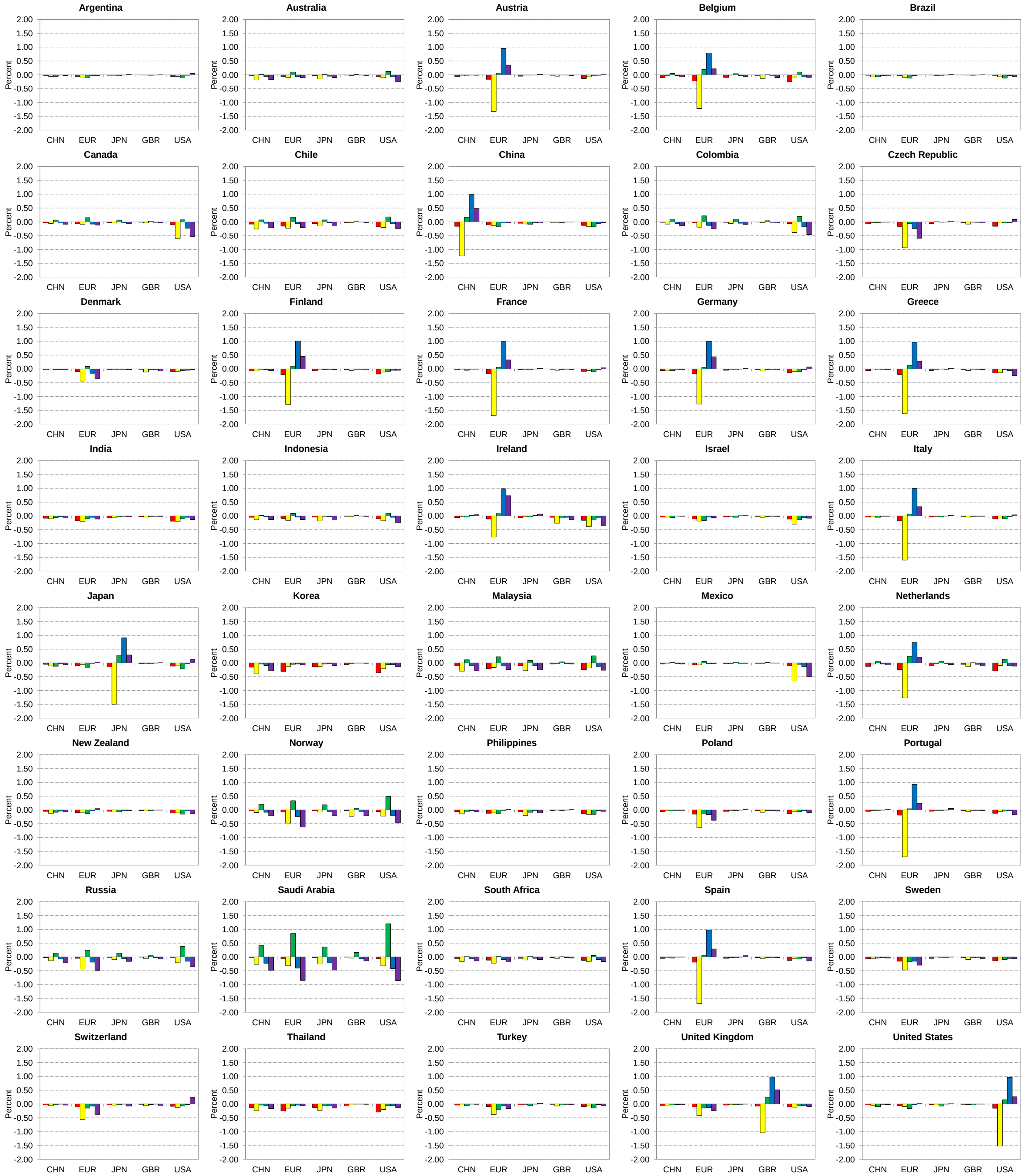
Note: Depicts the peak impulse responses of consumption price inflation ■, output ■, the real effective exchange rate ■, the fiscal balance ratio ■, and the current account balance ratio ■ to duration risk premium shocks in systemic economies which raise their long term nominal market interest rate by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

Figure 33. Peak Impulse Responses to Foreign Equity Risk Premium Shocks



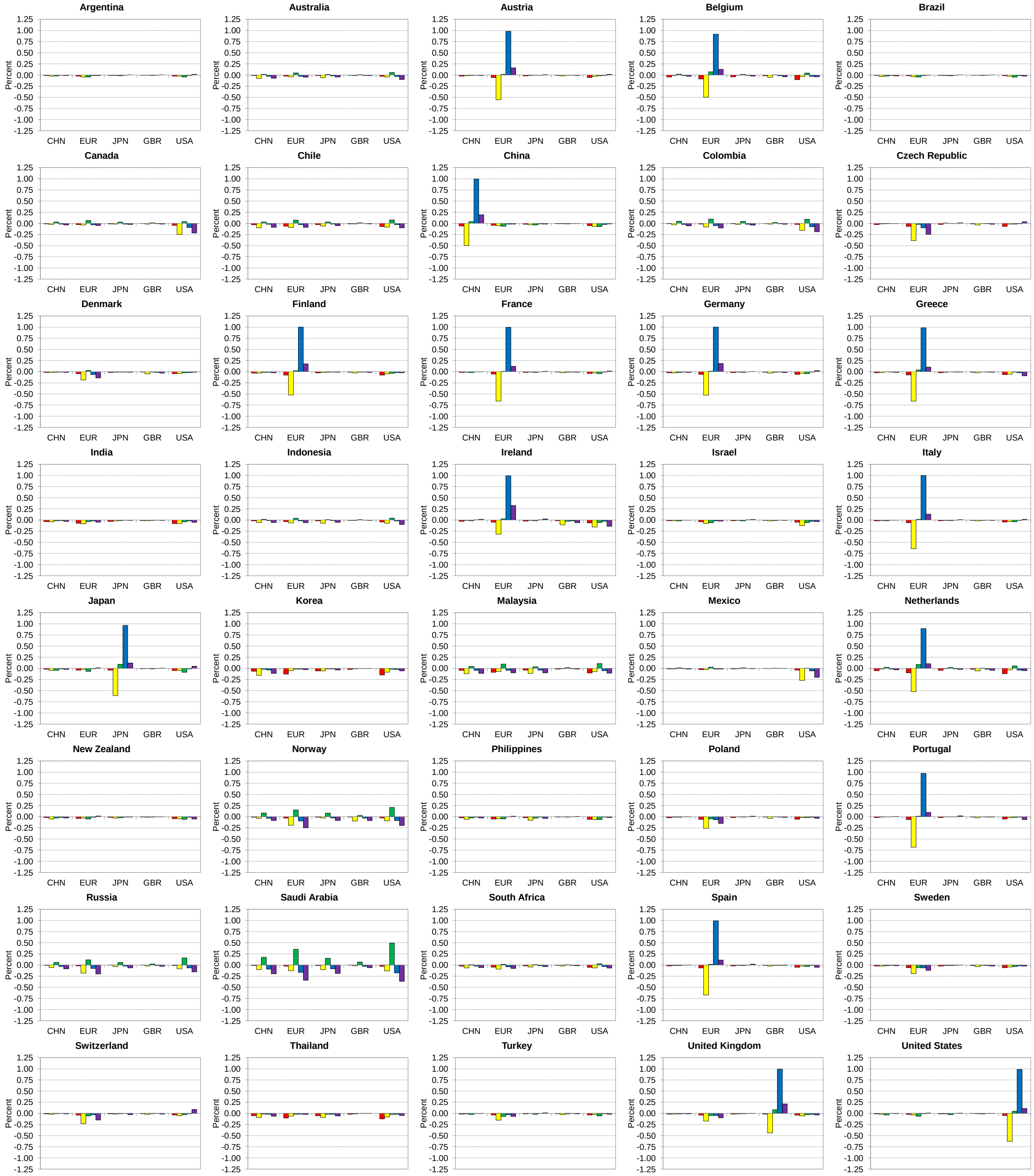
Note: Depicts the peak impulse responses of consumption price inflation ■, output ■, the real effective exchange rate ■, the fiscal balance ratio ■, and the current account balance ratio ■ to equity risk premium shocks in systemic economies which raise their price of equity by ten percent. Results are annualized where applicable.

Figure 34. Peak Impulse Responses to Foreign Fiscal Expenditure Shocks



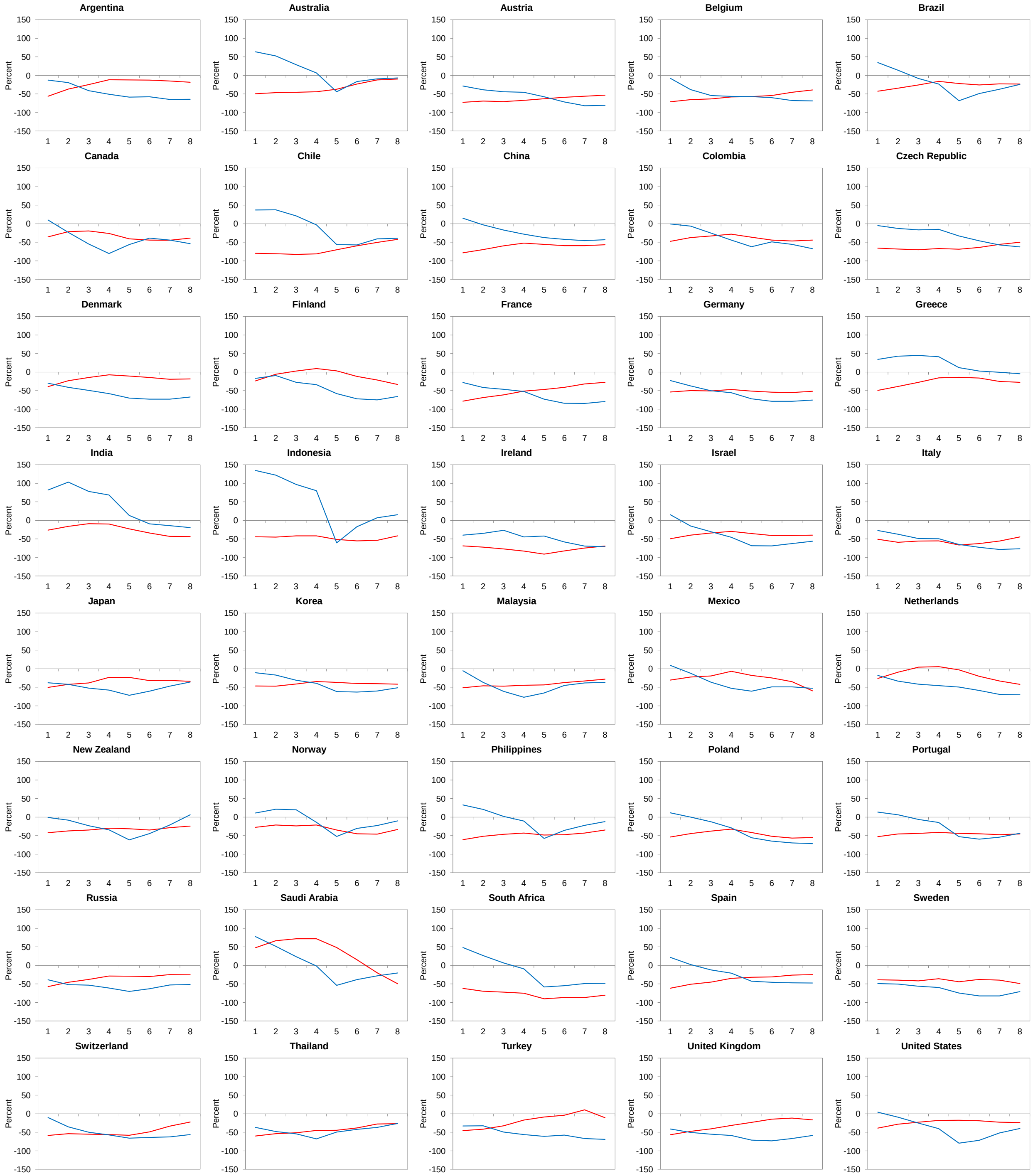
Note: Depicts the peak impulse responses of consumption price inflation ■, output ■, the real effective exchange rate ■, the fiscal balance ratio ■, and the current account balance ratio ■ to fiscal expenditure shocks in systemic economies which raise their primary fiscal balance ratio by one percentage point. Results are annualized where applicable.

Figure 35. Peak Impulse Responses to Foreign Fiscal Revenue Shocks



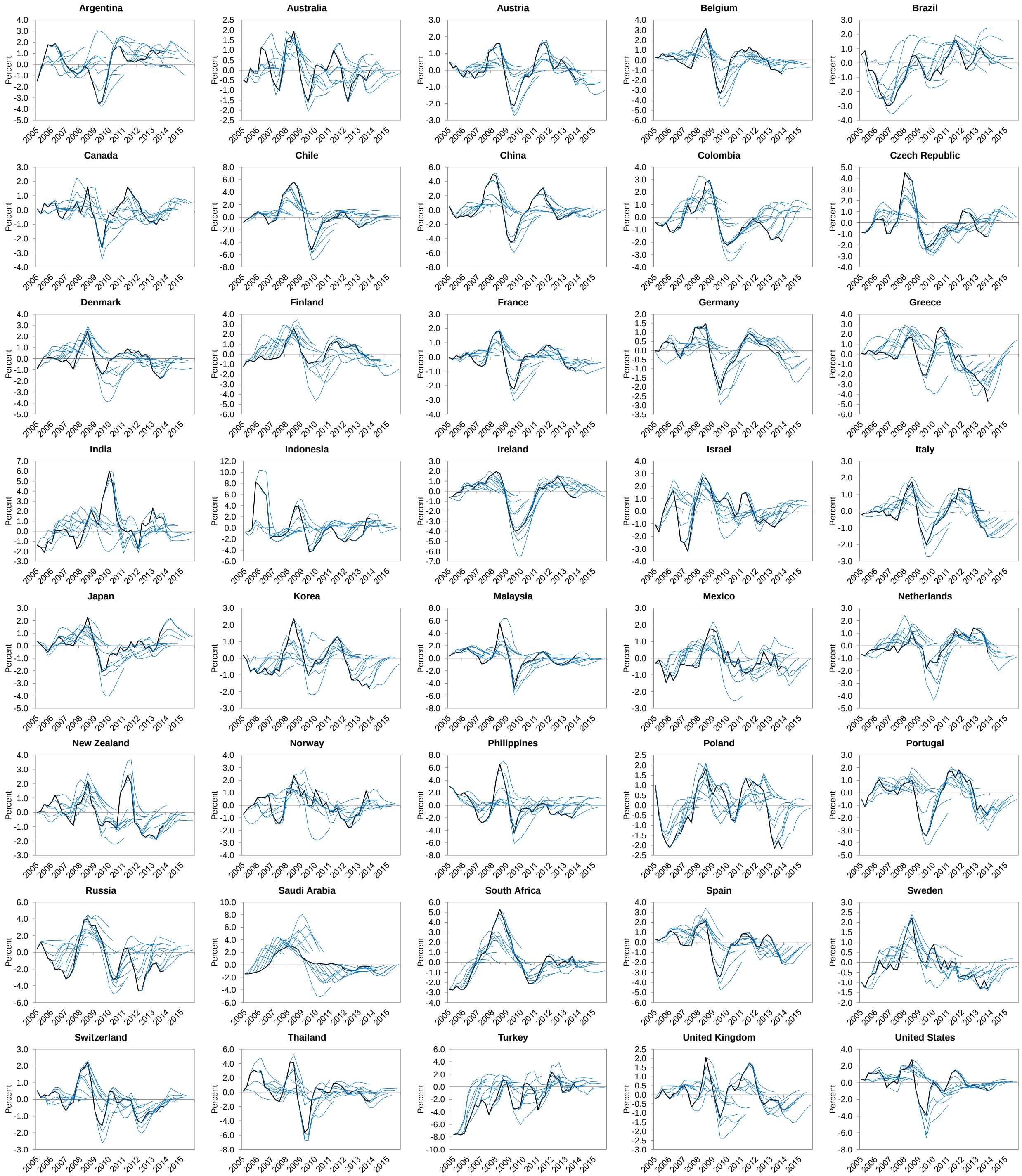
Note: Depicts the peak impulse responses of consumption price inflation ■, output ■, the real effective exchange rate ■, the fiscal balance ratio ■, and the current account balance ratio ■ to fiscal revenue shocks in systemic economies which raise their primary fiscal balance ratio by one percentage point. Results are annualized where applicable.

Figure 36. Forecast Performance Evaluation Statistics



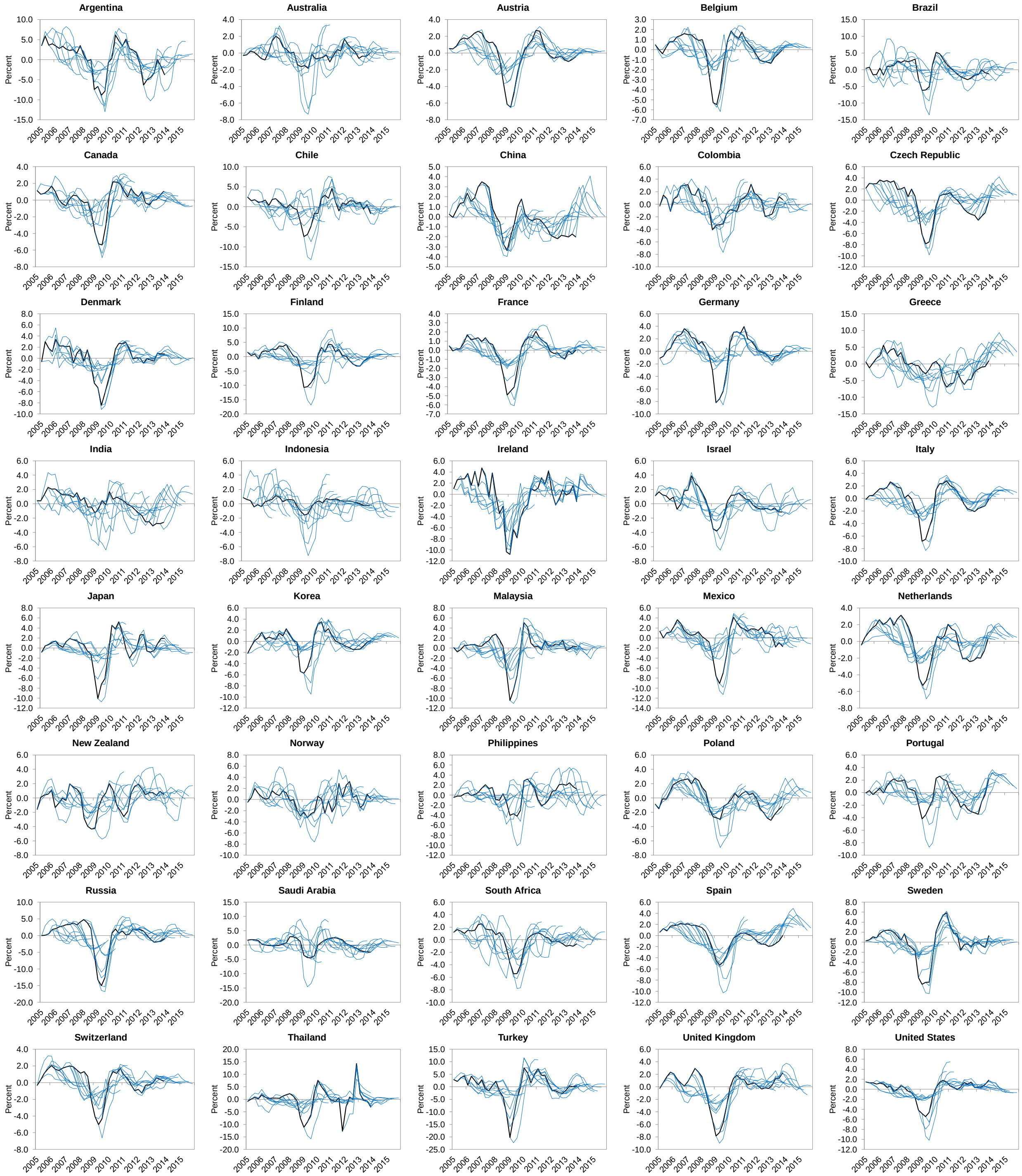
Note: Depicts the horizon dependent logarithmic root mean squared prediction error ratio for consumption price inflation ■ and output growth ■ relative to a random walk, expressed in percent.

Figure 37. Sequential Unconditional Forecasts of Consumption Price Inflation



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

Figure 38. Sequential Unconditional Forecasts of Output Growth



Note: Depicts the cyclical component of observed output growth ■ as measured by the seasonal difference of the cyclical component of the logarithm of output versus sequential unrestricted forecasts ■.

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