

WP/17/89

# IMF Working Paper

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Policy, Risk and Spillover Analysis in the World  
Economy: A Panel Dynamic Stochastic  
General Equilibrium Approach

by Francis Vitek

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I N T E R N A T I O N A L M O N E T A R Y F U N D

**IMF Working Paper**

Monetary and Capital Markets Department

**Policy, Risk and Spillover Analysis in the World Economy: A Panel Dynamic Stochastic  
General Equilibrium Approach**

**Prepared by Francis Vitek<sup>1</sup>**

Authorized for distribution by Ulric Eriksson von Allmen

April 2017

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**Abstract**

This paper develops a structural macroeconometric model of the world economy, disaggregated into forty national economies, to facilitate multilaterally consistent macrofinancial policy, risk and spillover analysis. This panel dynamic stochastic general equilibrium model features a range of nominal and real rigidities, extensive macrofinancial linkages, and diverse spillover transmission channels. These macrofinancial linkages encompass bank and capital market based financial intermediation, with financial accelerator mechanisms linked to the values of the housing and physical capital stocks. A variety of monetary policy analysis, fiscal policy analysis, macroprudential policy analysis, spillover analysis, and forecasting applications of the estimated model are demonstrated. These include quantifying the monetary, fiscal and macroprudential transmission mechanisms, accounting for business cycle fluctuations, and generating relatively accurate forecasts of inflation and output growth.

JEL Classification Numbers: C11; C33; C50; E30; E40; E52; E62; F40; G21; G28

Keywords: Monetary policy analysis; Fiscal policy analysis; Macroprudential policy analysis; Spillover analysis; Forecasting; World economy; Bayesian econometrics

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<sup>1</sup> The author gratefully acknowledges advice provided by Tamim Bayoumi and Peter Dattels, as well as comments and suggestions received from seminar participants at the International Monetary Fund and the People's Bank of China.

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## I. INTRODUCTION

Estimated dynamic stochastic general equilibrium models are widely used by 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 an expanding array of 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, to facilitate multilaterally consistent macrofinancial policy, risk and spillover analysis. 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. Building on 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 residential and business investment, and variable capital utilization. Following Galí (2011), the model incorporates involuntary unemployment through a reinterpretation of the labor market. Households are differentiated according to whether they are bank intermediated, capital market intermediated, or credit constrained. Bank intermediated households have access to domestic banks where they accumulate deposits, as well as to domestic property markets where they trade real estate, whereas capital market intermediated households have access to domestic and foreign capital markets where they trade money, bond and stock market securities. Motivated by Tobin (1969), these households solve portfolio balance problems, allocating their financial wealth across alternative assets which are imperfect substitutes. To cope with the curse of dimensionality, targeted parameter restrictions are imposed on the optimality conditions determining the solutions to these portfolio balance problems, avoiding the need to track the evolution of granular asset allocations. Firms are grouped into differentiated industries. The energy and nonenergy commodity industries produce internationally homogeneous goods for foreign absorption, while all other industries produce internationally heterogeneous goods for domestic and foreign absorption. Banks perform global financial intermediation subject to financial frictions and regulatory constraints. Building on Hülsewig, Mayer and Wollmershäuser (2009), they issue risky mortgage loans to domestic developers at infrequently

adjusted predetermined mortgage loan rates, as well as risky domestic currency denominated corporate loans to domestic and foreign firms at infrequently adjusted predetermined corporate loan rates, given regulatory loan to value ratio limits. Also building on Gerali, Neri, Sessa and Signoretti (2010), they obtain funding from domestic bank intermediated households via deposits and from the domestic money market via loans, accumulating bank capital out of retained earnings given credit losses to satisfy a regulatory capital requirement. Motivated by Kiyotaki and Moore (1997), the model incorporates financial accelerator mechanisms linked to borrowing by developers and firms collateralized against the values of the housing and physical capital stocks, respectively. 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 by Bayesian maximum likelihood, conditional on prior information concerning the generally common values of structural parameters across economies.

A variety of monetary policy analysis, fiscal policy analysis, macroprudential 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, fiscal and macroprudential transmission mechanisms, accounting for business cycle fluctuations, and generating forecasts of inflation and output growth. The monetary, fiscal and macroprudential transmission mechanisms, as estimated with impulse responses, are broadly in line with the empirical literature, as are the drivers of business cycle fluctuations, as identified with 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.

This paper is the latest in a series that progressively develops a structural macroeconomic model of the world economy, disaggregated into forty national economies, to facilitate multilaterally consistent macrofinancial policy, risk and spillover analysis. It primarily adds a housing sector to the panel dynamic stochastic general equilibrium model developed in Vitek (2015), which in turn primarily added a banking sector to the model developed in Vitek (2014). These extensions have significantly enhanced the macrofinancial linkages embedded in the model while expanding its macroprudential policy analysis capabilities.

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. Policy and spillover analysis within the framework of the estimated model is conducted in section five, while forecasting is undertaken in section six. Finally, section seven offers conclusions and outlines future model development plans.

## II. THE THEORETICAL FRAMEWORK

Consider a finite set of structurally isomorphic national economies indexed by  $i \in \{1, \dots, N\}$  which constitutes the world economy. Each of these economies consists of households, developers, firms, banks, and a government. The government in turn consists of a monetary authority, a fiscal authority, and a macroprudential authority. Households, developers, firms and banks optimize intertemporally, interacting with governments in an uncertain environment to determine equilibrium prices and quantities under rational expectations in globally integrated output and financial 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, and according to how they save if they are credit unconstrained, but are otherwise identical. Credit unconstrained households of type  $Z = B$  and measure  $\phi^B$  have access to domestic banks where they accumulate deposits, and to domestic property markets where they trade real estate, where  $0 < \phi^B < 1$ . In contrast, credit unconstrained households of type  $Z = A$  and measure  $\phi^A$  have access to domestic and foreign capital markets where they trade financial assets, where  $0 < \phi^A < 1$ . Finally, credit constrained households of type  $Z = C$  and measure  $\phi^C$  do not have access to banks or capital markets, where  $0 < \phi^C < 1$  and  $\phi^B + \phi^A + \phi^C = 1$ . All households are originally endowed with one share of each domestic developer, firm and bank.

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 bank intermediated, capital market intermediated, and credit constrained households are perfect substitutes.

### Consumption and Saving

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

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



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 and labor supply,

$$u \left( C_{h,i,s}, H_{h,i,s}, \{L_{h,f,i,s}\}_{f=0}^1, \frac{A_{h,i,s+1}^{B,H}}{P_{i,s}^C}, \frac{A_{h,i,s+1}^{A,H}}{P_{i,s}^C} \right) = v_{i,s}^C \left[ \frac{1}{1-1/\sigma} \left( C_{h,i,s} - \alpha^C \frac{C_{i,s-1}^Z}{\phi^Z} \right)^{1-1/\sigma} + \frac{v_{i,s}^{H,H}}{1-1/\zeta} (H_{h,i,s})^{1-1/\zeta} \right. \\ \left. - v_{i,s}^{L,H} \int_0^1 \int_{\alpha^L \frac{L_{f,i,s-1}^Z}{\phi^Z}}^{L_{h,f,i,s}} \left( g - \alpha^L \frac{L_{f,i,s-1}^Z}{\phi^Z} \right)^{1/\eta} dgdf + \frac{v_{i,s}^{B,H}}{1-1/\mu} \left( \frac{A_{h,i,s+1}^{B,H}}{P_{i,s}^C} \right)^{1-1/\mu} + \frac{v_{i,s}^{A,H}}{1-1/\mu} \left( \frac{A_{h,i,s+1}^{A,H}}{P_{i,s}^C} \right)^{1-1/\mu} \right], \quad (2)$$

where  $0 \leq \alpha^C < 1$  and  $0 \leq \alpha^L < 1$ . Endogenous preference shifters  $v_{i,s}^{H,H}$ ,  $v_{i,s}^{L,H}$ ,  $v_{i,s}^{B,H}$  and  $v_{i,s}^{A,H}$  depend on aggregate consumption or employment according to intratemporal subutility functions

$$v_{i,s}^{H,H} = v_i^{H,H} \left( \frac{C_{i,s}^Z}{\phi^Z} - \alpha^C \frac{C_{i,s-1}^Z}{\phi^Z} \right)^{-1/\sigma} (C_{i,s})^{1/\zeta}, \quad (3)$$

$$v_{i,s}^{L,H} = \mathcal{A}_{i,s} \left( \frac{C_{i,s}^Z}{\phi^Z} - \alpha^C \frac{C_{i,s-1}^Z}{\phi^Z} \right)^{-1/\sigma} \left( \frac{L_{i,s} - \alpha^L L_{i,s-1}}{(L_{i,s} / \mathcal{N}_{i,s})^\iota} \right)^{-1/\eta}, \quad (4)$$

$$v_{i,s}^{B,H} = v_i^{B,H} \left( \frac{C_{i,s}^Z}{\phi^Z} - \alpha^C \frac{C_{i,s-1}^Z}{\phi^Z} \right)^{-1/\sigma} (C_{i,s})^{1/\mu}, \quad (5)$$

$$v_{i,s}^{A,H} = v_i^{A,H} \left( \frac{C_{i,s}^Z}{\phi^Z} - \alpha^C \frac{C_{i,s-1}^Z}{\phi^Z} \right)^{-1/\sigma} (C_{i,s})^{1/\mu}, \quad (6)$$

where  $\iota > 0$ . The intratemporal utility function is strictly increasing with respect to consumption if and only if serially correlated consumption demand shock  $v_{i,s}^C$  satisfies  $v_{i,s}^C > 0$ . Given this parameter restriction, this intratemporal utility function is strictly increasing with respect to housing if and only if  $v_i^{H,H} > 0$ , is strictly decreasing with respect to labor supply if and only if serially correlated labor supply shock  $\mathcal{N}_{i,s}$  satisfies  $\mathcal{N}_{i,s} > 0$ , is strictly increasing with respect to real property balances if and only if  $v_i^{B,H} > 0$ , and is strictly increasing with respect to real portfolio balances if and only if  $v_i^{A,H} > 0$ . Given these parameter restrictions, this intratemporal utility function is strictly concave if  $\sigma > 0$ ,  $\zeta > 0$ ,  $\eta > 0$  and  $\mu > 0$ . In steady state equilibrium,  $v_i^{B,H}$  equates the marginal rate of substitution between real property balances and consumption to one, while  $v_i^{A,H}$  equates the marginal rate of substitution between real portfolio balances and consumption to one.

The representative household enters period  $s$  in possession of previously accumulated property balances  $A_{h,i,s}^{B,H}$  which yield return  $i_{h,i,s}^{A,B,H}$ , and portfolio balances  $A_{h,i,s}^{A,H}$  which yield return  $i_{h,i,s}^{A,A,H}$ . Property balances are distributed across the values of bank deposits  $B_{h,i,s}^{D,H}$  which bear interest at deposit rate  $i_{i,s-1}^D$ , and a real estate portfolio  $S_{h,i,s}^{H,H}$  which yields return  $i_{h,i,s}^{S,H,H}$ . It follows that  $(1 + i_{h,i,s}^{A,B,H})A_{h,i,s}^{B,H} = (1 + i_{i,s-1}^D)B_{h,i,s}^{D,H} + (1 + i_{h,i,s}^{S,H,H})S_{h,i,s}^{H,H}$ . The value of this real estate portfolio is in turn

distributed across the values of developer specific shares  $\{V_{i,e,s}^H S_{h,i,e,s}^{H,H}\}_{e=0}^1$ , where  $V_{i,e,s}^H$  denotes the price per share. It follows that  $(1+i_{h,i,s}^{S^{H,H}})S_{h,i,s}^{H,H} = \int_0^1 (\Pi_{i,e,s}^H + V_{i,e,s}^H) S_{h,i,e,s}^{H,H} de$ , where  $\Pi_{i,e,s}^H$  denotes the dividend payment per share. Portfolio balances are distributed across the values of internationally diversified short term bond  $B_{h,i,s}^{S,H}$ , long term bond  $B_{h,i,s}^{L,H}$  and stock  $S_{h,i,s}^{F,H}$  portfolios which yield returns  $i_{h,i,s}^{B^{S,H}}$ ,  $i_{h,i,s}^{B^{L,H}}$  and  $i_{h,i,s}^{S^{F,H}}$ , respectively. It follows that  $(1+i_{h,i,s}^{A^{A,H}})A_{h,i,s}^{A,H} = (1+i_{h,i,s}^{B^{S,H}})B_{h,i,s}^{S,H} + (1+i_{h,i,s}^{B^{L,H}})B_{h,i,s}^{L,H} + (1+i_{h,i,s}^{S^{F,H}})S_{h,i,s}^{F,H}$ . 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  $\{\mathcal{E}_{i,j,s} B_{h,i,j,s}^{S,H}\}_{j=1}^N$ , long term bond  $\{\mathcal{E}_{i,j,s} B_{h,i,j,s}^{L,H}\}_{j=1}^N$  and stock  $\{\mathcal{E}_{i,j,s} S_{h,i,j,s}^{F,H}\}_{j=1}^N$  portfolios, where nominal bilateral exchange rate  $\mathcal{E}_{i,j,s}$  measures the price of foreign currency in terms of domestic currency. It follows that  $(1+i_{h,i,s}^{B^{S,H}})B_{h,i,s}^{S,H} = \sum_{j=1}^N \mathcal{E}_{i,j,s} (1+i_{j,s-1}^S) B_{h,i,j,s}^{S,H}$  where  $i_{j,s-1}^S$  denotes the economy specific yield to maturity on short term bonds,  $(1+i_{h,i,s}^{B^{L,H}})B_{h,i,s}^{L,H} = \sum_{j=1}^N \mathcal{E}_{i,j,s} (1+i_{h,i,j,s}^{B^{L,H}}) B_{h,i,j,s}^{L,H}$  where  $i_{h,i,j,s}^{B^{L,H}}$  denotes the economy specific return on long term bonds, and  $(1+i_{h,i,s}^{S^{F,H}})S_{h,i,s}^{F,H} = \sum_{j=1}^N \mathcal{E}_{i,j,s} (1+i_{h,i,j,s}^{S^{F,H}}) S_{h,i,j,s}^{F,H}$  where  $i_{h,i,j,s}^{S^{F,H}}$  denotes the economy specific return on stocks. The local currency denominated values of economy specific long term bond portfolios  $\{B_{h,i,j,s}^{L,H}\}_{j=1}^N$  are in turn distributed across the values of economy and vintage specific long term bonds  $\{V_{j,k,s}^B B_{h,i,j,k,s}^{L,H}\}_{k=1}^{s-1}\}_{j=1}^N$ , where  $V_{j,k,s}^B$  denotes the local currency denominated price per long term bond, with  $V_{j,k,k}^B = 1$ . It follows that  $(1+i_{h,i,j,s}^{B^{L,H}})B_{h,i,j,s}^{L,H} = \sum_{k=1}^{s-1} (\Pi_{j,k,s}^B + V_{j,k,s}^B) B_{h,i,j,k,s}^{L,H}$ , where  $\Pi_{j,k,s}^B = (1+i_{j,k}^L - \omega^B)(\omega^B)^{s-k} V_{j,k,k}^B$  denotes the local currency denominated coupon payment per long term bond, and  $i_{j,k}^L$  denotes the economy and vintage specific yield to maturity on long term bonds at issuance. In parallel, the local currency denominated values of economy specific stock portfolios  $\{S_{h,i,j,s}^{F,H}\}_{j=1}^N$  are distributed across the values of economy, industry and firm specific shares  $\{\{V_{j,k,l,s}^S S_{h,i,j,k,l,s}^{F,H}\}_{l=0}^1\}_{k=1}^M\}_{j=1}^N$ , where  $V_{j,k,l,s}^S$  denotes the local currency denominated price per share. It follows that  $(1+i_{h,i,j,s}^{S^{F,H}})S_{h,i,j,s}^{F,H} = \sum_{k=1}^M \int_0^1 (\Pi_{j,k,l,s}^S + V_{j,k,l,s}^S) S_{h,i,j,k,l,s}^{F,H} dl$ , where  $\Pi_{j,k,l,s}^S$  denotes the local currency denominated dividend payment per share. During period  $s$ , the representative household receives profit income from banks  $\Pi_{i,s}^C$ , and supplies differentiated intermediate labor services  $\{L_{h,f,i,s}\}_{f=0}^1$ , earning labor income at trade specific nominal wages  $\{W_{f,i,s}\}_{f=0}^1$ . The government levies a tax on household labor income at rate  $\tau_{i,s}^L$ , and remits household type specific lump sum transfer payment  $T_{i,s}^Z$ . These sources of wealth are summed in household dynamic budget constraint:

$$A_{h,i,s+1}^{B,H} + A_{h,i,s+1}^{A,H} = (1+i_{h,i,s}^{A^{B,H}})A_{h,i,s}^{B,H} + (1+i_{h,i,s}^{A^{A,H}})A_{h,i,s}^{A,H} + \Pi_{i,s}^C + (1-\tau_{i,s}^L) \int_0^1 W_{f,i,s} L_{h,f,i,s} df + T_{i,s}^Z - P_{i,s}^C C_{h,i,s} - t_{i,s}^H H_{h,i,s}. \quad (7)$$

According to this dynamic budget constraint, at the end of period  $s$ , the representative household holds property balances  $A_{h,i,s+1}^{B,H}$  and portfolio balances  $A_{h,i,s+1}^{A,H}$ . Property balances are allocated across the values of bank deposits  $B_{h,i,s+1}^{D,H}$  and the real estate portfolio  $S_{h,i,s+1}^{H,H}$ , that is  $A_{h,i,s+1}^{B,H} = B_{h,i,s+1}^{D,H} + S_{h,i,s+1}^{H,H}$ . The value of this real estate portfolio is in turn allocated across the values of developer specific shares  $\{V_{i,e,s+1}^H S_{h,i,e,s+1}^{H,H}\}_{e=0}^1$  subject to  $S_{h,i,s+1}^{H,H} = \int_0^1 V_{i,e,s+1}^H S_{h,i,e,s+1}^{H,H} de$ . Portfolio balances are allocated across the values of internationally diversified short term bond  $B_{h,i,s+1}^{S,H}$ , long term bond  $B_{h,i,s+1}^{L,H}$  and stock portfolios  $S_{h,i,s+1}^{F,H}$ , that is  $A_{h,i,s+1}^{A,H} = B_{h,i,s+1}^{S,H} + B_{h,i,s+1}^{L,H} + S_{h,i,s+1}^{F,H}$ . The values of these internationally diversified short term bond, long term bond and stock portfolios are in turn allocated across the domestic currency denominated values of economy specific short term bond  $\{\mathcal{E}_{i,j,s} B_{h,i,j,s+1}^{S,H}\}_{j=1}^N$ , long term bond  $\{\mathcal{E}_{i,j,s} B_{h,i,j,s+1}^{L,H}\}_{j=1}^N$  and stock  $\{\mathcal{E}_{i,j,s} S_{h,i,j,s+1}^{F,H}\}_{j=1}^N$  portfolios

subject to  $B_{h,i,s+1}^{S,H} = \sum_{j=1}^N \mathcal{E}_{i,j,s} B_{h,i,j,s+1}^{S,H}$ ,  $B_{h,i,s+1}^{L,H} = \sum_{j=1}^N \mathcal{E}_{i,j,s} B_{h,i,j,s+1}^{L,H}$  and  $S_{h,i,s+1}^{F,H} = \sum_{j=1}^N \mathcal{E}_{i,j,s} S_{h,i,j,s+1}^{F,H}$ , respectively. The local currency denominated values of economy specific long term bond portfolios  $\{B_{h,i,j,s+1}^{L,H}\}_{j=1}^N$  are in turn allocated across the local currency denominated values of economy and vintage specific long term bonds  $\{\{V_{j,k,s}^B B_{h,i,j,k,s+1}^{L,H}\}_{k=1}^s\}_{j=1}^N$  subject to  $B_{h,i,j,s+1}^{L,H} = \sum_{k=1}^s V_{j,k,s}^B B_{h,i,j,k,s+1}^{L,H}$ . In parallel, the local currency denominated values of economy specific stock portfolios  $\{S_{h,i,j,s+1}^{F,H}\}_{j=1}^N$  are allocated across the local currency denominated values of economy, industry and firm specific shares  $\{\{V_{j,k,l,s}^S S_{h,i,j,k,l,s+1}^{F,H}\}_{l=0}^1\}_{k=1}^M\}_{j=1}^N$  subject to  $S_{h,i,j,s+1}^{F,H} = \sum_{k=1}^M \int_0^1 V_{j,k,l,s}^S S_{h,i,j,k,l,s+1}^{F,H} dl$ . Finally, the representative household purchases final private consumption good  $C_{h,i,s}$  at price  $P_{i,s}^C$ , and rents final housing service  $H_{h,i,s}$  at price  $t_{i,s}^H$ .

### Bank Intermediated Households

The representative bank intermediated household has a capitalist spirit motive for holding real property balances, independent of financing deferred consumption, motivated by Weber (1905). It also has a diversification motive over the allocation of real property balances across alternative assets which are imperfect substitutes, motivated by Tobin (1969). The set of assets under consideration consists of bank deposits and domestically traded real estate. Preferences over the real values of bank deposits  $B_{h,i,s+1}^{D,H} / P_{i,s}^C$  and the real estate portfolio  $S_{h,i,s+1}^{H,H} / P_{i,s}^C$  are represented by constant elasticity of substitution intratemporal subutility function

$$\frac{A_{h,i,s+1}^{B,H}}{P_{i,s}^C} = \left[ (1 - \phi^H)^{\frac{1}{\psi^H}} \left( \frac{B_{h,i,s+1}^{D,H}}{P_{i,s}^C} \right)^{\frac{\psi^H - 1}{\psi^H}} + (\phi^H)^{\frac{1}{\psi^H}} \left( \frac{1}{v_{i,s}^H} \frac{S_{h,i,s+1}^{H,H}}{P_{i,s}^C} \right)^{\frac{\psi^H - 1}{\psi^H}} \right]^{\frac{\psi^H}{\psi^H - 1}}, \quad (8)$$

where serially correlated housing risk premium shock  $v_{i,s}^H$  satisfies  $v_{i,s}^H > 0$ , while  $0 \leq \phi^H \leq 1$  and  $\psi^H > 0$ . Preferences over the real values of developer specific shares  $\{V_{i,e,s}^H S_{h,i,e,s+1}^{H,H} / P_{i,s}^C\}_{e=0}^1$  are in turn represented by constant elasticity of substitution intratemporal subutility function:

$$\frac{S_{h,i,s+1}^{H,H}}{P_{i,s}^C} = \left[ \int_0^1 \left( \frac{V_{i,e,s}^H S_{h,i,e,s+1}^{H,H}}{P_{i,s}^C} \right)^{\frac{\psi^H - 1}{\psi^H}} de \right]^{\frac{\psi^H}{\psi^H - 1}}. \quad (9)$$

In the limit as  $v_i^{B,H} \rightarrow 0$  there is no capitalist spirit motive for holding real property balances, while in the limit as  $\psi^H \rightarrow \infty$  there is no diversification motive over the allocation of real property balances across alternative assets which in this case are perfect substitutes.

In period  $t$ , the representative bank intermediated household chooses state contingent sequences for consumption  $\{C_{h,i,s}\}_{s=t}^\infty$ , housing  $\{H_{h,i,s}\}_{s=t}^\infty$ , labor force participation  $\{\{N_{h,f,i,s}\}_{f=0}^1\}_{s=t}^\infty$ , property balances  $\{A_{h,i,s+1}^{B,H}\}_{s=t}^\infty$ , bank deposit holdings  $\{B_{h,i,s+1}^{D,H}\}_{s=t}^\infty$ , and real estate holdings  $\{\{S_{h,i,e,s+1}^{H,H}\}_{e=0}^1\}_{s=t}^\infty$  to maximize intertemporal utility function (1) subject to dynamic budget constraint (7), the applicable restrictions on financial asset holdings, and terminal nonnegativity constraints  $B_{h,i,T+1}^{D,H} \geq 0$  and  $S_{h,i,e,T+1}^{H,H} \geq 0$  for  $T \rightarrow \infty$ . In equilibrium, abstracting from the capitalist spirit

motive for holding real property balances, the solutions to this utility maximization problem satisfy intertemporal optimality condition

$$E_t \frac{\beta u_C(h, i, t+1)}{u_C(h, i, t)} \frac{P_{i,t}^C}{P_{i,t+1}^C} (1 + i_{h,i,t+1}^{A^B,H}) = 1, \quad (10)$$

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

$$\frac{u_H(h, i, t)}{u_C(h, i, t)} = \frac{t_{i,t}^H}{P_{i,t}^C}, \quad (11)$$

which equates the marginal rate of substitution between housing and consumption to the real rental price of housing. Furthermore, these solutions satisfy intratemporal optimality condition

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

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 property return satisfies intratemporal optimality condition

$$(1 - \phi^H) \left\{ 1 + E_t \frac{\beta u_C(h, i, t+1)}{u_C(h, i, t)} \frac{u_C(h, i, t)}{u_{A^B}(h, i, t)} \frac{P_{i,t}^C}{P_{i,t+1}^C} \left[ (1 + i_{h,i,t+1}^{A^B,H}) - (1 + i_{i,t}^D) \right] \right\}^{1-\psi^H} \\ + \phi^H \int_0^1 \left\{ 1 + E_t \frac{\beta u_C(h, i, t+1)}{u_C(h, i, t)} \frac{u_C(h, i, t)}{u_{A^B}(h, i, t)} \frac{P_{i,t}^C}{P_{i,t+1}^C} \left[ (1 + i_{h,i,t+1}^{A^B,H}) - \frac{\Pi_{i,e,t+1}^H + V_{i,e,t+1}^H}{V_{i,e,t}^H} \right] \right\}^{1-\psi^H} de = 1, \quad (13)$$

which relates it to the expected present values of the gross real returns on bank deposits and real estate. Finally, abstracting from the portfolio diversification motive over the allocation of real property balances these solutions satisfy intratemporal optimality condition

$$E_t \frac{\beta u_C(h, i, t+1)}{u_C(h, i, t)} \frac{P_{i,t}^C}{P_{i,t+1}^C} \left[ (1 + i_{i,t}^D) - \frac{\Pi_{i,e,t+1}^H + V_{i,e,t+1}^H}{V_{i,e,t}^H} \right] = -\frac{u_{A^B}(h, i, t)}{u_C(h, i, t)} \left( 1 - \frac{1}{v_{i,t}^H} \right), \quad (14)$$

which equates the expected present values of the gross real risk adjusted returns on bank deposits and real estate. 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 bank intermediated household allocations.

### Capital Market Intermediated Households

The representative capital market intermediated household has a capitalist spirit motive for holding real portfolio balances, independent of financing deferred consumption, motivated by Weber (1905). It also has a diversification motive over the allocation of real portfolio balances across alternative financial assets which are imperfect substitutes, motivated by Tobin (1969). 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 with coupon payments that decay exponentially at rate  $\omega^B$  where  $0 < \omega^B < 1$ , following Woodford (2001). 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  $S_{h,i,s+1}^{F,H} / P_{i,s}^C$  portfolios are represented by constant elasticity of substitution intratemporal subutility function

$$\frac{A_{h,i,s+1}^{A,H}}{P_{i,s}^C} = \left[ (\phi_M^A)^{\frac{1}{\psi^A}} \left( \frac{B_{h,i,s+1}^{S,H}}{P_{i,s}^C} \right)^{\frac{\psi^A-1}{\psi^A}} + (\phi_B^A)^{\frac{1}{\psi^A}} \left( \frac{1}{v_{i,s}^B} \frac{B_{h,i,s+1}^{L,H}}{P_{i,s}^C} \right)^{\frac{\psi^A-1}{\psi^A}} + (\phi_S^A)^{\frac{1}{\psi^A}} \left( \frac{1}{v_{i,s}^S} \frac{S_{h,i,s+1}^{F,H}}{P_{i,s}^C} \right)^{\frac{\psi^A-1}{\psi^A}} \right]^{\frac{\psi^A}{\psi^A-1}}, \quad (15)$$

where internationally and serially correlated duration risk premium shock  $v_{i,s}^B$  satisfies  $v_{i,s}^B > 0$ , and internationally and serially correlated equity risk premium shock  $v_{i,s}^S$  satisfies  $v_{i,s}^S > 0$ , while  $0 \leq \phi_M^A \leq 1$ ,  $0 \leq \phi_B^A \leq 1$ ,  $0 \leq \phi_S^A \leq 1$ ,  $\phi_M^A + \phi_B^A + \phi_S^A = 1$  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  $\{\mathcal{E}_{i,j,s} S_{h,i,j,s+1}^{F,H} / P_{i,s}^C\}_{j=1}^N$  portfolios are in turn represented by constant elasticity of substitution intratemporal subutility functions

$$\frac{B_{h,i,s+1}^{S,H}}{P_{i,s}^C} = \left[ \sum_{j=1}^N (\phi_{i,j}^B)^{\frac{1}{\psi^A}} \left( \frac{1}{v_{j,s}^\mathcal{E}} \frac{\mathcal{E}_{i,j,s} B_{h,i,j,s+1}^{S,H}}{P_{i,s}^C} \right)^{\frac{\psi^A-1}{\psi^A}} \right]^{\frac{\psi^A}{\psi^A-1}}, \quad (16)$$

$$\frac{B_{h,i,s+1}^{L,H}}{P_{i,s}^C} = \left[ \sum_{j=1}^N (\phi_{i,j}^B)^{\frac{1}{\psi^A}} \left( \frac{1}{v_{j,s}^\mathcal{E}} \frac{\mathcal{E}_{i,j,s} B_{h,i,j,s+1}^{L,H}}{P_{i,s}^C} \right)^{\frac{\psi^A-1}{\psi^A}} \right]^{\frac{\psi^A}{\psi^A-1}}, \quad (17)$$

$$\frac{S_{h,i,s+1}^{F,H}}{P_{i,s}^C} = \left[ \sum_{j=1}^N (\phi_{i,j}^S)^{\frac{1}{\psi^A}} \left( \frac{1}{v_{j,s}^\mathcal{E}} \frac{\mathcal{E}_{i,j,s} S_{h,i,j,s+1}^{F,H}}{P_{i,s}^C} \right)^{\frac{\psi^A-1}{\psi^A}} \right]^{\frac{\psi^A}{\psi^A-1}}, \quad (18)$$

where serially correlated currency risk premium shocks  $v_{j,s}^\mathcal{E}$  satisfy  $v_{j,s}^\mathcal{E} > 0$ , while  $0 \leq \phi_{i,j}^B \leq 1$ ,  $\sum_{j=1}^N \phi_{i,j}^B = 1$ ,  $0 \leq \phi_{i,j}^S \leq 1$  and  $\sum_{j=1}^N \phi_{i,j}^S = 1$ . Finally, preferences over the real values of economy and vintage specific long term bonds  $\{\{\mathcal{E}_{i,j,s} V_{j,k,s}^B B_{h,i,j,k,s+1}^{L,H} / P_{i,s}^C\}_{k=1}^N\}_{j=1}^N$  and economy, industry and

firm specific shares  $\{ \{ \{ \mathcal{E}_{i,j,s} V_{j,k,l,s}^S S_{h,i,j,k,l,s+1}^{F,H} / P_{i,s}^C \}_{l=0}^M \}_{k=1}^N \}_{j=1}^N$  are represented by constant elasticity of substitution intratemporal subutility functions

$$\frac{\mathcal{E}_{i,j,s} B_{h,i,j,s+1}^{L,H}}{P_{i,s}^C} = \left[ \sum_{k=1}^s (\phi_{i,j,k,s}^B)^{\frac{1}{\psi^A}} \left( \frac{\mathcal{E}_{i,j,s} V_{j,k,s}^B B_{h,i,j,k,s+1}^{L,H}}{P_{i,s}^C} \right)^{\frac{\psi^A-1}{\psi^A}} \right]^{\frac{\psi^A}{\psi^A-1}}, \quad (19)$$

$$\frac{\mathcal{E}_{i,j,s} S_{h,i,j,s+1}^{F,H}}{P_{i,s}^C} = \left[ \sum_{k=1}^M (\phi_{i,j,k}^S)^{\frac{1}{\psi^A}} \int_0^1 \left( \frac{\mathcal{E}_{i,j,s} V_{j,k,l,s}^S S_{h,i,j,k,l,s+1}^{F,H}}{P_{i,s}^C} \right)^{\frac{\psi^A-1}{\psi^A}} dl \right]^{\frac{\psi^A}{\psi^A-1}}, \quad (20)$$

where  $0 \leq \phi_{i,j,k,s}^B \leq 1$ ,  $\sum_{k=1}^s \phi_{i,j,k,s}^B = 1$ ,  $0 \leq \phi_{i,j,k}^S \leq 1$  and  $\sum_{k=1}^M \phi_{i,j,k}^S = 1$ . In the limit as  $v_i^{A,H} \rightarrow 0$  there is no capitalist spirit motive for holding real portfolio balances, while in the limit as  $\psi^A \rightarrow \infty$  there is no diversification motive over the allocation of real portfolio balances across alternative financial assets which in this case are perfect substitutes.

In period  $t$ , the representative capital market intermediated household chooses state contingent sequences for consumption  $\{C_{h,i,s}\}_{s=t}^\infty$ , housing  $\{H_{h,i,s}\}_{s=t}^\infty$ , labor force participation  $\{N_{h,f,i,s}\}_{f=0}^1\}_{s=t}^\infty$ , portfolio balances  $\{A_{h,i,s+1}^{A,H}\}_{s=t}^\infty$ , short term bond holdings  $\{B_{h,i,j,s+1}^{S,H}\}_{j=1}^N\}_{s=t}^\infty$ , long term bond holdings  $\{B_{h,i,j,k,s+1}^{L,H}\}_{k=1}^N\}_{j=1}^N\}_{s=t}^\infty$ , and stock holdings  $\{S_{h,i,j,k,l,s+1}^H\}_{l=0}^M\}_{k=1}^M\}_{j=1}^N\}_{s=t}^\infty$  to maximize intertemporal utility function (1) subject to dynamic budget constraint (7), the applicable restrictions on financial asset holdings, 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 for holding real portfolio balances, the solutions to this utility maximization problem satisfy intertemporal optimality condition

$$E_t \frac{\beta u_C(h,i,t+1)}{u_C(h,i,t)} \frac{P_{i,t}^C}{P_{i,t+1}^C} (1 + i_{h,i,t+1}^{A,H}) = 1, \quad (21)$$

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

$$\frac{u_H(h,i,t)}{u_C(h,i,t)} = \frac{t_{i,t}^H}{P_{i,t}^C}, \quad (22)$$

which equates the marginal rate of substitution between housing and consumption to the real rental price of housing. Furthermore, these solutions satisfy intratemporal optimality condition

$$-\frac{u_{L_f}(h,f,i,t)}{u_C(h,i,t)} = (1 - \tau_{i,t}^L) \frac{W_{f,i,t}}{P_{i,t}^C}, \quad (23)$$

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

$$\begin{aligned} & \phi_M^A \sum_{j=1}^N \phi_{i,j}^B \left\{ 1 + E_t \frac{\beta u_C(h,i,t+1)}{u_C(h,i,t)} \frac{u_C(h,i,t)}{u_{A^A}(h,i,t)} \frac{P_{i,t}^C}{P_{i,t+1}^C} \left[ (1+i_{h,i,t+1}^{A^A}) - (1+i_{j,t}^S) \frac{\mathcal{E}_{i,j,t+1}}{\mathcal{E}_{i,j,t}} \right] \right\}^{1-\psi^A} \\ & + \phi_B^A \sum_{j=1}^N \phi_{i,j}^B \sum_{k=1}^I \phi_{i,j,k,t}^B \left\{ 1 + E_t \frac{\beta u_C(h,i,t+1)}{u_C(h,i,t)} \frac{u_C(h,i,t)}{u_{A^A}(h,i,t)} \frac{P_{i,t}^C}{P_{i,t+1}^C} \left[ (1+i_{h,i,t+1}^{A^A}) - \frac{\Pi_{j,k,t+1}^B + V_{j,k,t+1}^B}{V_{j,k,t}^B} \frac{\mathcal{E}_{i,j,t+1}}{\mathcal{E}_{i,j,t}} \right] \right\}^{1-\psi^A} \\ & + \phi_S^A \sum_{j=1}^N \phi_{i,j}^S \sum_{k=1}^M \phi_{i,j,k}^S \int_0^1 \left\{ 1 + E_t \frac{\beta u_C(h,i,t+1)}{u_C(h,i,t)} \frac{u_C(h,i,t)}{u_{A^A}(h,i,t)} \frac{P_{i,t}^C}{P_{i,t+1}^C} \left[ (1+i_{h,i,t+1}^{A^A}) - \frac{\Pi_{j,k,l,t+1}^S + V_{j,k,l,t+1}^S}{V_{j,k,l,t}^S} \frac{\mathcal{E}_{i,j,t+1}}{\mathcal{E}_{i,j,t}} \right] \right\}^{1-\psi^A} dl = 1, \end{aligned} \quad (24)$$

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. In addition, abstracting from the portfolio diversification motive over the allocation of real portfolio balances these solutions satisfy intratemporal optimality condition

$$E_t \frac{\beta u_C(h,i,t+1)}{u_C(h,i,t)} \frac{P_{i,t}^C}{P_{i,t+1}^C} \left[ (1+i_{i,t}^S) - (1+i_{j,t}^S) \frac{\mathcal{E}_{i,j,t+1}}{\mathcal{E}_{i,j,t}} \right] = - \frac{u_{A^A}(h,i,t)}{u_C(h,i,t)} \left( \frac{1}{v_{i,t}^\mathcal{E}} - \frac{1}{v_{j,t}^\mathcal{E}} \right), \quad (25)$$

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

$$E_t \frac{\beta u_C(h,i,t+1)}{u_C(h,i,t)} \frac{P_{i,t}^C}{P_{i,t+1}^C} \left[ (1+i_{i,t}^S) - \frac{\Pi_{i,k,t+1}^B + V_{i,k,t+1}^B}{V_{i,k,t}^B} \right] = - \frac{u_{A^A}(h,i,t)}{u_C(h,i,t)} \frac{1}{v_{i,t}^\mathcal{E}} \left( 1 - \frac{1}{v_{i,t}^B} \right), \quad (26)$$

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 over the allocation of real portfolio balances these solutions satisfy intratemporal optimality condition

$$E_t \frac{\beta u_C(h,i,t+1)}{u_C(h,i,t)} \frac{P_{i,t}^C}{P_{i,t+1}^C} \left[ (1+i_{i,t}^S) - \frac{\Pi_{i,k,l,t+1}^S + V_{i,k,l,t+1}^S}{V_{i,k,l,t}^S} \right] = - \frac{u_{A^A}(h,i,t)}{u_C(h,i,t)} \frac{1}{v_{i,t}^\mathcal{E}} \left( 1 - \frac{1}{v_{i,t}^S} \right), \quad (27)$$

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 capital market intermediated household allocations.

### *Credit Constrained Households*

In period  $t$ , the representative credit constrained household chooses state contingent sequences for consumption  $\{C_{h,i,s}\}_{s=t}^\infty$ , housing  $\{H_{h,i,s}\}_{s=t}^\infty$ , 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 (7), and the

applicable restrictions on financial asset holdings. In equilibrium, the solutions to this utility maximization problem satisfy household static budget constraint

$$P_{i,t}^C C_{h,i,t} + t_{i,t}^H H_{i,t} = \Pi_{i,t} + (1 - \tau_{i,t}^L) \int_0^1 W_{f,i,t} L_{h,f,i,t} df + T_{i,t}^C, \quad (28)$$

which equates the sum of consumption and housing expenditures to the sum of profit and disposable labor income net of transfers, where profit income  $\Pi_{i,t}$  satisfies

$\Pi_{i,t} = \Pi_{i,t}^H + \Pi_{i,t}^S + \Pi_{i,t}^C$ . The evaluation of this result abstracts from international bank lending. Furthermore, these solutions satisfy intratemporal optimality condition

$$\frac{u_H(h,i,t)}{u_C(h,i,t)} = \frac{t_{i,t}^H}{P_{i,t}^C}, \quad (29)$$

which equates the marginal rate of substitution between housing and consumption to the real rental price of housing. Finally, these solutions satisfy intratemporal optimality condition

$$-\frac{u_{L_f}(h,f,i,t)}{u_C(h,i,t)} = (1 - \tau_{i,t}^L) \frac{W_{f,i,t}}{P_{i,t}^C}, \quad (30)$$

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  $u_{i,t}^L = U_{i,t} / N_{i,t}$ , 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

$$L_{i,t} = \left[ \int_0^1 (L_{f,i,t})^{\frac{\theta_{i,t}^L - 1}{\theta_{i,t}^L}} df \right]^{\frac{\theta_{i,t}^L}{\theta_{i,t}^L - 1}}, \quad (31)$$

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:



$$L_{f,i,t} = \left( \frac{W_{f,i,t}}{W_{i,t}} \right)^{-\theta_{i,t}^L} L_{i,t}. \quad (32)$$

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

$$W_{i,t} = \left[ \int_0^1 (W_{f,i,t})^{1-\theta_{i,t}^L} df \right]^{\frac{1}{1-\theta_{i,t}^L}}. \quad (33)$$

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, where  $0 \leq \omega^L < 1$ . The remaining fraction  $\omega^L$  of trade unions adjust their wage to account for past consumption price inflation and productivity growth according to partial indexation rule

$$W_{f,i,t} = \left( \frac{P_{i,t-1}^C \mathcal{A}_{i,t-1}}{P_{i,t-2}^C \mathcal{A}_{i,t-2}} \right)^{\gamma^L} \left( \frac{\bar{P}_{i,t-1}^C \bar{\mathcal{A}}_{i,t-1}}{\bar{P}_{i,t-2}^C \bar{\mathcal{A}}_{i,t-2}} \right)^{1-\gamma^L} W_{f,i,t-1}, \quad (34)$$

where  $0 \leq \gamma^L \leq 1$ . 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 (7), intermediate labor service demand function (32), 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:

$$\frac{W_{i,t}^*}{W_{i,t}} = \frac{E_t \sum_{s=t}^{\infty} (\omega^L)^{s-t} \frac{\beta^{s-t} u_C(h,i,s)}{u_C(h,i,t)} \theta_{i,s}^L \frac{u_{L_f}(h,f,i,s)}{u_C(h,i,s)} \left[ \left( \frac{P_{i,t-1}^C \mathcal{A}_{i,t-1}}{P_{i,s-1}^C \mathcal{A}_{i,s-1}} \right)^{\gamma^L} \left( \frac{\bar{P}_{i,t-1}^C \bar{\mathcal{A}}_{i,t-1}}{\bar{P}_{i,s-1}^C \bar{\mathcal{A}}_{i,s-1}} \right)^{1-\gamma^L} \frac{W_{i,s}}{W_{i,t}} \right]^{\theta_{i,s}^L} \left( \frac{W_{i,t}^*}{W_{i,t}} \right)^{-\theta_{i,s}^L} L_{h,i,s}}{E_t \sum_{s=t}^{\infty} (\omega^L)^{s-t} \frac{\beta^{s-t} u_C(h,i,s)}{u_C(h,i,t)} (\theta_{i,s}^L - 1) (1 - \tau_{i,s}^L) \frac{W_{i,s}}{P_{i,s}^C} \left[ \left( \frac{P_{i,t-1}^C \mathcal{A}_{i,t-1}}{P_{i,s-1}^C \mathcal{A}_{i,s-1}} \right)^{\gamma^L} \left( \frac{\bar{P}_{i,t-1}^C \bar{\mathcal{A}}_{i,t-1}}{\bar{P}_{i,s-1}^C \bar{\mathcal{A}}_{i,s-1}} \right)^{1-\gamma^L} \frac{W_{i,s}}{W_{i,t}} \right]^{\theta_{i,s}^L - 1} \left( \frac{W_{i,t}^*}{W_{i,t}} \right)^{-\theta_{i,s}^L} L_{h,i,s}}. \quad (35)$$

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 (33) 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  $\omega^L$  of trade unions that adjust their wage according to partial indexation rule (34):

$$W_{i,t} = \left\{ (1 - \omega^L)(W_{i,t}^*)^{1-\theta_{i,t}^L} + \omega^L \left[ \left( \frac{P_{i,t-1}^C \mathcal{A}_{i,t-1}}{P_{i,t-2}^C \mathcal{A}_{i,t-2}} \right)^{\gamma^L} \left( \frac{\bar{P}_{i,t-1}^C \bar{\mathcal{A}}_{i,t-1}}{\bar{P}_{i,t-2}^C \bar{\mathcal{A}}_{i,t-2}} \right)^{1-\gamma^L} W_{i,t-1} \right]^{1-\theta_{i,t}^L} \right\}^{\frac{1}{1-\theta_{i,t}^L}}. \quad (36)$$

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 and productivity growth.

## B. The Construction Sector

The construction sector supplies housing services to domestic households. In doing so, developers obtain mortgage loans from domestic banks and accumulate the housing stock through residential investment.

### Housing Demand

There exist a large number of perfectly competitive developers which combine differentiated intermediate housing services  $H_{i,e,t}$  supplied by intermediate developers to produce final housing service  $H_{i,t}$  according to constant elasticity of substitution production function

$$H_{i,t} = \left[ \int_0^1 (H_{i,e,t})^{\frac{\theta_{i,t}^H - 1}{\theta_{i,t}^H}} de \right]^{\frac{\theta_{i,t}^H}{\theta_{i,t}^H - 1}}, \quad (37)$$

where endogenous rental price of housing markup  $\theta_{i,t}^H$  satisfies  $\theta_{i,t}^H > 1$  with  $\theta_i^H = \theta^H$ . The representative final developer maximizes profits derived from production of the final housing service with respect to inputs of intermediate housing services, implying demand functions:

$$H_{i,e,t} = \left( \frac{t_{i,e,t}^H}{t_{i,t}^H} \right)^{-\theta_{i,t}^H} H_{i,t}. \quad (38)$$

Since the production function exhibits constant returns to scale, in equilibrium the representative final developer generates zero profit, implying aggregate rental price of housing index:

$$t_{i,t}^H = \left[ \int_0^1 (t_{i,e,t}^H)^{1-\theta_{i,t}^H} de \right]^{\frac{1}{1-\theta_{i,t}^H}}. \quad (39)$$

As the price elasticity of demand for intermediate housing services  $\theta_{i,t}^H$  increases, they become closer substitutes, and individual intermediate developers have less market power.

## Residential Investment

There exist continuums of monopolistically competitive intermediate developers indexed by  $e \in [0,1]$ . Intermediate developers supply differentiated intermediate housing services, but are otherwise identical. We rule out entry into and exit out of the monopolistically competitive intermediate construction sector.

The representative intermediate developer sells shares to domestic bank intermediated households at price  $V_{i,e,t}^H$ . Acting in the interests of its shareholders, it maximizes its pre-dividend stock market value, which abstracting from the capitalist spirit motive for holding real property balances equals the expected present value of current and future dividend payments

$$\Pi_{i,e,t}^H + V_{i,e,t}^H = E_t \sum_{s=t}^{\infty} \frac{\beta^{s-t} \lambda_{i,t}^B}{\lambda_{i,t}^B} \Pi_{i,e,s}^H, \quad (40)$$

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

Shares entitle households to dividend payments equal to profits  $\Pi_{i,e,s}^H$ , defined as the sum of earnings and net borrowing less residential investment expenditures:

$$\Pi_{i,e,s}^H = t_{i,e,s}^H H_{i,e,s} + (B_{i,e,s+1}^{C,D} - (1 - \delta_{i,s}^M)(1 + i_{i,s-1}^M)B_{i,e,s}^{C,D}) - P_{i,s}^{I^H} I_{i,e,s}^H. \quad (41)$$

Earnings are defined as revenues derived from sales of differentiated intermediate housing service  $H_{i,e,s}$  at rental price  $t_{i,e,s}^H$ .

Motivated by the collateralized borrowing variant of the financial accelerator mechanism due to Kiyotaki and Moore (1997), the financial policy of the representative intermediate developer is to maintain debt equal to a fraction of the value of the housing stock,

$$\frac{B_{i,e,s+1}^{C,D}}{P_{i,s}^{I^H} H_{i,e,s+1}} = \phi_{i,s}^D, \quad (42)$$

given by regulatory mortgage loan to value ratio limit  $\phi_{i,s}^D$ . Net borrowing is defined as the increase in mortgage loans  $B_{i,e,s+1}^{C,D}$  from domestic banks net of writedowns at mortgage loan default rate  $\delta_{i,s}^M$  and interest payments at mortgage loan rate  $i_{i,s-1}^M$ .

The representative intermediate developer enters period  $s$  in possession of previously accumulated housing stock  $H_{i,e,s}$ , which subsequently evolves according to accumulation function

$$H_{i,e,s+1} = (1 - \delta^H) H_{i,e,s} + \mathcal{H}^H(I_{i,e,s}^H, I_{i,e,s-1}^H), \quad (43)$$

where  $0 \leq \delta^H \leq 1$ . Effective residential investment function  $\mathcal{H}^H(I_{i,e,s}^H, I_{i,e,s-1}^H)$  incorporates convex adjustment costs,

$$\mathcal{H}^H(I_{i,e,s}^H, I_{i,e,s-1}^H) = v_{i,s}^{I^H} \left[ 1 - \frac{\chi^H}{2} \left( \frac{I_{i,e,s}^H}{I_{i,e,s-1}^H} - 1 \right)^2 \right] I_{i,e,s}^H, \quad (44)$$

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

In period  $t$ , the representative intermediate developer chooses state contingent sequences for residential investment  $\{I_{i,e,s}^H\}_{s=t}^{\infty}$  and the housing stock  $\{H_{i,e,s+1}\}_{s=t}^{\infty}$  to maximize pre-dividend stock market value (40) subject to housing accumulation function (43) and terminal nonnegativity constraint  $H_{i,e,T+1} \geq 0$  for  $T \rightarrow \infty$ . In equilibrium, demand for the final residential investment good satisfies necessary first order condition

$$Q_{i,e,t}^H \mathcal{H}_1^H(I_{i,e,t}^H, I_{i,e,t-1}^H) + E_t \frac{\beta \lambda_{i,t+1}^B}{\lambda_{i,t}^B} Q_{i,e,t+1}^H \mathcal{H}_2^H(I_{i,e,t+1}^H, I_{i,e,t}^H) = P_{i,t}^{I^H}, \quad (45)$$

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

$$Q_{i,e,t}^H = E_t \frac{\beta \lambda_{i,t+1}^B}{\lambda_{i,t}^B} \left\{ P_{i,t+1}^{I^H} \left[ \frac{I_{i,e,t+1}^H}{P_{i,t+1}^{I^H}} - \phi_{i,t}^D \frac{P_{i,t}^{I^H}}{P_{i,t+1}^{I^H}} \left[ (1 - \delta_{i,t+1}^M)(1 + i_{i,t}^M) - \frac{\lambda_{i,t}^B}{\beta \lambda_{i,t+1}^B} \right] \right] + (1 - \delta^H) Q_{i,e,t+1}^H \right\}, \quad (46)$$

which equates it to the expected present value of the sum of the future marginal revenue product of housing, and the future shadow price of housing net of depreciation, less the product of the loan to value ratio with the spread of the effective cost of bank over capital market funding. 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 intermediate developer allocations.

## Housing Supply

In period  $t$ , the representative intermediate developer adjusts its rental price of housing to maximize pre-dividend stock market value (40) subject to housing accumulation function (43) and intermediate housing service demand function (38). We consider a symmetric equilibrium under which all developer specific endogenous state variables are restricted to equal their aggregate counterparts. It follows that all intermediate developers solve an identical value

maximization problem, which implies that they all choose a common rental price of housing  $t_{i,t}^{H,*}$  given by necessary first order condition:

$$\frac{t_{i,t}^{H,*}}{P_{i,t}^{H,*}} = \frac{\theta_{i,t}^H}{\theta_{i,t}^H - 1} \left[ \phi_{i,t-1}^D (1 - \delta_{i,t}^M) (1 + i_{i,t-1}^M) \frac{P_{i,t-1}^{H,*}}{P_{i,t}^{H,*}} - (1 - \delta^H) \frac{Q_{i,t}^H}{P_{i,t}^{H,*}} \right]. \quad (47)$$

This necessary first order condition equates the marginal revenue gained from housing supply to the marginal cost incurred from construction. Aggregate rental price of housing index (39) satisfies  $t_{i,t}^H = t_{i,t}^{H,*}$ .

### C. The Production Sector

The production sector supplies output goods for domestic and foreign absorption. In doing so, firms demand labor services from domestic households, obtain corporate loans from domestic and foreign banks, and accumulate the physical capital stock through business investment.

The production sector consists of a finite set of industries indexed by  $k \in \{1, \dots, M\}$ , 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 output goods for foreign absorption, while all other industries produce internationally heterogeneous output goods for domestic and foreign absorption.

#### 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

$$Y_{i,t} = \min \left\{ \frac{Y_{i,k,t}}{\phi_{i,k}^Y} \right\}_{k=1}^M, \quad (48)$$

where  $0 \leq \phi_{i,k}^Y \leq 1$  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:

$$Y_{i,k,t} = \phi_{i,k}^Y Y_{i,t}. \quad (49)$$

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:

$$P_{i,t}^Y = \sum_{k=1}^M \phi_{i,k}^Y P_{i,k,t}^Y. \quad (50)$$

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

$$Y_{i,k,t} = \left[ \int_0^1 (Y_{i,k,l,t})^{\frac{\theta_{i,k,t}^Y - 1}{\theta_{i,k,t}^Y}} dl \right]^{\frac{\theta_{i,k,t}^Y}{\theta_{i,k,t}^Y - 1}}, \quad (51)$$

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

$$Y_{i,k,l,t} = \left( \frac{P_{i,k,l,t}^Y}{P_{i,k,t}^Y} \right)^{-\theta_{i,k,t}^Y} Y_{i,k,t}. \quad (52)$$

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:

$$P_{i,k,t}^Y = \left[ \int_0^1 (P_{i,k,l,t}^Y)^{1-\theta_{i,k,t}^Y} dl \right]^{\frac{1}{1-\theta_{i,k,t}^Y}}. \quad (53)$$

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

### Labor Demand and Business 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. We rule out entry into and exit out of the monopolistically competitive industry specific intermediate output good sectors.

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

capitalist spirit motive for holding real portfolio balances equals the expected present value of current and future dividend payments

$$\Pi_{i,k,l,t}^S + V_{i,k,l,t}^S = E_t \sum_{s=t}^{\infty} \frac{\beta^{s-t} \lambda_{i,s}^A}{\lambda_{i,t}^A} \Pi_{i,k,l,s}^S, \quad (54)$$

where  $\lambda_{i,s}^A$  denotes the Lagrange multiplier associated with the period  $s$  capital market intermediated 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  $\Pi_{i,k,l,s}^S$ , defined as the sum of after tax corporate earnings and net borrowing less business investment expenditures,

$$\Pi_{i,k,l,s}^S = (1 - \tau_{i,s}^K)(P_{i,k,l,s}^Y Y_{i,k,l,s} - W_{i,s} L_{i,k,l,s} - \Phi_{i,k,l,s}) + (B_{i,k,l,s+1}^{C,F} - (1 - \delta_{i,s}^C)(1 + i_{i,s}^{C,E}) B_{i,k,l,s}^{C,F}) - P_{i,s}^{I^K} I_{i,k,l,s}^K, \quad (55)$$

where  $Y_{i,k,l,s} = \mathcal{F}(u_{i,k,l,s}^K K_{i,k,l,s}, \mathcal{A}_{i,s} L_{i,k,l,s})$ . Corporate earnings are defined as revenues derived from sales of industry specific differentiated intermediate output good  $Y_{i,k,l,s}$  at price  $P_{i,k,l,s}^Y$  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 corporate earnings at rate  $\tau_{i,s}^K$ .

Motivated by the collateralized borrowing variant of the financial accelerator mechanism due to Kiyotaki and Moore (1997), the financial policy of the representative industry specific intermediate output good firm is to maintain debt equal to a fraction of the value of the physical capital stock,

$$\frac{B_{i,k,l,s+1}^{C,F}}{P_{i,s}^{I^K} K_{i,k,l,s+1}} = \phi_{i,s}^F, \quad (56)$$

given by regulatory corporate loan to value ratio limit  $\phi_{i,s}^F$ . Net borrowing is defined as the increase in corporate loans  $B_{i,k,l,s+1}^{C,F}$  from domestic and foreign banks net of writedowns at corporate loan default rate  $\delta_{i,s}^C$  and interest payments at effective corporate loan rate  $i_{i,s}^{C,E}$ . This corporate loan default rate applies uniformly to all corporate loans received from domestic and foreign banks.

The representative industry specific intermediate output good firm utilizes physical capital  $K_{i,k,l,s}$  at rate  $u_{i,k,l,s}^K$  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

$$\mathcal{F}(u_{i,k,l,s}^K K_{i,k,l,s}, \mathcal{A}_{i,s} L_{i,k,l,s}) = (u_{i,k,l,s}^K K_{i,k,l,s})^{\phi_{i,s}^K} (\mathcal{A}_{i,s} L_{i,k,l,s})^{1-\phi_{i,s}^K}, \quad (57)$$

where serially correlated productivity shock  $\mathcal{A}_{i,s}$  satisfies  $\mathcal{A}_{i,s} > 0$ . This production function exhibits constant returns to scale, with  $0 \leq \phi_{i,s}^K \leq 1$ .

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

$$\Phi_{i,k,l,s} = P_{i,s}^{I^K} \mathcal{G}(u_{i,k,l,s}^K, K_{i,k,l,s}) + F_{i,k,s}^F, \quad (58)$$

where industry specific fixed cost  $F_{i,k,s}^F$  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,

$$\mathcal{G}(u_{i,k,l,s}^K, K_{i,k,l,s}) = \mu_i^K \left[ e^{\eta^K (u_{i,k,l,s}^K)^{-1}} - 1 \right] K_{i,k,l,s}, \quad (59)$$

where  $\eta^K > 0$ , while  $\mu_i^K = \frac{\mu^K}{1-\tau_i^K}$  with  $\mu^K > 0$ . In steady state equilibrium, the capital utilization rate equals one, and the cost of utilizing physical capital equals zero.

The representative industry specific intermediate output good firm enters period  $s$  in possession of previously accumulated physical capital stock  $K_{i,k,l,s}$ , which subsequently evolves according to accumulation function

$$K_{i,k,l,s+1} = (1 - \delta^K) K_{i,k,l,s} + \mathcal{H}(I_{i,k,l,s}^K, I_{i,k,l,s-1}^K), \quad (60)$$

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

$$\mathcal{H}(I_{i,k,l,s}^K, I_{i,k,l,s-1}^K) = v_{i,s}^{I^K} \left[ 1 - \frac{\chi^K}{2} \left( \frac{I_{i,k,l,s}^K}{I_{i,k,l,s-1}^K} - 1 \right)^2 \right] I_{i,k,l,s}^K, \quad (61)$$

where serially correlated business investment demand shock  $v_{i,s}^{I^K}$  satisfies  $v_{i,s}^{I^K} > 0$ , while  $\chi^K > 0$ . In steady state equilibrium, these adjustment costs equal zero, and effective business investment equals actual business 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  $\{u_{i,k,l,s}^K\}_{s=t}^{\infty}$ , business investment  $\{I_{i,k,l,s}^K\}_{s=t}^{\infty}$ , and the physical capital stock  $\{K_{i,k,l,s+1}\}_{s=t}^{\infty}$  to maximize pre-dividend stock market value (54) subject to production function (57), physical capital accumulation function (60), and terminal nonnegativity constraint  $K_{i,k,l,T+1} \geq 0$  for  $T \rightarrow \infty$ . In equilibrium, demand for the final labor service satisfies necessary first order condition

$$\mathcal{F}_{AL}(u_{i,k,l,t}^K, K_{i,k,l,t}, \mathcal{A}_{i,t} L_{i,k,l,t}) \Psi_{i,k,l,t} = (1 - \tau_{i,t}^K) \frac{W_{i,t}}{P_{i,k,t}^Y \mathcal{A}_{i,t}}, \quad (62)$$

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

$$\mathcal{F}_{u^K}(u_{i,k,l,t}^K, K_{i,k,l,t}, \mathcal{A}_{i,t} L_{i,k,l,t}) \frac{P_{i,k,t}^Y \Psi_{i,k,l,t}}{P_{i,t}^{I^K}} = (1 - \tau_{i,t}^K) \frac{\mathcal{G}_{u^K}(u_{i,k,l,t}^K, K_{i,k,l,t})}{K_{i,k,l,t}}, \quad (63)$$



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

$$Q_{i,k,l,t}^K \mathcal{H}_1(I_{i,k,l,t}^K, I_{i,k,l,t-1}^K) + E_t \frac{\beta \lambda_{i,t+1}^A}{\lambda_{i,t}^A} Q_{i,k,l,t+1}^K \mathcal{H}_2(I_{i,k,l,t+1}^K, I_{i,k,l,t}^K) = P_{i,t}^{I^K}, \quad (64)$$

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

$$Q_{i,k,l,t}^K = E_t \frac{\beta \lambda_{i,t+1}^A}{\lambda_{i,t}^A} \left\{ P_{i,t+1}^{I^K} \left\{ u_{i,k,l,t+1}^K \mathcal{F}_{u^K K} (u_{i,k,l,t+1}^K K_{i,k,l,t+1}, A_{i,t+1} L_{i,k,l,t+1}) \frac{P_{i,k,t+1}^Y \Psi_{i,k,l,t+1}}{P_{i,t+1}^{I^K}} \right. \right. \\ \left. \left. - (1 - \tau_{i,t+1}^K) \mathcal{G}_K (u_{i,k,l,t+1}^K, K_{i,k,l,t+1}) - \phi_{i,t}^F \frac{P_{i,t}^{I^K}}{P_{i,t+1}^{I^K}} \left[ (1 - \delta_{i,t+1}^C)(1 + i_{i,t+1}^{C,E}) - \frac{\lambda_{i,t}^A}{\beta \lambda_{i,t+1}^A} \right] \right\} + (1 - \delta^K) Q_{i,k,l,t+1}^K \right\}, \quad (65)$$

which equates it to the expected present value of the sum of the future marginal revenue product of physical capital net of its marginal utilization cost, and the future shadow price of physical capital net of depreciation, less the product of the loan to value ratio with the spread of the effective cost of bank over capital market funding. 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  $0 \leq \omega_k^Y < 1$  with  $\omega_k^Y = \omega^Y$  for  $k > M^*$ . The remaining fraction  $\omega_k^Y$  of intermediate output good firms adjust their price to account for past industry specific output price inflation according to partial indexation rule

$$P_{i,k,l,t}^Y = \left( \frac{P_{i,k,t-1}^Y}{P_{i,k,t-2}^Y} \right)^{\gamma_k^Y} \left( \frac{\bar{P}_{i,k,t-1}^Y}{\bar{P}_{i,k,t-2}^Y} \right)^{1-\gamma_k^Y} P_{i,k,l,t-1}^Y, \quad (66)$$

where  $0 \leq \gamma_k^Y \leq 1$  with  $\gamma_k^Y = 0$  for  $1 \leq k \leq M^*$  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 (54) subject to production function (57), industry specific intermediate output good demand function (52), and the assumed form of nominal output price rigidity. We consider a symmetric equilibrium under which all industry and firm specific endogenous state variables are restricted to equal their industry specific aggregate counterparts. It follows that all intermediate output good firms that adjust their price optimally in period  $t$  solve an identical value maximization problem, which implies that they all choose a common price  $P_{i,k,t}^{Y,*}$  given by necessary first order condition:

$$\frac{P_{i,k,t}^{Y,*}}{P_{i,k,t}^Y} = \frac{E_t \sum_{s=t}^{\infty} (\omega_k^Y)^{s-t} \frac{\beta^{s-t} \lambda_{i,s}^A}{\lambda_{i,t}^A} \theta_{i,k,s}^Y \Psi_{i,k,l,s} \left[ \left( \frac{P_{i,k,t-1}^Y}{P_{i,k,s-1}^Y} \right)^{\gamma_k^Y} \left( \frac{\bar{P}_{i,k,t-1}^Y}{\bar{P}_{i,k,s-1}^Y} \right)^{1-\gamma_k^Y} \frac{P_{i,k,s}^Y}{P_{i,k,t}^Y} \right]^{\theta_{i,k,s}^Y} \left( \frac{P_{i,k,t}^{Y,*}}{P_{i,k,t}^Y} \right)^{-\theta_{i,k,s}^Y} P_{i,k,s}^Y Y_{i,k,s}}{E_t \sum_{s=t}^{\infty} (\omega_k^Y)^{s-t} \frac{\beta^{s-t} \lambda_{i,s}^A}{\lambda_{i,t}^A} (\theta_{i,k,s}^Y - 1)(1 - \tau_{i,s}^K) \left[ \left( \frac{P_{i,k,t-1}^Y}{P_{i,k,s-1}^Y} \right)^{\gamma_k^Y} \left( \frac{\bar{P}_{i,k,t-1}^Y}{\bar{P}_{i,k,s-1}^Y} \right)^{1-\gamma_k^Y} \frac{P_{i,k,s}^Y}{P_{i,k,t}^Y} \right]^{\theta_{i,k,s}^Y - 1} \left( \frac{P_{i,k,t}^{Y,*}}{P_{i,k,t}^Y} \right)^{-\theta_{i,k,s}^Y} P_{i,k,s}^Y Y_{i,k,s}}. \quad (67)$$

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 (53) 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  $\omega_k^Y$  of intermediate output good firms that adjust their price according to partial indexation rule (66):

$$P_{i,k,t}^Y = \left\{ (1 - \omega_k^Y) (P_{i,k,t}^{Y,*})^{1-\theta_{i,k,t}^Y} + \omega_k^Y \left[ \left( \frac{P_{i,k,t-1}^Y}{P_{i,k,t-2}^Y} \right)^{\gamma_k^Y} \left( \frac{\bar{P}_{i,k,t-1}^Y}{\bar{P}_{i,k,t-2}^Y} \right)^{1-\gamma_k^Y} P_{i,k,t-1}^Y \right]^{1-\theta_{i,k,t}^Y} \right\}^{\frac{1}{1-\theta_{i,k,t}^Y}}. \quad (68)$$

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.

#### D. The Banking Sector

The banking sector supplies global financial intermediation services subject to financial frictions and regulatory constraints. In particular, banks issue risky mortgage loans to domestic developers at infrequently adjusted predetermined mortgage loan rates, as well as risky domestic currency denominated corporate loans to domestic and foreign firms at infrequently adjusted predetermined corporate loan rates, given regulatory loan to value ratio limits. They obtain funding from domestic bank intermediated households via deposits and from the domestic money market via loans, accumulating bank capital out of retained earnings given credit losses to satisfy a regulatory capital requirement.

## Credit Demand

There exist a large number of perfectly competitive banks which combine local currency denominated final corporate loans  $\{B_{i,j,t}^{C,F}\}_{j=1}^N$  to produce domestic currency denominated final corporate loan  $B_{i,t}^{C,F}$  according to fixed proportions portfolio aggregator

$$B_{i,t}^{C,F} = \min \left\{ \frac{\mathcal{E}_{i,j,t-1} B_{i,j,t}^{C,F}}{\phi_{i,j}^F} \right\}_{j=1}^N, \quad (69)$$

where  $0 \leq \phi_{i,j}^F \leq 1$  and  $\sum_{j=1}^N \phi_{i,j}^F = 1$ . The representative global final bank maximizes profits derived from intermediation of the domestic currency denominated final corporate loan with respect to inputs of local currency denominated final corporate loans, implying demand functions:

$$B_{i,j,t}^{C,F} = \phi_{i,j}^F \frac{B_{i,t}^{C,F}}{\mathcal{E}_{i,j,t-1}}. \quad (70)$$

Since the portfolio aggregator exhibits constant returns to scale, in equilibrium the representative global final bank generates zero profit, implying aggregate effective gross corporate loan rate index:

$$1 + i_{i,t}^{C,E} = \sum_{j=1}^N \phi_{i,j}^F (1 + i_{j,t-1}^C) \frac{\mathcal{E}_{i,j,t}}{\mathcal{E}_{i,j,t-1}}. \quad (71)$$

This aggregate effective gross corporate loan rate index equals the minimum cost of producing one unit of the domestic currency denominated final corporate loan, given the rates on local currency denominated final corporate loans.

There exist a large number of perfectly competitive banks which combine differentiated intermediate mortgage or corporate loans  $B_{i,m,t+1}^{C,Z}$  supplied by intermediate banks to produce final mortgage or corporate loan  $B_{i,t+1}^{C,Z}$  according to constant elasticity of substitution portfolio aggregator

$$B_{i,t+1}^{C,Z} = \left[ \int_0^1 (B_{i,m,t+1}^{C,Z})^{\frac{\theta_{i,t+1}^{C,Z}-1}{\theta_{i,t+1}^{C,Z}}} dm \right]^{\frac{\theta_{i,t+1}^{C,Z}}{\theta_{i,t+1}^{C,Z}-1}}, \quad (72)$$

where  $Z \in \{D, F\}$ , while serially uncorrelated mortgage or corporate loan rate markup shock  $\theta_{i,t+1}^{C,Z}$  satisfies  $\theta_{i,t+1}^{C,Z} > 1$  with  $\theta_i^{C,Z} = \theta^C$ . The representative domestic final bank maximizes profits derived from intermediation of the final mortgage or corporate loan with respect to inputs of intermediate mortgage or corporate loans, implying demand functions

$$B_{i,m,t+1}^{C^Z,B} = \left( \frac{1 + i_{i,m,t}^{f(Z)}}{1 + i_{i,t}^{f(Z)}} \right)^{-\theta_{i,t+1}^{C^Z}} B_{i,t+1}^{C^Z,B}, \quad (73)$$

where  $f(D) = M$  and  $f(F) = C$ . Since the portfolio aggregator exhibits constant returns to scale, in equilibrium the representative domestic final bank generates zero profit, implying aggregate gross mortgage or corporate loan rate index:

$$1 + i_{i,t}^{f(Z)} = \left[ \int_0^1 (1 + i_{i,m,t}^{f(Z)})^{1-\theta_{i,t+1}^{C^Z}} dm \right]^{\frac{1}{1-\theta_{i,t+1}^{C^Z}}}. \quad (74)$$

As the rate elasticity of demand for intermediate mortgage or corporate loans  $\theta_{i,t+1}^{C^Z}$  increases, they become closer substitutes, and individual intermediate banks have less market power.

### Funding Demand and Bank Capital Accumulation

There exists a continuum of monopolistically competitive intermediate banks indexed by  $m \in [0,1]$ . Intermediate banks supply differentiated intermediate mortgage and corporate loans, but are otherwise identical. We rule out entry into and exit out of the monopolistically competitive intermediate banking sector.

The representative intermediate bank sells shares to domestic bank intermediated households at price  $V_{i,m,t}^C$ . Acting in the interests of its shareholders, it maximizes its pre-dividend stock market value, which equals the expected present value of current and future dividend payments:

$$\Pi_{i,m,t}^C + V_{i,m,t}^C = E_t \sum_{s=t}^{\infty} \frac{\beta^{s-t} \lambda_{i,s}^B}{\lambda_{i,t}^B} \Pi_{i,m,s}^C. \quad (75)$$

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

Shares entitle households to dividend payments  $\Pi_{i,m,s}^C$ , defined as profits derived from providing financial intermediation services less retained earnings  $I_{i,m,s}^B$ :

$$\begin{aligned} \Pi_{i,m,s}^C = & (B_{i,m,s+1}^{D,B} - (1 + i_{i,s-1}^D) B_{i,m,s}^{D,B}) + (B_{i,m,s+1}^{S,B} - (1 + i_{i,s-1}^S) B_{i,m,s}^{S,B}) \\ & - (B_{i,m,s+1}^{C^D,B} - (1 - \delta_{i,s}^M)(1 + i_{i,m,s-1}^M) B_{i,m,s}^{C^D,B}) - (B_{i,m,s+1}^{C^F,B} - (1 - \delta_{i,s}^{C,E})(1 + i_{i,m,s-1}^C) B_{i,m,s}^{C^F,B}) - \Phi_{i,m,s}^B - I_{i,m,s}^B. \end{aligned} \quad (76)$$

Profits are defined as the sum of the increase in deposits  $B_{i,m,s+1}^{D,B}$  from domestic bank intermediated households net of interest payments at the deposit rate and the increase in loans  $B_{i,m,s+1}^{S,B}$  from the domestic money market net of interest payments at the yield to maturity on short term bonds, less the increase in differentiated intermediate mortgage loans  $B_{i,m,s+1}^{C^D,B}$  to domestic developers net of writedowns at mortgage credit loss rate  $\delta_{i,s}^M$  and interest receipts at mortgage loan rate  $i_{i,m,s-1}^M$ , less the increase in differentiated intermediate corporate loans  $B_{i,m,s+1}^{C^F,B}$  to domestic and foreign firms net of writedowns at corporate credit loss rate  $\delta_{i,s}^{C,E}$  and interest

receipts at corporate loan rate  $i_{i,m,s-1}^C$ , less a cost of satisfying the regulatory capital requirement  $\Phi_{i,m,s}^B$ .

The representative intermediate bank transforms deposit and money market funding into risky differentiated intermediate mortgage and corporate loans according to balance sheet identity:

$$B_{i,m,s+1}^{C^D,B} + B_{i,m,s+1}^{C^F,B} = B_{i,m,s+1}^{D,B} + B_{i,m,s+1}^{S,B} + K_{i,m,s+1}^B. \quad (77)$$

The bank credit stock  $B_{i,s+1}^{C,B}$  measures aggregate bank assets, that is  $B_{i,s+1}^{C,B} = B_{i,s+1}^{C^D,B} + B_{i,s+1}^{C^F,B}$ , while the money stock  $M_{i,s+1}^S$  measures aggregate bank funding, that is  $M_{i,s+1}^S = B_{i,s+1}^{D,B} + B_{i,s+1}^{S,B}$ . The bank capital ratio  $\kappa_{i,s+1}$  equals the ratio of aggregate bank capital to assets, that is  $\kappa_{i,s+1} = K_{i,s+1}^B / B_{i,s+1}^{C,B}$ .

In transforming deposit and money market funding into risky mortgage and corporate loans, the representative intermediate bank incurs a cost of satisfying the regulatory capital requirement,

$$\Phi_{i,m,s}^B = \mathcal{G}^B(B_{i,m,s}^{C^D,B}, B_{i,m,s}^{C^F,B}, K_{i,m,s}^B) + F_{i,s}^B, \quad (78)$$

where fixed cost  $F_{i,s}^B$  ensures that  $\Phi_{i,s}^B = -I_{i,s}^B$ . Motivated by Gerali, Neri, Sessa and Signoretti (2010), this regulation cost is decreasing in the ratio of bank capital to assets at a decreasing rate,

$$\mathcal{G}^B(B_{i,m,s}^{C^D,B}, B_{i,m,s}^{C^F,B}, K_{i,m,s}^B) = \mu^C \left[ e^{(2+\eta^C) \left( 1 - \frac{1}{\kappa_{i,s}^R} \frac{K_{i,m,s}^B}{B_{i,m,s}^{C^D,B} + B_{i,m,s}^{C^F,B}} \right)} - 1 \right] K_{i,m,s}^B, \quad (79)$$

given regulatory capital requirement  $\kappa_{i,s}^R$ , where  $\eta^C > 0$  and  $\mu^C > 0$ . In steady state equilibrium, the bank capital ratio equals its required value, and the cost of regulation is constant.

The financial policy of the representative intermediate bank is to smooth retained earnings intertemporally, given credit losses. It enters period  $s$  in possession of previously accumulated bank capital stock  $K_{i,m,s}^B$ , which subsequently evolves according to accumulation function

$$K_{i,m,s+1}^B = (1 - \delta_{i,s}^B) K_{i,m,s}^B + \mathcal{H}^B(I_{i,m,s}^B, I_{i,m,s-1}^B), \quad (80)$$

where bank capital destruction rate  $\delta_{i,s}^B$  satisfies  $\delta_{i,s}^B = \chi^C (w_i^C \delta_{i,s}^M + (1 - w_i^C) \delta_{i,s}^{C,E})$  with  $\chi^C > 0$ , while mortgage loan weight  $w_i^C$  satisfies  $0 < w_i^C < 1$ . Effective retained earnings function  $\mathcal{H}^B(I_{i,m,s}^B, I_{i,m,s-1}^B)$  incorporates convex adjustment costs,

$$\mathcal{H}^B(I_{i,m,s}^B, I_{i,m,s-1}^B) = \left[ 1 - \frac{\chi^B}{2} \left( \frac{I_{i,m,s}^B}{I_{i,m,s-1}^B} - 1 \right)^2 \right] I_{i,m,s}^B, \quad (81)$$

where  $\chi^B > 0$ . In steady state equilibrium, these adjustment costs equal zero, and effective retained earnings equals actual retained earnings.

In period  $t$ , the representative intermediate bank chooses state contingent sequences for deposit funding  $\{B_{i,m,s+1}^{D,B}\}_{s=t}^\infty$ , money market funding  $\{B_{i,m,s+1}^{S,B}\}_{s=t}^\infty$ , retained earnings  $\{I_{i,m,s}^B\}_{s=t}^\infty$ , and the bank

capital stock  $\{K_{i,m,s+1}^B\}_{s=t}^\infty$  to maximize pre-dividend stock market value (75) subject to balance sheet identity (77), bank capital accumulation function (80), and terminal nonnegativity constraints  $B_{i,m,T+1}^{D,B} \geq 0$ ,  $B_{i,m,T+1}^{S,B} \geq 0$  and  $K_{i,m,T+1}^B \geq 0$  for  $T \rightarrow \infty$ . In equilibrium, the solutions to this value maximization problem satisfy necessary first order condition

$$1 + i_{i,t}^D = 1 + i_{i,t}^S, \quad (82)$$

which equates the deposit rate to the yield to maturity on short term bonds. In equilibrium, retained earnings satisfies necessary first order condition

$$Q_{i,m,t}^B \mathcal{H}_1^B(I_{i,m,t}^B, I_{i,m,t-1}^B) + E_t \frac{\beta \lambda_{i,t+1}^B}{\lambda_{i,t}^B} Q_{i,m,t+1}^B \mathcal{H}_2^B(I_{i,m,t+1}^B, I_{i,m,t}^B) = 1, \quad (83)$$

which equates the expected present value of an additional unit of retained earnings to its marginal cost, where  $Q_{i,m,s}^B$  denotes the Lagrange multiplier associated with the period  $s$  bank capital accumulation function. In equilibrium, this shadow price of bank capital satisfies necessary first order condition

$$Q_{i,m,t}^B = E_t \frac{\beta \lambda_{i,t+1}^B}{\lambda_{i,t}^B} \left\{ (1 - \delta_{i,t+1}^B) Q_{i,m,t+1}^B - \left[ \mathcal{G}_3^B(B_{i,m,t+1}^{C^D,B}, B_{i,m,t+1}^{C^F,B}, K_{i,m,t+1}^B) + \left[ \frac{\lambda_{i,t}^B}{\beta \lambda_{i,t+1}^B} - (1 + i_{i,t}^S) \right] \right] \right\}, \quad (84)$$

which equates it to the expected present value of the future shadow price of bank capital net of destruction, less the sum of the marginal utilization cost of bank capital and the spread of the cost of deposit over money market funding. The evaluation of this result abstracts from risk premium shocks. Provided that the pre-dividend stock market value is bounded and strictly concave, together with other necessary first order conditions, and transversality conditions derived from the necessary complementary slackness conditions associated with the terminal nonnegativity constraints, these necessary first order conditions are sufficient for the unique value maximizing state contingent sequence of intermediate bank allocations.

## Credit Supply

In an adaptation of the model of nominal output price rigidity proposed by Calvo (1983) to the banking sector along the lines of Hülsewig, Mayer and Wollmershäuser (2009), each period a randomly selected fraction  $1 - \omega^C$  of intermediate banks adjust their gross mortgage and corporate loan rates optimally, where  $0 \leq \omega^C < 1$ . The remaining fraction  $\omega^C$  of intermediate banks do not adjust their loan rates,

$$1 + i_{i,m,t}^{f(Z)} = 1 + i_{i,m,t-1}^{f(Z)}, \quad (85)$$

where  $Z \in \{D, F\}$ , while  $f(D) = M$  and  $f(F) = C$ . Under this financial friction, intermediate banks infrequently adjust their loan rates, mimicking the effect of maturity transformation on the spreads between the loan and deposit rates.

If the representative intermediate bank can adjust its gross mortgage and corporate loan rates in period  $t$ , then it does so to maximize pre-dividend stock market value (75) subject to balance sheet identity (77), intermediate loan demand function (73), and the assumed financial friction. We consider a symmetric equilibrium under which all bank specific endogenous state variables are restricted to equal their aggregate counterparts. It follows that all intermediate banks that adjust their loan rates in period  $t$  solve an identical value maximization problem, which implies that they all choose common loan rates  $i_{i,t}^{f(Z),*}$  given by necessary first order conditions

$$\frac{1+i_{i,t}^{f(Z),*}}{1+i_{i,t}^{f(Z)}} = \frac{E_t \sum_{s=t}^{\infty} (\omega^C)^{s-t} \frac{\beta^{s-t} \lambda_{i,t}^B}{\lambda_{i,t}^B} \theta_{i,t}^{C^Z} \frac{(1+i_{i,t}^{f(Z)})}{1+i_{i,t}^{f(Z)}} + \mathcal{G}_{h(Z)}^B(B_{i,t}^{C^D,B}, B_{i,t}^{C^E,B}, K_{i,t}^B) \left( \frac{1+i_{i,t}^{f(Z)}}{1+i_{i,t}^{f(Z)}} \right)^{\theta_{i,t}^{C^Z}} \left( \frac{1+i_{i,t}^{f(Z),*}}{1+i_{i,t}^{f(Z)}} \right)^{-\theta_{i,t}^{C^Z}} (1+i_{i,t}^{f(Z)}) B_{i,t}^{C^Z,B}}{E_t \sum_{s=t}^{\infty} (\omega^C)^{s-t} \frac{\beta^{s-t} \lambda_{i,t}^B}{\lambda_{i,t}^B} (\theta_{i,t}^{C^Z} - 1) (1 - \delta_{i,t}^{g(Z)}) \left( \frac{1+i_{i,t}^{f(Z)}}{1+i_{i,t}^{f(Z)}} \right)^{\theta_{i,t}^{C^Z}-1} \left( \frac{1+i_{i,t}^{f(Z),*}}{1+i_{i,t}^{f(Z)}} \right)^{-\theta_{i,t}^{C^Z}} (1+i_{i,t}^{f(Z)}) B_{i,t}^{C^Z,B}}, \quad (86)$$

where  $g(D) = M$  and  $g(F) = C, E$ , while  $h(D) = 1$  and  $h(F) = 2$ . These necessary first order conditions equate the expected present value of the marginal revenue gained from mortgage or corporate loan supply to the expected present value of the marginal cost incurred from intermediation. Aggregate gross mortgage or corporate loan rate index (74) equals an average of the gross mortgage or corporate loan rate set by the fraction  $1 - \omega^C$  of intermediate banks that adjust their loan rates in period  $t$ , and the average of the gross mortgage or corporate loan rates set by the remaining fraction  $\omega^C$  of intermediate banks that do not adjust their loan rates:

$$1+i_{i,t}^{f(Z)} = \left[ (1 - \omega^C) (1+i_{i,t}^{f(Z),*})^{1-\theta_{i,t}^{C^Z}} + \omega^C (1+i_{i,t-1}^{f(Z)})^{1-\theta_{i,t}^{C^Z}} \right]^{1-\theta_{i,t}^{C^Z}}. \quad (87)$$

Since those intermediate banks able to adjust their loan rates in period  $t$  are selected randomly from among all intermediate banks, the average gross mortgage or corporate loan rate set by the remaining intermediate banks equals the value of the aggregate gross mortgage or corporate loan rate index that prevailed during period  $t-1$ .

## E. 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,

$$\mathcal{E}_{i,t} = \prod_{j=1}^N (\mathcal{E}_{i,j,t})^{w_{i,j}^T}, \quad \mathcal{Q}_{i,t} = \prod_{j=1}^N (\mathcal{Q}_{i,j,t})^{w_{i,j}^T}, \quad (88)$$

where the real bilateral exchange rate  $\mathcal{Q}_{i,j,t}$  satisfies  $\mathcal{Q}_{i,j,t} = \mathcal{E}_{i,j,t} P_{j,t}^Y / P_{i,t}^Y$ , and bilateral trade weight  $w_{i,j}^T$  satisfies  $w_{i,i}^T = 0$ ,  $0 \leq w_{i,j}^T \leq 1$  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,

$$\mathcal{T}_{i,t} = \nu_t^T \frac{\mathcal{T}_{i,t}^X}{\mathcal{T}_{i,t}^M}, \quad \mathcal{T}_{i,t}^X = \frac{P_{i,t}^X}{P_{i,t}}, \quad \mathcal{T}_{i,t}^M = \frac{P_{i,t}^M}{P_{i,t}}, \quad (89)$$

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  $1 \leq k \leq M^*$ , which implies that

$$P_{k,t}^Y = \sum_{i=1}^N w_i^Y \mathcal{E}_{i^*,i,t} P_{i,k,t}^Y, \quad (90)$$

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  $\sum_{i=1}^N w_i^Y = 1$ . Endogenous terms of trade shifter  $\nu_i^T$  adjusts to ensure multilateral consistency in nominal trade flows, and in steady state equilibrium satisfies  $\nu^T = 1$ .

### 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

$$X_{i,t} = \min \left\{ \frac{X_{i,k,t}}{\phi_{i,k}^X} \right\}_{k=1}^M, \quad (91)$$

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

$$X_{i,k,t} = \phi_{i,k}^X X_{i,t}. \quad (92)$$

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:

$$P_{i,t}^X = \sum_{k=1}^M \phi_{i,k}^X P_{i,k,t}^Y. \quad (93)$$

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



$$Z_{i,t} = \left[ (1 - \phi_i^M)^{\frac{1}{\psi^M}} (Z_{i,t}^h)^{\frac{\psi^M - 1}{\psi^M}} + (\phi_i^M)^{\frac{1}{\psi^M}} (v_{i,t}^M Z_{i,t}^f)^{\frac{\psi^M - 1}{\psi^M}} \right]^{\frac{\psi^M}{\psi^M - 1}}, \quad (94)$$

where serially correlated import demand shock  $v_{i,t}^M$  satisfies  $v_{i,t}^M > 0$ , while  $0 \leq \phi_i^M \leq 1$  and  $\psi^M > 0$ . The representative final absorption good firm maximizes profits derived from production of the final private consumption, residential investment, business investment or public consumption good, with respect to inputs of the final noncommodity output and import goods, implying demand functions:

$$Z_{i,t}^h = (1 - \phi_i^M) \left( \frac{P_{i,t}}{P^Z} \right)^{-\psi^M} Z_{i,t}, \quad Z_{i,t}^f = \phi_i^M \left( \frac{1}{v_i^M} \frac{P_{i,t}^M}{P^Z} \right)^{-\psi^M} \frac{Z_{i,t}}{v_{i,t}^M}. \quad (95)$$

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

$$P_{i,t}^Z = \left[ (1 - \phi_i^M) (P_{i,t})^{1 - \psi^M} + \phi_i^M \left( \frac{P_{i,t}^M}{v_i^M} \right)^{1 - \psi^M} \right]^{\frac{1}{1 - \psi^M}}. \quad (96)$$

Combination of this aggregate private consumption, residential investment, business investment or public consumption price index with final noncommodity output and import good demand functions (95) yields:

$$Z_{i,t}^h = (1 - \phi_i^M) \left[ (1 - \phi_i^M) + \phi_i^M \left( \frac{T_{i,t}^M}{v_i^M} \right)^{1 - \psi^M} \right]^{\frac{\psi^M}{1 - \psi^M}} Z_{i,t}, \quad Z_{i,t}^f = \phi_i^M \left[ \phi_i^M + (1 - \phi_i^M) \left( \frac{T_{i,t}^M}{v_i^M} \right)^{\psi^M - 1} \right]^{\frac{\psi^M}{1 - \psi^M}} \frac{Z_{i,t}}{v_{i,t}^M}. \quad (97)$$

These demand functions for the final noncommodity output and import goods are directly proportional to final private consumption, residential investment, business 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

$$M_{i,t} = \min \left\{ v_{j,t}^X \frac{M_{i,j,t}}{\phi_{i,j}^M} \right\}_{j=1}^N, \quad (98)$$

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

$$M_{i,j,t} = \phi_{i,j}^M \frac{M_{i,t}}{v_{j,t}^X}. \quad (99)$$

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

$$P_{i,t}^M = \sum_{j=1}^N \phi_{i,j}^M \frac{P_{i,j,t}^M}{v_j^X}. \quad (100)$$

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  $M_{i,j,n,t}$  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

$$M_{i,j,t} = \left[ \int_0^1 (M_{i,j,n,t})^{\frac{\theta_{i,t}^M - 1}{\theta_{i,t}^M}} dn \right]^{\frac{\theta_{i,t}^M}{\theta_{i,t}^M - 1}}, \quad (101)$$

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:

$$M_{i,j,n,t} = \left( \frac{P_{i,j,n,t}^M}{P_{i,j,t}^M} \right)^{-\theta_{i,t}^M} M_{i,j,t}. \quad (102)$$

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:

$$P_{i,j,t}^M = \left[ \int_0^1 (P_{i,j,n,t}^M)^{1-\theta_{i,t}^M} dn \right]^{\frac{1}{1-\theta_{i,t}^M}}. \quad (103)$$

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  $n \in [0,1]$ . Intermediate import good firms supply economy specific differentiated intermediate import goods, but are otherwise identical. We rule out entry into and exit out of the monopolistically competitive economy specific intermediate import good sectors.

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

$$\Pi_{i,j,n,t}^M + V_{i,j,n,t}^M = E_t \sum_{s=t}^{\infty} \frac{\beta^{s-t} \lambda_{i,s}^A}{\lambda_{i,t}^A} \Pi_{i,j,n,s}^M. \quad (104)$$

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

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

$$\Pi_{i,j,n,s}^M = P_{i,j,n,s}^M M_{i,j,n,s} - \mathcal{E}_{i,j,s} P_{j,s}^X M_{i,j,n,s} - F_{i,j,s}^M. \quad (105)$$

Earnings are defined as revenues derived from sales of economy specific differentiated intermediate import good  $M_{i,j,n,s}$  at price  $P_{i,j,n,s}^M$  less expenditures on foreign final export good  $M_{i,j,n,s}$ . The representative economy specific intermediate import good firm purchases the foreign final export good and differentiates it. Fixed cost  $F_{i,j,s}^M$  ensures that  $\Pi_{i,j,s}^M = 0$ .

In an extension of the model of nominal import price rigidity proposed by Monacelli (2005), 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  $\omega^M$  of intermediate import good firms adjust their price to account for past economy specific import price inflation, as well as contemporaneous changes in the domestic currency denominated prices of energy and nonenergy commodities, according to partial indexation rule

$$P_{i,j,n,t}^M = \left[ \left( \frac{P_{i,j,t-1}^M}{P_{i,j,t-2}^M} \right)^{1-\mu_i^M} \prod_{k=1}^{M^*} \left( \frac{\mathcal{E}_{i,j^*,t} P_{k,t}^Y}{\mathcal{E}_{i,j^*,t-1} P_{k,t-1}^Y} \right)^{\mu_{i,k}^M} \right]^{\gamma^M} \left[ \left( \frac{\bar{P}_{i,j,t-1}^M}{\bar{P}_{i,j,t-2}^M} \right)^{1-\mu_i^M} \prod_{k=1}^{M^*} \left( \frac{\bar{\mathcal{E}}_{i,j^*,t} \bar{P}_{k,t}^Y}{\bar{\mathcal{E}}_{i,j^*,t-1} \bar{P}_{k,t-1}^Y} \right)^{\mu_{i,k}^M} \right]^{1-\gamma^M} P_{i,j,n,t-1}^M, \quad (106)$$

where  $0 \leq \gamma^M \leq 1$ , while  $\mu_i^M = \sum_{k=1}^{M^*} \mu_{i,k}^M$  with  $\mu_{i,k}^M = \mu^M \frac{\bar{M}_{i,k,t}}{\bar{M}_{i,t}^M}$  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 (104) subject to economy specific intermediate import good demand function (102), and the assumed form of nominal import price rigidity. Since all intermediate import good firms that adjust their price optimally in period  $t$  solve an identical value maximization problem, in equilibrium they all choose a common price  $P_{i,j,t}^{M,*}$  given by necessary first order condition:

$$\frac{P_{i,j,t}^{M,*}}{P_{i,j,t}^M} = \frac{E_t \sum_{s=t}^{\infty} (\omega^M)^{s-t} \frac{\beta^{s-t} \lambda_{i,s}^A}{\lambda_{i,t}^A} \theta_{i,s}^M \mathcal{E}_{i,j,s}^M \frac{P_{i,j,s}^X}{P_{i,j,s}^M} \left\{ \left[ \left( \frac{P_{i,j,t-1}^M}{P_{i,j,s-1}^M} \right)^{1-\mu_k^M} \prod_{k=1}^{M^*} \left( \frac{\mathcal{E}_{i,j^*,t}^Y P_{k,t}^Y}{\mathcal{E}_{i,j^*,s}^Y P_{k,s}^Y} \right)^{\mu_k^M} \right]^{\gamma^M} \left[ \left( \frac{\bar{P}_{i,j,t-1}^M}{\bar{P}_{i,j,s-1}^M} \right)^{1-\mu_k^M} \prod_{k=1}^{M^*} \left( \frac{\bar{\mathcal{E}}_{i,j^*,t}^Y \bar{P}_{k,t}^Y}{\bar{\mathcal{E}}_{i,j^*,s}^Y \bar{P}_{k,s}^Y} \right)^{\mu_k^M} \right]^{1-\gamma^M} \frac{P_{i,j,s}^M}{P_{i,j,t}^M} \right\}^{\theta_{i,s}^M} \left( \frac{P_{i,j,t}^{M,*}}{P_{i,j,t}^M} \right)^{-\theta_{i,s}^M} P_{i,j,s}^M M_{i,j,s}}{E_t \sum_{s=t}^{\infty} (\omega^M)^{s-t} \frac{\beta^{s-t} \lambda_{i,s}^A}{\lambda_{i,t}^A} (\theta_{i,s}^M - 1) \left\{ \left[ \left( \frac{P_{i,j,t-1}^M}{P_{i,j,s-1}^M} \right)^{1-\mu_k^M} \prod_{k=1}^{M^*} \left( \frac{\mathcal{E}_{i,j^*,t}^Y P_{k,t}^Y}{\mathcal{E}_{i,j^*,s}^Y P_{k,s}^Y} \right)^{\mu_k^M} \right]^{\gamma^M} \left[ \left( \frac{\bar{P}_{i,j,t-1}^M}{\bar{P}_{i,j,s-1}^M} \right)^{1-\mu_k^M} \prod_{k=1}^{M^*} \left( \frac{\bar{\mathcal{E}}_{i,j^*,t}^Y \bar{P}_{k,t}^Y}{\bar{\mathcal{E}}_{i,j^*,s}^Y \bar{P}_{k,s}^Y} \right)^{\mu_k^M} \right]^{1-\gamma^M} \frac{P_{i,j,s}^M}{P_{i,j,t}^M} \right\}^{\theta_{i,s}^M - 1} \left( \frac{P_{i,j,t}^{M,*}}{P_{i,j,t}^M} \right)^{-\theta_{i,s}^M} P_{i,j,s}^M M_{i,j,s}}. \quad (107)$$

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 (103) 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  $\omega^M$  of intermediate import good firms that adjust their price according to partial indexation rule (106):

$$P_{i,j,t}^M = \left\{ (1 - \omega^M) (P_{i,j,t}^{M,*})^{1-\theta_{i,t}^M} + \omega^M \left\{ \left[ \left( \frac{P_{i,j,t-1}^M}{P_{i,j,t-2}^M} \right)^{1-\mu_k^M} \prod_{k=1}^{M^*} \left( \frac{\mathcal{E}_{i,j^*,t}^Y P_{k,t}^Y}{\mathcal{E}_{i,j^*,t-1}^Y P_{k,t-1}^Y} \right)^{\mu_k^M} \right]^{\gamma^M} \left[ \left( \frac{\bar{P}_{i,j,t-1}^M}{\bar{P}_{i,j,t-2}^M} \right)^{1-\mu_k^M} \prod_{k=1}^{M^*} \left( \frac{\bar{\mathcal{E}}_{i,j^*,t}^Y \bar{P}_{k,t}^Y}{\bar{\mathcal{E}}_{i,j^*,t-1}^Y \bar{P}_{k,t-1}^Y} \right)^{\mu_k^M} \right]^{1-\gamma^M} P_{i,j,t-1}^M \right\}^{1-\theta_{i,t}^M} \right\}^{\frac{1}{1-\theta_{i,t}^M}}. \quad (108)$$

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, as well as contemporaneous changes in the domestic currency denominated prices of energy and nonenergy commodities.

## F. Monetary, Fiscal, and Macroprudential Policy

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

$$i_{i,t}^P - \bar{i}_{i,t}^P = \rho_j^i (i_{i,t-1}^P - \bar{i}_{i,t-1}^P) + (1 - \rho_j^i) \left[ \xi_j^\pi E_t(\pi_{i,t+1}^C - \bar{\pi}_{i,t+1}^C) + \xi_j^Y (\ln Y_{i,t} - \ln \tilde{Y}_{i,t}) + \xi_j^{\Delta\mathcal{E}} (\Delta \ln \mathcal{E}_{i,t} - \Delta \ln \bar{\mathcal{E}}_{i,t}) \right. \\ \left. + \xi_j^i (i_{k,t}^S - \bar{i}_{k,t}^S) + \xi_j^\mathcal{E} (\ln \mathcal{E}_{i,k,t} - \ln \bar{\mathcal{E}}_{i,k,t}) \right] + v_{i,t}^{i^P}, \quad (109)$$

where  $0 \leq \rho_j^i < 1$ ,  $\xi_j^\pi \geq 0$ ,  $\xi_j^Y \geq 0$ ,  $\xi_j^{\Delta\mathcal{E}} \geq 0$ ,  $\xi_j^i \geq 0$  and  $\xi_j^\mathcal{E} \geq 0$ . 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 expected future deviation of consumption price inflation from its target value with  $\xi_j^\pi > 1$ , as well as the contemporaneous output gap with  $\xi_j^Y > 0$ . We define the output gap as the deviation of output from its potential value, which we define as that output level consistent with full utilization of physical capital and effective labor, given the physical capital stock and effective labor force. Under a managed exchange rate regime  $j = 1$ , and the desired deviation of the nominal policy interest rate from its steady state equilibrium value is also increasing in the contemporaneous deviation of the change in the nominal effective exchange rate from its steady state equilibrium value with  $\xi_j^{\Delta\mathcal{E}} > 0$ . 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 yield to maturity on short term bonds of 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 with  $\xi_j^\mathcal{E} > 0$ . For economies belonging to a monetary 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 rates applicable to corporate earnings and household labor income. It also operates a budget neutral lump sum transfer program which redistributes national financial wealth from capital market intermediated households to credit constrained households, while equalizing steady state equilibrium consumption across households. The fiscal authority 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 public and national financial wealth stabilization objectives.

Public consumption satisfies a countercyclical fiscal expenditure rule exhibiting partial adjustment dynamics of the form

$$\ln \frac{G_{i,t}}{\bar{G}_{i,t}} - \ln \frac{\tilde{Y}_{i,t}}{\bar{Y}_{i,t}} = \rho_G \left( \ln \frac{G_{i,t-1}}{\bar{G}_{i,t-1}} - \ln \frac{\tilde{Y}_{i,t-1}}{\bar{Y}_{i,t-1}} \right) + (1 - \rho_G) \zeta^G \left( \frac{A_{i,t+1}^G}{P_{i,t}^Y Y_{i,t}} - \frac{\bar{A}_{i,t+1}^G}{\bar{P}_{i,t}^Y \bar{Y}_{i,t}} \right) + v_{i,t}^G, \quad (110)$$

where  $0 \leq \rho_G < 1$  and  $\zeta^G > 0$ . As specified, the deviation of public consumption from its steady state equilibrium value, less the deviation of potential output from its steady state equilibrium value, depends on a weighted average of its past value and its desired value, 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 government expenditure shock  $v_{i,t}^G$ .

The tax rates applicable to corporate earnings and household labor income satisfy acyclical fiscal revenue rules exhibiting partial adjustment dynamics of the form

$$\tau_{i,t}^Z - \tau_i = \rho_\tau (\tau_{i,t-1}^Z - \tau_i) - (1 - \rho_\tau) \zeta^\tau \left( \frac{A_{i,t+1}^G}{P_{i,t}^Y Y_{i,t}} - \frac{\bar{A}_{i,t+1}^G}{\bar{P}_{i,t}^Y \bar{Y}_{i,t}} \right) + v_{i,t}^{\tau^Z}, \quad (111)$$

where  $Z \in \{K, L\}$ , while  $0 < \tau_i < 1$ ,  $0 \leq \rho_\tau < 1$  and  $\zeta^\tau > 0$ . As specified, the deviations of these tax rates from their steady state equilibrium value depend on a weighted average of their past deviations and their 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 these fiscal revenue rules are captured by mean zero and serially uncorrelated corporate and labor income tax rate shocks  $v_{i,t}^{\tau^Z}$ .

The real lump sum transfer payment to credit constrained households satisfies a transfer payment rule exhibiting partial adjustment dynamics of the form

$$\ln \frac{T_{i,t}^C}{P_{i,t}^C} - \ln \frac{\bar{T}_{i,t}^C}{\bar{P}_{i,t}^C} = \rho_T \left( \ln \frac{T_{i,t-1}^C}{P_{i,t-1}^C} - \ln \frac{\bar{T}_{i,t-1}^C}{\bar{P}_{i,t-1}^C} \right) + (1 - \rho_T) \zeta^T \left( \frac{A_{i,t+1}^G}{P_{i,t}^Y Y_{i,t}} - \frac{\bar{A}_{i,t+1}^G}{\bar{P}_{i,t}^Y \bar{Y}_{i,t}} \right), \quad (112)$$

where  $0 \leq \rho_T < 1$  and  $\zeta^T > 0$ . As specified, the deviation of the real transfer payment from its steady state equilibrium value depends on a weighted average of its past deviation and its desired deviation, which in turn is increasing in the contemporaneous deviation of the ratio of national financial wealth to nominal output from its target value. For economies belonging to a monetary union, the ratio of national financial wealth to nominal output is expressed as an output weighted average across union members.

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

$$1 + i_{i,t}^S = v_{i,t}^{i^S} (1 + i_{i,t}^P). \quad (113)$$

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

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  $B_{i,t}^{S,G}$  and long term bond  $B_{i,t}^{L,G}$  portfolios which yield returns  $i_{i,t-1}^S$  and  $i_{i,t}^{B^{L,G}}$ , respectively. It follows that  $(1+i_{i,t}^{A^G})A_{i,t}^G = (1+i_{i,t-1}^S)B_{i,t}^{S,G} + (1+i_{i,t}^{B^{L,G}})B_{i,t}^{L,G}$ , where  $(1+i_{i,t}^{B^{L,G}})B_{i,t}^{L,G} = \sum_{k=1}^{t-1} (\Pi_{i,k,t}^B + V_{i,k,t}^B)B_{i,k,t}^{L,G}$  with  $\Pi_{i,k,t}^B = (1+i_{i,k}^L - \omega^B)(\omega^B)^{t-k}V_{i,k,k}^B$  and  $V_{i,k,k}^B = 1$ . At the end of period  $t$ , the fiscal authority levies taxes on corporate earnings at rate  $\tau_{i,t}^K$  and household labor income at rate  $\tau_{i,t}^L$ , generating tax revenues  $T_{i,t}$ . It also remits household type specific lump sum transfer payments  $T_{i,t}^Z$ , where  $\int_0^1 T_{i,t}^Z dh = 0$ . These sources of public wealth are summed in government dynamic budget constraint:

$$A_{i,t+1}^G = (1+i_{i,t}^{A^G})A_{i,t}^G + \sum_{k=1}^M \int_0^1 \tau_{i,t}^K (P_{i,k,l,t}^Y Y_{i,k,l,t} - W_{i,t} L_{i,k,l,t}) dl + \int_0^1 \tau_{i,t}^L \int_0^1 W_{f,i,t} L_{h,f,i,t} df dh - P_{i,t}^G G_{i,t}. \quad (114)$$

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 across the values of domestic short term bond  $B_{i,t+1}^{S,G}$  and long term bond  $B_{i,t+1}^{L,G}$  portfolios, that is  $A_{i,t+1}^G = B_{i,t+1}^{S,G} + B_{i,t+1}^{L,G}$  where  $B_{i,t+1}^{L,G} = \sum_{k=1}^t V_{i,k,t}^B B_{i,k,t+1}^{L,G}$ . Finally, the fiscal authority purchases final public consumption good  $G_{i,t}$  at price  $P_{i,t}^G$ .

## The Macroprudential Authority

The macroprudential authority implements macroprudential policy through control of a regulatory capital requirement and loan to value ratio limits. It imposes the regulatory capital requirement on lending by domestic banks, and the regulatory loan to value ratio limits on borrowing by domestic developers and firms.

The regulatory capital ratio requirement applicable to lending by domestic banks to domestic and foreign developers and firms satisfies a countercyclical capital buffer rule exhibiting partial adjustment dynamics of the form

$$\begin{aligned} \kappa_{i,t+1}^R - \kappa^R &= \rho_\kappa (\kappa_{i,t}^R - \kappa^R) + (1 - \rho_\kappa) \left[ \zeta^{\kappa,B} (\Delta \ln B_{i,t+1}^{C,B} - \Delta \ln \bar{B}_{i,t+1}^{C,B}) + \zeta^{\kappa,V^H} (\Delta \ln V_{i,t}^H - \Delta \ln \bar{V}_{i,t}^H) \right. \\ &\quad \left. + \zeta^{\kappa,V^S} (\Delta \ln V_{i,t}^S - \Delta \ln \bar{V}_{i,t}^S) \right] + v_{i,t}^\kappa, \end{aligned} \quad (115)$$

where  $0 < \kappa^R < 1$ ,  $0 \leq \rho_\kappa < 1$ ,  $\zeta^{\kappa,B} > 0$ ,  $\zeta^{\kappa,V^H} > 0$  and  $\zeta^{\kappa,V^S} > 0$ . As specified, the deviation of the regulatory capital ratio requirement from its steady state equilibrium value depends on a weighted average of its past deviation and its desired deviation. This desired deviation is increasing in the contemporaneous deviation of bank credit growth from its steady state equilibrium value, as well as the contemporaneous deviations of the changes in the prices of housing and equity from their steady state equilibrium values. Deviations from this countercyclical capital buffer rule are captured by mean zero and serially uncorrelated capital requirement shock  $v_{i,t}^\kappa$ .

The regulatory loan to value ratio limits applicable to borrowing by domestic developers and firms from domestic and foreign banks satisfy loan to value limit rules exhibiting partial adjustment dynamics of the form

$$\phi_{i,t}^Z - \phi^Z = \rho_{\phi^Z} (\phi_{i,t-1}^Z - \phi^Z) - (1 - \rho_{\phi^Z}) \left[ \zeta^{\phi^Z, B} (\Delta \ln B_{i,t+1}^{C,Z} - \Delta \ln \bar{B}_{i,t+1}^{C,Z}) + \zeta^{\phi^Z, V} (\Delta \ln V_{i,t}^{f(Z)} - \Delta \ln \bar{V}_{i,t}^{f(Z)}) \right] + v_{i,t}^{\phi^Z}, \quad (116)$$

where  $Z \in \{D, F\}$ , while  $f(D) = H$  and  $f(F) = S$ . As specified, the deviations of the regulatory loan to value ratio limits from their steady state equilibrium values depend on a weighted average of their past deviations and their desired deviations, where  $0 < \phi^Z < 1$ ,  $0 \leq \rho_{\phi^Z} < 1$ ,  $\zeta^{\phi^Z, B} > 0$  and  $\zeta^{\phi^Z, V} > 0$ . These desired deviations are decreasing in the contemporaneous deviation of mortgage or nonfinancial corporate debt growth from its steady state equilibrium value, as well as the contemporaneous deviation of the change in the price of housing or equity from its steady state equilibrium value, respectively. Deviations from these loan to value limit rules are captured by mean zero and serially uncorrelated mortgage or corporate loan to value limit shocks  $v_{i,t}^{\phi^Z}$ .

The loan default rates applicable to borrowing by domestic developers and firms from domestic and foreign banks satisfy default rate relationships exhibiting partial adjustment dynamics of the form

$$\delta_{i,t}^Z - \delta = \rho_{\delta} (\delta_{i,t-1}^Z - \delta) - (1 - \rho_{\delta}) \left[ \zeta^{\delta^Z, Y} (\ln Y_{i,t} - \ln \tilde{Y}_{i,t}) + \zeta^{\delta^Z, V} (\Delta \ln V_{i,t}^{f(Z)} - \Delta \ln \bar{V}_{i,t}^{f(Z)}) \right] + v_{i,t}^{\delta^Z}, \quad (117)$$

where  $Z \in \{M, C\}$ , while  $f(M) = H$  and  $f(C) = S$ . As specified, the deviations of the mortgage or corporate loan default rates from their steady state equilibrium value depend on a weighted average of their past deviations and their attractor deviations, where  $0 < \delta < 1$ ,  $0 \leq \rho_{\delta} < 1$ ,  $\zeta^{\delta^Z, Y} > 0$  and  $\zeta^{\delta^Z, V} > 0$ . These attractor deviations are decreasing in the contemporaneous deviations of output from its potential value and the change in the price of housing or equity from its steady state equilibrium value, which affect the probability of default and loss given default, respectively. Deviations from these default rate relationships are captured by mean zero and serially uncorrelated mortgage or corporate loan default shocks  $v_{i,t}^{\delta^Z}$ .

## G. 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, developers, firms and banks 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, developers, firms and the government,



$$X_{i,t} = Y_{i,t} - C_{i,t}^h - I_{i,t}^{H,h} - I_{i,t}^{K,h} - G_{i,t}^h, \quad (118)$$

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, developers, firms and the government:

$$M_{i,t} = C_{i,t}^f + I_{i,t}^{H,f} + I_{i,t}^{K,f} + G_{i,t}^f. \quad (119)$$

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

$$P_{i,t}^Y Y_{i,t} = P_{i,t}^C C_{i,t} + P_{i,t}^I I_{i,t} + P_{i,t}^G G_{i,t} + P_{i,t}^X X_{i,t} - P_{i,t}^M M_{i,t}, \quad (120)$$

where the price of investment satisfies  $P_{i,t}^I = P_{i,t}^{I^H} = P_{i,t}^{I^K}$ , while investment satisfies  $I_{i,t} = I_{i,t}^H + I_{i,t}^K$ . 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  $D_{i,t} = C_{i,t} + I_{i,t} + G_{i,t}$ .

Clearing of the final bank loan markets requires that mortgage loan supply equals the total demand of domestic developers, that is  $B_{i,t+1}^{C^D,B} = B_{i,t+1}^{C,D}$ , while corporate loan supply equals the total demand of domestic and foreign firms:

$$B_{i,t+1}^{C^F,B} = \sum_{j=1}^N B_{j,i,t+1}^{C,F}. \quad (121)$$

In equilibrium, clearing of the final corporate loan payments system implies that the corporate credit loss rate satisfies:

$$1 - \delta_{i,t}^{C,E} = \sum_{j=1}^N \frac{B_{j,i,t}^{C,F}}{B_{i,t}^{C^F,B}} (1 - \delta_{j,t}^C). \quad (122)$$

The derivation of this result equates the principal and interest receipts of the banking sector to the total domestic currency denominated principal and interest payments of domestic and foreign firms.

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

$$A_{i,t+1} = A_{i,t+1}^H + A_{i,t+1}^D + A_{i,t+1}^F + A_{i,t+1}^B + A_{i,t+1}^G, \quad (123)$$

where  $A_{i,t+1}^H = A_{i,t+1}^{B,H} + A_{i,t+1}^{A,H} + V_{i,t}^C$ ,  $A_{i,t+1}^D = -B_{i,t+1}^{C,D} - V_{i,t}^H$ ,  $A_{i,t+1}^F = -B_{i,t+1}^{C,F} - V_{i,t}^S$  and  $A_{i,t+1}^B = K_{i,t+1}^B - V_{i,t}^C$ . Imposing equilibrium conditions on government dynamic budget constraint (114) 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  $PB_{i,t} = T_{i,t} - P_{i,t}^G G_{i,t}$ ,

$$FB_{i,t} = \left[ \frac{B_i^{S,G}}{A_i^G} i_{i,t-1}^S + \frac{B_i^{L,G}}{A_i^G} i_{i,t-1}^{L,E} \right] A_{i,t}^G + PB_{i,t}, \quad (124)$$

where  $T_{i,t} = \tau_{i,t}^K(P_{i,t}^Y Y_{i,t} - W_{i,t} L_{i,t}) + \tau_{i,t}^L W_{i,t} L_{i,t}$ , while nominal effective long term bond yield  $i_{i,t}^{L,E}$  satisfies  $i_{i,t}^{L,E} = \omega^B i_{i,t-1}^{L,E} + (1 - \omega^B) [\omega^B ((1 + i_{i,t}^L - \omega^B) + 1) - 1]$ . The derivation of this result abstracts from valuation gains on long term bond holdings, and imposes restrictions  $B_{i,k,t}^{L,G} = B_{i,k-1,t}^{L,G}$ ,  $B_{i,t}^{S,G} / A_{i,t}^G = B_{i,t}^{S,G} / A_{i,t}^G$  and  $B_{i,t}^{L,G} / A_{i,t}^G = B_{i,t}^{L,G} / A_{i,t}^G$ . Imposing equilibrium conditions on household dynamic budget constraint (7), and combining it with government dynamic budget constraint (124), developer dividend payment definition (41), firm dividend payment definition (55), bank dividend payment definition (76), bank balance sheet identity (77), output expenditure decomposition (120), and final corporate loan payments system clearing condition (122) 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  $TB_{i,t} = \mathcal{E}_{i^*,i,t} P_{i,t}^X X_{i,t} - \mathcal{E}_{i^*,i,t} P_{i,t}^M M_{i,t}$ :

$$CA_{i,t} = \left\{ \sum_{j=1}^N w_j^M \left[ (1 + i_{j,t-1}^S) \frac{\mathcal{E}_{i^*,j,t}}{\mathcal{E}_{i^*,j,t-1}} - 1 \right] \right\} \mathcal{E}_{i^*,i,t-1} A_{i,t} + TB_{i,t}. \quad (125)$$

The derivation of this result abstracts from international financial intermediation except via the money markets and imposes restriction  $\mathcal{E}_{i^*,j,t-1} B_{i,j,t}^S / A_{i,t}^M = w_j^M$ , where world money market capitalization weight  $w_i^M$  satisfies  $0 < w_i^M < 1$  and  $\sum_{i=1}^N w_i^M = 1$ . Multilateral consistency in nominal trade flows requires that  $\sum_{j=1}^N TB_{j,t} = 0$ .

### 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 analytically 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. The response coefficients of these consolidated approximate linear equilibrium conditions are functions of behavioral structural parameters that have been restricted to coincide across economies—occasionally within groups sharing a structural characteristic—and economy specific structural characteristics implied by steady state equilibrium relationships. Except where stated otherwise, this steady state equilibrium features zero inflation, productivity and labor force growth, as well as public and national financial wealth.<sup>2</sup>

In what follows,  $\hat{x}_{i,t}$  denotes the deviation of variable  $x_{i,t}$  from its steady state equilibrium value  $x_i$ , while  $E_t x_{i,t+s}$  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

<sup>2</sup> In steady state equilibrium  $\mathcal{A}_i = \nu_i^C = \nu_i^H = \nu_i^K = \nu_i^X = \nu_i^H = \nu_i^S = \nu_i^B = \nu_i^S = \nu_i^E = 1$ ,  $\nu_i^{\delta^M} = \nu_i^{\delta^C} = \nu_i^{\delta^P} = \nu_i^G = \nu_i^{\tau^K} = \nu_i^{\tau^L} = \nu_i^K = \nu_i^{\delta^D} = \nu_i^{\delta^F} = 0$ ,  $\nu_i^M = \frac{\theta^M}{\theta^M - 1}$ , and  $\sigma_{\mathcal{A}}^2 = \sigma_{\mathcal{N}}^2 = \sigma_{\nu^C}^2 = \sigma_{\nu^H}^2 = \sigma_{\nu^J}^2 = \sigma_{\nu^K}^2 = \sigma_{\nu^X}^2 = \sigma_{\nu^M}^2 = \sigma_{\nu^S}^2 = \sigma_{\nu^E}^2 = \sigma_{\nu^G}^2 = \sigma_{\nu^{\delta^C}}^2 = \sigma_{\nu^{\delta^P}}^2 = \sigma_{\nu^{\delta^D}}^2 = \sigma_{\nu^{\delta^F}}^2 = \sigma_{\nu^{\delta^M}}^2 = \sigma_{\nu^{\delta^S}}^2 = \sigma_{\nu^{\delta^T}}^2 = \sigma_{\nu^{\delta^U}}^2 = \sigma_{\nu^{\delta^V}}^2 = \sigma_{\nu^{\delta^W}}^2 = \sigma_{\nu^{\delta^X}}^2 = \sigma_{\nu^{\delta^Y}}^2 = \sigma_{\nu^{\delta^Z}}^2 = \sigma_{\nu^{\delta^{\theta^M}}^2} = \sigma_{\nu^{\delta^{\theta^N}}^2} = \sigma_{\nu^{\delta^{\theta^O}}^2} = \sigma_{\nu^{\delta^{\theta^P}}^2} = \sigma_{\nu^{\delta^{\theta^Q}}^2} = \sigma_{\nu^{\delta^{\theta^R}}^2} = \sigma_{\nu^{\delta^{\theta^S}}^2} = \sigma_{\nu^{\delta^{\theta^T}}^2} = \sigma_{\nu^{\delta^{\theta^U}}^2} = \sigma_{\nu^{\delta^{\theta^V}}^2} = \sigma_{\nu^{\delta^{\theta^W}}^2} = \sigma_{\nu^{\delta^{\theta^X}}^2} = \sigma_{\nu^{\delta^{\theta^Y}}^2} = \sigma_{\nu^{\delta^{\theta^Z}}^2} = 0$ .

$x_{i,t}$  across the trading partners of economy  $i$  are based on exports for  $Z = X$ , imports for  $Z = M$ , and their average for  $Z = T$ . In addition, bilateral weights  $w_{i,j}^Z$  for evaluating the weighted average of variable  $x_{i,t}$  across the lending destinations and borrowing sources of economy  $i$  are based on bank lending for  $Z = C$  and nonfinancial corporate borrowing for  $Z = F$ . Furthermore, bilateral weights  $w_{i,j}^Z$  for evaluating the portfolio weighted average of 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  $Z = S$ . Auxiliary parameters  $\lambda_j^Z$  are theoretically predicted to equal one, and satisfy  $\lambda = 0$  and  $\lambda_j^Z > 0$ .

### 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 and the internal terms of trade according to output price Phillips curve:

$$\begin{aligned} \hat{\pi}_{i,t}^Y &= \frac{\gamma^Y}{1 + \gamma^Y \beta} \hat{\pi}_{i,t-1}^Y + \frac{\beta}{1 + \gamma^Y \beta} E_t \hat{\pi}_{i,t+1}^Y \\ &+ \frac{(1 - \omega^Y)(1 - \omega^Y \beta)}{\omega^Y (1 + \gamma^Y \beta)} \left[ \ln \frac{\hat{W}_{i,t} \hat{L}_{i,t}}{\hat{P}_{i,t}^Y \hat{Y}_{i,t}} + \frac{X_i}{Y_i} \ln \hat{T}_{i,t}^X - \frac{1}{\theta^Y - 1} \ln \hat{\theta}_{i,t}^Y \right] + \frac{X_i}{Y_i} \mathcal{P}_1(L) \Delta \ln \hat{T}_{i,t}^X. \end{aligned} \quad (126)$$

Output price inflation also depends on contemporaneous, past and expected future changes in the internal terms of trade, where polynomial in the lag operator  $\mathcal{P}_1(L) = 1 - \frac{\gamma^Y}{1 + \gamma^Y \beta} L - \frac{\beta}{1 + \gamma^Y \beta} E_t L^{-1}$ . The response coefficients of this relationship vary across economies with their trade openness. Output price inflation satisfies  $\hat{\pi}_{i,t}^Y = \ln \hat{P}_{i,t}^Y - \ln \hat{P}_{i,t-1}^Y$ , which determines the output price level  $\ln \hat{P}_{i,t}^Y$ .

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 and the internal terms of trade according to consumption price Phillips curve:

$$\begin{aligned} \hat{\pi}_{i,t}^C &= \frac{\gamma^Y}{1 + \gamma^Y \beta} \hat{\pi}_{i,t-1}^C + \frac{\beta}{1 + \gamma^Y \beta} E_t \hat{\pi}_{i,t+1}^C \\ &+ \frac{(1 - \omega^Y)(1 - \omega^Y \beta)}{\omega^Y (1 + \gamma^Y \beta)} \left[ \ln \frac{\hat{W}_{i,t} \hat{L}_{i,t}}{\hat{P}_{i,t}^Y \hat{Y}_{i,t}} + \frac{X_i}{Y_i} \ln \hat{T}_{i,t}^X - \frac{1}{\theta^Y - 1} \ln \hat{\theta}_{i,t}^Y \right] + \frac{M_i}{Y_i} \mathcal{P}_1(L) \Delta \ln \hat{T}_{i,t}^M. \end{aligned} \quad (127)$$

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. Consumption price inflation satisfies  $\hat{\pi}_{i,t}^C = \ln \hat{P}_{i,t}^C - \ln \hat{P}_{i,t-1}^C$ , which determines the consumption price level  $\ln \hat{P}_{i,t}^C$ .

Output  $\ln \hat{Y}_{i,t}$  depends on contemporaneous domestic demand, exports and imports according to output demand relationship:

$$\ln \hat{Y}_{i,t} = \ln \hat{D}_{i,t} + \frac{X_i}{Y_i} \ln \frac{\hat{X}_{i,t}}{\hat{M}_{i,t}}. \quad (128)$$

Domestic demand  $\ln \hat{D}_{i,t}$  depends on a weighted average of contemporaneous consumption, investment and public domestic demand according to domestic demand relationship:

$$\ln \hat{D}_{i,t} = \frac{C_i}{Y_i} \ln \hat{C}_{i,t} + \frac{I_i}{Y_i} \ln \hat{I}_{i,t} + \frac{G_i}{Y_i} \ln \hat{G}_{i,t}. \quad (129)$$

Investment  $\ln \hat{I}_{i,t}$  depends on a weighted average of contemporaneous residential and business investment according to investment demand relationship:

$$\ln \hat{I}_{i,t} = \frac{I_i^H}{I_i} \ln \hat{I}_{i,t}^H + \frac{I_i^K}{I_i} \ln \hat{I}_{i,t}^K. \quad (130)$$

The response coefficients of these relationships vary across economies with the composition of their domestic demand or their trade openness.

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

$$\begin{aligned} \ln \hat{C}_{i,t} = & \frac{\alpha^C}{1 + \alpha^C} \ln \hat{C}_{i,t-1} + \frac{1}{1 + \alpha^C} E_t \ln \hat{C}_{i,t+1} \\ & - (1 - \phi^C) \sigma \frac{1 - \alpha^C}{1 + \alpha^C} E_t \left[ \frac{\phi^B}{1 - \phi^C} \hat{r}_{i,t+1}^{A^B,H} + \left( 1 - \frac{\phi^B}{1 - \phi^C} \right) \hat{r}_{i,t+1}^{A^A,H} - \ln \frac{\hat{v}_{i,t}^C}{\hat{v}_{i,t+1}^C} \right] + \phi^C \mathcal{P}_2(L) \ln \hat{C}_{i,t}. \end{aligned} \quad (131)$$

Reflecting the existence of credit constraints, consumption also depends on contemporaneous, past and expected future credit constrained consumption, where polynomial in the lag operator  $\mathcal{P}_2(L) = 1 - \frac{\alpha^C}{1 + \alpha^C} L - \frac{1}{1 + \alpha^C} E_t L^{-1}$ . Credit constrained consumption  $\ln \hat{C}_{i,t}^C$  depends on contemporaneous output and the terms of trade according to credit constrained consumption demand relationship

$$\begin{aligned} \ln \hat{C}_{i,t}^C = & \lambda_i^C \left( \frac{C_i}{Y_i} \right)^{-1} \left\{ (1 - \tau_i) \left\{ \ln \hat{Y}_{i,t} + \frac{X_i}{Y_i} (\ln \hat{T}_{i,t} - \lambda \ln \hat{v}_i^T) - \frac{1}{1 - \tau_i} \left[ \left( 1 - \frac{W_i L_i}{P_i^Y Y_i} \right) \hat{\tau}_{i,t}^K + \frac{W_i L_i}{P_i^Y Y_i} \hat{\tau}_{i,t}^L \right] \right\} \right. \\ & \left. + \lambda \left\{ \frac{M_i^S}{P_i^Y Y_i} \left[ \ln \frac{\hat{M}_{i,t+1}^S}{\hat{P}_{i,t}^C} - \frac{1}{\beta} \left( \hat{i}_{i,t-1}^S - \hat{\pi}_{i,t}^C \right) + \ln \frac{\hat{M}_{i,t}^S}{\hat{P}_{i,t-1}^C} \right] - \frac{I_i}{Y_i} \ln \hat{I}_{i,t} \right\} + \frac{1 - \beta}{\beta} \frac{M_i^S}{P_i^Y Y_i} \ln \frac{\hat{T}_{i,t}^C}{\hat{P}_{i,t}^C} \right\}, \end{aligned} \quad (132)$$

where economy specific auxiliary parameter  $\lambda_i^C = \frac{1}{1 - \tau_i} \frac{C_i}{Y_i}$ . Credit constrained consumption also depends on a weighted average of the contemporaneous corporate and labor income tax rates, as well as the contemporaneous real transfer payment to credit constrained households. The

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

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

$$\ln \hat{I}_{i,t}^H = \frac{1}{1+\beta} \ln \hat{I}_{i,t-1}^H + \frac{\beta}{1+\beta} E_t \ln \hat{I}_{i,t+1}^H + \frac{1}{\chi^H (1+\beta)} \ln \left( \hat{v}_{i,t}^H \frac{\hat{Q}_{i,t}^H}{\hat{P}_{i,t}^C} \right). \quad (133)$$

Reflecting the existence of a financial accelerator mechanism, the relative shadow price of housing depends on its expected future value, as well as the contemporaneous real property return and mortgage loan rate, according to residential investment Euler equation

$$\ln \frac{\hat{Q}_{i,t}^H}{\hat{P}_{i,t}^C} = E_t \left\{ \beta(1-\delta^H) \ln \frac{\hat{Q}_{i,t+1}^H}{\hat{P}_{i,t+1}^C} - \left[ (1-\phi^D) \left( \hat{r}_{i,t+1}^{A^H} + \frac{\hat{\phi}_{i,t}^D}{\phi^D} \right) + \phi^D \beta \frac{\theta^C}{\theta^C-1} \frac{1+\kappa^R(1-\beta(1-\chi^C\delta))}{\beta} \left( \hat{r}_{i,t}^M - \lambda \hat{\delta}_{i,t+1}^M + \lambda \frac{\hat{\phi}_{i,t}^D}{\phi^D} \right) \right] \right. \\ \left. + \left[ (1-\beta(1-\delta^H)) + \phi^D \beta \left( \frac{\theta^C}{\theta^C-1} \frac{1+\kappa^R(1-\beta(1-\chi^C\delta))}{\beta} - \frac{1}{\beta} \right) \right] \ln \frac{\hat{I}_{i,t+1}^H}{\hat{P}_{i,t+1}^C} \right\} + \frac{\hat{\phi}_{i,t}^D}{\phi^D}, \quad (134)$$

which determines the shadow price of housing  $\ln \hat{Q}_{i,t}^H$ . The relative shadow price of housing also depends on the expected future real rental price of housing and the contemporaneous regulatory mortgage loan to value ratio limit. The real rental price of housing depends on the deviation of contemporaneous consumption from the past housing stock according to rental price of housing function

$$\ln \frac{\hat{I}_{i,t}^H}{\hat{P}_{i,t}^C} = \frac{1}{\varsigma} \ln \frac{\hat{C}_{i,t}}{\hat{H}_{i,t}}, \quad (135)$$

which determines the rental price of housing  $\ln \hat{I}_{i,t}^H$ . The housing stock  $\ln \hat{H}_{i,t+1}$  is accumulated according to  $\ln \hat{H}_{i,t+1} = (1-\delta^H) \ln \hat{H}_{i,t} + \delta^H \ln(\hat{v}_{i,t}^H \hat{I}_{i,t}^H)$ .

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

$$\ln \hat{I}_{i,t}^K = \frac{1}{1+\beta} \ln \hat{I}_{i,t-1}^K + \frac{\beta}{1+\beta} E_t \ln \hat{I}_{i,t+1}^K + \frac{1}{\chi^K (1+\beta)} \ln \left( \hat{v}_{i,t}^K \frac{\hat{Q}_{i,t}^K}{\hat{P}_{i,t}^C} \right). \quad (136)$$

Reflecting the existence of a financial accelerator mechanism, the relative shadow price of physical capital depends on its expected future value, as well as the contemporaneous real portfolio return and effective corporate loan rate, according to business investment Euler equation

$$\ln \frac{\hat{Q}_{i,t}^K}{\hat{P}_{i,t}^C} = E_t \left\{ \beta(1-\delta^K) \ln \frac{\hat{Q}_{i,t+1}^K}{\hat{P}_{i,t+1}^C} - \left[ (1-\phi^F) \left( \hat{v}_{i,t+1}^{A^H} + \frac{\hat{\phi}_{i,t}^F}{\phi^F} \right) + \phi^F \beta \frac{\theta^C}{\theta^C-1} \frac{1+\kappa^R(1-\beta(1-\chi^C\delta))}{\beta} \left( \hat{v}_{i,t+1}^{C,E} - \lambda \hat{\delta}_{i,t+1}^C + \lambda \frac{\hat{\phi}_{i,t}^F}{\phi^F} \right) \right] \right. \\ \left. + \left[ (1-\beta(1-\delta^K)) + \phi^F \beta \left( \frac{\theta^C}{\theta^C-1} \frac{1+\kappa^R(1-\beta(1-\chi^C\delta))}{\beta} - \frac{1}{\beta} \right) \right] \left( \eta^K \ln \hat{u}_{i,t+1}^K - \frac{1}{1-\tau_i} \hat{z}_{i,t+1}^K \right) \right\} + \frac{\hat{\phi}_{i,t}^F}{\phi^F}, \quad (137)$$

which determines the shadow price of physical capital  $\ln \hat{Q}_{i,t}^K$ . The relative shadow price of physical capital also depends on the expected future capital utilization and corporate tax rates, as well as the contemporaneous regulatory corporate loan to value ratio limit. The capital utilization rate  $\ln \hat{u}_{i,t}^K$  depends on the contemporaneous real effective wage according to capital utilization relationship:

$$\ln \hat{u}_{i,t}^K = \frac{1}{\eta^K} \left( \ln \frac{\hat{W}_{i,t}}{\hat{P}_{i,t}^C \hat{A}_{i,t}} - \ln \frac{\hat{u}_{i,t}^K \hat{K}_{i,t}}{\hat{A}_{i,t} \hat{L}_{i,t}} \right). \quad (138)$$

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

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:

$$\ln \hat{X}_{i,t} = \sum_{j=1}^N w_{i,j}^X \left[ \ln \frac{\hat{D}_{j,t}}{\hat{v}_{i,t}^X \hat{V}_{j,t}^M} - \psi^M \left( 1 - \frac{M_j}{Y_j} \right) \ln \hat{T}_{j,t}^M \right]. \quad (139)$$

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:

$$\ln \hat{M}_{i,t} = \ln \frac{\hat{D}_{i,t}}{\hat{V}_{i,t}^M} - \psi^M \left( 1 - \frac{M_i}{Y_i} \right) \ln \hat{T}_{i,t}^M. \quad (140)$$

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

The nominal property return  $E_t \hat{i}_{i,t+1}^{A^B,H}$  depends on the contemporaneous nominal money market interest rate according to property return function:

$$E_t \hat{i}_{i,t+1}^{A^B,H} = \hat{i}_{i,t}^S + \phi^H \ln \hat{v}_{i,t}^H. \quad (141)$$

Reflecting the existence of a portfolio balance mechanism, the nominal property return also depends on the contemporaneous housing risk premium. The real property return  $E_t \hat{r}_{i,t+1}^{A^B,H}$  satisfies  $E_t \hat{r}_{i,t+1}^{A^B,H} = E_t \hat{i}_{i,t+1}^{A^B,H} - E_t \hat{\pi}_{i,t+1}^C$ .

The price of housing  $\ln \hat{V}_{i,t}^H$  depends on its expected future value driven by expected future developer profits, and the contemporaneous nominal money market interest rate adjusted by the housing risk premium, according to housing market relationship:

$$\ln \hat{V}_{i,t}^H = \beta E_t \ln \hat{V}_{i,t+1}^H + (1 - \beta) E_t \ln \hat{\Pi}_{i,t+1}^H - (\hat{i}_{i,t}^S + \ln \hat{v}_{i,t}^H). \quad (142)$$

Developer profits  $\ln \hat{\Pi}_{i,t}^H$  depend on contemporaneous housing rental revenues according to developer profit function

$$\begin{aligned} \ln \hat{\Pi}_{i,t}^H = & \lambda_i^H \left( \frac{\Pi_i^H}{P_i^Y Y_i} \right)^{-1} \left\{ \frac{t_i^H}{P_i^Y} \frac{H_i}{Y_i} \ln(\hat{t}_{i,t}^H \hat{H}_{i,t}^H) \right. \\ & \left. + \lambda \frac{B_i^{C,D}}{P_i^Y Y_i} \left[ \ln \hat{B}_{i,t+1}^{C,D} - (1 - \delta)(1 + i_i^M)(\hat{i}_{i,t-1}^M - \delta \hat{i}_{i,t}^M + \ln \hat{B}_{i,t}^{C,D}) \right] - \lambda \frac{I_i^H}{Y_i} \ln(\hat{P}_{i,t}^C \hat{I}_{i,t}^H) \right\}, \end{aligned} \quad (143)$$

where economy specific auxiliary parameter  $\lambda_i^H = \frac{\Pi_i^H}{P_i^Y Y_i} \left( \frac{t_i^H}{P_i^Y} \frac{H_i}{Y_i} \right)^{-1}$ .

The nominal portfolio return  $E_t \hat{i}_{i,t+1}^{A,H}$  depends on the contemporaneous nominal money market interest rate according to portfolio return function:

$$E_t \hat{i}_{i,t+1}^{A,H} = \hat{i}_{i,t}^S + \phi_B^A \sum_{j=1}^N w_{i,j}^B \left( \ln \hat{v}_{j,t}^B + \lambda \frac{1 - \phi_S^A}{\phi_B^A} \ln \frac{\hat{v}_{j,t}^\mathcal{E}}{\hat{v}_{i,t}^\mathcal{E}} \right) + \phi_S^A \sum_{j=1}^N w_{i,j}^S \left( \ln \hat{v}_{j,t}^S + \lambda \ln \frac{\hat{v}_{j,t}^\mathcal{E}}{\hat{v}_{i,t}^\mathcal{E}} \right). \quad (144)$$

Reflecting the existence of a portfolio balance mechanism, the nominal portfolio return also depends on contemporaneous domestic and foreign duration and equity risk premia. The response coefficients of this relationship vary across economies with their domestic and foreign bond and stock market exposures. The real portfolio return  $E_t \hat{r}_{i,t+1}^{A,H}$  satisfies

$$E_t \hat{r}_{i,t+1}^{A,H} = E_t \hat{i}_{i,t+1}^{A,H} - E_t \hat{\pi}_{i,t+1}^C.$$

The nominal money market interest rate  $\hat{i}_{i,t}^S$  depends on the contemporaneous nominal policy interest rate adjusted by the credit risk premium according to money market relationship:

$$\hat{i}_{i,t}^S = \hat{i}_{i,t}^P + \ln \hat{v}_{i,t}^S. \quad (145)$$

The real money market interest rate  $\hat{r}_{i,t}^S$  satisfies  $\hat{r}_{i,t}^S = \hat{i}_{i,t}^S - E_t \hat{\pi}_{i,t+1}^C$ . The credit risk premium  $\ln \hat{v}_{i,t}^S$  satisfies dynamic factor process  $\ln \hat{v}_{i,t}^S = \lambda_k^M \sum_{j=1}^N w_j^M \ln \hat{v}_{j,t}^S + (1 - \lambda_k^M w_i^M) \ln \hat{v}_{i,t}^S$ , except under a fixed exchange rate regime where  $\ln \hat{v}_{i,t}^S = \ln \hat{v}_{i,t}^*$ . The intensity of international money market contagion varies across economies, with  $k = 0$  for low debt contagion economies,  $k = 1$  for medium debt contagion economies, and  $k = 2$  for high debt contagion economies, where  $\lambda_0^M < \lambda_1^M < \lambda_2^M$ .

The nominal long term bond yield  $\hat{i}_{i,t}^L$  depends on its expected future value, driven by the contemporaneous nominal money market interest rate adjusted by the duration risk premium, according to bond market relationship:

$$\hat{i}_{i,t}^L = \omega^B \beta E_t \hat{i}_{i,t+1}^L + \frac{1 - \omega^B \beta}{\omega^B \beta} \left( \omega^B + \frac{1 - \omega^B \beta}{\omega^B \beta} \right)^{-1} (\hat{i}_{i,t}^S + \ln \hat{v}_{i,t}^B). \quad (146)$$

The real long term bond yield  $\hat{r}_{i,t}^L$  depends on its expected future value, driven by the contemporaneous real money market interest rate adjusted by the duration risk premium, according to:

$$\hat{r}_{i,t}^L = \omega^B \beta E_t \hat{r}_{i,t+1}^L + \frac{1 - \omega^B \beta}{\omega^B \beta} \left( \omega^B + \frac{1 - \omega^B \beta}{\omega^B \beta} \right)^{-1} (\hat{r}_{i,t}^S + \ln \hat{v}_{i,t}^B). \quad (147)$$

The term premium  $\ln \hat{\mu}_{i,t}^B$  depends on its expected future value driven by the contemporaneous duration risk premium according to:

$$\ln \hat{\mu}_{i,t}^B = \omega^B \beta E_t \ln \hat{\mu}_{i,t+1}^B + \frac{1 - \omega^B \beta}{\omega^B \beta} \left( \omega^B + \frac{1 - \omega^B \beta}{\omega^B \beta} \right)^{-1} \ln \hat{v}_{i,t}^B. \quad (148)$$

The duration risk premium  $\ln \hat{v}_{i,t}^B$  satisfies dynamic factor process  $\ln \hat{v}_{i,t}^B = \lambda_k^B \sum_{j=1}^N w_j^B \ln \hat{v}_{j,t}^B + (1 - \lambda_k^B w_i^B) \ln \hat{v}_{i,t}^B$ . The intensity of international bond market contagion varies across economies, with  $k = 0$  for low debt contagion economies,  $k = 1$  for medium debt contagion economies, and  $k = 2$  for high debt contagion economies, where  $\lambda_0^B < \lambda_1^B < \lambda_2^B$ .

The price of equity  $\ln \hat{V}_{i,t}^S$  depends on its expected future value driven by expected future nonfinancial corporate profits, and the contemporaneous nominal money market interest rate adjusted by the equity risk premium, according to stock market relationship:

$$\ln \hat{V}_{i,t}^S = \beta E_t \ln \hat{V}_{i,t+1}^S + (1 - \beta) E_t \ln \hat{\Pi}_{i,t+1}^S - (\hat{i}_{i,t}^S + \ln \hat{v}_{i,t}^S). \quad (149)$$

Nonfinancial corporate profits  $\ln \hat{\Pi}_{i,t}^S$  depend on contemporaneous nominal output and the corporate tax rate according to nonfinancial corporate profit function

$$\begin{aligned} \ln \hat{\Pi}_{i,t}^S = & \lambda_i^S \left( \frac{\Pi_i^S}{P_i^Y Y_i} \right)^{-1} \left\{ (1 - \tau_i) \left[ \ln(\hat{P}_{i,t}^Y \hat{Y}_{i,t}) - \lambda \frac{W_i L_i}{P_i^Y Y_i} \ln(\hat{W}_{i,t} \hat{L}_{i,t}) - \frac{1}{1 - \tau_i} \left( 1 - \frac{W_i L_i}{P_i^Y Y_i} \right) \hat{\tau}_{i,t}^K \right] \right. \\ & \left. + \lambda \frac{B_i^{C,F}}{P_i^Y Y_i} \left[ \ln \hat{B}_{i,t+1}^{C,F} - (1 - \delta)(1 + i_i^C)(\hat{i}_{i,t}^{C,E} - \hat{\delta}_{i,t}^C + \ln \hat{B}_{i,t}^{C,F}) \right] - \lambda \frac{I_i^K}{Y_i} \ln(\hat{P}_{i,t}^C \hat{I}_{i,t}^K) \right\}, \end{aligned} \quad (150)$$

where economy specific auxiliary parameter  $\lambda_i^S = \frac{1}{1 - \tau_i} \frac{\Pi_i^S}{P_i^Y Y_i}$ . The response coefficients of this relationship vary across economies with the size of their government and their labor income share.

The equity risk premium  $\ln \hat{v}_{i,t}^S$  satisfies dynamic factor process  $\ln \hat{v}_{i,t}^S = \lambda_k^S \sum_{j=1}^N w_j^S \ln \hat{v}_{j,t}^S + (1 - \lambda_k^S w_i^S) \ln \hat{v}_{i,t}^S$ . The intensity of international stock market contagion varies across economies, with  $k = 0$  for low equity contagion economies,  $k = 1$  for medium equity contagion economies, and  $k = 2$  for high equity contagion economies, where  $\lambda_0^S < \lambda_1^S < \lambda_2^S$ .

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:



$$\hat{i}_{i,t}^P = \rho^i \hat{i}_{i,t-1}^P + (1 - \rho^i) (\xi_j^\pi E_t \hat{\pi}_{i,t+1}^C + \xi_j^Y \ln \hat{Y}_{i,t} + \xi_j^{\Delta E} \Delta \ln \hat{\mathcal{E}}_{i,t} + \xi_j^i \hat{i}_{k,t}^S + \xi_j^E \ln \hat{\mathcal{E}}_{i,k,t}) + \hat{v}_{i,t}^P. \quad (151)$$

Under a flexible inflation targeting regime  $j = 0$ , and the desired nominal policy interest rate responds to expected future consumption price inflation and the contemporaneous output gap. Under a managed exchange rate regime  $j = 1$ , and it also responds to the contemporaneous change in the nominal effective exchange rate. Under a fixed exchange rate regime  $j = 2$ , and the nominal policy interest rate instead tracks the contemporaneous nominal money market interest rate of the economy that issues the anchor currency one for one, while responding to the contemporaneous corresponding nominal bilateral exchange rate. For economies belonging to a monetary 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  $\hat{r}_{i,t}^P = \hat{i}_{i,t}^P - E_t \hat{\pi}_{i,t+1}^C$ .

Bank credit depends on a weighted average of the contemporaneous money and bank capital stocks according to bank balance sheet identity

$$\ln \hat{B}_{i,t+1}^{C,B} = (1 - \kappa^R) \ln \hat{M}_{i,t+1}^S + \kappa^R \ln \hat{K}_{i,t+1}^B, \quad (152)$$

which determines the money stock  $\ln \hat{M}_{i,t+1}^S$ . Bank credit  $\ln \hat{B}_{i,t+1}^{C,B}$  depends on a weighted average of contemporaneous mortgage debt, and the bank lending weighted average of contemporaneous domestic currency denominated domestic and foreign nonfinancial corporate debt, according to bank credit demand function:

$$\ln \hat{B}_{i,t+1}^{C,B} = w_i^C \ln \hat{B}_{i,t+1}^{C,D} + (1 - w_i^C) \sum_{j=1}^N w_{i,j}^C \ln \frac{\hat{B}_{j,t+1}^{C,F}}{\hat{\mathcal{E}}_{j,t}}. \quad (153)$$

Mortgage debt  $\ln \hat{B}_{i,t+1}^{C,D}$  satisfies  $\ln \hat{B}_{i,t+1}^{C,D} = \ln \hat{P}_{i,t}^C + \ln \hat{H}_{i,t+1} + \frac{\hat{\phi}_{i,t}^D}{\phi^D}$ , while nonfinancial corporate debt  $\ln \hat{B}_{i,t+1}^{C,F}$  satisfies  $\ln \hat{B}_{i,t+1}^{C,F} = \ln \hat{P}_{i,t}^C + \ln \hat{K}_{i,t+1} + \frac{\hat{\phi}_{i,t}^F}{\phi^F}$ . The bank capital ratio  $\hat{\kappa}_{i,t+1}$  satisfies  $\hat{\kappa}_{i,t+1} = \kappa^R (\ln \hat{K}_{i,t+1}^B - \ln \hat{B}_{i,t+1}^{C,B})$ .

The nominal effective corporate loan rate  $\hat{i}_{i,t}^{C,E}$  depends on the nonfinancial corporate borrowing weighted average of past domestic and foreign nominal corporate loan rates, adjusted for contemporaneous changes in nominal bilateral exchange rates, according to effective corporate loan rate function:

$$\hat{i}_{i,t}^{C,E} = \sum_{j=1}^N w_{i,j}^F \left( \hat{i}_{j,t-1}^C + \ln \frac{\hat{\mathcal{E}}_{i,j,t}}{\hat{\mathcal{E}}_{i,j,t-1}} \right). \quad (154)$$

The corporate credit loss rate  $\hat{\delta}_{i,t}^{C,E}$  depends on the bank lending weighted average of contemporaneous domestic and foreign corporate loan default rates according to corporate credit loss rate function:

$$\hat{\delta}_{i,t}^{C,E} = \sum_{j=1}^N w_{i,j}^C \hat{\delta}_{j,t}^C. \quad (155)$$

The real effective corporate loan rate  $E_t \hat{r}_{i,t+1}^{C,E}$  satisfies  $E_t \hat{r}_{i,t+1}^{C,E} = E_t \hat{i}_{i,t+1}^{C,E} - E_t \hat{\pi}_{i,t+1}^C$ .

The nominal mortgage or corporate loan rate  $\hat{i}_{i,t}^{f(Z)}$  depends on a weighted average of its past and expected future values, driven by the deviation of the past nominal money market interest rate from the contemporaneous nominal mortgage or corporate loan rate net of the contemporaneous mortgage or corporate credit loss rate, according to lending rate Phillips curves

$$\hat{i}_{i,t}^{f(Z)} = \frac{1}{1+\beta} \hat{i}_{i,t-1}^{f(Z)} + \frac{\beta}{1+\beta} E_t \hat{i}_{i,t+1}^{f(Z)} + \frac{(1-\omega^C)(1-\omega^C\beta)}{\omega^C(1+\beta)} \left\{ \left[ \hat{i}_{i,t-1}^S - (\hat{i}_{i,t}^{f(Z)} - \hat{\delta}_{i,t}^{g(Z)}) \right] - \frac{1-\beta(1-\chi^C\delta)}{1+\kappa^R(1-\beta(1-\chi^C\delta))} \left[ \eta^C(\hat{\kappa}_{i,t} - \hat{\kappa}_{i,t}^R) - (\hat{\kappa}_{i,t}^R - \kappa^R \hat{i}_{i,t-1}^S) \right] - \frac{1}{\theta^C - 1} \ln \hat{\theta}_{i,t}^{CZ} \right\}, \quad (156)$$

where  $Z \in \{D, F\}$ , while  $f(D) = M$  and  $f(F) = C$ . The nominal mortgage or corporate loan rate also depends on the past deviation of the bank capital ratio from its required value, as well as the past deviation of the regulatory bank capital ratio requirement from its funding cost, where  $g(D) = M$  and  $g(F) = C, E$ . The real mortgage or corporate loan rate  $\hat{r}_{i,t}^{f(Z)}$  satisfies  $\hat{r}_{i,t}^{f(Z)} = \hat{i}_{i,t}^{f(Z)} - E_t \hat{\pi}_{i,t+1}^C$ .

Bank retained earnings  $\ln \hat{I}_{i,t}^B$  depends on a weighted average of its past and expected future values driven by the contemporaneous shadow price of bank capital according to retained earnings relationship:

$$\ln \hat{I}_{i,t}^B = \frac{1}{1+\beta} \ln \hat{I}_{i,t-1}^B + \frac{\beta}{1+\beta} E_t \ln \hat{I}_{i,t+1}^B + \frac{1}{\chi^B(1+\beta)} \ln \hat{Q}_{i,t}^B. \quad (157)$$

The shadow price of bank capital  $\ln \hat{Q}_{i,t}^B$  depends on its expected future value net of the expected future bank capital destruction rate, as well as the contemporaneous nominal money market interest rate, according to retained earnings Euler equation:

$$\ln \hat{Q}_{i,t}^B = E_t \left\{ \beta(1-\chi^C\delta)(\ln \hat{Q}_{i,t+1}^B - \hat{\delta}_{i,t+1}^B) - \left[ \hat{i}_{i,t+1}^S + (1-\beta(1-\chi^C\delta)) \frac{\eta^C}{\kappa^R} (\hat{\kappa}_{i,t+1} - \hat{\kappa}_{i,t+1}^R) \right] \right\}. \quad (158)$$

The shadow price of bank capital also depends on the contemporaneous deviation of the bank capital ratio from its required value. The bank capital stock  $\ln \hat{K}_{i,t+1}^B$  is accumulated according to  $\ln \hat{K}_{i,t+1}^B = (1-\chi^C\delta)(\ln \hat{K}_{i,t}^B - \hat{\delta}_{i,t}^B) + \chi^C\delta \ln \hat{I}_{i,t}^B$ , where the bank capital destruction rate  $\hat{\delta}_{i,t}^B$  satisfies  $\hat{\delta}_{i,t}^B = \chi^C(w_i^C \hat{\delta}_{i,t}^M + (1-w_i^C) \hat{\delta}_{i,t}^{C,E})$ .

The regulatory bank capital ratio requirement  $\hat{\kappa}_{i,t+1}^R$  depends on a weighted average of its past and desired values according to countercyclical capital buffer rule:

$$\hat{\kappa}_{i,t+1}^R = \rho_\kappa \hat{\kappa}_{i,t}^R + (1-\rho_\kappa) (\zeta^{\kappa,B} \Delta \ln \hat{B}_{i,t+1}^{C,B} + \zeta^{\kappa,V^H} \Delta \ln \hat{V}_{i,t}^H + \zeta^{\kappa,V^S} \Delta \ln \hat{V}_{i,t}^S) + \hat{v}_{i,t}^\kappa. \quad (159)$$

The desired regulatory bank capital ratio requirement responds to contemporaneous bank credit growth, as well as contemporaneous changes in the prices of housing and equity. The regulatory mortgage or corporate loan to value ratio limit  $\hat{\phi}_{i,t}^Z$  depends on a weighted average of its past and desired values according to loan to value limit rules

$$\hat{\phi}_{i,t}^Z = \rho_{\phi^Z} \hat{\phi}_{i,t-1}^Z - (1 - \rho_{\phi^Z}) (\zeta^{\phi^Z, B} \Delta \ln \hat{B}_{i,t+1}^{C,Z} + \zeta^{\phi^Z, Y} \Delta \ln \hat{V}_{i,t}^{f(Z)}) + \hat{v}_{i,t}^{\phi^Z}, \quad (160)$$

where  $Z \in \{D, F\}$ , while  $f(D) = H$  and  $f(F) = S$ . The desired regulatory mortgage or corporate loan to value ratio limit responds to contemporaneous mortgage or nonfinancial corporate debt growth, as well as the contemporaneous change in the price of housing or equity, respectively. The mortgage or corporate loan default rate  $\hat{\delta}_{i,t}^Z$  depends on a weighted average of its past and attractor values according to default rate relationships

$$\hat{\delta}_{i,t}^Z = \rho_{\delta} \hat{\delta}_{i,t-1}^Z - (1 - \rho_{\delta}) (\zeta^{\delta^Z, Y} \ln \hat{Y}_{i,t} + \zeta^{\delta^Z, V} \Delta \ln \hat{V}_{i,t}^{f(Z)}) + \hat{v}_{i,t}^{\delta^Z}, \quad (161)$$

where  $Z \in \{M, C\}$ , while  $f(M) = H$  and  $f(C) = S$ . The attractor loan default rate depends on the contemporaneous output gap, as well as the contemporaneous change in the price of housing or equity, respectively.

The real effective wage depends on a weighted average of its past and expected future values driven by the contemporaneous and past unemployment rates according to wage Phillips curve

$$\begin{aligned} \ln \frac{\hat{W}_{i,t}}{\hat{P}_{i,t}^C \hat{A}_{i,t}} &= \frac{1}{1 + \beta} \ln \frac{\hat{W}_{i,t-1}}{\hat{P}_{i,t-1}^C \hat{A}_{i,t-1}} + \frac{\beta}{1 + \beta} E_t \ln \frac{\hat{W}_{i,t+1}}{\hat{P}_{i,t+1}^C \hat{A}_{i,t+1}} \\ &\quad - \frac{(1 - \omega^L)(1 - \omega^L \beta)}{\omega^L (1 + \beta)} \left[ \frac{1}{\eta} \frac{1}{1 - \alpha^L} (\hat{u}_{i,t}^L - \alpha^L \hat{u}_{i,t-1}^L) + \frac{1}{\theta^L - 1} \ln \hat{\theta}_{i,t}^L \right] - \frac{1 + \gamma^L \beta}{1 + \beta} \mathcal{P}_3(L) \Delta \ln(\hat{P}_{i,t}^C \hat{A}_{i,t}), \end{aligned} \quad (162)$$

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

The unemployment rate depends on its past value driven by contemporaneous employment and the after tax real effective wage according to labor supply relationship

$$\hat{u}_{i,t}^L = \alpha^L \hat{u}_{i,t-1}^L - (1 - \alpha^L) \left[ \iota \ln \frac{\hat{L}_{i,t}}{\hat{N}_{i,t}} - \eta \left( \ln \frac{\hat{W}_{i,t}}{\hat{P}_{i,t}^C \hat{A}_{i,t}} - \frac{1}{1 - \tau_i} \hat{\tau}_{i,t}^L \right) \right], \quad (163)$$

which determines the labor force  $\ln \hat{N}_{i,t}$ . The response coefficients of this relationship vary across economies with the size of their government.

Output depends on the contemporaneous utilized physical capital stock and effective employment according to production function

$$\ln \hat{Y}_{i,t} = \left( 1 - \frac{\theta^Y}{\theta^Y - 1} \frac{W_i L_i}{P_i^Y Y_i} \right) \ln(\hat{u}_{i,t}^K \hat{K}_{i,t}) + \frac{\theta^Y}{\theta^Y - 1} \frac{W_i L_i}{P_i^Y Y_i} \ln(\hat{A}_{i,t} \hat{L}_{i,t}), \quad (164)$$

which determines employment  $\ln \hat{L}_{i,t}$ . The output gap  $\ln \hat{Y}_{i,t}$  satisfies  $\ln \hat{Y}_{i,t} = \ln \hat{Y}_{i,t} - \ln \hat{Y}_{i,t}$ , where potential output  $\ln \hat{Y}_{i,t}$  depends on the contemporaneous physical capital stock and effective labor force according to

$$\ln \hat{Y}_{i,t} = \left(1 - \frac{\theta^Y}{\theta^Y - 1} \frac{W_i L_i}{P_i^Y Y_i}\right) \ln \hat{K}_{i,t} + \frac{\theta^Y}{\theta^Y - 1} \frac{W_i L_i}{P_i^Y Y_i} \ln(\hat{\mathcal{A}}_{i,t} \hat{N}_{i,t}), \quad (165)$$

given that full utilization of physical capital and effective labor is defined by  $\ln \hat{u}_{i,t}^K = 0$  and  $\hat{u}_{i,t}^L = 0$ , respectively. It follows that the output gap depends on the contemporaneous capital utilization and unemployment rates according to:

$$\ln \hat{Y}_{i,t} = \left(1 - \frac{\theta^Y}{\theta^Y - 1} \frac{W_i L_i}{P_i^Y Y_i}\right) \ln \hat{u}_{i,t}^K - \frac{\theta^Y}{\theta^Y - 1} \frac{W_i L_i}{P_i^Y Y_i} \hat{u}_{i,t}^L. \quad (166)$$

The response coefficients of these relationships vary across economies with their labor income share.

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

$$\ln \hat{\mathcal{E}}_{i,j^*,t} = E_t \ln \hat{\mathcal{E}}_{i,j^*,t+1} - \left[ (\hat{i}_{i,t}^S - \ln \hat{v}_{i,t}^\varepsilon) - (\hat{i}_{j^*,t}^S - \ln \hat{v}_{j^*,t}^\varepsilon) \right]. \quad (167)$$

For economies belonging to a monetary union, the variables entering into their common foreign exchange market relationship are expressed as output weighted averages across union members, while under a fixed exchange rate regime  $\ln \hat{v}_{i,t}^\varepsilon = \ln \hat{v}_{k,t}^\varepsilon$ . The real bilateral exchange rate  $\ln \hat{Q}_{i,j^*,t}$  satisfies  $\ln \hat{Q}_{i,j^*,t} = \ln \hat{\mathcal{E}}_{i,j^*,t} + \ln \hat{P}_{i,t}^Y - \ln \hat{P}_{j^*,t}^Y$ , while the terms of trade  $\ln \hat{\mathcal{T}}_{i,t}$  satisfies  $\ln \hat{\mathcal{T}}_{i,t} = \ln \hat{v}_{i,t}^T + \ln \hat{\mathcal{T}}_{i,t}^X - \ln \hat{\mathcal{T}}_{i,t}^M$ .<sup>3</sup>

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

$$\begin{aligned} \Delta \ln \hat{\mathcal{T}}_{i,t}^X &= \lambda_1^T \left(1 - \frac{X_i}{Y_i} \sum_{k=1}^{M^*} \frac{X_{i,k}}{X_i}\right)^{-1} \sum_{k=1}^{M^*} \frac{X_{i,k}}{X_i} \Delta \ln \frac{\hat{\mathcal{E}}_{i,j^*,t} \hat{P}_{k,t}^Y}{\hat{P}_{i,t}^Y} \\ &\quad - \lambda_2^T \left[ \ln \hat{\mathcal{T}}_{i,t-1}^X - \lambda \left(1 - \frac{X_i}{Y_i} \sum_{k=1}^{M^*} \frac{X_{i,k}}{X_i}\right)^{-1} \sum_{k=1}^{M^*} \frac{X_{i,k}}{X_i} \ln \frac{\hat{\mathcal{E}}_{i,j^*,t-1} \hat{P}_{k,t-1}^Y}{\hat{P}_{i,t-1}^Y} \right]. \end{aligned} \quad (168)$$

The change in the internal terms of trade also depends on the past internal terms of trade. 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

<sup>3</sup> The nominal effective exchange rate  $\ln \hat{\mathcal{E}}_{i,t}$  satisfies  $\ln \hat{\mathcal{E}}_{i,t} = \ln \hat{\mathcal{E}}_{i,j^*,t} - \sum_{j=1}^N w_{i,j}^T \ln \hat{\mathcal{E}}_{j,i^*,t}$ , while the real effective exchange rate  $\ln \hat{Q}_{i,t}$  satisfies  $\ln \hat{Q}_{i,t} = \ln \hat{Q}_{i,j^*,t} - \sum_{j=1}^N w_{i,j}^T \ln \hat{Q}_{j,i^*,t}$ .

real bilateral exchange rate from the external terms of trade according to import price Phillips curve:

$$\begin{aligned} \Delta \ln \hat{T}_{i,t}^M &= \frac{\gamma^M (1 - \mu_i^M)}{1 + \gamma^M \beta (1 - \mu_i^M)} \Delta \ln \hat{T}_{i,t-1}^M + \frac{\beta}{1 + \gamma^M \beta (1 - \mu_i^M)} E_t \Delta \ln \hat{T}_{i,t+1}^M \\ &+ \frac{(1 - \omega^M)(1 - \omega^M \beta)}{\omega^M (1 + \gamma^M \beta (1 - \mu_i^M))} \left\{ \sum_{j=1}^N w_{i,j}^M \left[ \ln \frac{\hat{Q}_{i,j,t}}{\hat{T}_{i,t}^M} + \frac{X_i}{Y_i} \ln \hat{T}_{i,t}^X + \left( 1 - \frac{X_j}{Y_j} \right) \ln \hat{T}_{j,t}^X \right] - \frac{1}{\theta^M - 1} \ln \hat{\theta}_{i,t}^M \right\} \\ &- \mathcal{P}_4(L) \left( \hat{\pi}_{i,t}^Y - \frac{X_i}{Y_i} \Delta \ln \hat{T}_{i,t}^X \right) + \frac{\gamma^M (1 + \beta)}{1 + \gamma^M \beta (1 - \mu_i^M)} \mathcal{P}_5(L) \sum_{k=1}^{M^*} \mu_{i,k}^M \ln(\hat{\mathcal{E}}_{i,t^*,t} \hat{P}_{k,t}^Y). \end{aligned} \quad (169)$$

The change in the external terms of trade also depends on the contemporaneous domestic and import weighted average foreign internal terms of trade. Furthermore, 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

$\mathcal{P}_4(L) = 1 - \frac{\gamma^M (1 - \mu_i^M)}{1 + \gamma^M \beta (1 - \mu_i^M)} L - \frac{\beta}{1 + \gamma^M \beta (1 - \mu_i^M)} E_t L^{-1}$ . 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.

The deviation of public domestic demand from potential output depends on a weighted average of its past and desired values according to fiscal expenditure rule

$$\ln \hat{G}_{i,t} - \ln \hat{Y}_{i,t} = \rho_G (\ln \hat{G}_{i,t-1} - \ln \hat{Y}_{i,t-1}) + (1 - \rho_G) \zeta^G \frac{\hat{A}_{i,t+1}^G}{P_{i,t}^Y Y_{i,t}} + \hat{v}_{i,t}^G, \quad (170)$$

which determines public domestic demand  $\ln \hat{G}_{i,t}$ . Desired public domestic demand responds to the contemporaneous net government asset ratio. The corporate or labor income tax rate  $\hat{\tau}_{i,t}^Z$  depends on a weighted average of its past and desired values according to fiscal revenue rules

$$\hat{\tau}_{i,t}^Z = \rho_\tau \hat{\tau}_{i,t-1}^Z - (1 - \rho_\tau) \zeta^\tau \frac{\hat{A}_{i,t+1}^G}{P_{i,t}^Y Y_{i,t}} + \hat{v}_{i,t}^{\tau Z}, \quad (171)$$

where  $Z \in \{K, L\}$ . The desired corporate or labor income tax rate responds to the contemporaneous net government asset ratio. The real transfer payment to credit constrained households depends on a weighted average of its past and desired values according to transfer payment rule

$$\ln \frac{\hat{T}_{i,t}^C}{\hat{P}_{i,t}^C} = \rho_T \ln \frac{\hat{T}_{i,t-1}^C}{\hat{P}_{i,t-1}^C} + (1 - \rho_T) \zeta^T \frac{\hat{A}_{i,t+1}^G}{P_{i,t}^Y Y_{i,t}}, \quad (172)$$

which determines transfer payment  $\ln \hat{T}_{i,t}^C$ . The desired real transfer payment responds to the contemporaneous net foreign asset ratio. For economies belonging to a monetary union, the net foreign asset ratio is expressed as an output weighted average across union members.

The fiscal balance ratio  $\frac{\widehat{FB}_{i,t}}{P_i^Y Y_{i,t}}$  depends on the contemporaneous primary fiscal balance ratio, as well as a weighted average of the past nominal money market interest rate and nominal effective long term bond yield, and the past net government asset ratio adjusted by contemporaneous nominal output growth, according to government dynamic budget constraint:

$$\frac{\widehat{FB}_{i,t}}{P_i^Y Y_{i,t}} = \frac{1}{\beta} \frac{1}{1+g} \left[ \frac{A_i^G}{P_i^Y Y_i} \left( \frac{B_i^{S,G}}{A_i^G} \hat{i}_{i,t-1}^S + \frac{B_i^{L,G}}{A_i^G} \hat{i}_{i,t-1}^{L,E} \right) + (1-\beta) \left( \frac{\hat{A}_{i,t}^G}{P_{i,t-1}^Y Y_{i,t-1}} - \frac{A_i^G}{P_i^Y Y_i} \ln \frac{\hat{P}_{i,t}^Y \hat{Y}_{i,t}}{\hat{P}_{i,t-1}^Y \hat{Y}_{i,t-1}} \right) \right] + \frac{\widehat{PB}_{i,t}}{P_{i,t-1}^Y Y_{i,t-1}}. \quad (173)$$

The nominal effective long term bond yield  $\hat{i}_{i,t}^{L,E}$  depends on its past value driven by the contemporaneous nominal long term bond yield according to:

$$\hat{i}_{i,t}^{L,E} = \omega^B \hat{i}_{i,t-1}^{L,E} + \omega^B \beta (1 - \omega^B) \left( \omega^B + \frac{1 - \omega^B \beta}{\omega^B \beta} \right) \hat{i}_{i,t}^L. \quad (174)$$

Furthermore, the primary fiscal balance ratio  $\frac{\widehat{PB}_{i,t}}{P_i^Y Y_{i,t}}$  depends on the contemporaneous deviations of tax revenues from nominal output and of public domestic demand from output, as well as the contemporaneous terms of trade, according to:

$$\frac{\widehat{PB}_{i,t}}{P_i^Y Y_{i,t}} = \frac{G_i}{Y_i} \left[ \ln \frac{\hat{T}_{i,t}}{\hat{P}_{i,t}^Y \hat{Y}_{i,t}} - \left( \ln \frac{\hat{G}_{i,t}}{\hat{Y}_{i,t}} - \frac{X_i}{Y_i} (\ln \hat{\mathcal{T}}_{i,t} - \lambda \ln \hat{\mathcal{U}}_i^T) \right) \right]. \quad (175)$$

The deviation of tax revenues from nominal output depends on a weighted average of the contemporaneous corporate and labor income tax rates according to

$$\ln \frac{\hat{T}_{i,t}}{\hat{P}_{i,t}^Y \hat{Y}_{i,t}} = \frac{1}{\tau_i} \left[ \left( 1 - \frac{W_i L_i}{P_i^Y Y_i} \right) \hat{\tau}_{i,t}^K + \frac{W_i L_i}{P_i^Y Y_i} \hat{\tau}_{i,t}^L \right], \quad (176)$$

which determines tax revenues  $\ln \hat{T}_{i,t}$ . Finally, the net government asset ratio  $\frac{\hat{A}_{i,t+1}^G}{P_{i,t}^Y Y_{i,t}}$  depends on its past value adjusted by contemporaneous nominal output growth, as well as the contemporaneous fiscal balance ratio, according to:

$$\frac{\hat{A}_{i,t+1}^G}{P_{i,t}^Y Y_{i,t}} = \frac{1}{1+g} \left( \frac{\hat{A}_{i,t}^G}{P_{i,t-1}^Y Y_{i,t-1}} - \frac{A_i^G}{P_i^Y Y_i} \ln \frac{\hat{P}_{i,t}^Y \hat{Y}_{i,t}}{\hat{P}_{i,t-1}^Y \hat{Y}_{i,t-1}} \right) + \frac{\widehat{FB}_{i,t}}{P_{i,t}^Y Y_{i,t}}. \quad (177)$$

The linearization of these relationships assumes nominal output growth at rate  $g$  in steady state equilibrium. Their response coefficients vary across economies with the size of their government, their trade openness, their labor income share, and the size and composition of their public financial wealth.

The current account balance ratio  $\frac{\widehat{CA}_{i,t}}{\mathcal{E}_{i^*,j,t} P_i^Y Y_{i,t}}$  depends on the contemporaneous trade balance ratio, as well as the contemporaneous quotation currency denominated world money market portfolio return, and the past net foreign asset ratio adjusted by contemporaneous world nominal output growth, according to national dynamic budget constraint:

$$\frac{\widehat{CA}_{i,t}}{\mathcal{E}_{i^*,j,t} P_i^Y Y_{i,t}} = \frac{1}{\beta} \frac{1}{1+g} \left[ \frac{A_i}{P_i^Y Y_i} \sum_{j=1}^N w_j^M \left( \hat{i}_{j,t-1}^S + \ln \frac{\hat{\mathcal{E}}_{i^*,j,t}}{\hat{\mathcal{E}}_{i^*,j,t-1}} \right) + (1-\beta) \left( \frac{\hat{A}_{i,t}}{P_{i,t-1}^Y Y_{i,t-1}} - \frac{A_i}{P_i^Y Y_i} \ln \frac{\hat{P}_{i,t}^Y \hat{Y}_{i,t}}{\hat{P}_{i,t-1}^Y \hat{Y}_{i,t-1}} \right) \right] + \frac{\widehat{TB}_{i,t}}{\mathcal{E}_{i^*,j,t} P_{i,t-1}^Y Y_{i,t-1}}. \quad (178)$$

Furthermore, the trade balance ratio  $\frac{\widehat{TB}_{i,t}}{\mathcal{E}_{i^*,i,t} P_{i,t}^Y Y_{i,t}}$  depends on the contemporaneous deviation of exports from imports, as well as the contemporaneous terms of trade, according to:

$$\frac{\widehat{TB}_{i,t}}{\mathcal{E}_{i^*,i,t} P_{i,t}^Y Y_{i,t}} = \frac{X_i}{Y_i} \left[ \ln \frac{\widehat{X}_{i,t}}{\widehat{M}_{i,t}} + (\ln \widehat{\mathcal{T}}_{i,t} - \lambda \ln \widehat{\nu}_i^T) \right]. \quad (179)$$

Finally, the net foreign asset ratio  $\frac{\widehat{A}_{i,t+1}}{P_{i,t}^Y Y_{i,t}}$  depends on its past value adjusted by contemporaneous world nominal output growth, as well as the contemporaneous current account balance ratio, according to:

$$\frac{\widehat{A}_{i,t+1}}{P_{i,t}^Y Y_{i,t}} = \frac{1}{1+g} \left( \frac{\widehat{A}_{i,t}}{P_{i,t-1}^Y Y_{i,t-1}} - \frac{A_i}{P_i^Y Y_i} \ln \frac{\widehat{P}_t^Y \widehat{Y}_t}{\widehat{P}_{t-1}^Y \widehat{Y}_{t-1}} \right) + \frac{\widehat{CA}_{i,t}}{\mathcal{E}_{i^*,i,t} P_{i,t}^Y Y_{i,t}}. \quad (180)$$

Multilateral consistency in nominal trade flows requires that the world output weighted average trade balance ratio equals zero,

$$\sum_{j=1}^N w_j^Y \frac{\widehat{TB}_{j,t}}{\mathcal{E}_{i^*,j,t} P_{j,t}^Y Y_{j,t}} = 0, \quad (181)$$

which determines the endogenous terms of trade shifter  $\ln \widehat{\nu}_i^T$ . It follows that the world output weighted average current account balance and net foreign asset ratios also equal zero. The linearization of these relationships assumes nominal output growth at rate  $g$  in steady state equilibrium. Their response coefficients vary across economies with their trade openness and national financial wealth.

The price of energy or nonenergy commodities  $\ln \widehat{P}_{k,t}^Y$  depends on a weighted average of its past and expected future values driven by the contemporaneous world output weighted average labor income share and relative domestic currency denominated price of commodities according to commodity price Phillips curves:

$$\begin{aligned} \ln \widehat{P}_{k,t}^Y &= \frac{1}{1+\beta} \ln \widehat{P}_{k,t-1}^Y + \frac{\beta}{1+\beta} E_t \ln \widehat{P}_{k,t+1}^Y \\ &+ \frac{(1-\omega_k^Y)(1-\omega_k^Y \beta)}{\omega_k^Y (1+\beta)} \sum_{i=1}^N w_i^Y \left[ \ln \frac{\widehat{W}_{i,t} \widehat{L}_{i,t}}{\widehat{P}_{i,t}^Y \widehat{Y}_{i,t}} - \lambda_3^T \ln \frac{\widehat{\mathcal{E}}_{i^*,i,t} \widehat{P}_{k,t}^Y}{\widehat{P}_{i,t}^Y} - \frac{1}{\theta^Y - 1} \ln \widehat{\theta}_{k,t}^Y \right] - \mathcal{P}_5(L) \sum_{i=1}^N w_i^Y \ln \widehat{\mathcal{E}}_{i^*,i,t}. \end{aligned} \quad (182)$$

The price of energy or nonenergy commodities also depends on the contemporaneous, past and expected future world output weighted average nominal bilateral exchange rate, where polynomial in the lag operator  $\mathcal{P}_5(L) = 1 - \frac{1}{1+\beta} L - \frac{\beta}{1+\beta} E_t L^{-1}$ . The response coefficients of this relationship vary across commodity markets  $1 \leq k \leq M^*$ , with  $k=1$  for energy commodities and  $k=2$  for nonenergy commodities.

## B. Exogenous Variables

The productivity  $\ln \widehat{A}_{i,t}$  and labor supply  $\ln \widehat{N}_{i,t}$  shocks follow stationary first order autoregressive processes with normally distributed innovations:

$$\ln \hat{A}_{i,t} = \rho_A \ln \hat{A}_{i,t-1} + \varepsilon_{i,t}^A, \quad \varepsilon_{i,t}^A \sim \text{iid } \mathcal{N}(0, \sigma_A^2), \quad (183)$$

$$\ln \hat{N}_{i,t} = \rho_N \ln \hat{N}_{i,t-1} + \varepsilon_{i,t}^N, \quad \varepsilon_{i,t}^N \sim \text{iid } \mathcal{N}(0, \sigma_N^2). \quad (184)$$

In addition, the consumption demand  $\ln \hat{v}_{i,t}^C$ , residential investment demand  $\ln \hat{v}_{i,t}^{I^H}$ , business investment demand  $\ln \hat{v}_{i,t}^{I^K}$ , export demand  $\ln \hat{v}_{i,t}^X$ , and import demand  $\ln \hat{v}_{i,t}^M$  shocks follow stationary first order autoregressive processes with normally distributed innovations:

$$\ln \hat{v}_{i,t}^C = \rho_{v^C} \ln \hat{v}_{i,t-1}^C + \varepsilon_{i,t}^{v^C}, \quad \varepsilon_{i,t}^{v^C} \sim \text{iid } \mathcal{N}(0, \sigma_{v^C}^2), \quad (185)$$

$$\ln \hat{v}_{i,t}^{I^H} = \rho_{v^I} \ln \hat{v}_{i,t-1}^{I^H} + \varepsilon_{i,t}^{v^{I,H}}, \quad \varepsilon_{i,t}^{v^{I,H}} \sim \text{iid } \mathcal{N}(0, \sigma_{v^I}^2), \quad (186)$$

$$\ln \hat{v}_{i,t}^{I^K} = \rho_{v^I} \ln \hat{v}_{i,t-1}^{I^K} + \varepsilon_{i,t}^{v^{I,K}}, \quad \varepsilon_{i,t}^{v^{I,K}} \sim \text{iid } \mathcal{N}(0, \sigma_{v^I}^2), \quad (187)$$

$$\ln \hat{v}_{i,t}^X = \rho_{v^X} \ln \hat{v}_{i,t-1}^X + \varepsilon_{i,t}^{v^X}, \quad \varepsilon_{i,t}^{v^X} \sim \text{iid } \mathcal{N}(0, \sigma_{v^X}^2), \quad (188)$$

$$\ln \hat{v}_{i,t}^M = \rho_{v^M} \ln \hat{v}_{i,t-1}^M + \varepsilon_{i,t}^{v^M}, \quad \varepsilon_{i,t}^{v^M} \sim \text{iid } \mathcal{N}(0, \sigma_{v^M}^2). \quad (189)$$

The output price markup  $\ln \hat{\theta}_{i,t}^Y$ , wage markup  $\ln \hat{\theta}_{i,t}^L$ , import price markup  $\ln \hat{\theta}_{i,t}^M$ , and energy or nonenergy commodity price markup  $\ln \hat{\theta}_{k,t}^Y$  shocks follow normally distributed white noise processes:

$$\ln \hat{\theta}_{i,t}^Y = \varepsilon_{i,t}^{\theta^Y}, \quad \varepsilon_{i,t}^{\theta^Y} \sim \text{iid } \mathcal{N}(0, \sigma_{\theta^Y}^2), \quad (190)$$

$$\ln \hat{\theta}_{i,t}^L = \varepsilon_{i,t}^{\theta^L}, \quad \varepsilon_{i,t}^{\theta^L} \sim \text{iid } \mathcal{N}(0, \sigma_{\theta^L}^2), \quad (191)$$

$$\ln \hat{\theta}_{i,t}^M = \varepsilon_{i,t}^{\theta^M}, \quad \varepsilon_{i,t}^{\theta^M} \sim \text{iid } \mathcal{N}(0, \sigma_{\theta^M}^2), \quad (192)$$

$$\ln \hat{\theta}_{k,t}^Y = \varepsilon_{k,t}^{\theta^Y}, \quad \varepsilon_{k,t}^{\theta^Y} \sim \text{iid } \mathcal{N}(0, \sigma_{\theta^Y,k}^2). \quad (193)$$

Furthermore, the housing risk premium  $\ln \hat{v}_{i,t}^H$ , credit risk premium  $\ln \hat{v}_{i,t}^{i^S}$ , duration risk premium  $\ln \hat{v}_{i,t}^B$ , equity risk premium  $\ln \hat{v}_{i,t}^S$ , and currency risk premium  $\ln \hat{v}_{i,t}^\varepsilon$  shocks follow stationary first order autoregressive processes with normally distributed innovations:

$$\ln \hat{v}_{i,t}^H = \rho_{v^H} \ln \hat{v}_{i,t-1}^H + \varepsilon_{i,t}^{v^H}, \quad \varepsilon_{i,t}^{v^H} \sim \text{iid } \mathcal{N}(0, \sigma_{v^H}^2), \quad (194)$$

$$\ln \hat{v}_{i,t}^{i^S} = \rho_{v^{i,S}} \ln \hat{v}_{i,t-1}^{i^S} + \varepsilon_{i,t}^{v^{i,S}}, \quad \varepsilon_{i,t}^{v^{i,S}} \sim \text{iid } \mathcal{N}(0, \sigma_{v^{i,S}}^2), \quad (195)$$

$$\ln \hat{v}_{i,t}^B = \rho_{v^B} \ln \hat{v}_{i,t-1}^B + \varepsilon_{i,t}^{v^B}, \quad \varepsilon_{i,t}^{v^B} \sim \text{iid } \mathcal{N}(0, \sigma_{v^B}^2), \quad (196)$$

$$\ln \hat{v}_{i,t}^S = \rho_{v^S} \ln \hat{v}_{i,t-1}^S + \varepsilon_{i,t}^{v^S}, \quad \varepsilon_{i,t}^{v^S} \sim \text{iid } \mathcal{N}(0, \sigma_{v^S}^2), \quad (197)$$

$$\ln \hat{v}_{i,t}^\varepsilon = \rho_{v^\varepsilon} \ln \hat{v}_{i,t-1}^\varepsilon + \varepsilon_{i,t}^{v^\varepsilon}, \quad \varepsilon_{i,t}^{v^\varepsilon} \sim \text{iid } \mathcal{N}(0, \sigma_{v^\varepsilon}^2). \quad (198)$$

The mortgage loan rate markup  $\ln \hat{\theta}_{i,t}^{C^D}$ , corporate loan rate markup  $\ln \hat{\theta}_{i,t}^{C^F}$  and capital requirement  $\hat{v}_{i,t}^K$  shocks follow stationary first order autoregressive processes with normally distributed innovations, while the mortgage loan default  $\hat{v}_{i,t}^{\delta^M}$  and corporate loan default  $\hat{v}_{i,t}^{\delta^C}$  shocks follow normally distributed white noise processes:



$$\ln \hat{\theta}_{i,t}^{C^D} = \rho_{\theta^c} \ln \hat{\theta}_{i,t}^{C^D} + \varepsilon_{i,t}^{\theta^{c,D}}, \quad \varepsilon_{i,t}^{\theta^{c,D}} \sim \text{iid } \mathcal{N}(0, \sigma_{\theta^c}^2), \quad (199)$$

$$\ln \hat{\theta}_{i,t}^{C^F} = \rho_{\theta^c} \ln \hat{\theta}_{i,t}^{C^F} + \varepsilon_{i,t}^{\theta^{c,F}}, \quad \varepsilon_{i,t}^{\theta^{c,F}} \sim \text{iid } \mathcal{N}(0, \sigma_{\theta^c}^2), \quad (200)$$

$$\hat{v}_{i,t}^{\kappa} = \rho_{v^{\kappa}} \hat{v}_{i,t-1}^{\kappa} + \varepsilon_{i,t}^{v^{\kappa}}, \quad \varepsilon_{i,t}^{v^{\kappa}} \sim \text{iid } \mathcal{N}(0, \sigma_{v^{\kappa}}^2), \quad (201)$$

$$\hat{v}_{i,t}^{\delta^M} = \varepsilon_{i,t}^{v^{\delta,M}}, \quad \varepsilon_{i,t}^{v^{\delta,M}} \sim \text{iid } \mathcal{N}(0, \sigma_{v^{\delta}}^2), \quad (202)$$

$$\hat{v}_{i,t}^{\delta^C} = \varepsilon_{i,t}^{v^{\delta,C}}, \quad \varepsilon_{i,t}^{v^{\delta,C}} \sim \text{iid } \mathcal{N}(0, \sigma_{v^{\delta}}^2). \quad (203)$$

Finally, the monetary policy  $\hat{v}_{i,t}^{i^P}$ , government expenditure  $\hat{v}_{i,t}^G$ , corporate tax rate  $\hat{v}_{i,t}^{\tau^K}$ , labor income tax rate  $\hat{v}_{i,t}^{\tau^L}$ , mortgage loan to value limit  $\hat{v}_{i,t}^{\phi^D}$ , and corporate loan to value limit  $\hat{v}_{i,t}^{\phi^F}$  shocks follow normally distributed white noise processes:

$$\hat{v}_{i,t}^{i^P} = \varepsilon_{i,t}^{v^{i,P}}, \quad \varepsilon_{i,t}^{v^{i,P}} \sim \text{iid } \mathcal{N}(0, \sigma_{v^{i,P}}^2), \quad (204)$$

$$\hat{v}_{i,t}^G = \varepsilon_{i,t}^{v^G}, \quad \varepsilon_{i,t}^{v^G} \sim \text{iid } \mathcal{N}(0, \sigma_{v^G}^2), \quad (205)$$

$$\hat{v}_{i,t}^{\tau^K} = \varepsilon_{i,t}^{v^{\tau,K}}, \quad \varepsilon_{i,t}^{v^{\tau,K}} \sim \text{iid } \mathcal{N}(0, \sigma_{v^{\tau}}^2), \quad (206)$$

$$\hat{v}_{i,t}^{\tau^L} = \varepsilon_{i,t}^{v^{\tau,L}}, \quad \varepsilon_{i,t}^{v^{\tau,L}} \sim \text{iid } \mathcal{N}(0, \sigma_{v^{\tau}}^2), \quad (207)$$

$$\hat{v}_{i,t}^{\phi^D} = \varepsilon_{i,t}^{v^{\phi,D}}, \quad \varepsilon_{i,t}^{v^{\phi,D}} \sim \text{iid } \mathcal{N}(0, \sigma_{v^{\phi}}^2), \quad (208)$$

$$\hat{v}_{i,t}^{\phi^F} = \varepsilon_{i,t}^{v^{\phi,F}}, \quad \varepsilon_{i,t}^{v^{\phi,F}} \sim \text{iid } \mathcal{N}(0, \sigma_{v^{\phi}}^2). \quad (209)$$

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 a linear state space representation of an approximate multivariate linear rational expectations representation of our 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 maximum likelihood estimation procedure which respects this traditional econometric interpretation while conditioning on prior information concerning the generally 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.

In what follows, we generally employ a restricted approximate multivariate linear rational expectations representation of our panel dynamic stochastic general equilibrium model, which consolidates or eliminates those exogenous variables that are weakly identified by our multivariate panel data set. In particular, the residential and business investment demand shocks

are consolidated into an investment demand shock, while the corporate and labor income tax rate shocks are consolidated into a tax rate shock. Furthermore, the mortgage and corporate loan rate markup, mortgage and corporate loan default, capital requirement, and mortgage and corporate loan to value limit shocks are eliminated. The exception is impulse response analysis, which is based on the unrestricted approximate multivariate linear rational expectations representation of our panel dynamic stochastic general equilibrium model, as this does not depend on its innovation covariance matrix.

### **A. Data Transformations**

Estimation of the structural parameters of our panel dynamic stochastic general equilibrium model is based on the estimated cyclical components of a total of 659 endogenous variables observed for forty economies over the sample period 1999Q1 through 2016Q1. 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 nominal money market interest rate, the nominal long term bond yield, the price of housing, the price of equity, the nominal bilateral exchange rate, 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. For a detailed description of this multivariate panel data set, refer to Appendix A.

We estimate the cyclical components of all of the observed endogenous variables under consideration with the generalization of the filter described in Hodrick and Prescott (1997) due to Vitek (2014), which parameterizes the difference order associated with the penalty term determining the smoothness of the trend component. For those variables that exhibit long run growth, namely 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 housing, the price of equity, the nominal bilateral exchange rate, the nominal wage, employment, the quantity of public domestic demand, and the prices of nonrenewable energy and nonenergy commodities, we set the difference order to two and the smoothing parameter to 16,000. In contrast, for those variables that do not exhibit long run growth, namely the nominal policy interest rate, the nominal money market interest rate, the nominal long term bond yield, the unemployment rate, and the fiscal balance ratio, we set the difference order to one and the smoothing parameter to 400.

## B. Parameter Estimates

We estimate the structural parameters of a linear state space representation of the restricted approximate multivariate linear rational expectations representation of our panel dynamic stochastic general equilibrium model by Bayesian maximum likelihood, conditional on prior information concerning their generally common values across economies. Inference on these parameters is based on an asymptotic normal approximation to the posterior distribution around its mode, which is calculated by numerically maximizing the logarithm of the posterior density kernel with a customized implementation of the differential evolution algorithm due to Storn and Price (1997). We assume a multivariate normal prior distribution, which implies that the mode of the posterior distribution equals its mean. For a detailed discussion of this estimation procedure, refer to Vitek (2014).

The marginal prior distributions of 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 Euro Area, Japan, Mexico, Norway, Poland, Sweden, the United Kingdom and the United States, by a managed exchange rate regime in Argentina, Brazil, China, Colombia, the Czech Republic, India, Indonesia, Israel, Korea, Malaysia, New Zealand, the Philippines, Russia, South Africa, Switzerland, Thailand and Turkey, and by a fixed exchange rate regime in Denmark and Saudi Arabia, consistent with the de facto classification in IMF (2015). The high debt contagion economies are Argentina, Brazil, Colombia, Indonesia, Mexico, the Philippines, Poland, Russia, South Africa, Thailand and Turkey, while the low debt contagion economies are Chile, China, India and Malaysia. The high equity contagion economies are Argentina, Brazil, Colombia, India, Indonesia, Mexico, the Philippines, Poland, Russia, South Africa, Thailand and Turkey, while the low equity contagion economies are Chile, China and Malaysia. The quotation currency for transactions in the foreign exchange market is issued by the United States. All macroeconomic and financial great ratios are calibrated to match either their observed values, or the average of their observed values and their medians across economies, in 2014. All bilateral trade, bank lending, nonfinancial corporate borrowing, portfolio debt investment, and portfolio equity investment weights are calibrated to match their observed values in 2014, normalized to sum to one across economies.

Parameter estimation results based on effective sample period 1999Q3 through 2016Q1 are reported in Table 1 and Table 2 of Appendix B. The posterior means of most parameters are close to their prior means, reflecting the imposition of tight priors to preserve empirically plausible impulse responses. Nevertheless, the data are quite informative regarding some of these parameters, as evidenced by substantial updates from prior to posterior, which collectively result in substantial updates to impulse responses.

### C. Output Gap Estimates

Within the framework of our estimated panel dynamic stochastic general equilibrium model, the output gap is a business cycle indicator. Smoothed estimates of the output gap, conditional on full sample information and decomposed into contributions from capital versus labor utilization, are plotted in Figure 1 of Appendix B.

Our output gap estimates indicate a gradual global business cycle expansion during the build up to the Global Financial Crisis, synchronized across advanced and emerging economies. During the Global Financial Crisis, they indicate an abrupt synchronized global business cycle contraction, concentrated in those advanced economies at its epicenter. During the Euro Area Sovereign Debt Crisis, they indicate further protracted business cycle contractions in the Euro Area periphery. Our output gap estimates generally indicate that business cycle dynamics have since diverged across advanced and emerging economies, with the former experiencing sluggish business cycle expansions and the latter contractions. They generally primarily attribute these business cycle dynamics to fluctuations in labor utilization in advanced economies—where labor income shares are higher and unemployment rates more variable—versus fluctuations in capital utilization in emerging economies.

## V. INFERENCE

We analyze the interaction between macrofinancial developments in the world economy, and the systematic and unsystematic components of monetary, fiscal and macroprudential policy, within the framework of our estimated panel dynamic stochastic general equilibrium model. In particular, we estimate dynamic macrofinancial interrelationships, conditional on a variety of domestic and foreign structural shocks, with impulse responses. We also identify the time varying contributions of sets of these structural shocks to the evolution of inflation and output growth with historical decompositions.

### A. Impulse Responses

Impulse responses quantify the dynamic effects of selected structural shocks on endogenous variables. The estimated impulse responses of a variety of endogenous variables to a range of temporary structural shocks are plotted in Figure 2 through Figure 44 of Appendix B. In what follows, we discuss key dynamic macrofinancial interrelationships exhibited by these impulse responses, emphasizing patterns that emerge in general across economies, occasionally within groups sharing a structural characteristic. The macroeconomic shocks under consideration are domestic and foreign productivity, labor supply, consumption demand, and residential and business investment demand shocks. The financial shocks under consideration are domestic and foreign credit risk premium, duration risk premium, housing risk premium, equity risk premium, mortgage and corporate loan rate markup, and mortgage and corporate loan default shocks. The

policy shocks under consideration are domestic and foreign monetary policy, government expenditure, corporate and labor income tax rate, capital requirement, and mortgage and corporate loan to value limit shocks. Finally, the terms of trade shocks under consideration are currency risk premium, and energy and nonenergy commodity price markup shocks.

### **Macroeconomic Shocks**

The macroeconomic shocks under consideration shift either aggregate supply or demand. The aggregate supply shifters are productivity and labor supply shocks, while the aggregate demand shifters are consumption, residential investment and business investment demand shocks.

In response to a productivity or labor supply shock that increases aggregate supply, output rises less than potential. It follows that the output gap falls and the unemployment rate rises, associated with lower price and wage inflation. The monetary authority cuts the nominal policy interest rate to stimulate aggregate demand and inflation, transmitted via reductions in capital market and bank lending interest rates to varying degrees. This depreciates the currency in nominal and real effective terms, deteriorating the terms of trade. The money stock and bank credit rise. If the aggregate supply expansion is caused by a productivity shock then employment falls reflecting higher labor productivity, whereas if it is caused by a labor supply shock then employment rises given a higher labor force. The fiscal balance ratio falls in spite of higher tax revenues reflecting higher public domestic demand, but the net government debt ratio falls given higher potential output. The current account balance ratio also falls reflecting the deterioration in the terms of trade and higher imports, reducing the net foreign asset ratio. This rise in imports is reflected in higher exports and output in the rest of the world.

In response to a consumption, residential investment or business investment demand shock that increases aggregate demand, output rises more than potential. It follows that the output gap rises and the unemployment rate falls, associated with higher price and wage inflation. The monetary authority raises the nominal policy interest rate to control aggregate demand and inflation, transmitted via increases in capital market and bank lending interest rates to varying degrees. This appreciates the currency in nominal and real effective terms, improving the terms of trade. The money stock and bank credit rise, as does employment. The fiscal balance ratio increases reflecting higher tax revenues, reducing the net government debt ratio, but the current account balance ratio falls given higher imports, reducing the net foreign asset ratio. This rise in imports is reflected in higher exports and output in the rest of the world.

### **Financial Shocks**

The financial shocks under consideration shift either capital market interest rates, asset prices, or bank lending interest rates. The capital market interest rate shifters are credit and duration risk premium shocks, while the asset price shifters are housing and equity risk premium shocks, and

the bank lending interest rate shifters are mortgage and corporate loan rate markup and default shocks.

A credit risk premium shock that increases the nominal money market interest rate, or a duration risk premium shock that raises the nominal long term bond yield, reduces all of the components of private domestic demand reflecting tighter financial conditions, in particular residential and business investment. The resultant aggregate demand contraction reduces output more than potential, and the output gap falls while the unemployment rate rises, associated with lower price and wage inflation. In particular, a one percentage point credit risk premium induced nominal money market interest rate increase generates a 0.5 percent median peak output loss, while a one percentage point nominal long term bond yield increase caused by a duration risk premium shock induces a 0.4 percent median peak output loss. The monetary authority cuts the nominal policy interest rate to stimulate aggregate demand and inflation, but the money stock and bank credit fall, as does employment. The fiscal balance ratio falls reflecting lower tax revenues and higher debt service costs, raising the net government debt ratio. But the current account balance ratio increases given lower imports, raising the net foreign asset ratio. This fall in imports is reflected in lower exports and output in the rest of the world. In the case of a credit risk premium shock international money market contagion increases nominal money market interest rates, while for a duration risk premium shock international bond market contagion increases nominal long term bond yields, to varying degrees across recipient economies, also reducing private domestic demand and output.

In response to a housing risk premium shock that increases the price of housing, or an equity risk premium shock that raises the price of equity, private domestic demand rises, reflecting looser financial conditions. In particular, consumption and residential investment increase in response to the housing risk premium shock, while all of the components of private domestic demand rise in response to the equity risk premium shock. The resultant aggregate demand expansion increases output more than potential, and the output gap rises while the unemployment rate falls, associated with higher price and wage inflation. In particular, a ten percent housing risk premium induced house price increase generates a 0.7 percent median peak output gain, while a ten percent equity price increase caused by an equity risk premium shock induces a 0.2 percent median peak output gain. The monetary authority raises the nominal policy interest rate to control aggregate demand and inflation, transmitted via increases in capital market and bank lending interest rates to varying degrees. It follows that the currency appreciates in nominal and real effective terms, improving the terms of trade. The bank capital ratio rises, reflecting lower mortgage and corporate loan default rates, as does employment. The fiscal balance ratio rises reflecting higher tax revenues, reducing the net government debt ratio, but the current account balance ratio falls given higher imports, reducing the net foreign asset ratio. This rise in imports is reflected in higher exports and output in the rest of the world. In the case of an equity risk premium shock, international stock market contagion increases equity prices to varying degrees in recipient economies, also raising private domestic demand and output.

A mortgage or corporate loan rate markup shock that increases the nominal mortgage or corporate loan rate, or a mortgage or corporate loan default shock that does so by raising the mortgage or corporate loan default rate, reduces private domestic demand reflecting tighter financial conditions. In particular, consumption and residential investment decline in response to the mortgage loan rate markup shock, while consumption and business investment fall in response to the corporate loan rate markup shock, and all of the components of private domestic demand fall in response to the mortgage or corporate loan default shock. The resultant aggregate demand contraction reduces output more than potential, and the output gap falls while the unemployment rate rises, associated with lower price and wage inflation. The monetary authority cuts the nominal policy interest rate to stimulate aggregate demand and inflation, mitigating the increase in the nominal mortgage or corporate loan rate. It follows that the currency depreciates in nominal and real effective terms, deteriorating the terms of trade. In the case of a mortgage or corporate loan rate markup shock, the money stock and bank credit decline, while for a mortgage or corporate loan default shock, the bank capital ratio falls reflecting higher mortgage and corporate loan default rates. In all cases, employment falls. The fiscal balance ratio falls reflecting lower tax revenues, raising the net government debt ratio, but the current account balance ratio increases given lower imports, raising the net foreign asset ratio. This fall in imports is reflected in lower exports and output in the rest of the world. In the case of a corporate loan rate markup or default shock, the nominal effective corporate loan rate rises to varying degrees in recipient economies given international nonfinancial corporate borrowing, also reducing private domestic demand and output.

### **Policy Shocks**

The policy shocks under consideration propagate via either the monetary, fiscal, or macroprudential transmission mechanisms. The fiscal policy shocks under consideration are government expenditure, as well as corporate and labor income tax rate shocks. The macroprudential policy shocks under consideration are capital requirement, as well as mortgage and corporate loan to value limit shocks.

A monetary policy shock that increases the nominal policy interest rate raises capital market and bank lending interest rates to varying degrees. This reduces all of the components of private domestic demand reflecting tighter financial conditions, in particular residential and business investment. It follows that the currency appreciates in nominal and real effective terms, improving the terms of trade. This reduces exports through expenditure switching, in spite of which imports fall together with private domestic demand. The resultant aggregate demand contraction reduces output more than potential, and the output gap falls while the unemployment rate rises, associated with lower price and wage inflation. In particular, a one percentage point increase in the nominal policy interest rate induced by a monetary policy shock generates a 0.5 percent median peak output loss. The money stock and bank credit fall, as does employment. The fiscal balance ratio falls reflecting lower tax revenues and higher debt service costs, raising the net government debt ratio. But the current account balance ratio increases given the

improvement in the terms of trade and lower imports, raising the net foreign asset ratio. This fall in imports is reflected in lower exports and output in the rest of the world.

In response to a government expenditure or corporate or labor income tax rate shock that increases the primary fiscal balance ratio, output falls more than potential. It follows that the output gap falls and the unemployment rate rises, associated with lower price and wage inflation. In particular, a one percentage point increase in the primary fiscal balance ratio generates a median peak output loss of 1.0 percent if caused by a government expenditure shock, of 0.4 percent if caused by a corporate tax rate shock, and of 0.4 percent if caused by a labor income tax rate shock. The monetary authority cuts the nominal policy interest rate to stimulate aggregate demand and inflation, transmitted via reductions in capital market and bank lending interest rates to varying degrees. This depreciates the currency in nominal and real effective terms, deteriorating the terms of trade. In the case of a government expenditure shock, the money stock and bank credit rise as investment is crowded in, while in all cases employment falls. The increase in the fiscal balance ratio reduces the net government debt ratio, while the current account balance ratio also increases given lower imports, raising the net foreign asset ratio. This fall in imports is reflected in lower exports and output in the rest of the world.

A capital requirement shock that increases the bank capital ratio requirement, or a mortgage or corporate loan to value limit shock that reduces the mortgage or corporate loan to value ratio limit, reduces private domestic demand reflecting tighter effective financial conditions. In particular, all of the components of private domestic demand decline in response to the capital requirement shock, while consumption and residential investment fall in response to the mortgage loan to value limit shock, and consumption and business investment fall in response to the corporate loan to value limit shock. The resultant aggregate demand contraction reduces output more than potential, and the output gap falls while the unemployment rate rises, associated with lower price and wage inflation. The monetary authority cuts the nominal policy interest rate to stimulate aggregate demand and inflation, mitigating the increases in bank lending interest rates necessary to raise the bank capital ratio in the case of the capital requirement shock, and reducing capital market interest rates to varying degrees in all cases. It follows that the currency depreciates in nominal and real effective terms, deteriorating the terms of trade. The money stock and bank credit fall, as does employment. The fiscal balance ratio falls reflecting lower tax revenues, raising the net government debt ratio, but the current account balance ratio increases given lower imports, raising the net foreign asset ratio. This fall in imports is reflected in lower exports and output in the rest of the world. In the case of a capital requirement shock, the nominal effective corporate loan rate rises to varying degrees in recipient economies given international nonfinancial corporate borrowing, also reducing private domestic demand and output.



## Terms of Trade Shocks

The terms of trade shocks under consideration shift the terms of trade. The currency risk premium shock primarily shifts the external terms of trade, while the energy and nonenergy commodity price markup shocks primarily shift the internal terms of trade for net commodity exporters versus the external terms of trade for net commodity importers.

A currency risk premium shock that depreciates the currency in nominal and real effective terms deteriorates the terms of trade, increasing exports and reducing imports through expenditure switching. But the depreciation of the currency in nominal effective terms also raises the nominal effective corporate loan rate given international nonfinancial corporate borrowing, reducing private domestic demand. This mitigates the resultant aggregate demand expansion, which raises output more than potential. It follows that the output gap rises and the unemployment rate falls, associated with higher price and wage inflation, amplified and accelerated by exchange rate pass through. In particular, a ten percent depreciation of the currency in nominal effective terms induced by a currency risk premium shock generates a 0.4 percent median peak output gain. The monetary authority raises the nominal policy interest rate to control aggregate demand and inflation, transmitted via increases in capital market and bank lending interest rates to varying degrees. The money stock and bank credit rise, as does employment. The fiscal balance ratio increases reflecting higher tax revenues, reducing the net government debt ratio, while the current account balance ratio also rises given higher exports and lower imports, raising the net foreign asset ratio.

In response to an energy or nonenergy commodity price markup shock that increases the price of energy or nonenergy commodities, net commodity exporters experience a terms of trade improvement, whereas net commodity importers experience a terms of trade deterioration, respectively by commodity type. Consumption price inflation increases reflecting the rise in the external terms of trade, while output price inflation increases by more for net commodity exporters given the rise in the internal terms of trade. Private domestic demand increases for net commodity exporters, reflecting rises in consumption and residential investment given the improvement in the terms of trade, and vice versa for net commodity importers. The resultant aggregate demand expansion for net commodity exporters increases output more than potential, and the output gap rises while the unemployment rate falls, and vice versa for net commodity importers. The monetary authority raises the nominal policy interest rate to control inflation, by more for net commodity exporters to also control aggregate demand, transmitted via increases in capital market and bank lending interest rates to varying degrees. It follows that the currency appreciates in nominal and real effective terms for net commodity exporters, whereas it depreciates for net commodity importers. The money stock and bank credit increase, while employment rises for net commodity exporters and falls for net commodity importers. The fiscal balance ratio increases for net commodity exporters reflecting higher tax revenues, reducing the net government debt ratio, and vice versa for net commodity importers. The current account balance ratio also increases for net commodity exporters given the improvement in the terms of trade, raising the net foreign asset ratio, and vice versa for net commodity importers.

## **B. Historical Decompositions**

Historical decompositions quantify the time varying contributions of sets of structural shocks to the evolution of endogenous variables. The estimated historical decompositions of consumption price inflation and output growth are plotted in Figure 45 and Figure 46 of Appendix B. The sets of structural shocks under consideration are domestic and foreign macroeconomic, financial and policy shocks, as well as world terms of trade shocks.

Our estimated historical decompositions of inflation attribute deviations from trend rates primarily to economy specific combinations of domestic and foreign macroeconomic and financial shocks, as well as world terms of trade shocks. The contribution of domestic relative to foreign shocks is generally decreasing across economies with their trade openness and increasing with their monetary policy autonomy. Our estimated historical decompositions of output growth attribute business cycle dynamics around trend growth rates primarily to economy specific combinations of domestic and foreign macroeconomic and financial shocks. These business cycle fluctuations have generally been amplified by financial shocks and mitigated by policy shocks.

During the build up to the Global Financial Crisis, macroeconomic and financial shocks caused a gradual synchronized global business cycle expansion, reflected in a synchronized global rise in inflation generally amplified by world terms of trade shocks. During the Global Financial Crisis, adverse macroeconomic and financial shocks caused an abrupt synchronized global business cycle contraction—reflected in a synchronized global fall in inflation generally amplified by world terms of trade shocks—mitigated by countercyclical unsystematic policy interventions. In the aftermath of the Global Financial Crisis, macroeconomic and financial shocks contributed to a synchronized global business cycle recovery. In the Euro Area periphery, this recovery was derailed by adverse financial shocks. More recently, macroeconomic and financial shocks have contributed to sluggish business cycle expansions in many advanced economies versus contractions in many emerging economies.

## **VI. 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 47 through Figure 49 of Appendix B.

We measure the dynamic forecasting performance of our estimated panel dynamic stochastic general equilibrium model relative to that of a driftless random walk over holdout sample period 2005Q2 through 2016Q1 at the one through eight quarter horizons on the basis of the logarithm

of the  $U$  statistic due to Theil (1966), which equals the ratio of root mean squared prediction errors. 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 27 percent lower for inflation and 34 percent lower for output growth, on average across economies and horizons.

Sequential unconditional forecasts of inflation and output growth indicate that our estimated panel dynamic stochastic general equilibrium model is capable of predicting business cycle turning points. Indeed, these sequential unconditional forecasts indicate that a synchronized global business cycle moderation was overdue by the time of the Global Financial Crisis. Moreover, the model predicted the severity of this abrupt synchronized global business cycle contraction fairly accurately for most economies as it unfolded.

## VII. CONCLUSION

This paper develops a structural macroeconomic model of the world economy, disaggregated into forty national economies, to facilitate multilaterally consistent macrofinancial policy, risk and spillover analysis. This panel dynamic stochastic general equilibrium model features a range of nominal and real rigidities, extensive macrofinancial linkages, and diverse spillover transmission channels. These macrofinancial linkages encompass bank and capital market based financial intermediation, with financial accelerator mechanisms linked to the values of the housing and physical capital stocks. A variety of monetary policy analysis, fiscal policy analysis, macroprudential policy analysis, spillover analysis, and forecasting applications of the estimated model are demonstrated. These include quantifying the monetary, fiscal and macroprudential transmission mechanisms with impulse responses, 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. Its macrofinancial linkages could be extended by disaggregating the bond market into sovereign versus corporate submarkets, while its international trade, financial and commodity price linkages could be refined. These extensions and refinements remain plans for future model development.

## Appendix A. Data Description

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 2016Q1. 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, or from databases produced by Bloomberg and the Bank for International Settlements. Otherwise, it was extracted from the IFS database compiled by the International Monetary Fund or the WDI database produced by the World Bank Group.

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 price of housing, 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 price of housing is proxied by a broad residential property price index. 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 seasonally adjusted 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 nominal money market interest rate, the nominal long term bond yield, the price of equity, and the nominal bilateral exchange rate. The nominal policy interest rate is measured by the central bank policy rate, the nominal money market interest rate is measured by the three month Treasury bill yield, and the nominal long term bond yield 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 period average values.

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 BIS and IFS databases. Bilateral trade weights are derived for goods on a cost, insurance and freight basis from the DOTS database. Bilateral bank lending and nonfinancial corporate borrowing weights are derived on a consolidated ultimate risk basis from the BIS database. Bilateral portfolio debt and equity investment weights are derived from the CPIS, BIS, and WDI databases.

## Appendix B. Tables and Figures

Table 1. Parameter Estimation Results, Endogenous Variables

	Prior Mean	Prior S.D.	Post. Mean		Prior Mean	Prior S.D.	Post. Mean
$\alpha^C$	0.9000	0.0090	0.9040	$\rho_{\delta^F}$	0.4000	...	...
$\alpha^L$	0.7000	0.0070	0.6999	$\rho_{\delta}$	0.6000	...	...
$\beta$	0.9901	...	...	$\rho_G$	0.8000	0.0080	0.8037
$\chi^H$	2.1000	0.0210	2.1093	$\rho_{\tau}$	0.8000	0.0080	0.8038
$\chi^K$	1.3000	0.0130	1.2974	$\rho_T$	0.8000	...	...
$\chi^B$	1.5000	0.0150	1.4882	$\sigma$	2.7000	0.0270	2.7111
$\chi^C$	10.0000	0.1000	10.0127	$\zeta$	0.1000	0.0010	0.0999
$\delta$	0.0025	...	...	$\theta^Y$	7.6667	...	...
$\delta^H$	0.0250	...	...	$\theta^C$	801.0000	...	...
$\delta^K$	0.0250	...	...	$\theta^L$	7.6667	...	...
$\eta$	0.0100	0.0001	0.0100	$\theta^M$	7.6667	...	...
$\eta^K$	0.5000	0.0050	0.4978	$\xi_0^{\pi}$	1.7500	0.0175	1.7586
$\eta^C$	1.2500	0.0125	1.2471	$\xi_1^{\pi}$	1.7500	0.0175	1.7533
$\gamma^Y$	0.8000	0.0080	0.7973	$\xi_0^Y$	0.1250	0.0013	0.1254
$\gamma^L$	0.8000	0.0080	0.8016	$\xi_1^Y$	0.1250	0.0013	0.1252
$\gamma^M$	0.8000	0.0080	0.8020	$\xi_1^{\Delta E}$	0.1000	0.0010	0.0998
$\iota$	1.2500	0.0125	1.2456	$\xi_2^E$	0.2500	...	...
$\kappa^R$	0.1000	...	...	$\zeta^{\kappa,B}$	0.2000	...	...
$\lambda_1^T$	0.5000	0.0050	0.4985	$\zeta^{\kappa,V^H}$	0.1000	...	...
$\lambda_2^T$	0.0500	0.0005	0.0500	$\zeta^{\kappa,V^S}$	0.0500	...	...
$\lambda_3^T$	0.1000	0.0010	0.1008	$\zeta^{\phi^D,B}$	0.2000	...	...
$\mu^M$	0.2500	0.0025	0.2523	$\zeta^{\phi^D,V}$	0.2000	...	...
$\omega^Y$	0.9375	0.0094	0.9396	$\zeta^{\phi^F,B}$	0.4000	...	...
$\omega^B$	0.9500	0.0095	0.9520	$\zeta^{\phi^F,V}$	0.2000	...	...
$\omega^C$	0.5000	0.0050	0.5001	$\zeta^{\delta^M,Y}$	0.0250	...	...
$\omega^L$	0.9375	0.0094	0.9401	$\zeta^{\delta^M,V}$	0.0500	...	...
$\omega^M$	0.7500	0.0075	0.7489	$\zeta^{\delta^C,Y}$	0.0500	...	...
$\omega_1^Y$	0.4286	0.0043	0.4274	$\zeta^{\delta^C,V}$	0.0500	...	...
$\omega_2^Y$	0.6000	0.0060	0.6009	$\zeta^G$	0.0250	...	...
$\phi^B$	0.3500	0.0035	0.3503	$\zeta^{\tau}$	0.0250	...	...
$\phi^C$	0.5000	0.0050	0.4986	$\zeta^T$	0.0000	...	...
$\phi^D$	0.9000	0.0090	0.9023	$\lambda_0^M$	0.5101	0.0510	0.4975
$\phi^F$	0.7000	0.0070	0.6991	$\lambda_1^M$	1.0203	0.1020	1.0556
$\phi^H$	0.9500	0.0095	0.9479	$\lambda_2^M$	1.5304	0.1530	1.5063
$\phi_B^A$	0.9000	0.0090	0.8955	$\lambda_0^B$	0.5101	0.0510	0.4995
$\phi_S^A$	0.1000	0.0010	0.1002	$\lambda_1^B$	1.0203	0.1020	1.0191
$\psi^M$	1.5000	0.0150	1.5025	$\lambda_2^B$	1.5304	0.1530	1.5673
$\rho^i$	0.8000	0.0080	0.7985	$\lambda_0^S$	0.5743	0.0574	0.5764
$\rho_{\kappa}$	0.6000	...	...	$\lambda_1^S$	1.1486	0.1149	1.1804
$\rho_{\rho}$	0.8000	...	...	$\lambda_2^S$	1.7229	0.1723	1.7061

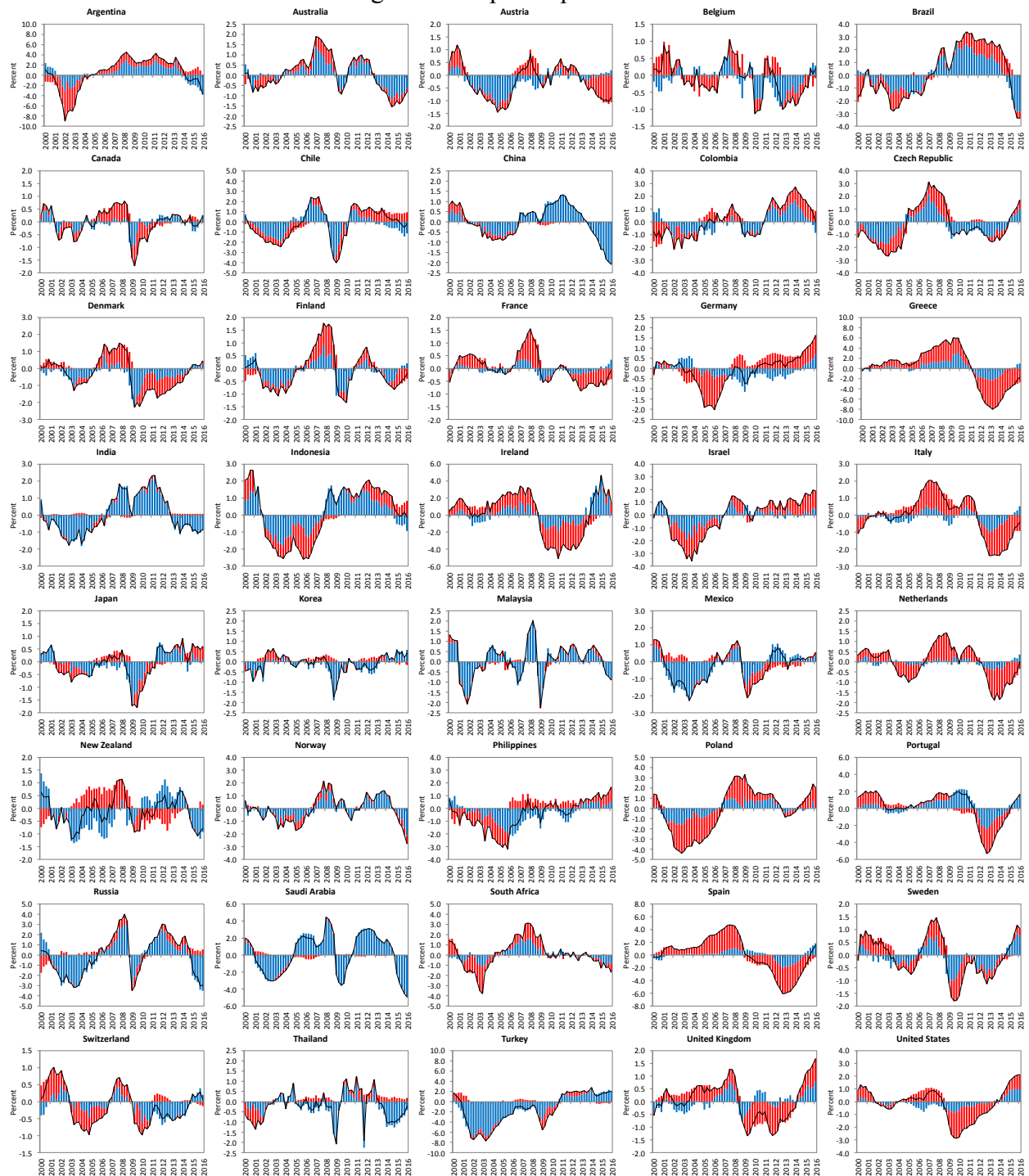
Note: All priors are normally distributed, while all posteriors are asymptotically normally distributed.

Table 2. Parameter Estimation Results, Exogenous Variables

	Prior Mean	Prior S.D.	Post. Mean		Prior Mean	Prior S.D.	Post. Mean
$\rho_A$	0.8000	0.0800	0.7883	$\sigma_{\nu,M}^2$	$8.73 \times 10^{+0}$	$8.73 \times 10^{-1}$	$8.86 \times 10^{+0}$
$\rho_N$	0.8000	0.0800	0.7990	$\sigma_{\nu^Y}^2$	$2.29 \times 10^{+6}$	$2.29 \times 10^{+5}$	$2.34 \times 10^{+6}$
$\rho_{\nu,c}$	0.4000	0.0400	0.3749	$\sigma_{\nu^L}^2$	$2.05 \times 10^{+7}$	$2.05 \times 10^{+6}$	$1.97 \times 10^{+7}$
$\rho_{\nu,l}$	0.6000	0.0600	0.6189	$\sigma_{\nu^M}^2$	$1.04 \times 10^{+4}$	$1.04 \times 10^{+3}$	$9.72 \times 10^{+3}$
$\rho_{\nu,x}$	0.8000	0.0800	0.7976	$\sigma_{\nu^H}^2$	$1.46 \times 10^{+0}$	$1.46 \times 10^{-1}$	$1.51 \times 10^{+0}$
$\rho_{\nu,M}$	0.8000	0.0800	0.7970	$\sigma_{\nu^S}^2$	$4.49 \times 10^{-2}$	$4.49 \times 10^{-3}$	$4.47 \times 10^{-2}$
$\rho_{\nu,H}$	0.6000	0.0600	0.5827	$\sigma_{\nu^B}^2$	$6.55 \times 10^{-1}$	$6.55 \times 10^{-2}$	$6.67 \times 10^{-1}$
$\rho_{\nu,i,S}$	0.8000	0.0800	0.7809	$\sigma_{\nu^S}^2$	$1.36 \times 10^{+1}$	$1.36 \times 10^{+0}$	$1.32 \times 10^{+1}$
$\rho_{\nu,B}$	0.8000	0.0800	0.8089	$\sigma_{\nu^E}^2$	$1.91 \times 10^{+0}$	$1.91 \times 10^{-1}$	$1.93 \times 10^{+0}$
$\rho_{\nu,S}$	0.4000	0.0400	0.4356	$\sigma_{\nu^C}^2$	$1.00 \times 10^{+0}$	...	...
$\rho_{\nu,E}$	0.4000	0.0400	0.4164	$\sigma_{\nu^B}^2$	$1.00 \times 10^{+0}$	...	...
$\rho_{\nu^C}$	0.6000	...	...	$\sigma_{\nu^i,p}^2$	$4.08 \times 10^{-1}$	$4.08 \times 10^{-2}$	$3.55 \times 10^{-1}$
$\rho_{\nu^x}$	0.8000	...	...	$\sigma_{\nu^G}^2$	$1.57 \times 10^{+0}$	$1.57 \times 10^{-1}$	$1.57 \times 10^{+0}$
$\sigma_A^2$	$5.58 \times 10^{-2}$	$5.58 \times 10^{-3}$	$6.08 \times 10^{-2}$	$\sigma_{\nu^F}^2$	$3.66 \times 10^{-2}$	$3.66 \times 10^{-3}$	$3.75 \times 10^{-2}$
$\sigma_N^2$	$1.17 \times 10^{+0}$	$1.17 \times 10^{-1}$	$1.16 \times 10^{+0}$	$\sigma_{\nu^K}^2$	$1.00 \times 10^{+0}$	...	...
$\sigma_{\nu^c}^2$	$1.04 \times 10^{+2}$	$1.04 \times 10^{+1}$	$9.66 \times 10^{+1}$	$\sigma_{\nu^B}^2$	$1.00 \times 10^{+0}$	...	...
$\sigma_{\nu^l}^2$	$2.89 \times 10^{+0}$	$2.89 \times 10^{-1}$	$3.06 \times 10^{+0}$	$\sigma_{\nu^Y,k}^2$	$2.46 \times 10^{+4}$	$2.46 \times 10^{+3}$	$2.46 \times 10^{+4}$
$\sigma_{\nu^x}^2$	$6.25 \times 10^{+0}$	$6.25 \times 10^{-1}$	$6.02 \times 10^{+0}$				

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

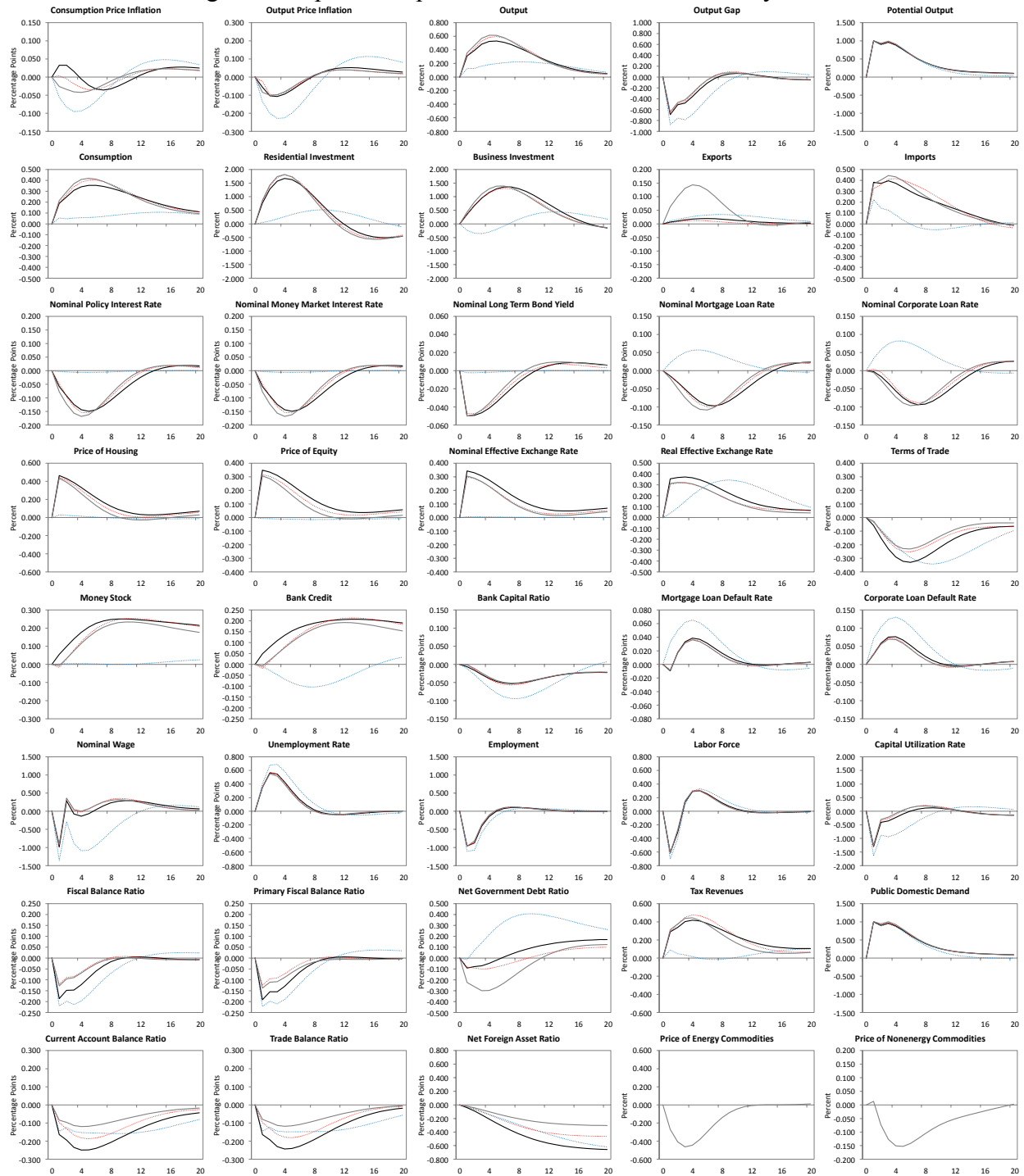
Figure 1. Output Gap Estimates



Note: Decomposes smoothed estimates of the output gap into contributions from capital utilization ■ and labor utilization ■.

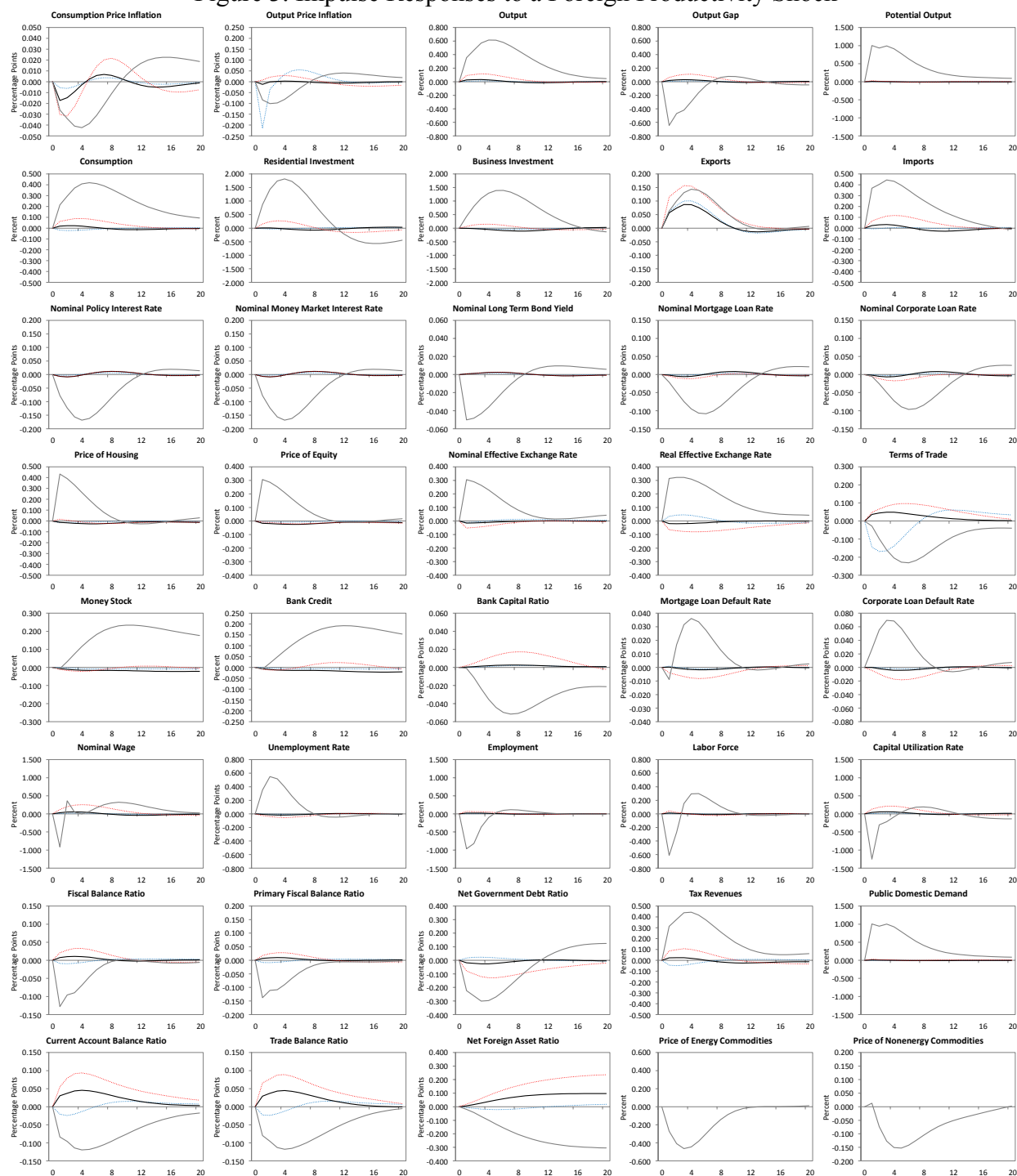


Figure 2. Impulse Responses to a Domestic Productivity Shock



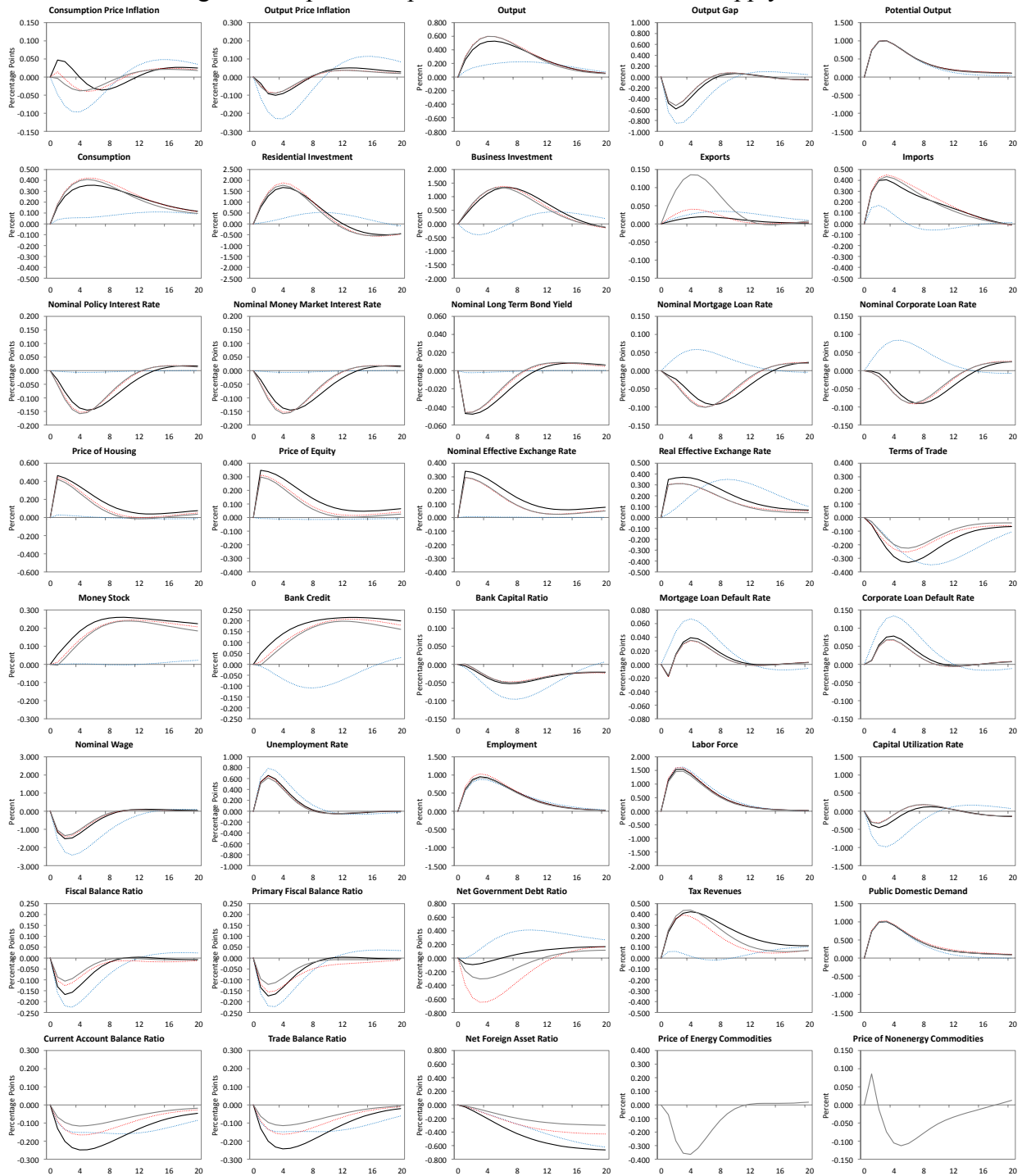
*Note:* Depicts impulse responses for the 2.5<sup>th</sup> percentile economy (Belgium) ■, the median economy (Sweden) ■, the 97.5<sup>th</sup> percentile economy (Indonesia) ■, and the reference economy (United States) ■ to productivity shocks that raise potential output by one percent, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

Figure 3. Impulse Responses to a Foreign Productivity Shock



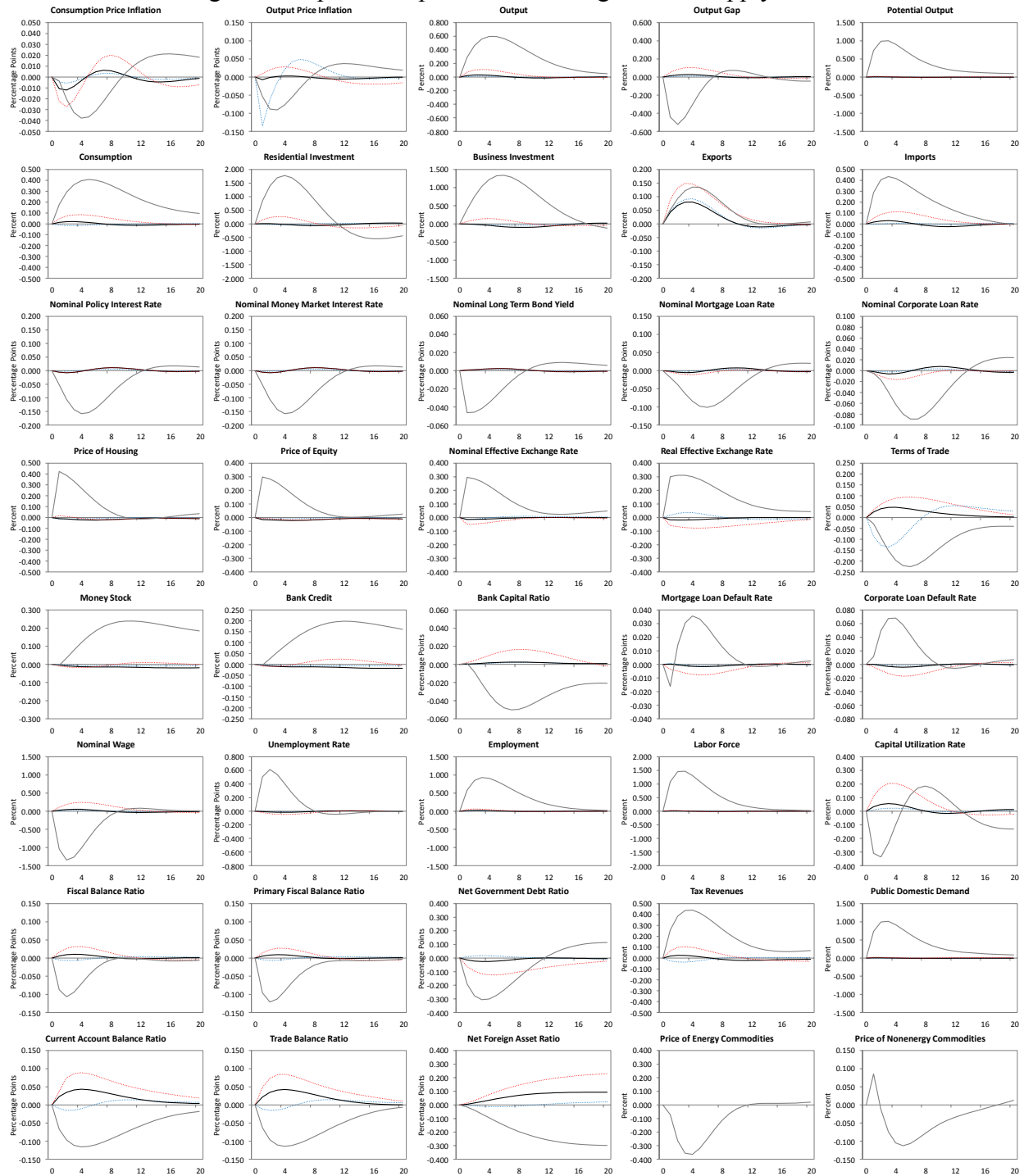
*Note:* Depicts impulse responses for the 2.5<sup>th</sup> percentile recipient economy (Russia) ■, the median recipient economy (Austria) ■, the 97.5<sup>th</sup> percentile recipient economy (Ireland) ■, and the source economy (United States) ■ to a productivity shock that raises potential output by one percent, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

Figure 4. Impulse Responses to a Domestic Labor Supply Shock



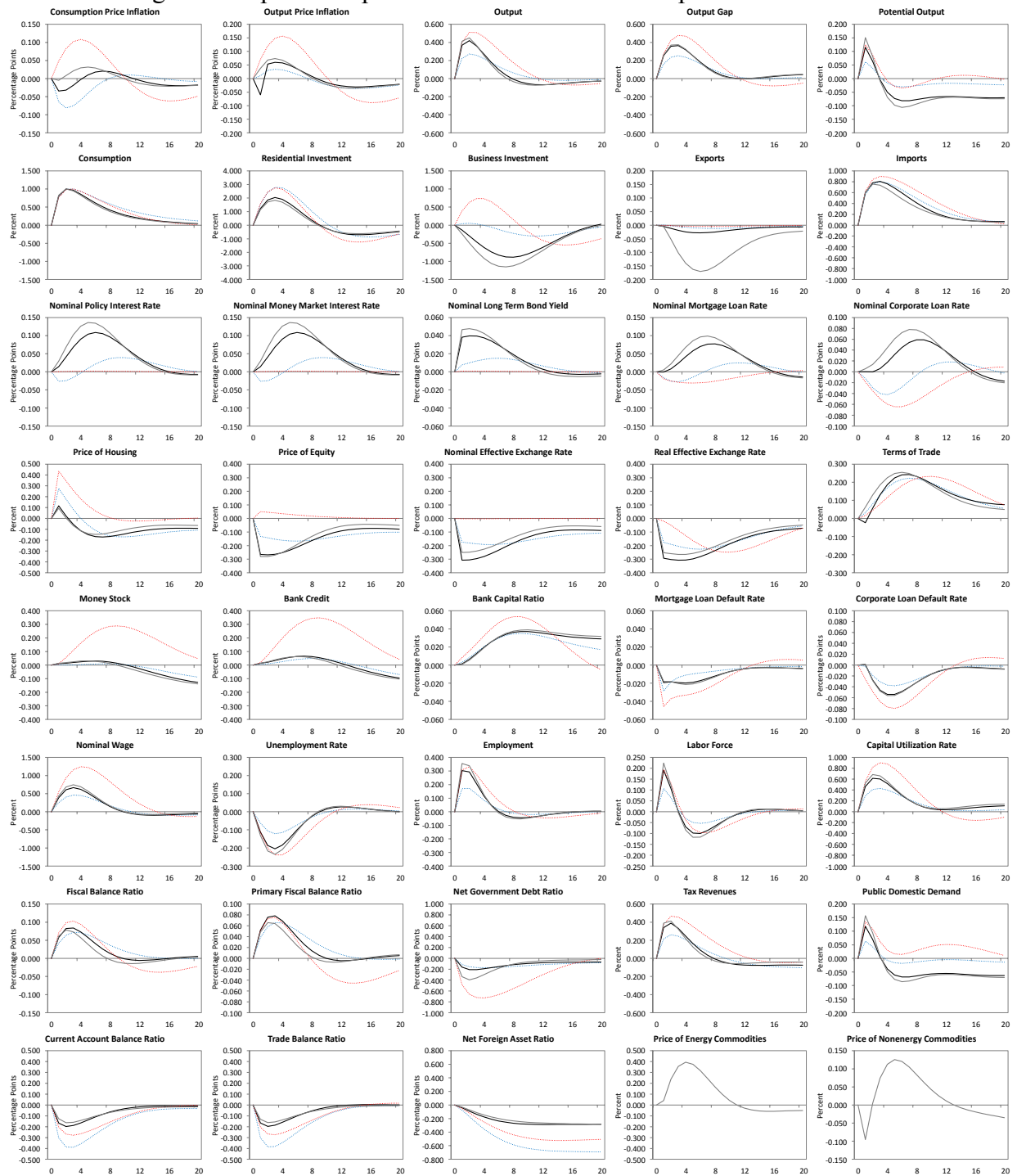
*Note:* Depicts impulse responses for the 2.5<sup>th</sup> percentile economy (Belgium) ■, the median economy (Sweden) ■, the 97.5<sup>th</sup> percentile economy (Japan) ■, and the reference economy (United States) ■ to labor supply shocks that raise potential output by one percent, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

Figure 5. Impulse Responses to a Foreign Labor Supply Shock



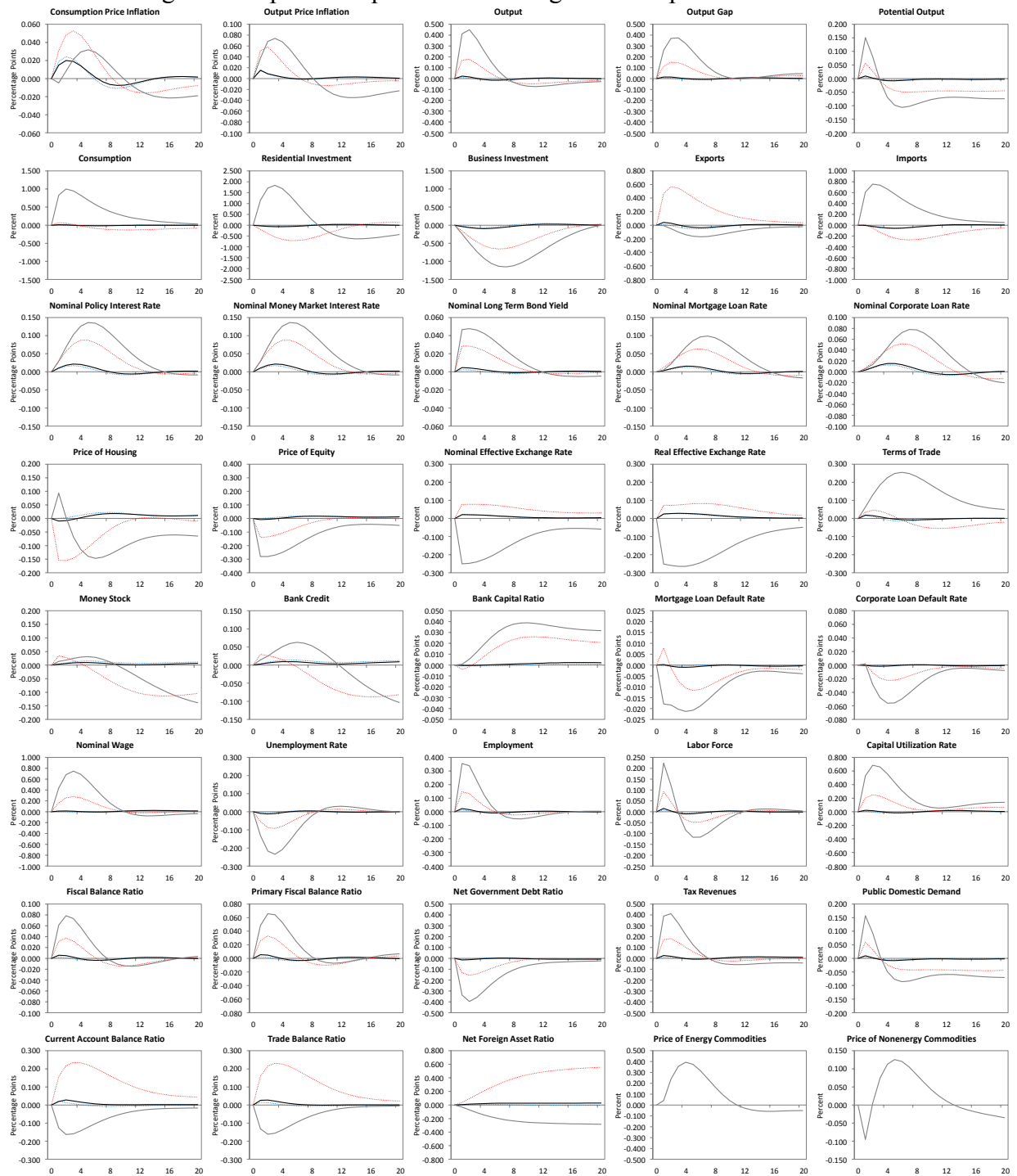
*Note:* Depicts impulse responses for the 2.5<sup>th</sup> percentile recipient economy (Russia) ■, the median recipient economy (Austria) ■, the 97.5<sup>th</sup> percentile recipient economy (Ireland) ■, and the source economy (United States) ■ to a labor supply shock that raises potential output by one percent, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

Figure 6. Impulse Responses to a Domestic Consumption Demand Shock



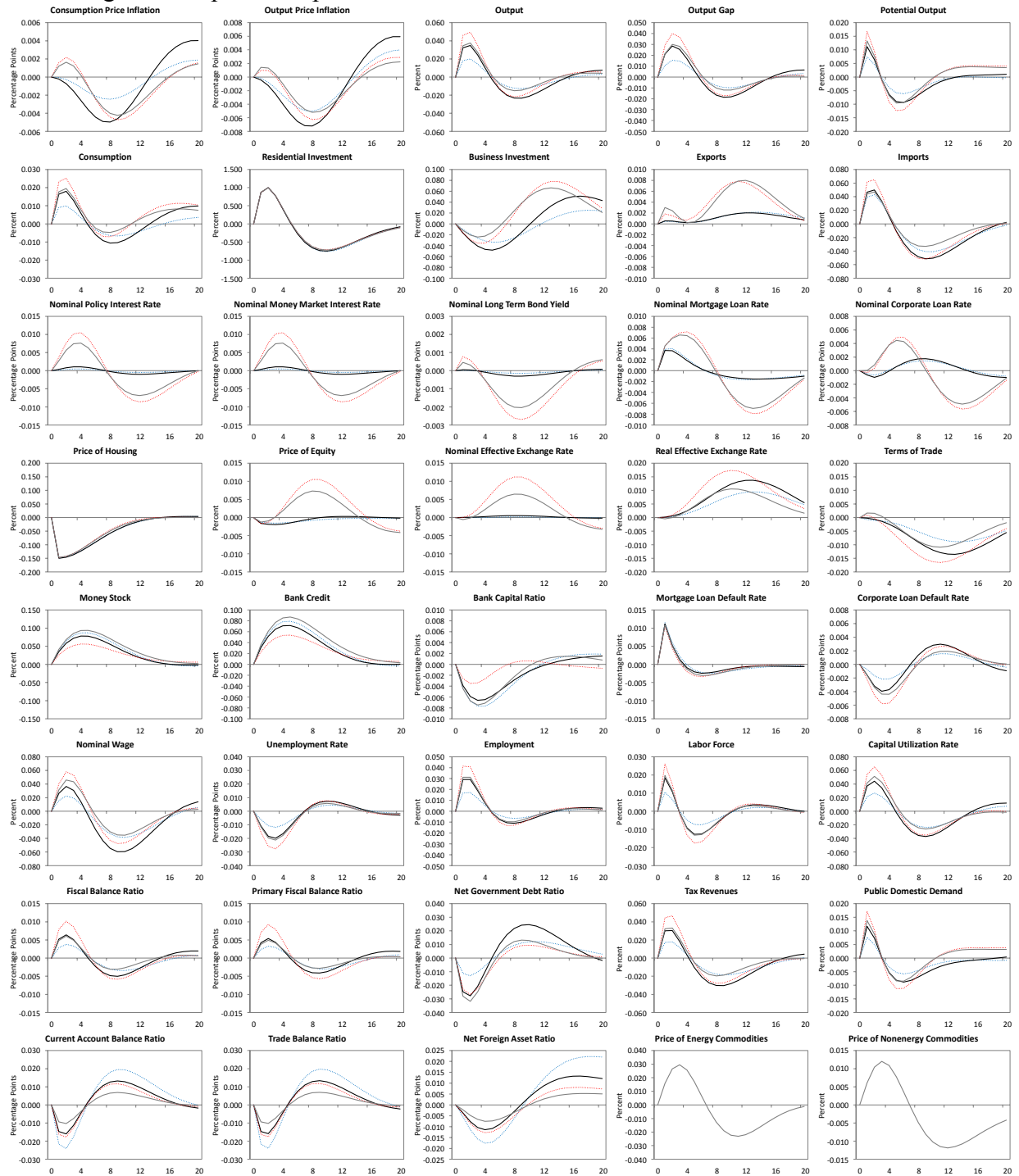
*Note:* Depicts impulse responses for the 2.5<sup>th</sup> percentile economy (Czech Republic) ■, the median economy (Australia) ■, the 97.5<sup>th</sup> percentile economy (Greece) ■, and the reference economy (United States) ■ to consumption demand shocks that raise consumption by one percent, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

Figure 7. Impulse Responses to a Foreign Consumption Demand Shock



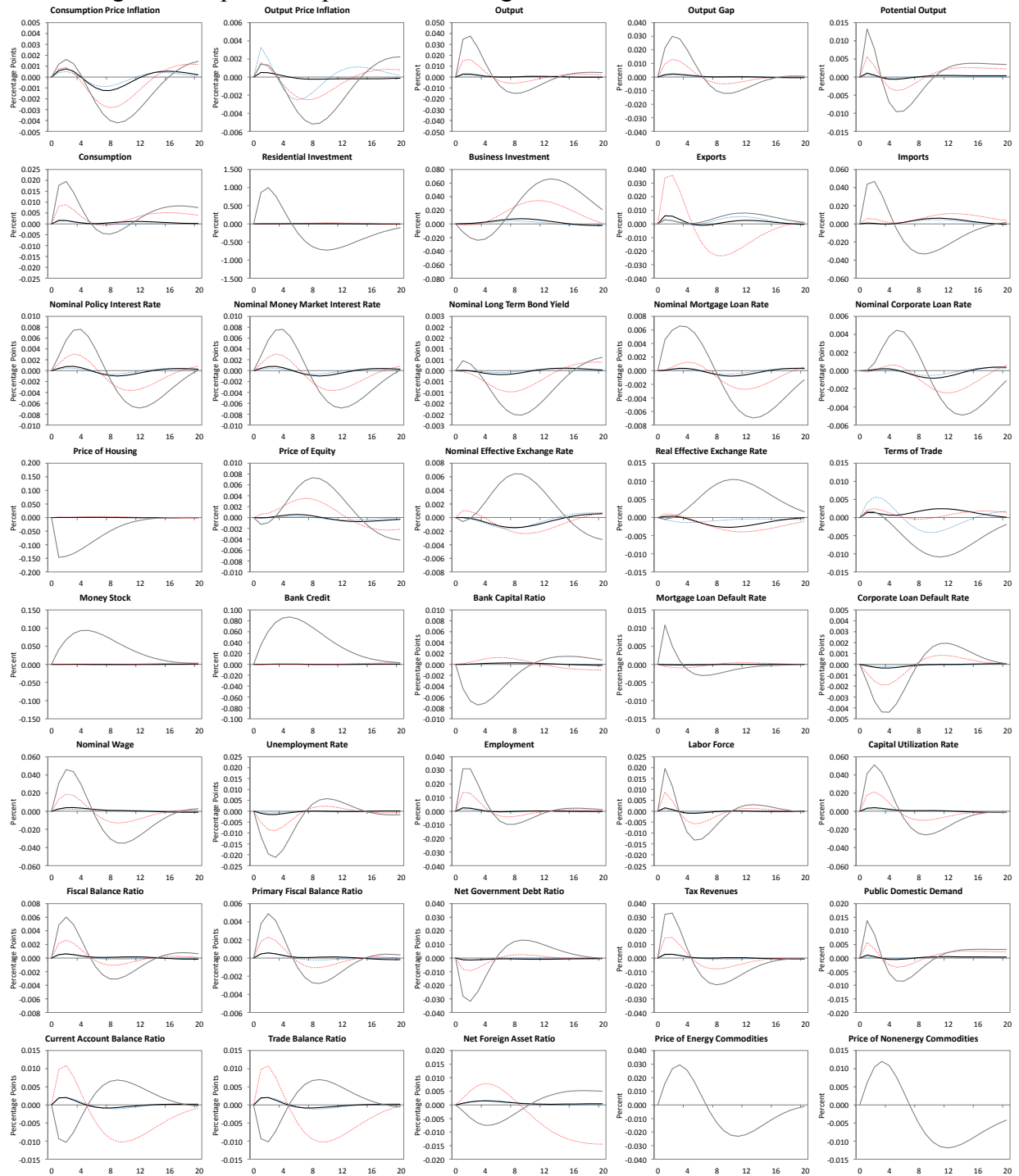
*Note:* Depicts impulse responses for the 2.5<sup>th</sup> percentile recipient economy (Poland) ■, the median recipient economy (Denmark) ■, the 97.5<sup>th</sup> percentile recipient economy (Canada) ■, and the source economy (United States) ■ to a consumption demand shock that raises consumption by one percent, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

Figure 8. Impulse Responses to a Domestic Residential Investment Demand Shock



*Note:* Depicts impulse responses for the 2.5<sup>th</sup> percentile economy (Netherlands) ■, the median economy (Spain) ■, the 97.5<sup>th</sup> percentile economy (China) ■, and the reference economy (United States) ■ to residential investment demand shocks that raise residential investment by one percent, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

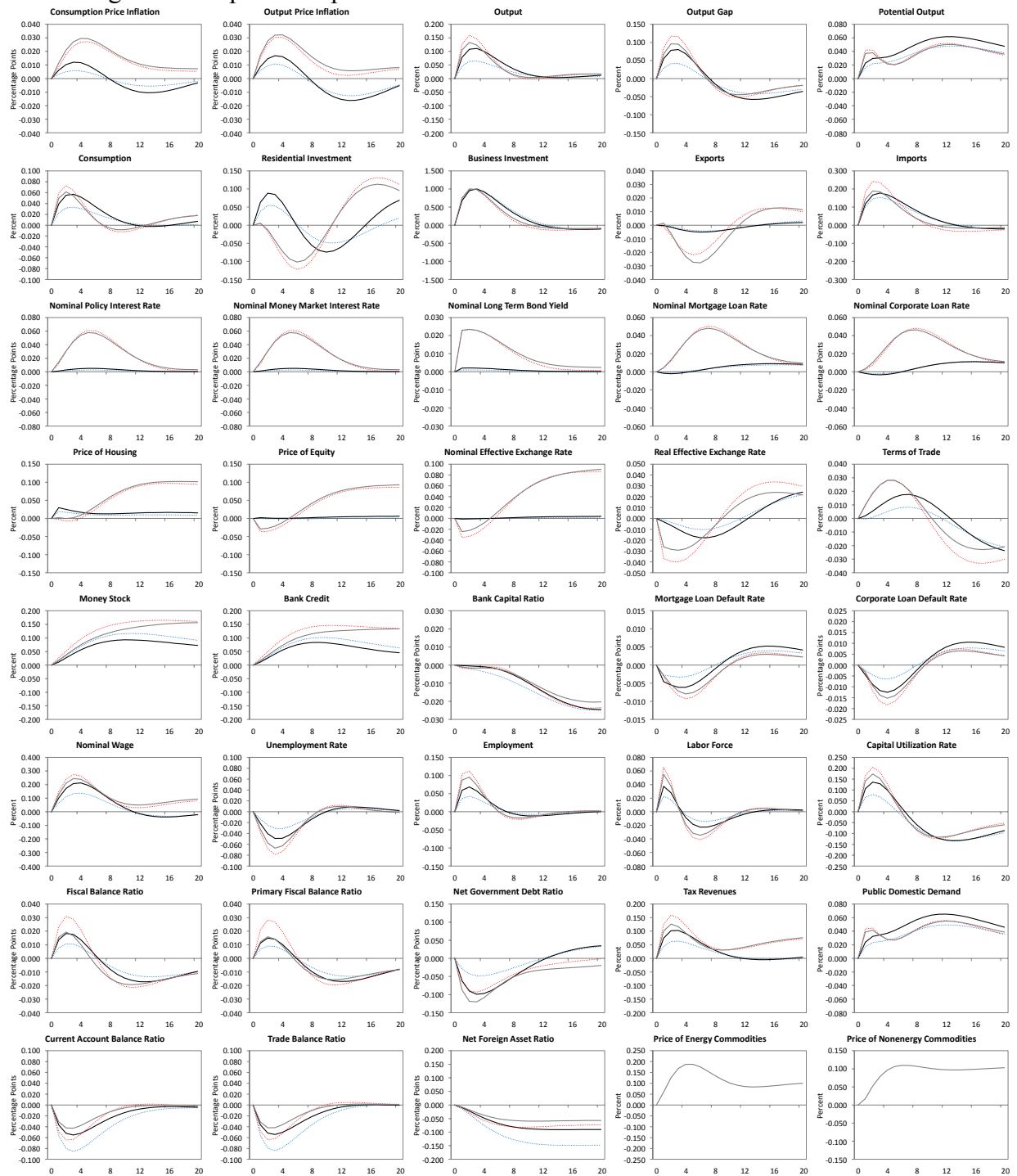
Figure 9. Impulse Responses to a Foreign Residential Investment Demand Shock



*Note:* Depicts impulse responses for the 2.5<sup>th</sup> percentile recipient economy (Australia) ■, the median recipient economy (New Zealand) ■, the 97.5<sup>th</sup> percentile recipient economy (Mexico) ■, and the source economy (United States) ■ to a residential investment demand shock that raises residential investment by one percent, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

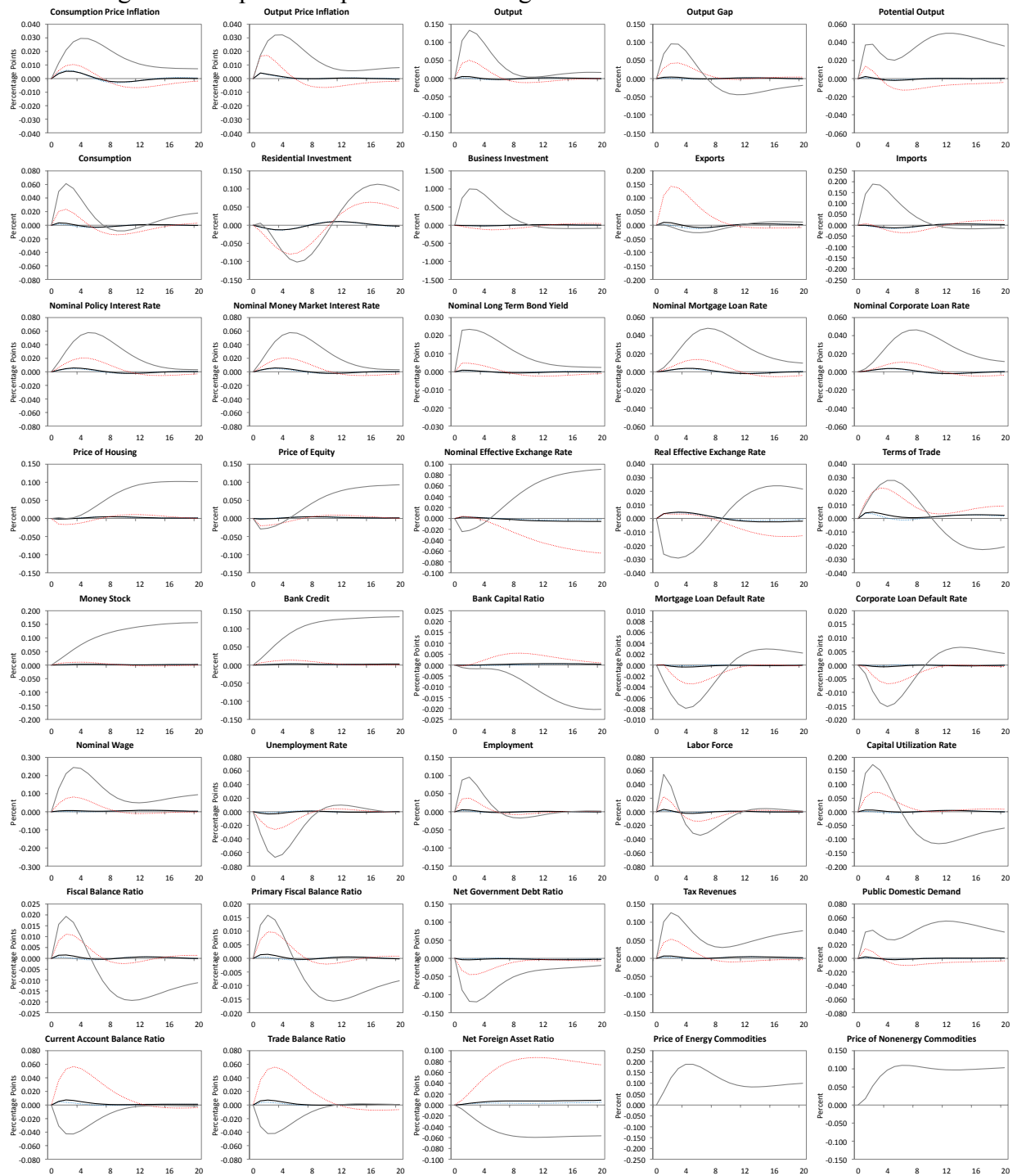


Figure 10. Impulse Responses to a Domestic Business Investment Demand Shock



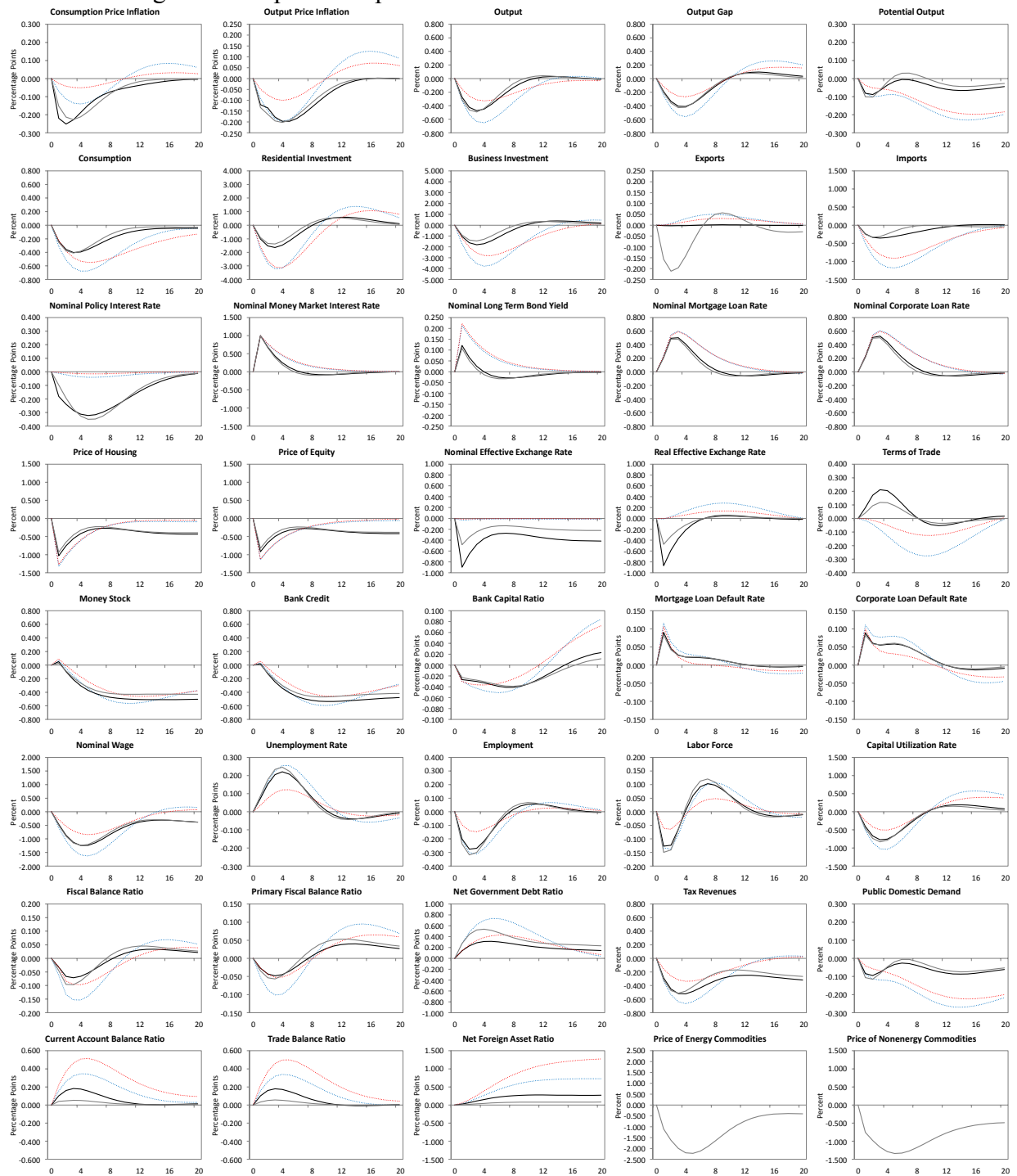
*Note:* Depicts impulse responses for the 2.5<sup>th</sup> percentile economy (Netherlands) ■, the median economy (Spain) ■, the 97.5<sup>th</sup> percentile economy (China) ■, and the reference economy (United States) ■ to business investment demand shocks that raise business investment by one percent, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

Figure 11. Impulse Responses to a Foreign Business Investment Demand Shock



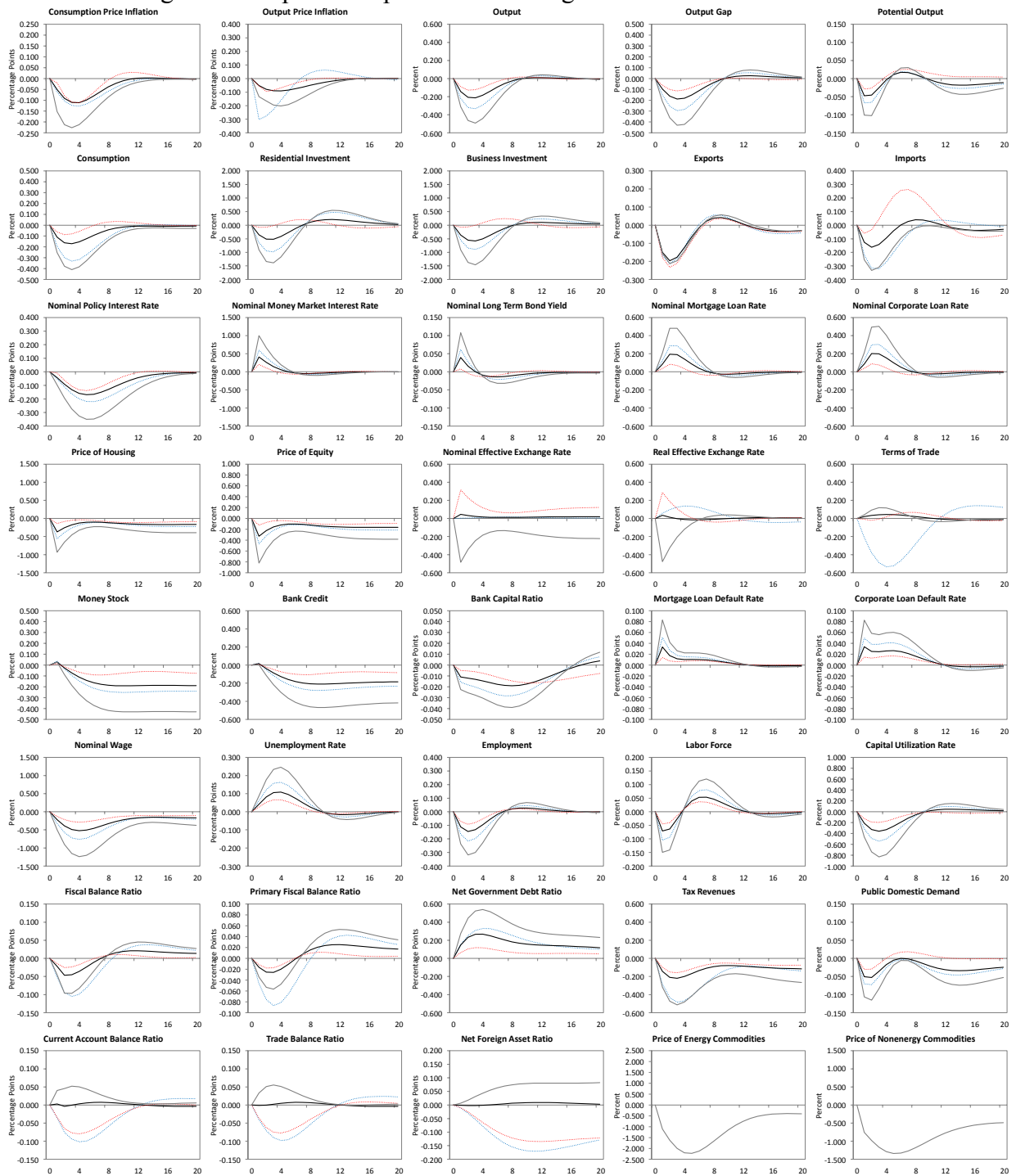
*Note:* Depicts impulse responses for the 2.5<sup>th</sup> percentile recipient economy (Poland) ■, the median recipient economy (Denmark) ■, the 97.5<sup>th</sup> percentile recipient economy (Canada) ■, and the source economy (United States) ■ to a business investment demand shock that raises business investment by one percent, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

Figure 12. Impulse Responses to a Domestic Credit Risk Premium Shock



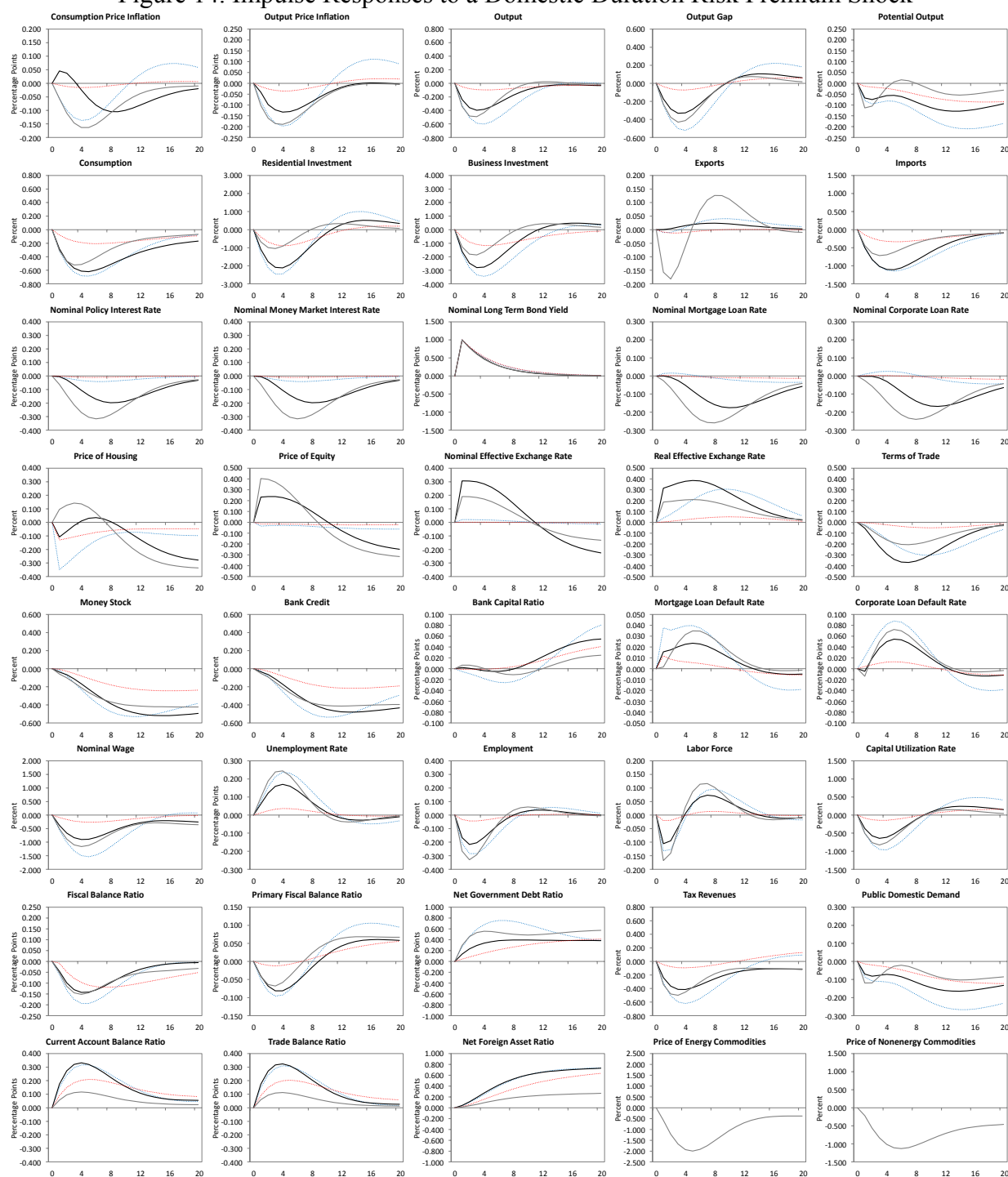
*Note:* Depicts impulse responses for the 2.5<sup>th</sup> percentile economy (Spain) ■, the median economy (Philippines) ■, the 97.5<sup>th</sup> percentile economy (Belgium) ■, and the reference economy (United States) ■ to credit risk premium shocks that raise the nominal money market interest rate by one percentage point, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

Figure 13. Impulse Responses to a Foreign Credit Risk Premium Shock



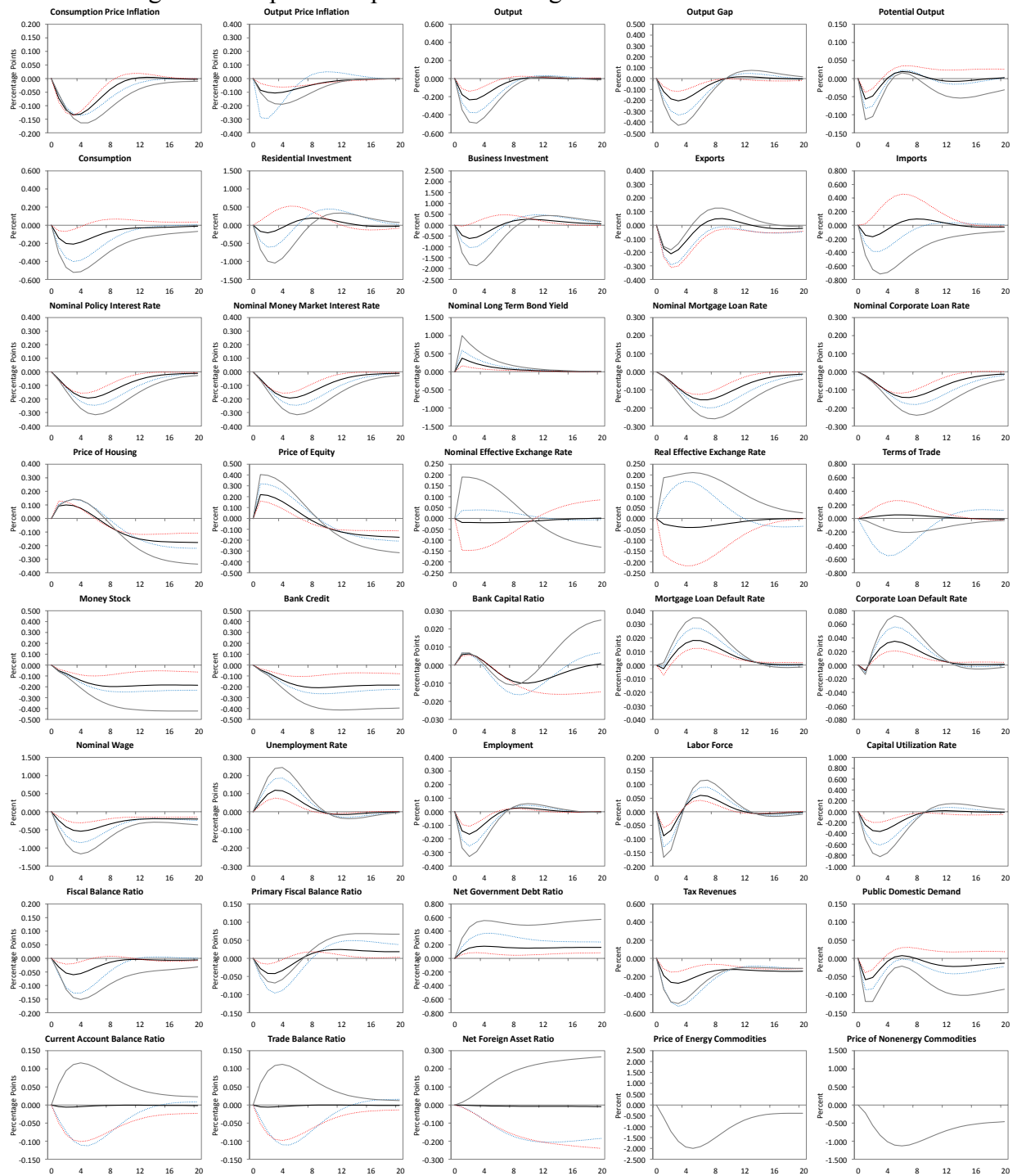
Note: Depicts impulse responses for the 2.5<sup>th</sup> percentile recipient economy (Colombia) ■, the median recipient economy (Italy) ■, the 97.5<sup>th</sup> percentile recipient economy (India) ■, and the source economy (United States) ■ to a credit risk premium shock that raises the nominal money market interest rate by one percentage point, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

Figure 14. Impulse Responses to a Domestic Duration Risk Premium Shock



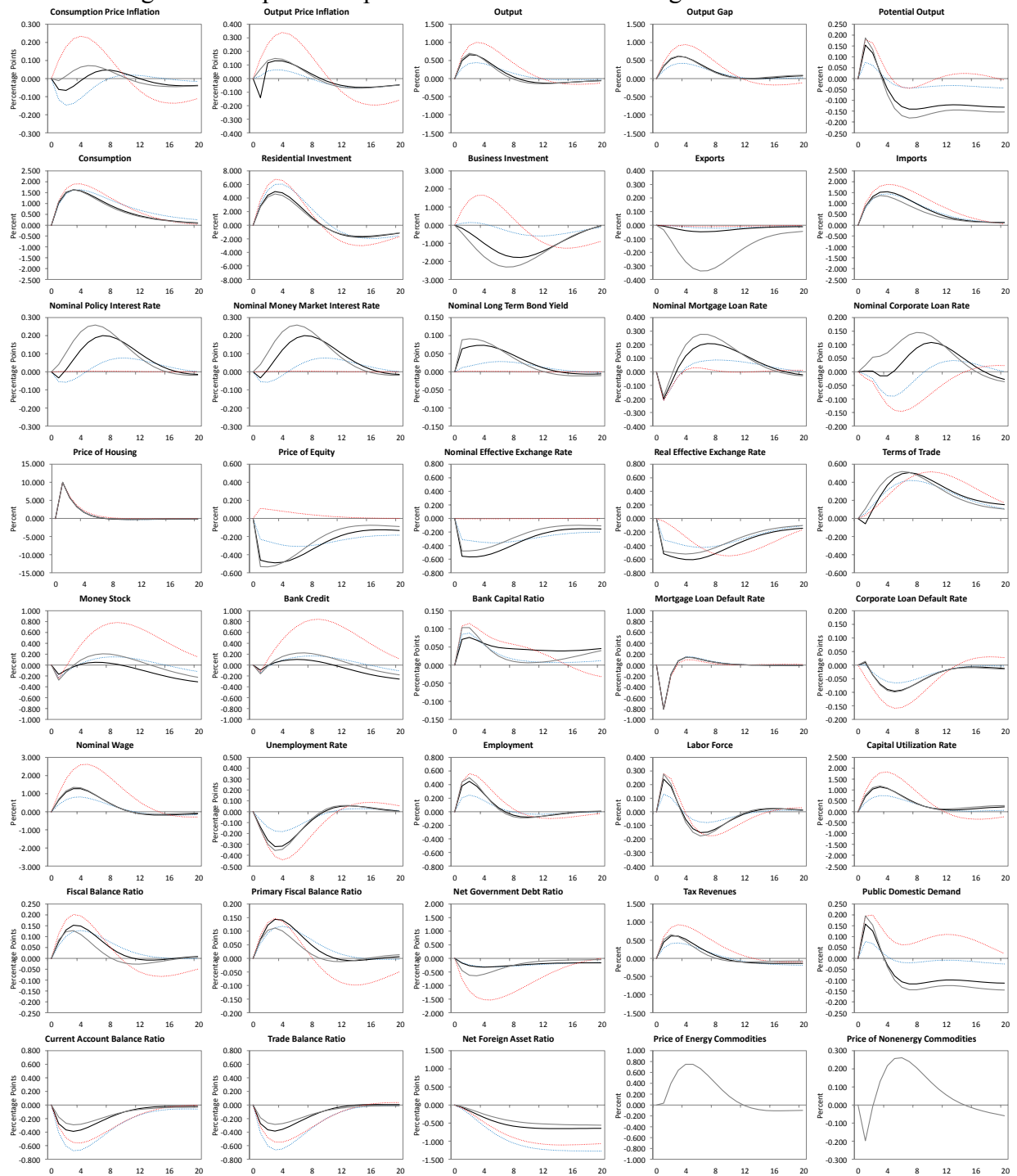
*Note:* Depicts impulse responses for the 2.5<sup>th</sup> percentile economy (Spain) ■, the median economy (Poland) ■, the 97.5<sup>th</sup> percentile economy (Ireland) ■, and the reference economy (United States) ■ to duration risk premium shocks that raise the nominal long term bond yield by one percentage point, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

Figure 15. Impulse Responses to a Foreign Duration Risk Premium Shock



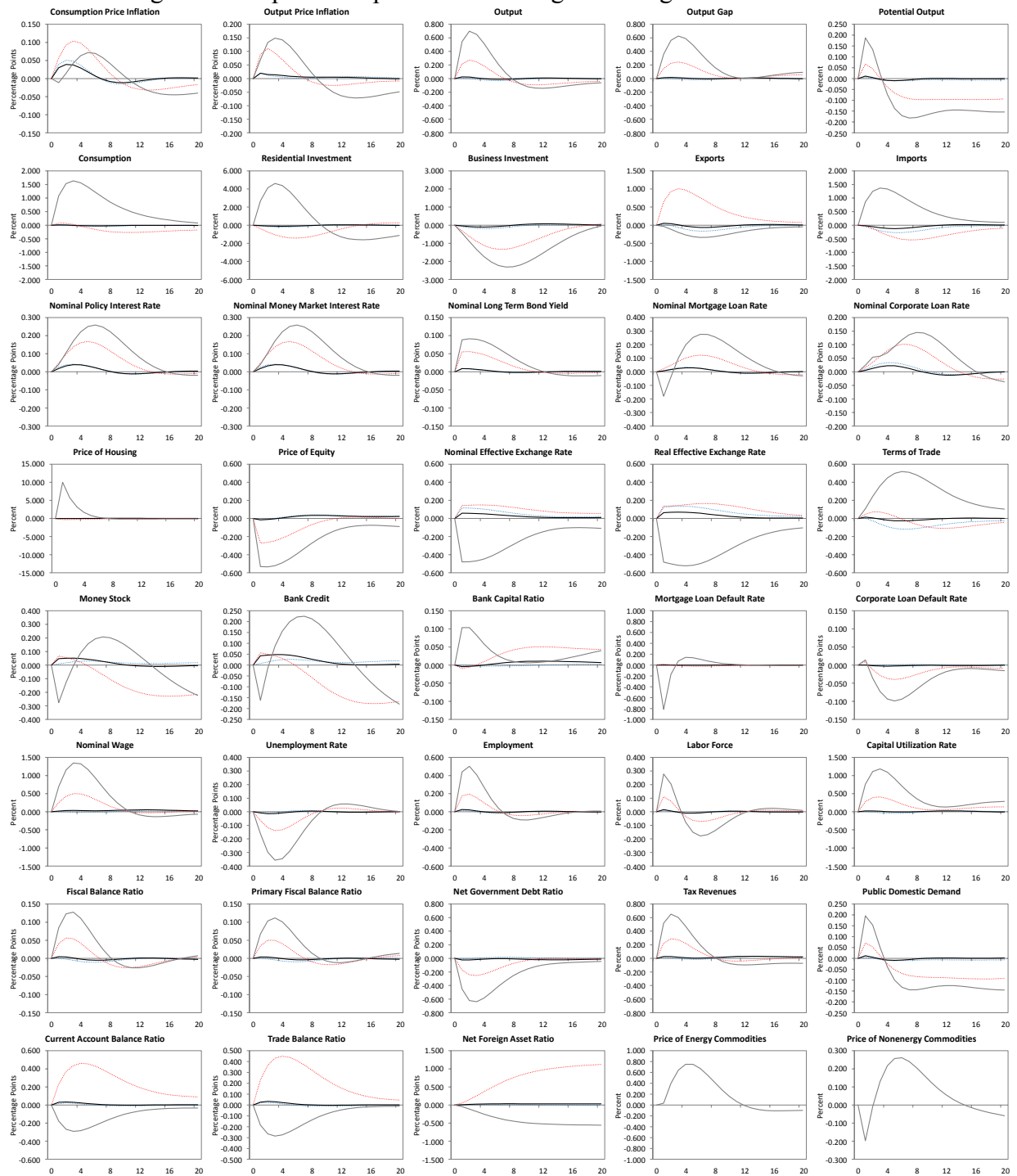
*Note:* Depicts impulse responses for the 2.5<sup>th</sup> percentile recipient economy (Colombia) ■, the median recipient economy (Sweden) ■, the 97.5<sup>th</sup> percentile recipient economy (China) ■, and the source economy (United States) ■ to a duration risk premium shock that raises the nominal long term bond yield by one percentage point, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

Figure 16. Impulse Responses to a Domestic Housing Risk Premium Shock



Note: Depicts impulse responses for the 2.5<sup>th</sup> percentile economy (Czech Republic) ■, the median economy (Russia) ■, the 97.5<sup>th</sup> percentile economy (Greece) ■, and the reference economy (United States) ■ to housing risk premium shocks that raise the price of housing by ten percent, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

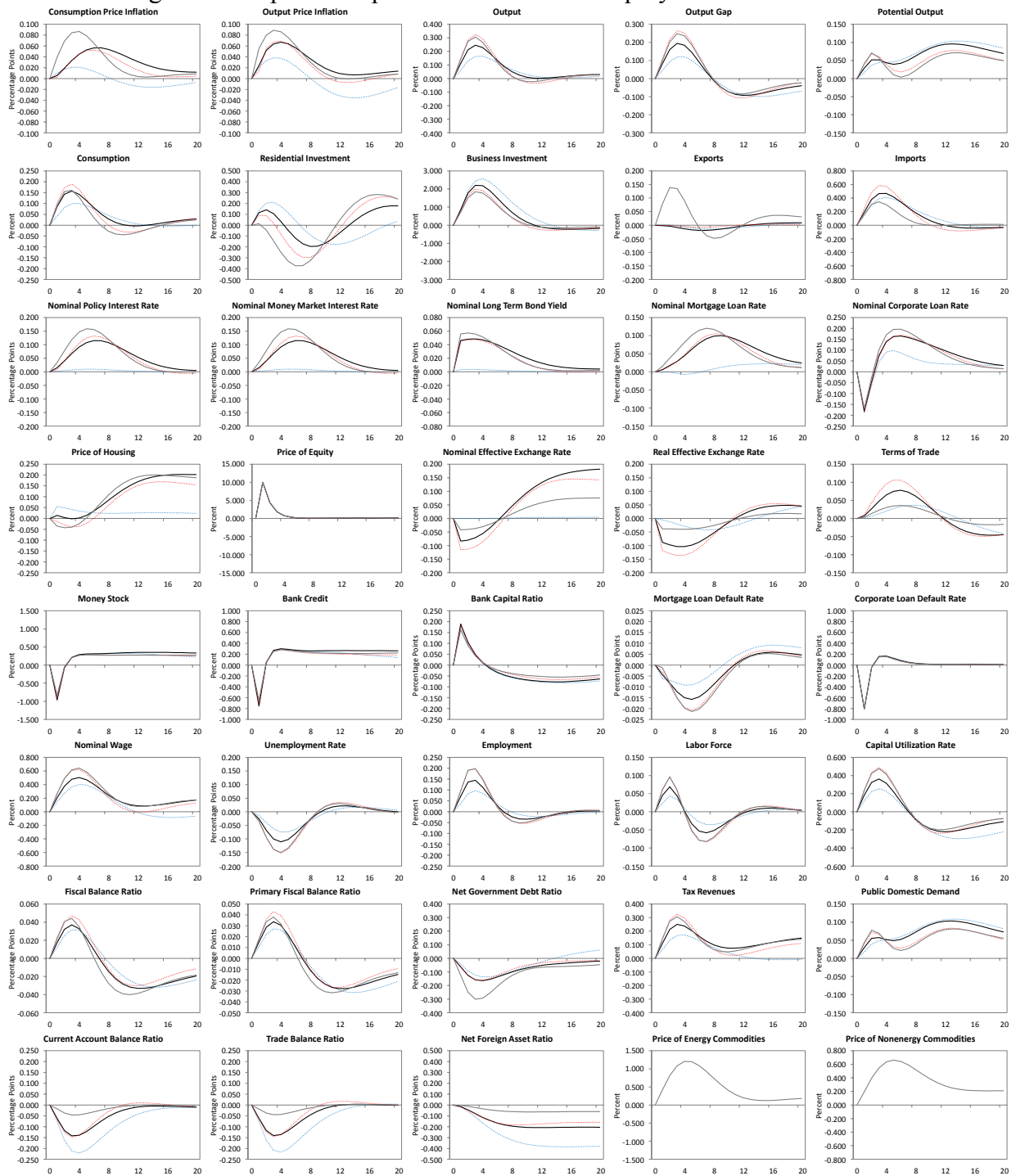
Figure 17. Impulse Responses to a Foreign Housing Risk Premium Shock



*Note:* Depicts impulse responses for the 2.5<sup>th</sup> percentile recipient economy (Argentina) ■, the median recipient economy (France) ■, the 97.5<sup>th</sup> percentile recipient economy (Canada) ■, and the source economy (United States) ■ to a housing risk premium shock that raises the price of housing by ten percent, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

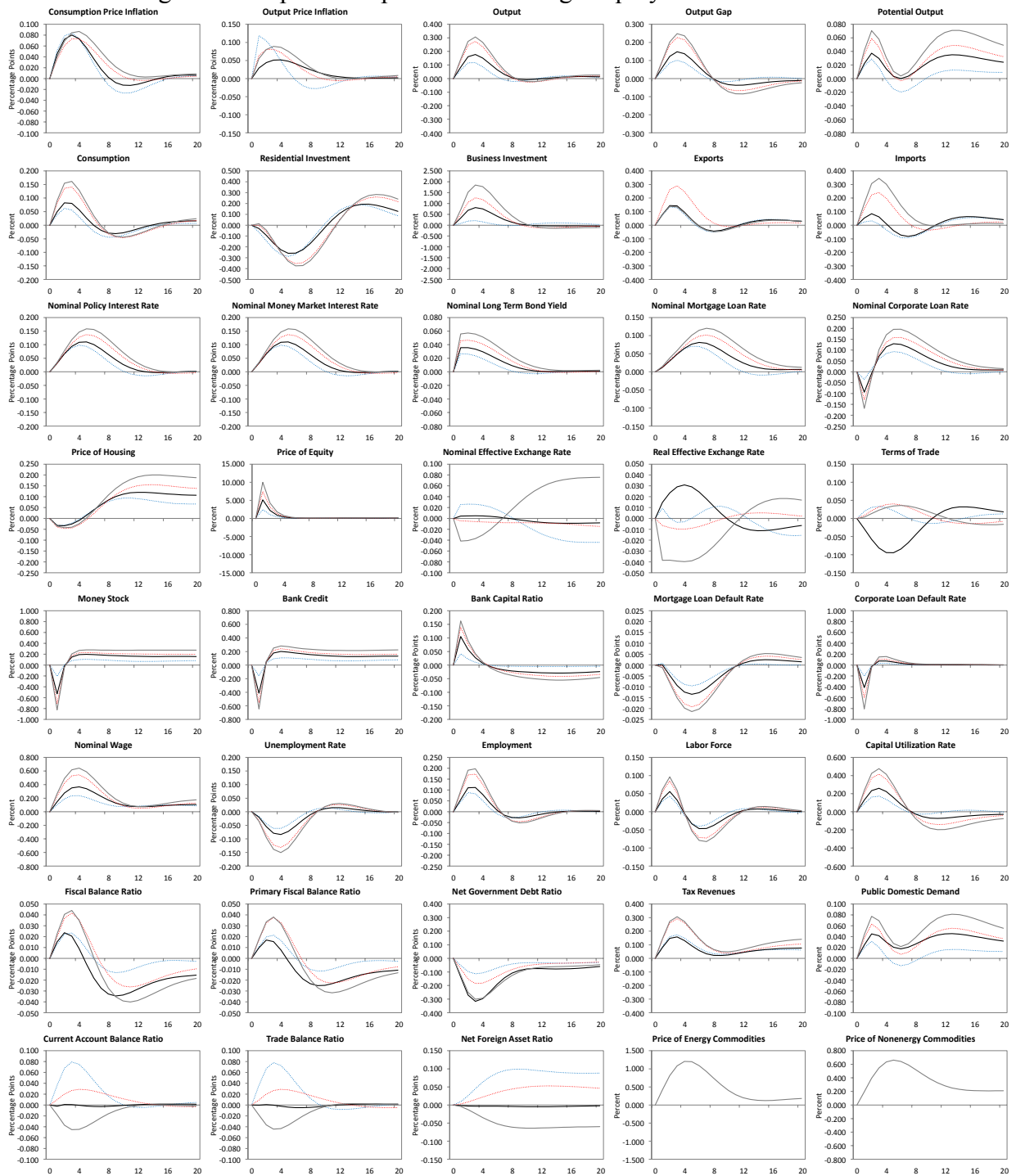


Figure 18. Impulse Responses to a Domestic Equity Risk Premium Shock



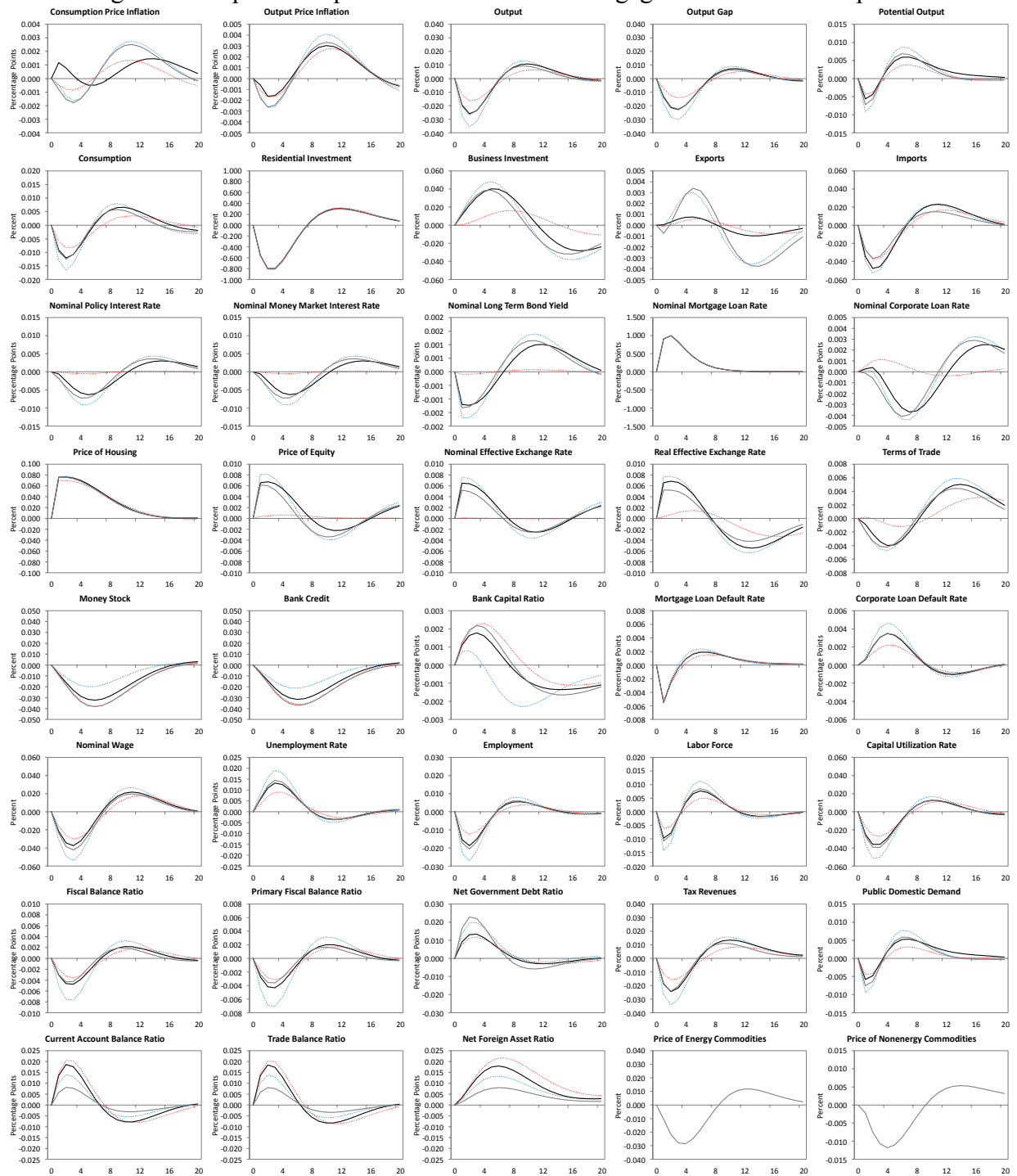
Note: Depicts impulse responses for the 2.5<sup>th</sup> percentile economy (Netherlands) ■, the median economy (Mexico) ■, the 97.5<sup>th</sup> percentile economy (Indonesia) ■, and the reference economy (United States) ■ to equity risk premium shocks that raise the price of equity by ten percent, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

Figure 19. Impulse Responses to a Foreign Equity Risk Premium Shock



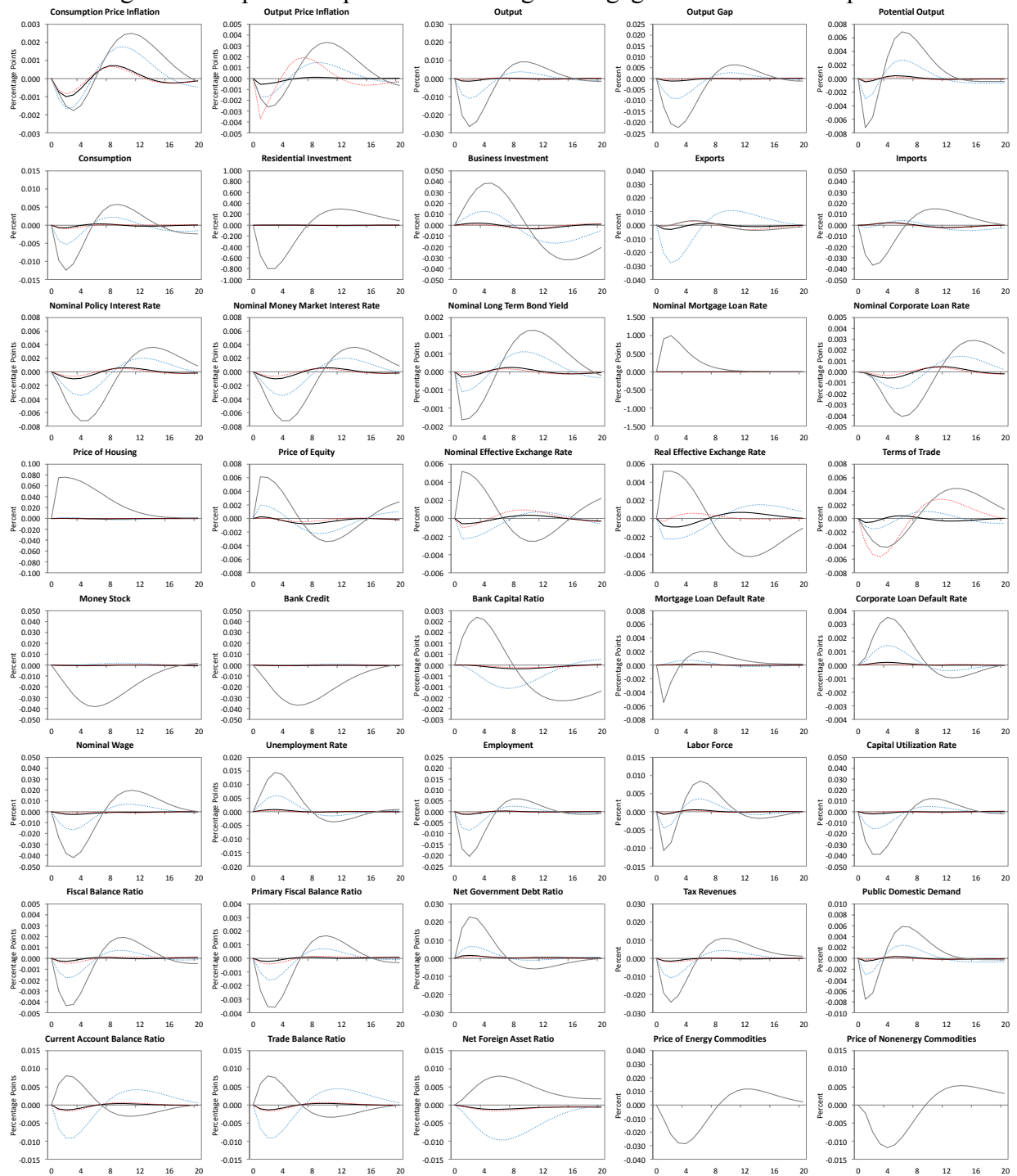
Note: Depicts impulse responses for the 2.5<sup>th</sup> percentile recipient economy (Malaysia) ■, the median recipient economy (Japan) ■, the 97.5<sup>th</sup> percentile recipient economy (Mexico) ■, and the source economy (United States) ■ to an equity risk premium shock that raises the price of equity by ten percent, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

Figure 20. Impulse Responses to a Domestic Mortgage Loan Rate Markup Shock



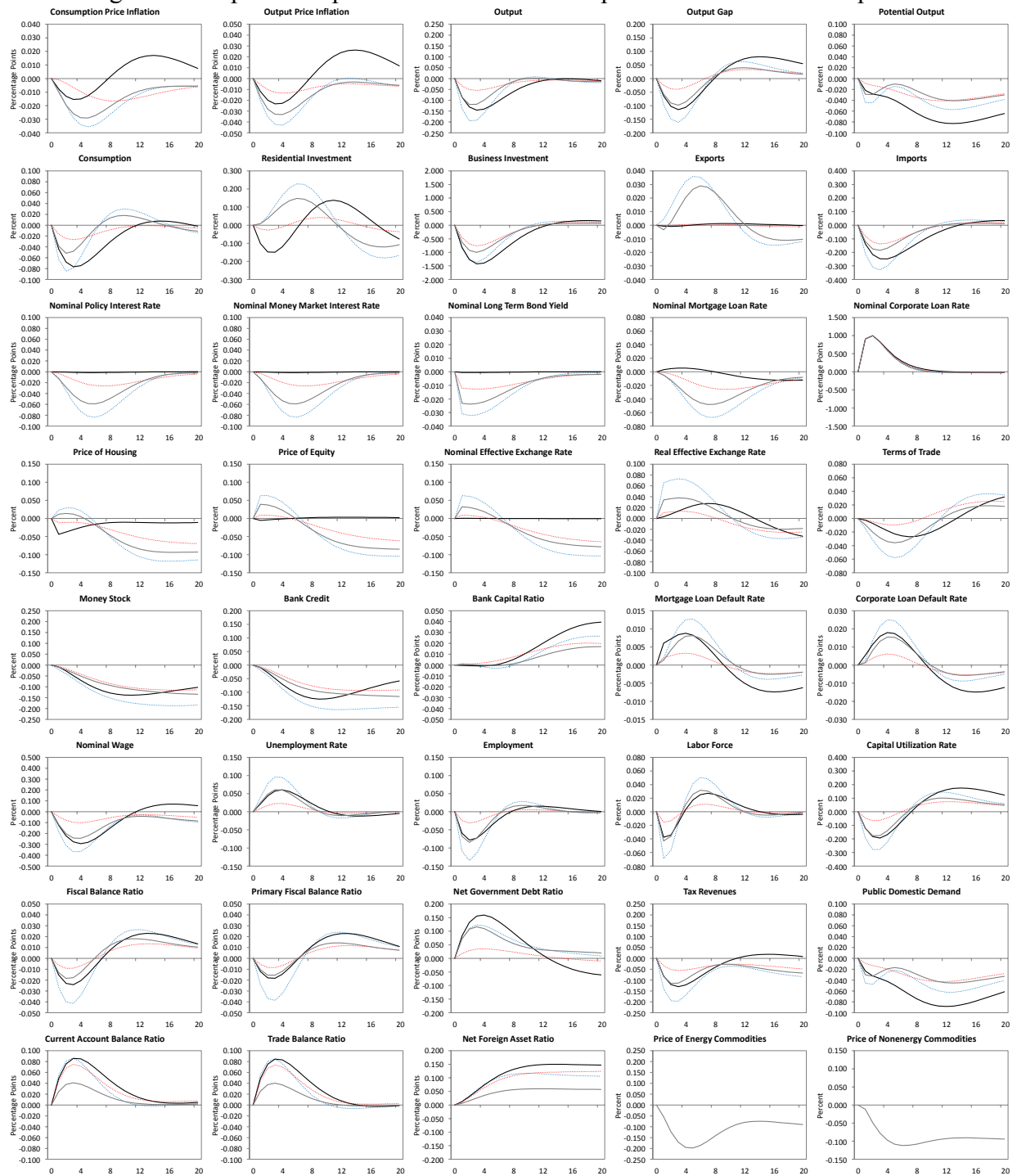
*Note:* Depicts impulse responses for the 2.5<sup>th</sup> percentile economy (China) ■, the median economy (Korea) ■, the 97.5<sup>th</sup> percentile economy (Netherlands) ■, and the reference economy (United States) ■ to mortgage loan rate markup shocks that raise the nominal mortgage loan rate by one percentage point, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

Figure 21. Impulse Responses to a Foreign Mortgage Loan Rate Markup Shock



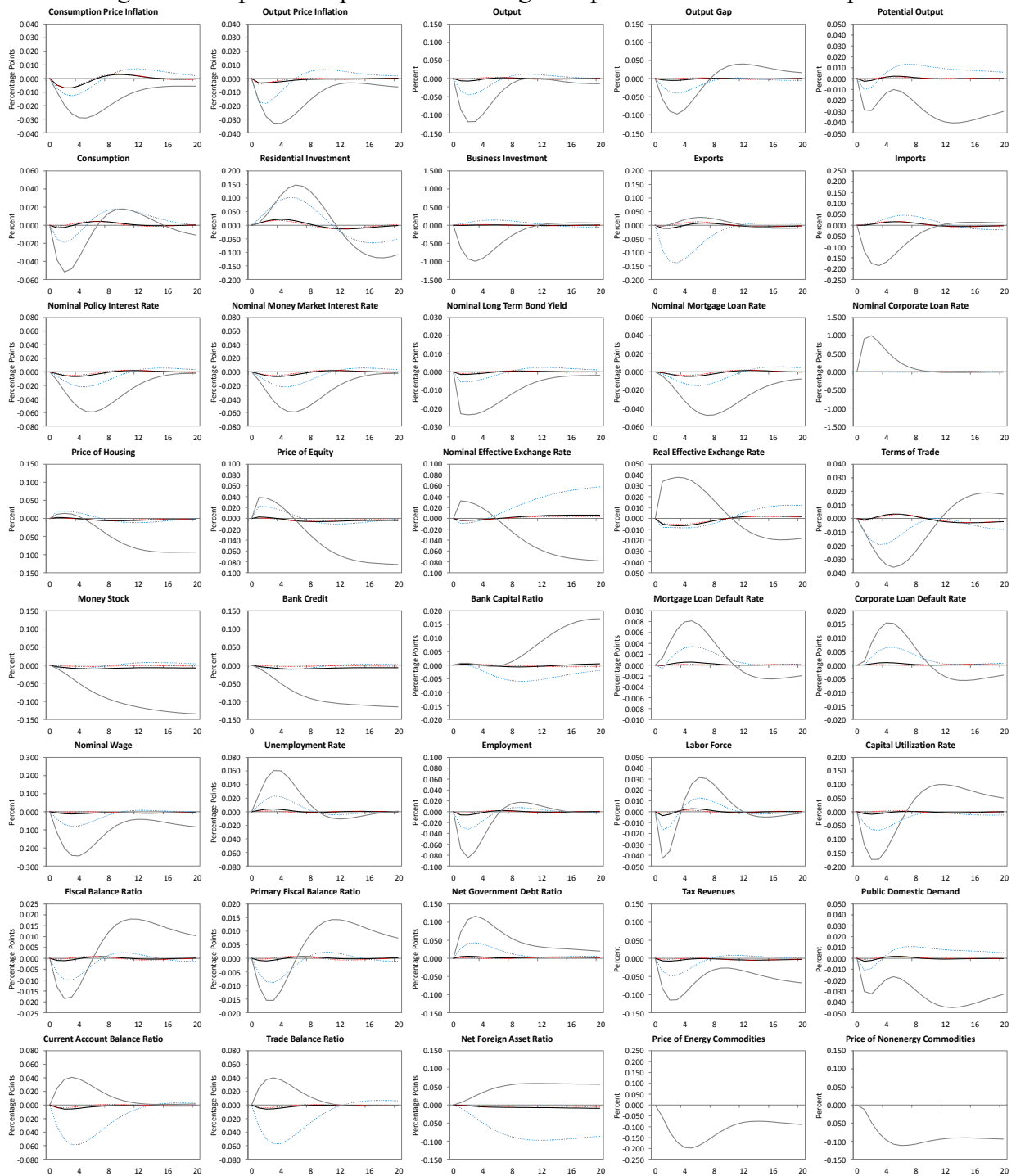
*Note:* Depicts impulse responses for the 2.5<sup>th</sup> percentile recipient economy (Mexico) ■, the median recipient economy (Italy) ■, the 97.5<sup>th</sup> percentile recipient economy (Australia) ■, and the source economy (United States) ■ to a mortgage loan rate markup shock that raises the nominal mortgage loan rate by one percentage point, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

Figure 22. Impulse Responses to a Domestic Corporate Loan Rate Markup Shock



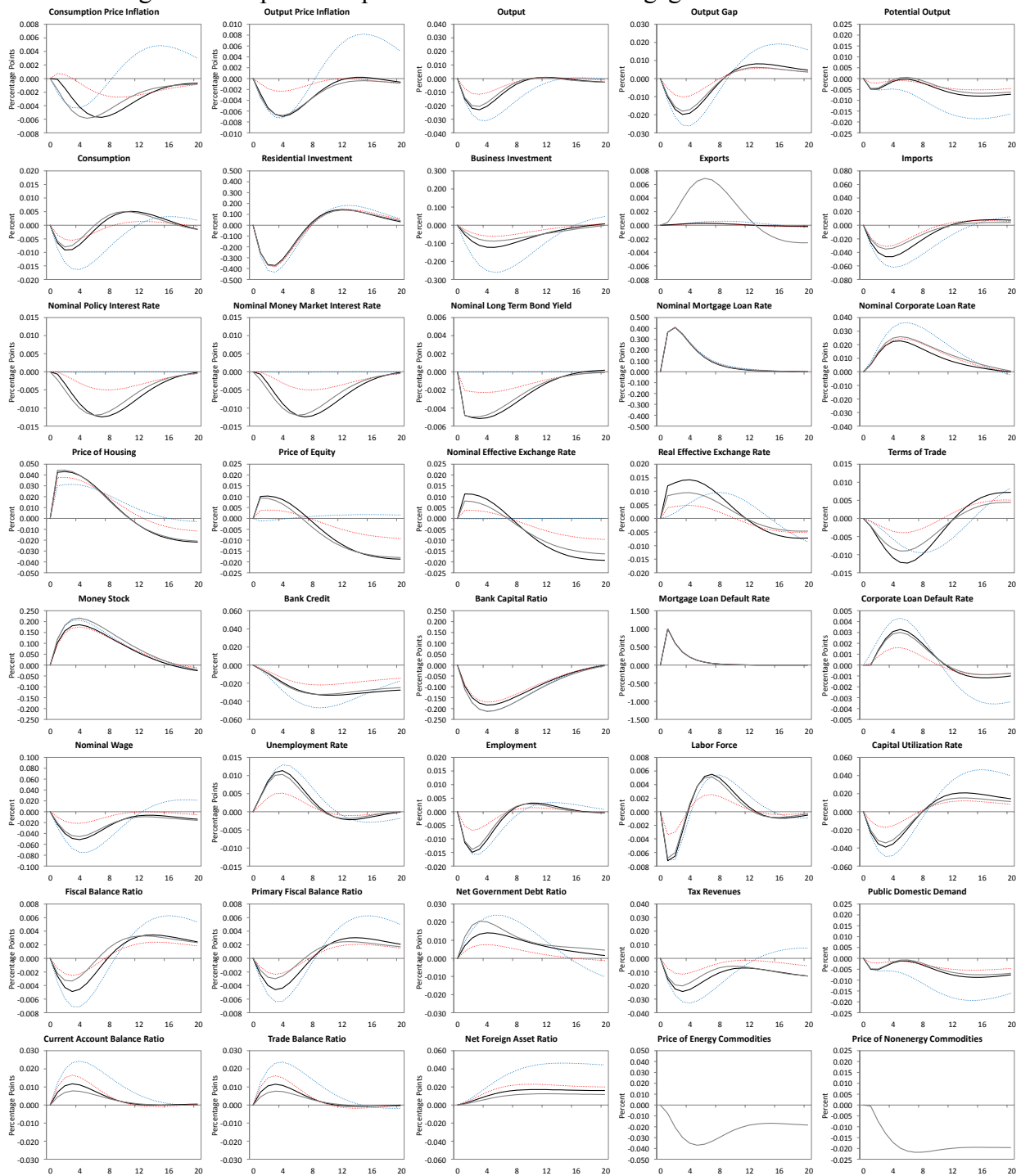
*Note:* Depicts impulse responses for the 2.5<sup>th</sup> percentile economy (China) ■, the median economy (Portugal) ■, the 97.5<sup>th</sup> percentile economy (Czech Republic) ■, and the reference economy (United States) ■ to corporate loan rate markup shocks that raise the nominal corporate loan rate by one percentage point, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

Figure 23. Impulse Responses to a Foreign Corporate Loan Rate Markup Shock



Note: Depicts impulse responses for the 2.5<sup>th</sup> percentile recipient economy (Canada) ■, the median recipient economy (Germany) ■, the 97.5<sup>th</sup> percentile recipient economy (Poland) ■, and the source economy (United States) ■ to a corporate loan rate markup shock that raises the nominal corporate loan rate by one percentage point, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

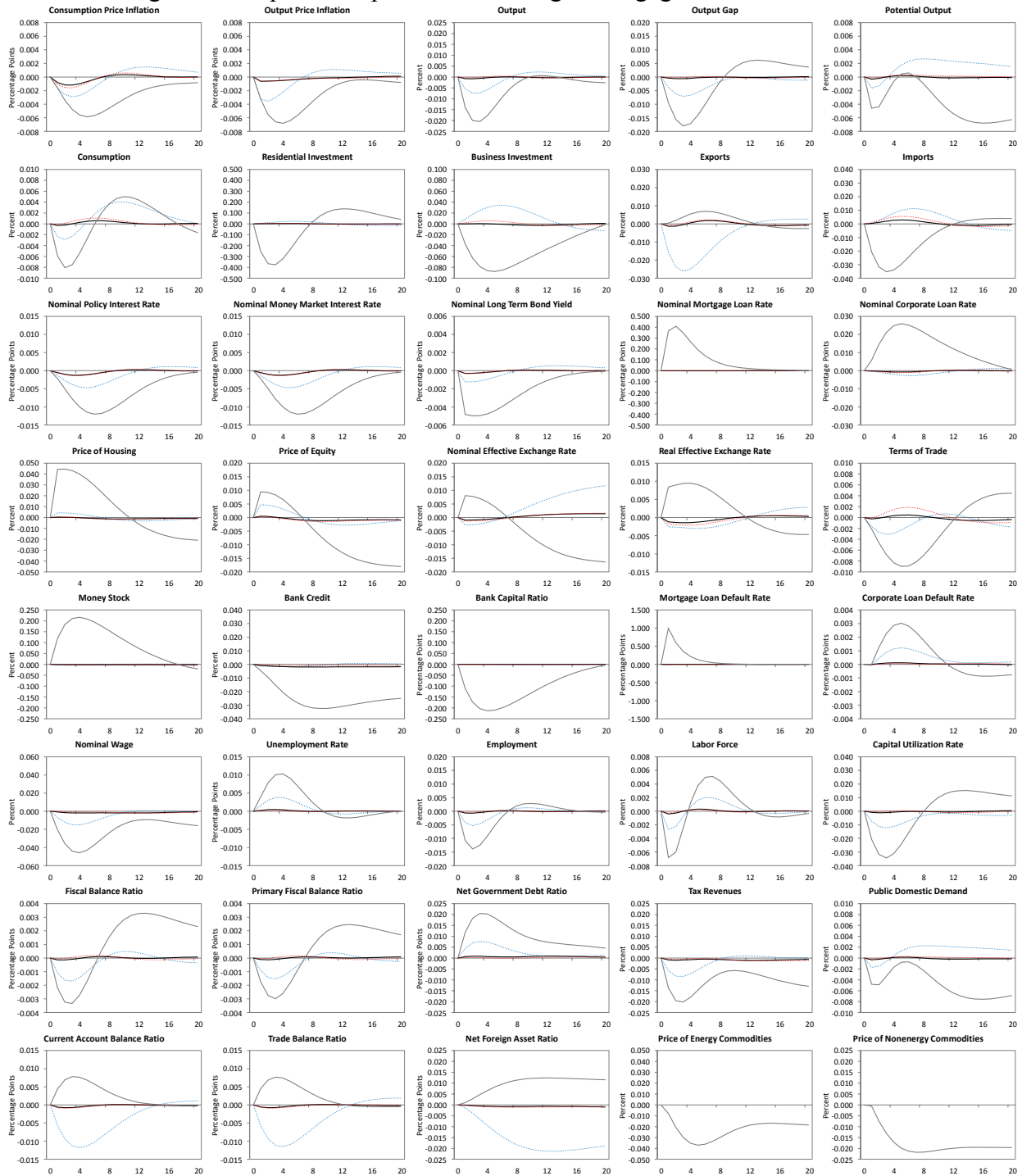
Figure 24. Impulse Responses to a Domestic Mortgage Loan Default Shock



Note: Depicts impulse responses for the 2.5<sup>th</sup> percentile economy (Denmark) ■, the median economy (New Zealand) ■, the 97.5<sup>th</sup> percentile economy (Czech Republic) ■, and the reference economy (United States) ■ to mortgage loan default shocks that raise the mortgage loan default rate by one percentage point, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.



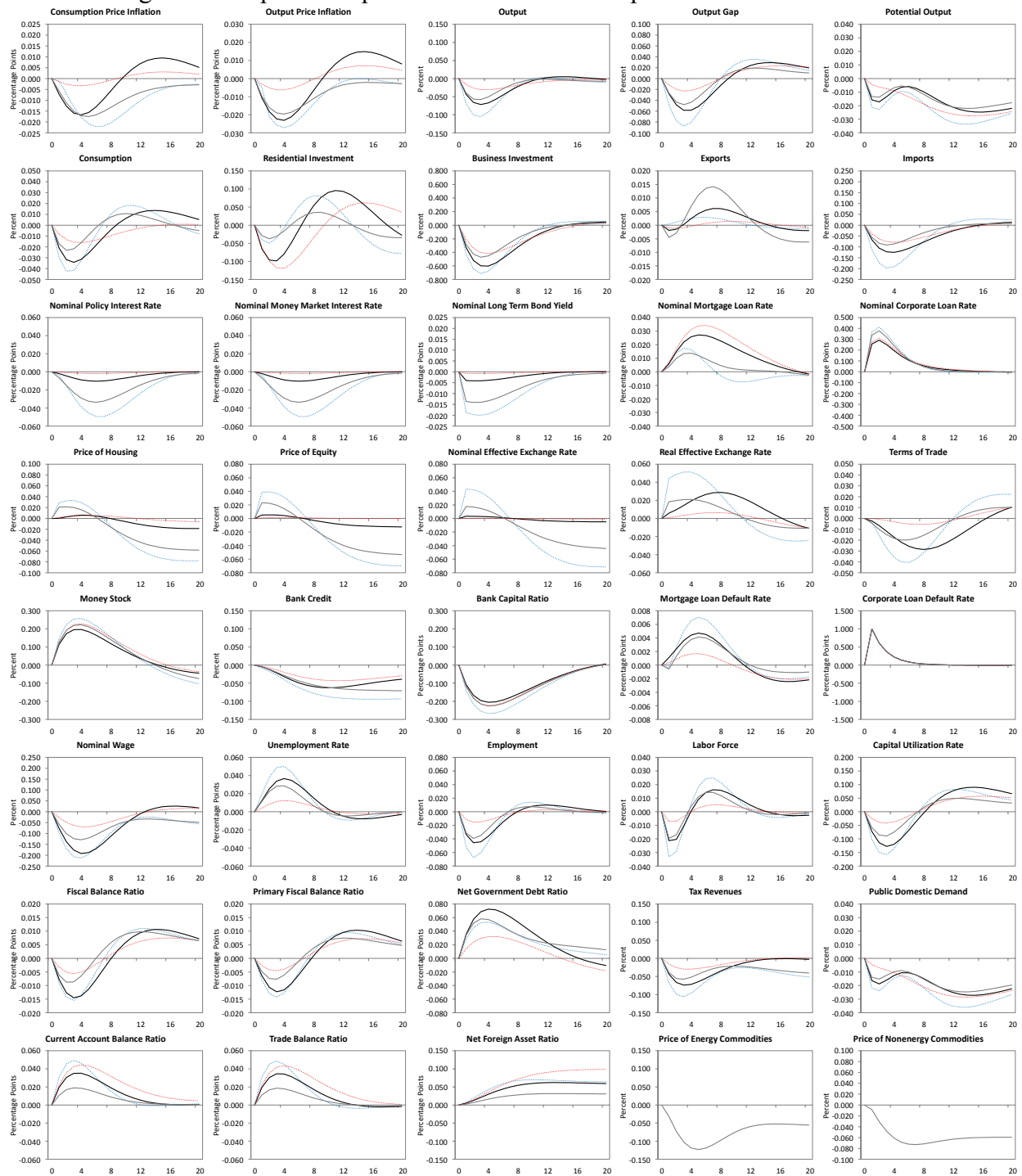
Figure 25. Impulse Responses to a Foreign Mortgage Loan Default Shock



Note: Depicts impulse responses for the 2.5<sup>th</sup> percentile recipient economy (Canada) ■, the median recipient economy (France) ■, the 97.5<sup>th</sup> percentile recipient economy (Turkey) ■, and the source economy (United States) ■ to a mortgage loan default shock that raises the mortgage loan default rate by one percentage point, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

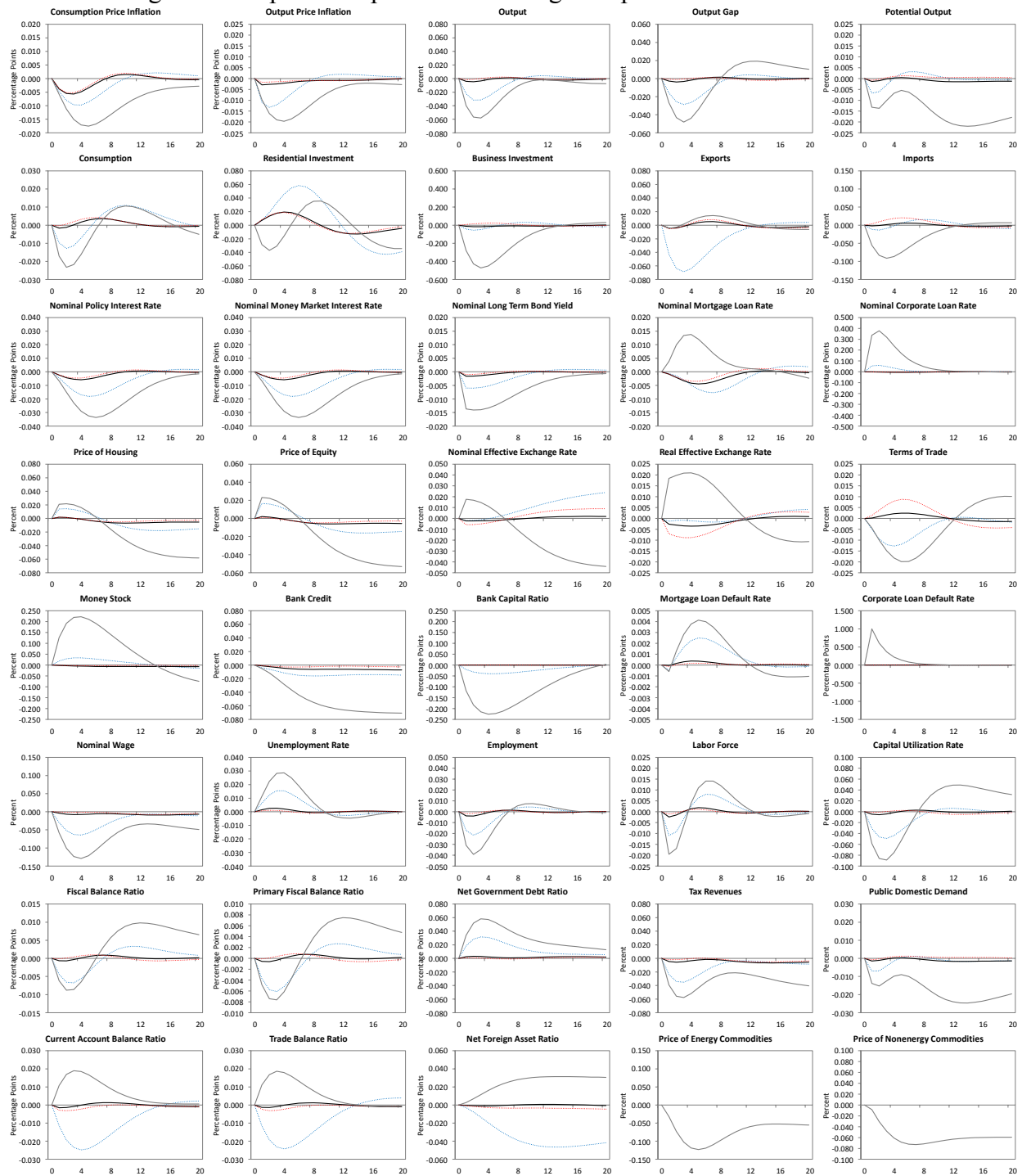


Figure 26. Impulse Responses to a Domestic Corporate Loan Default Shock



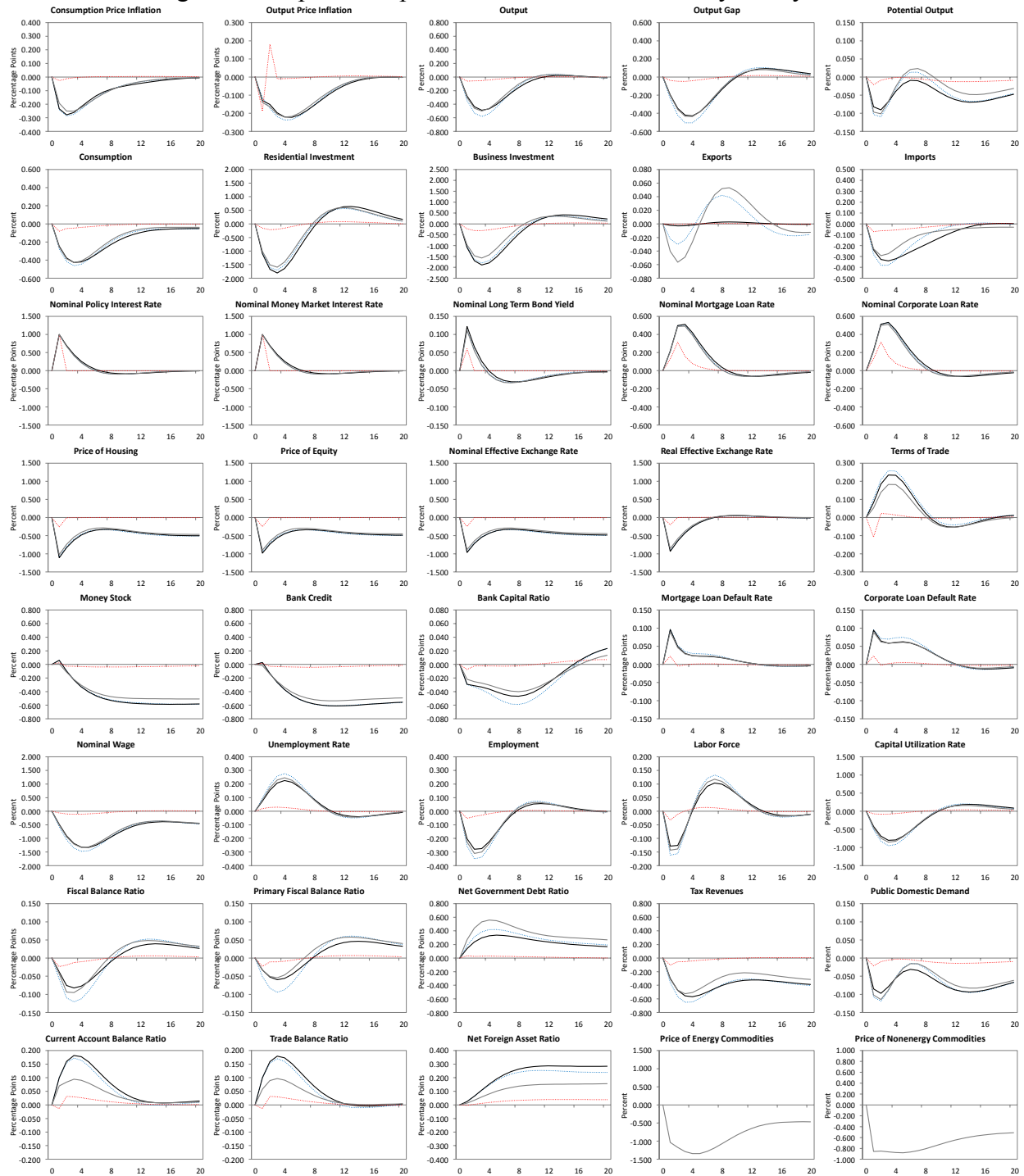
Note: Depicts impulse responses for the 2.5<sup>th</sup> percentile economy (Indonesia) ■, the median economy (France) ■, the 97.5<sup>th</sup> percentile economy (Belgium) ■, and the reference economy (United States) ■ to corporate loan default shocks that raise the corporate loan default rate by one percentage point, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

Figure 27. Impulse Responses to a Foreign Corporate Loan Default Shock



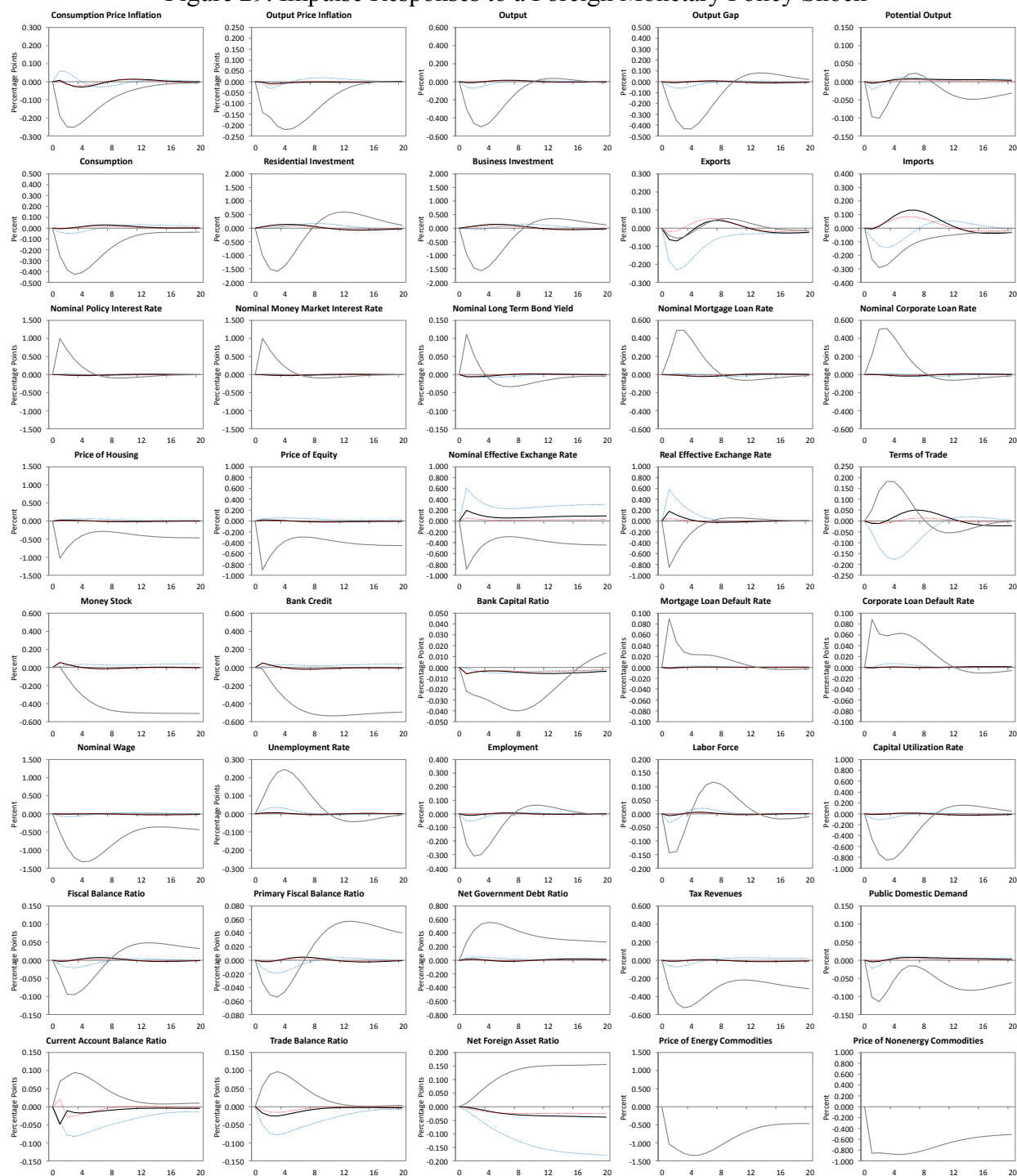
Note: Depicts impulse responses for the 2.5<sup>th</sup> percentile recipient economy (Canada) ■, the median recipient economy (Czech Republic) ■, the 97.5<sup>th</sup> percentile recipient economy (New Zealand) ■, and the source economy (United States) ■ to a corporate loan default shock that raises the corporate loan default rate by one percentage point, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

Figure 28. Impulse Responses to a Domestic Monetary Policy Shock



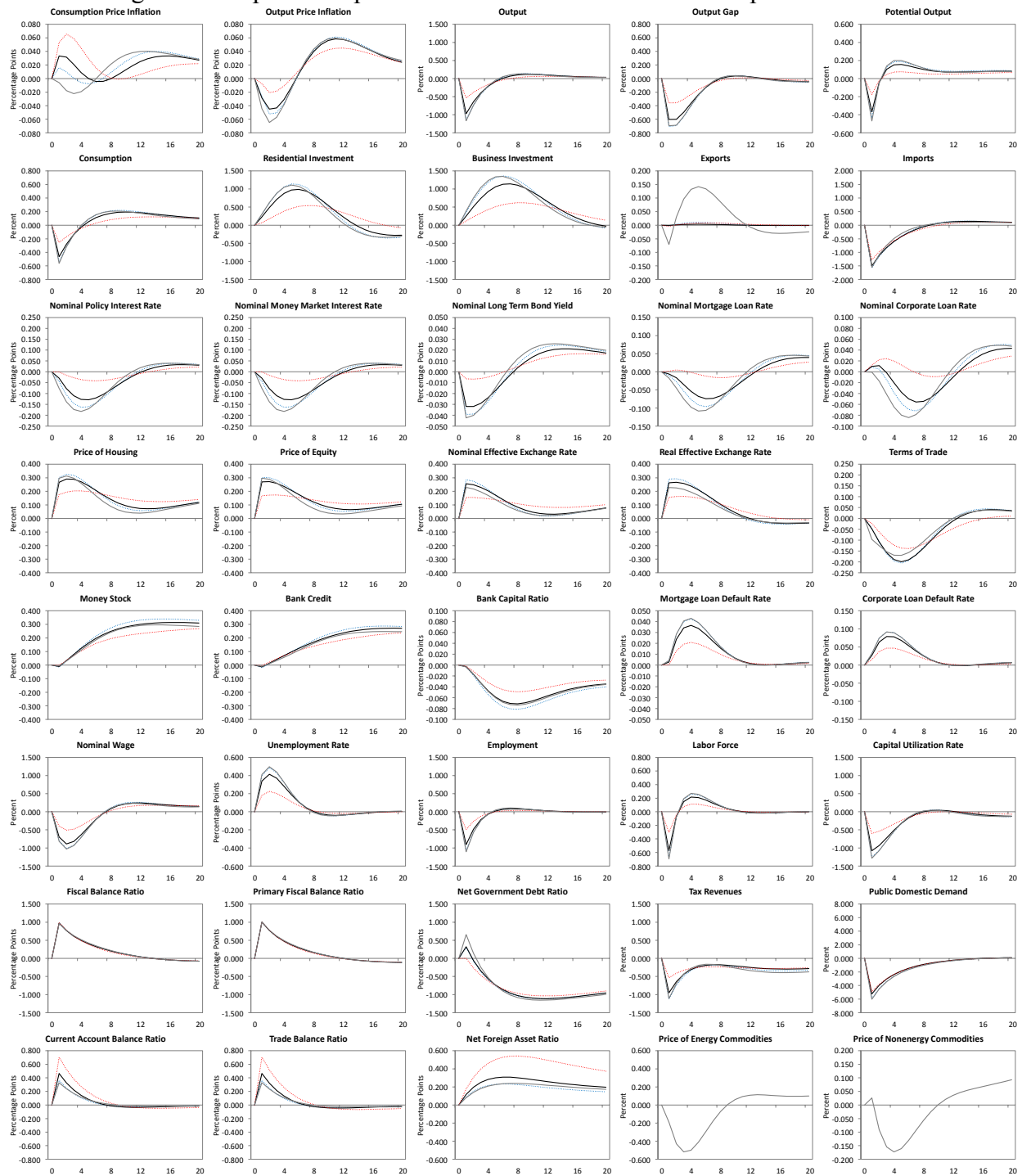
Note: Depicts impulse responses for the 2.5<sup>th</sup> percentile economy (China) ■, the median economy (Turkey) ■, the 97.5<sup>th</sup> percentile economy (Saudi Arabia) ■, and the reference economy (United States) ■ to monetary policy shocks that raise the nominal policy interest rate by one percentage point, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

Figure 29. Impulse Responses to a Foreign Monetary Policy Shock



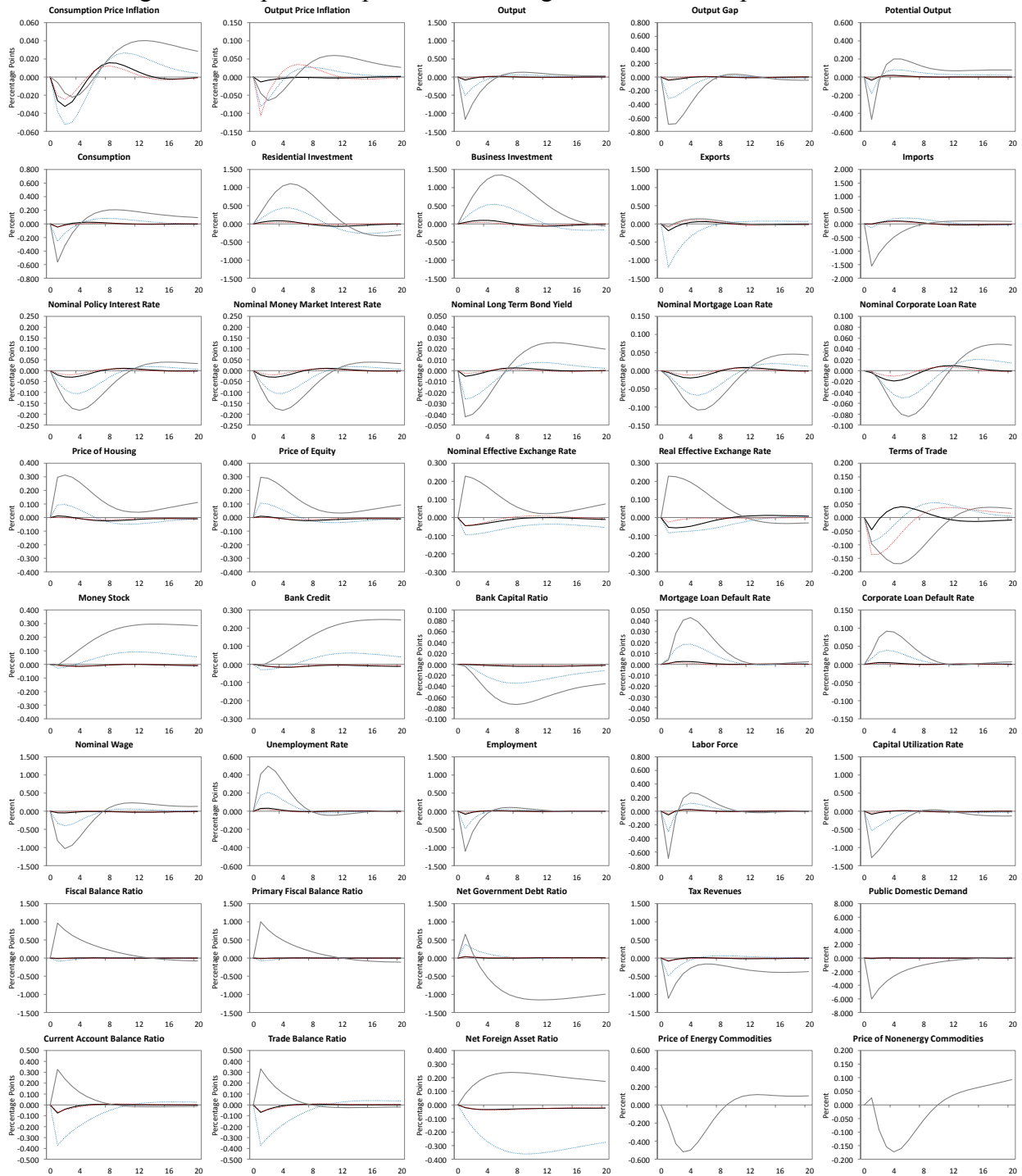
*Note:* Depicts impulse responses for the 2.5<sup>th</sup> percentile recipient economy (Mexico) ■, the median recipient economy (Japan) ■, the 97.5<sup>th</sup> percentile recipient economy (Spain) ■, and the source economy (United States) ■ to a monetary policy shock that raises the nominal policy interest rate by one percentage point, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

Figure 30. Impulse Responses to a Domestic Government Expenditure Shock



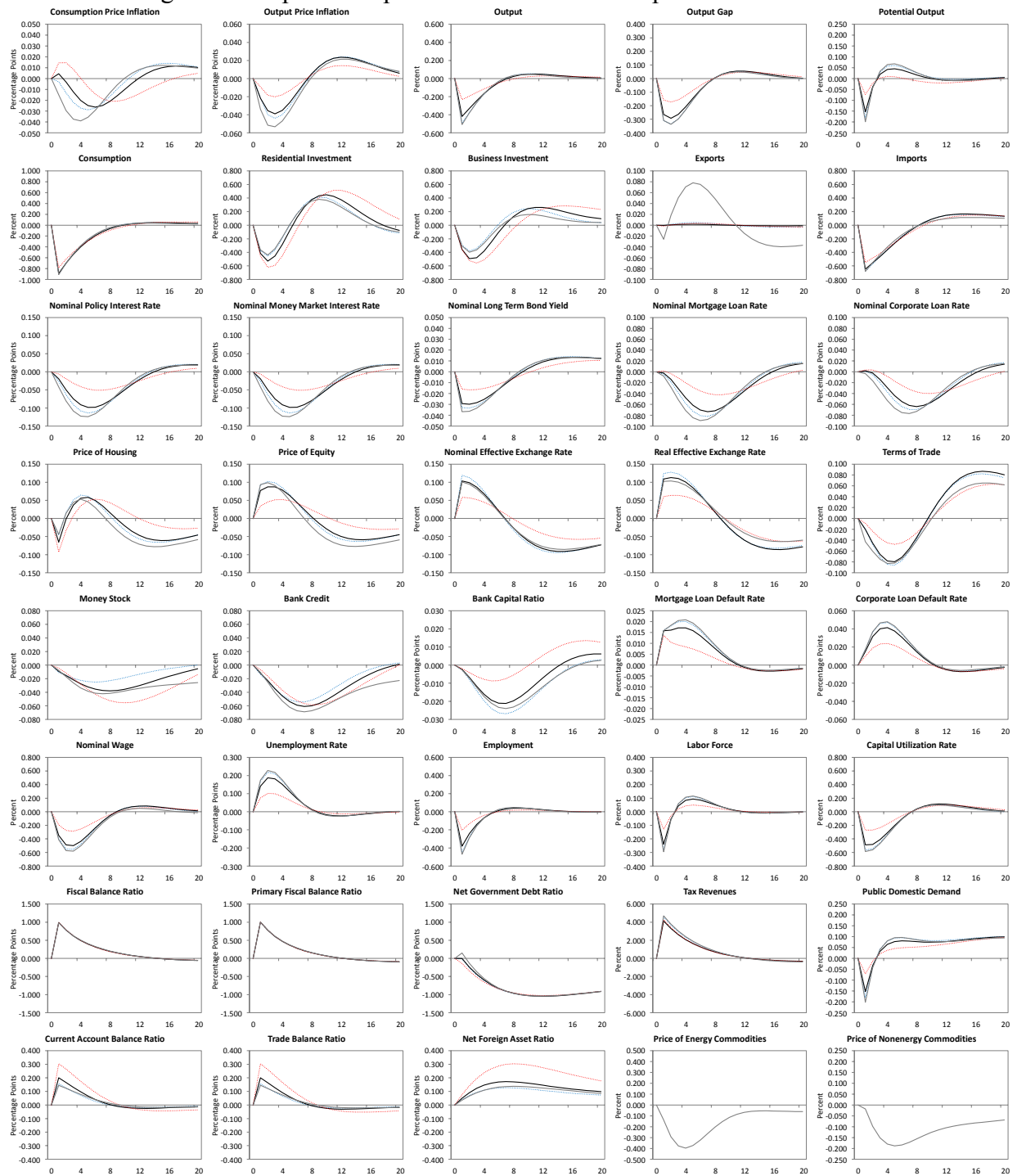
Note: Depicts impulse responses for the 2.5<sup>th</sup> percentile economy (Argentina) ■, the median economy (Israel) ■, the 97.5<sup>th</sup> percentile economy (Czech Republic) ■, and the reference economy (United States) ■ to government expenditure shocks that raise the primary fiscal balance ratio by one percentage point, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

Figure 31. Impulse Responses to a Foreign Government Expenditure Shock



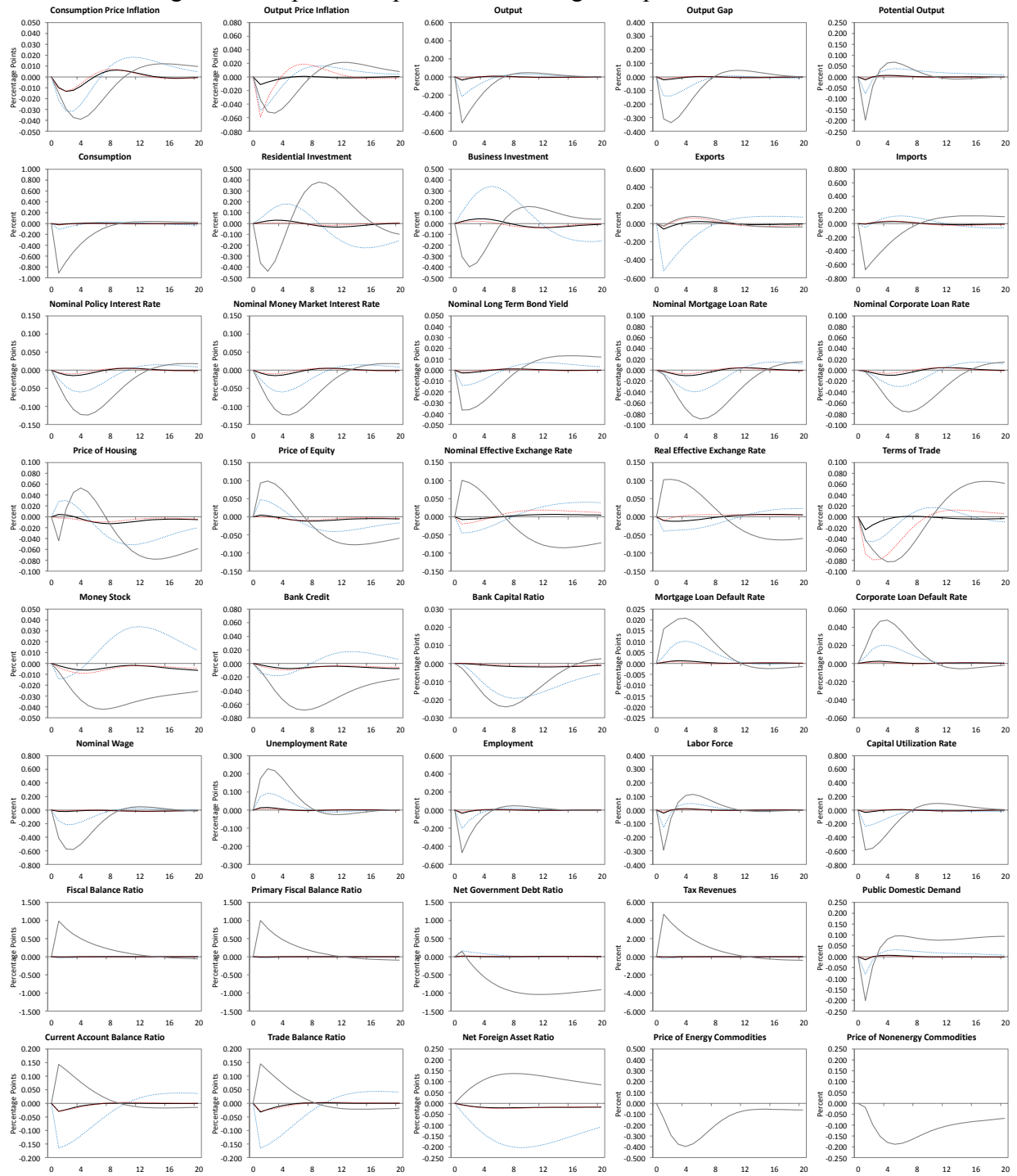
Note: Depicts impulse responses for the 2.5<sup>th</sup> percentile recipient economy (Canada) ■, the median recipient economy (New Zealand) ■, the 97.5<sup>th</sup> percentile recipient economy (Australia) ■, and the source economy (United States) ■ to a government expenditure shock that raises the primary fiscal balance ratio by one percentage point, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

Figure 32. Impulse Responses to a Domestic Corporate Tax Rate Shock



Note: Depicts impulse responses for the 2.5<sup>th</sup> percentile economy (Argentina) ■, the median economy (Israel) ■, the 97.5<sup>th</sup> percentile economy (Czech Republic) ■, and the reference economy (United States) ■ to corporate tax rate shocks that raise the primary fiscal balance ratio by one percentage point, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

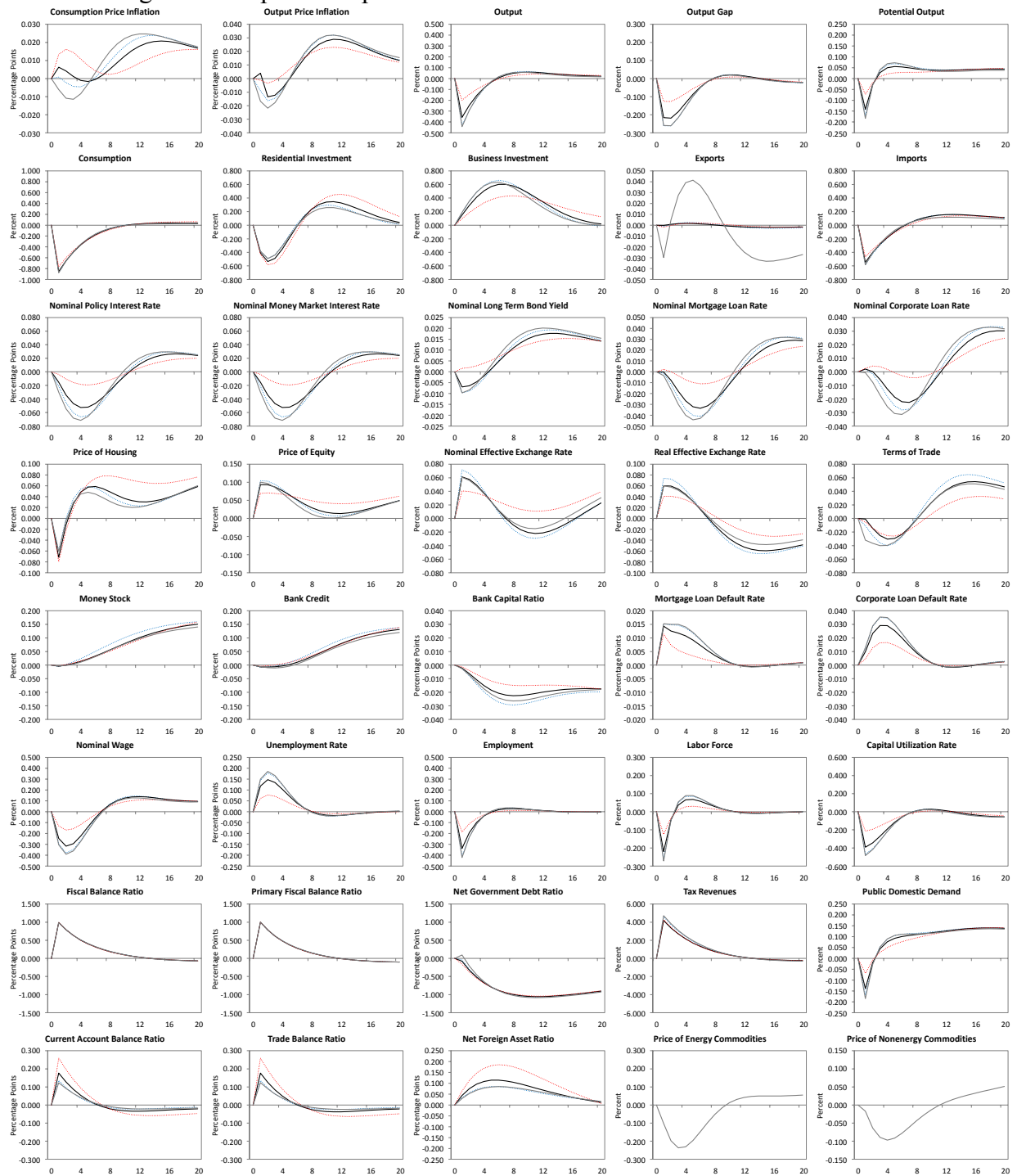
Figure 33. Impulse Responses to a Foreign Corporate Tax Rate Shock



Note: Depicts impulse responses for the 2.5<sup>th</sup> percentile recipient economy (Canada) ■, the median recipient economy (Denmark) ■, the 97.5<sup>th</sup> percentile recipient economy (Australia) ■, and the source economy (United States) ■ to a corporate tax rate shock that raises the primary fiscal balance ratio by one percentage point, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

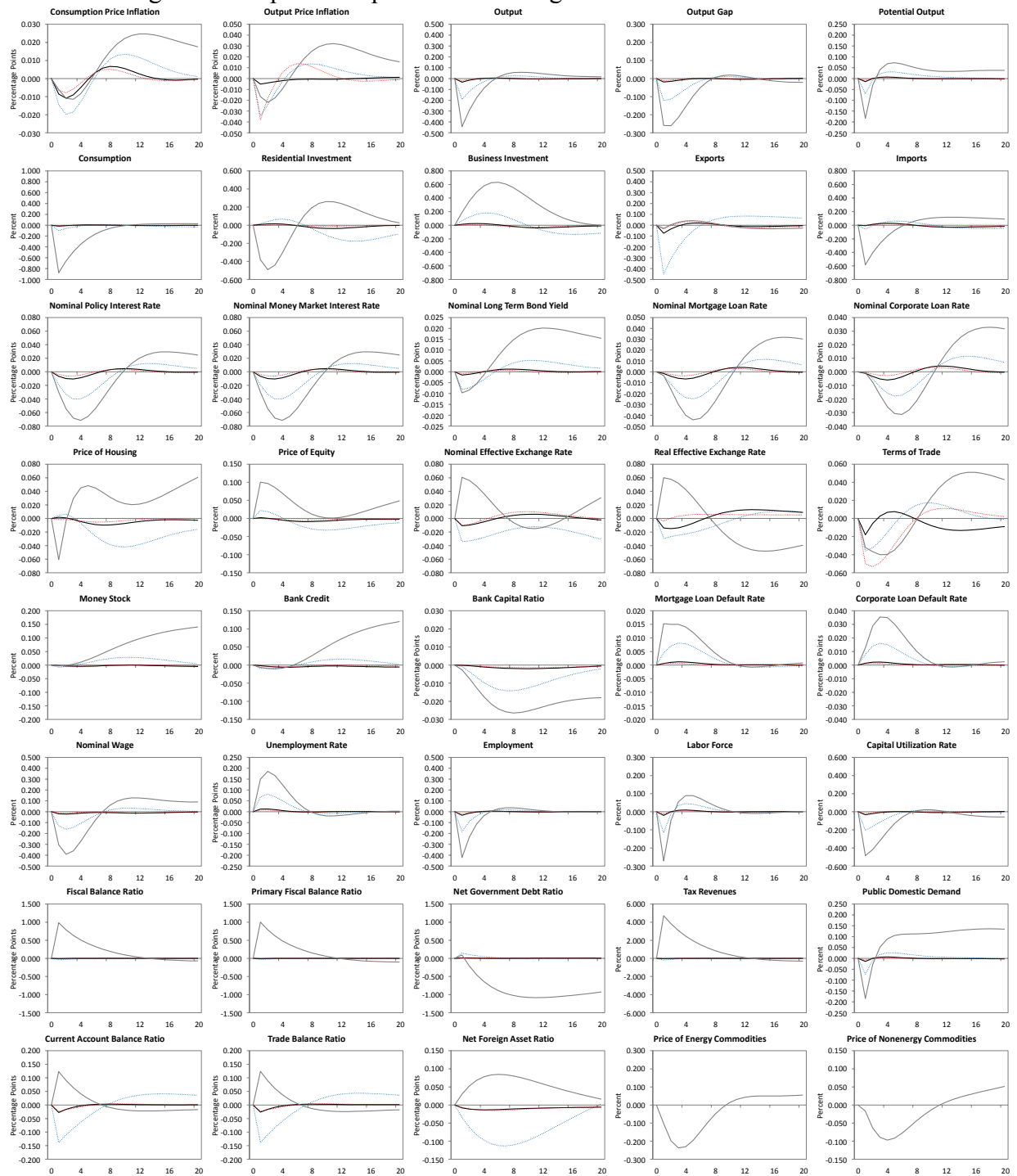


Figure 34. Impulse Responses to a Domestic Labor Income Tax Rate Shock



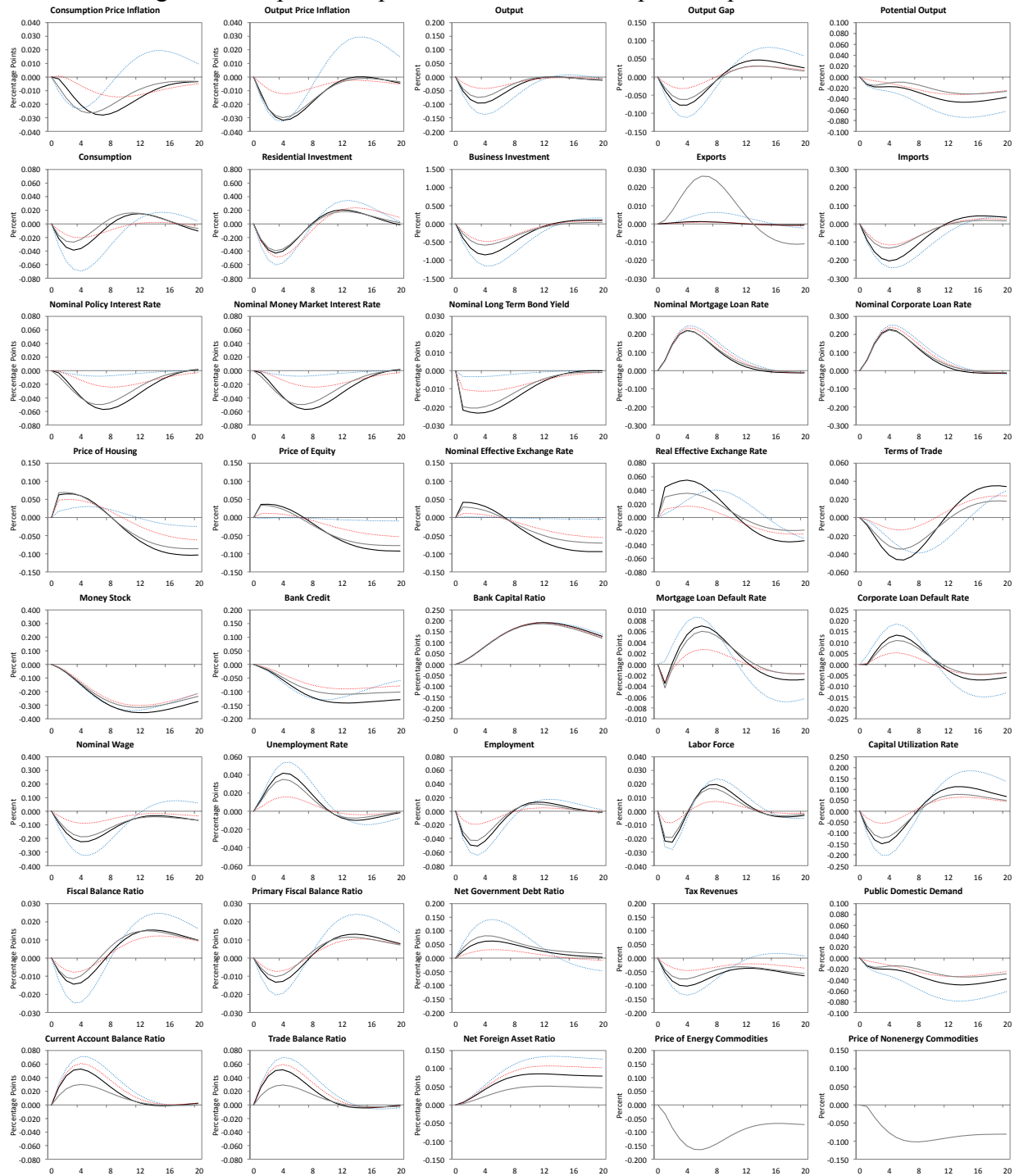
*Note:* Depicts impulse responses for the 2.5<sup>th</sup> percentile economy (Argentina) ■, the median economy (South Africa) ■, the 97.5<sup>th</sup> percentile economy (Czech Republic) ■, and the reference economy (United States) ■ to labor income tax rate shocks that raise the primary fiscal balance ratio by one percentage point, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

Figure 35. Impulse Responses to a Foreign Labor Income Tax Rate Shock



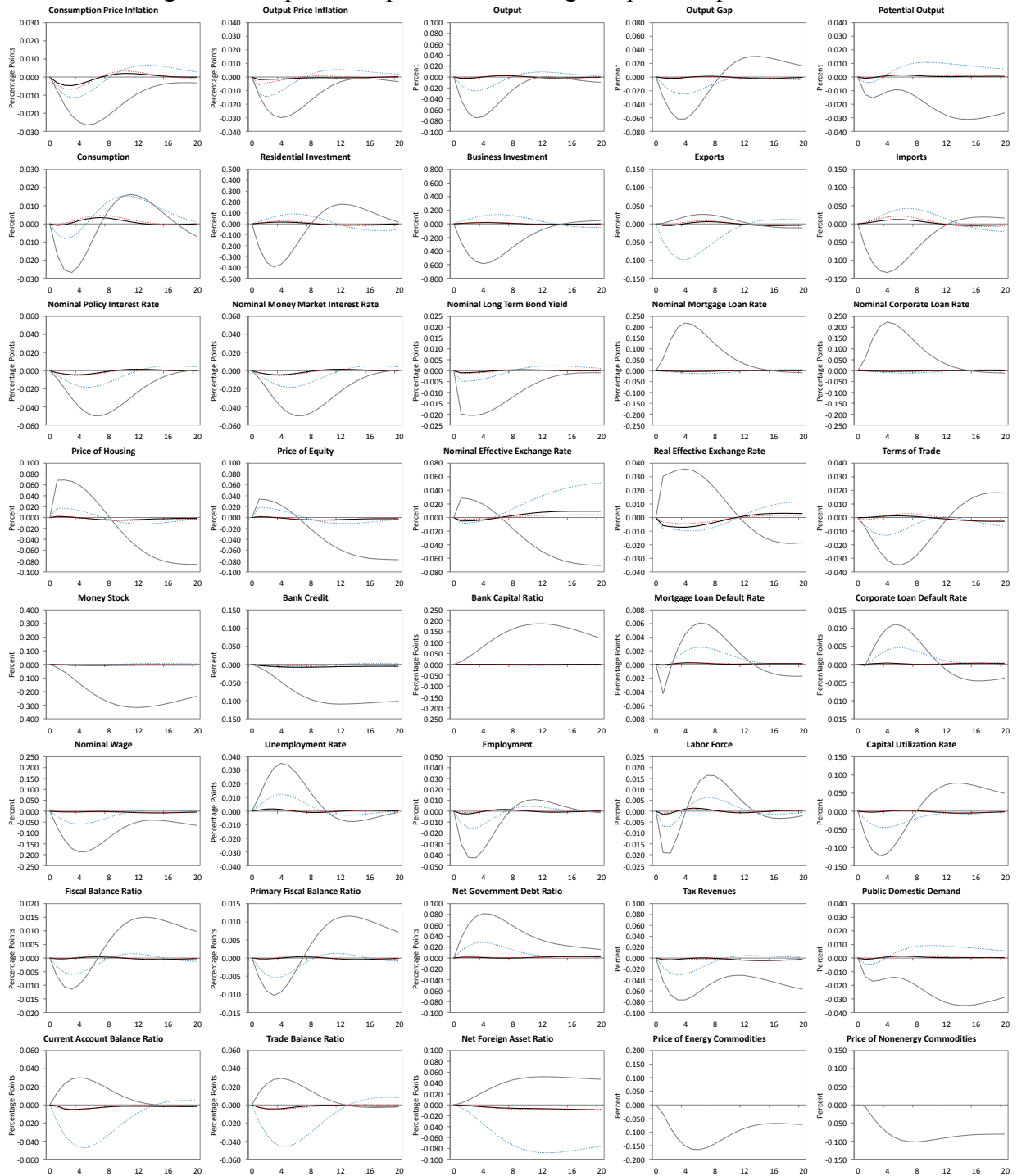
Note: Depicts impulse responses for the 2.5<sup>th</sup> percentile recipient economy (Canada) ■, the median recipient economy (New Zealand) ■, the 97.5<sup>th</sup> percentile recipient economy (Australia) ■, and the source economy (United States) ■ to a labor income tax rate shock that raises the primary fiscal balance ratio by one percentage point, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

Figure 36. Impulse Responses to a Domestic Capital Requirement Shock



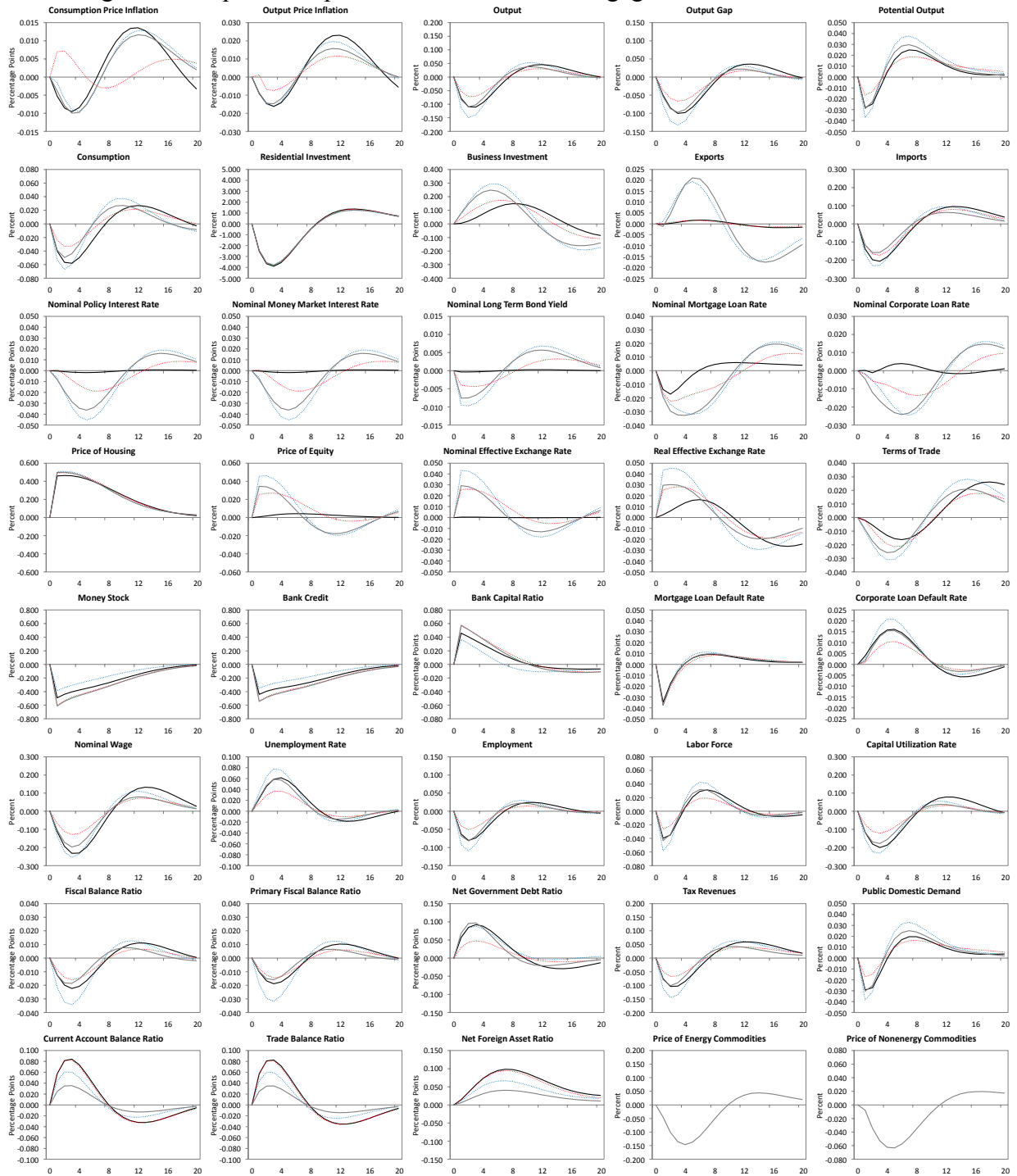
*Note:* Depicts impulse responses for the 2.5<sup>th</sup> percentile economy (Spain) ■, the median economy (Philippines) ■, the 97.5<sup>th</sup> percentile economy (Czech Republic) ■, and the reference economy (United States) ■ to capital requirement shocks that raise the bank capital ratio requirement by one percentage point, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

Figure 37. Impulse Responses to a Foreign Capital Requirement Shock



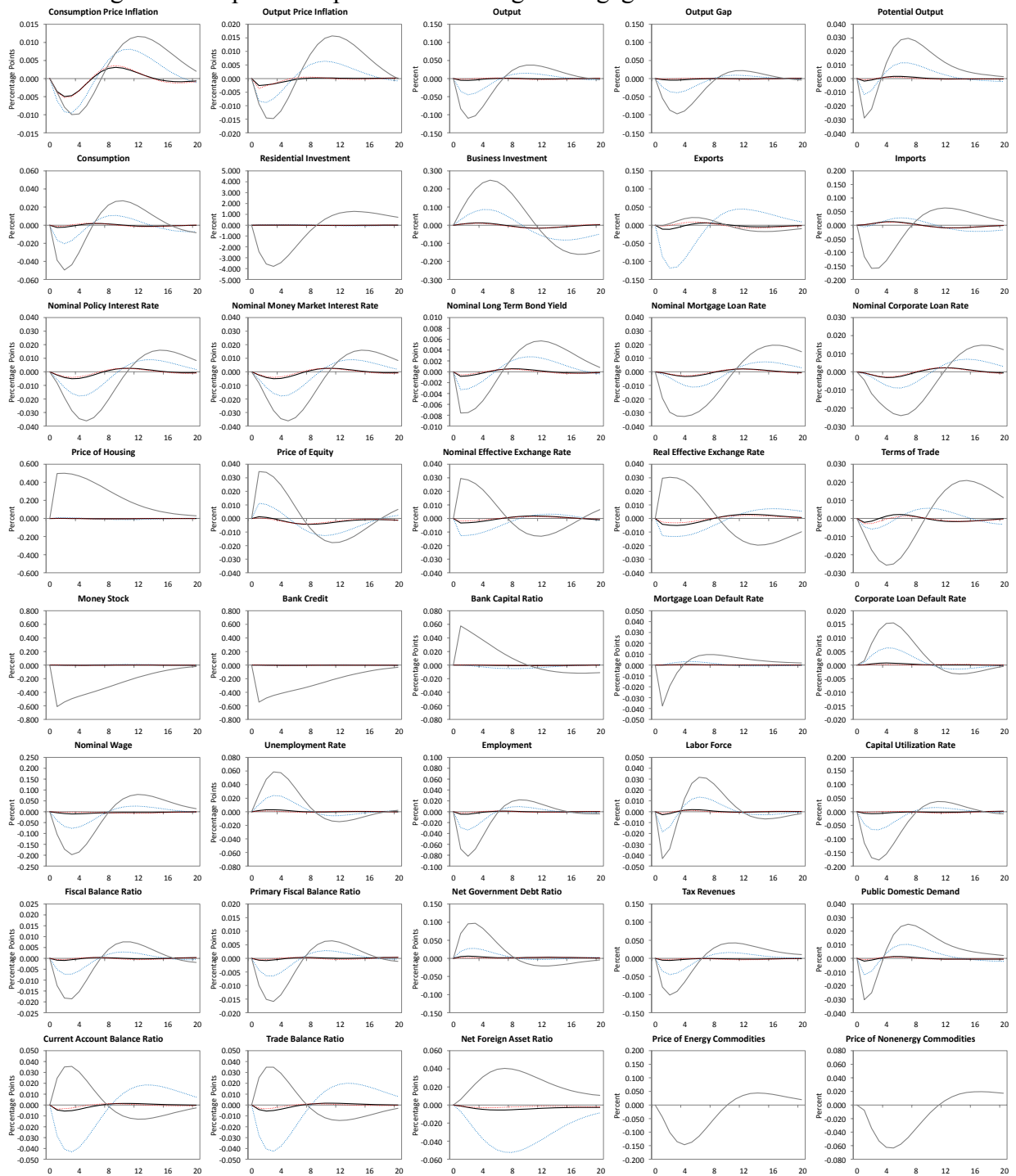
Note: Depicts impulse responses for the 2.5<sup>th</sup> percentile recipient economy (Canada) ■, the median recipient economy (Switzerland) ■, the 97.5<sup>th</sup> percentile recipient economy (Finland) ■, and the source economy (United States) ■ to a capital requirement shock that raises the bank capital ratio requirement by one percentage point, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

Figure 38. Impulse Responses to a Domestic Mortgage Loan to Value Limit Shock



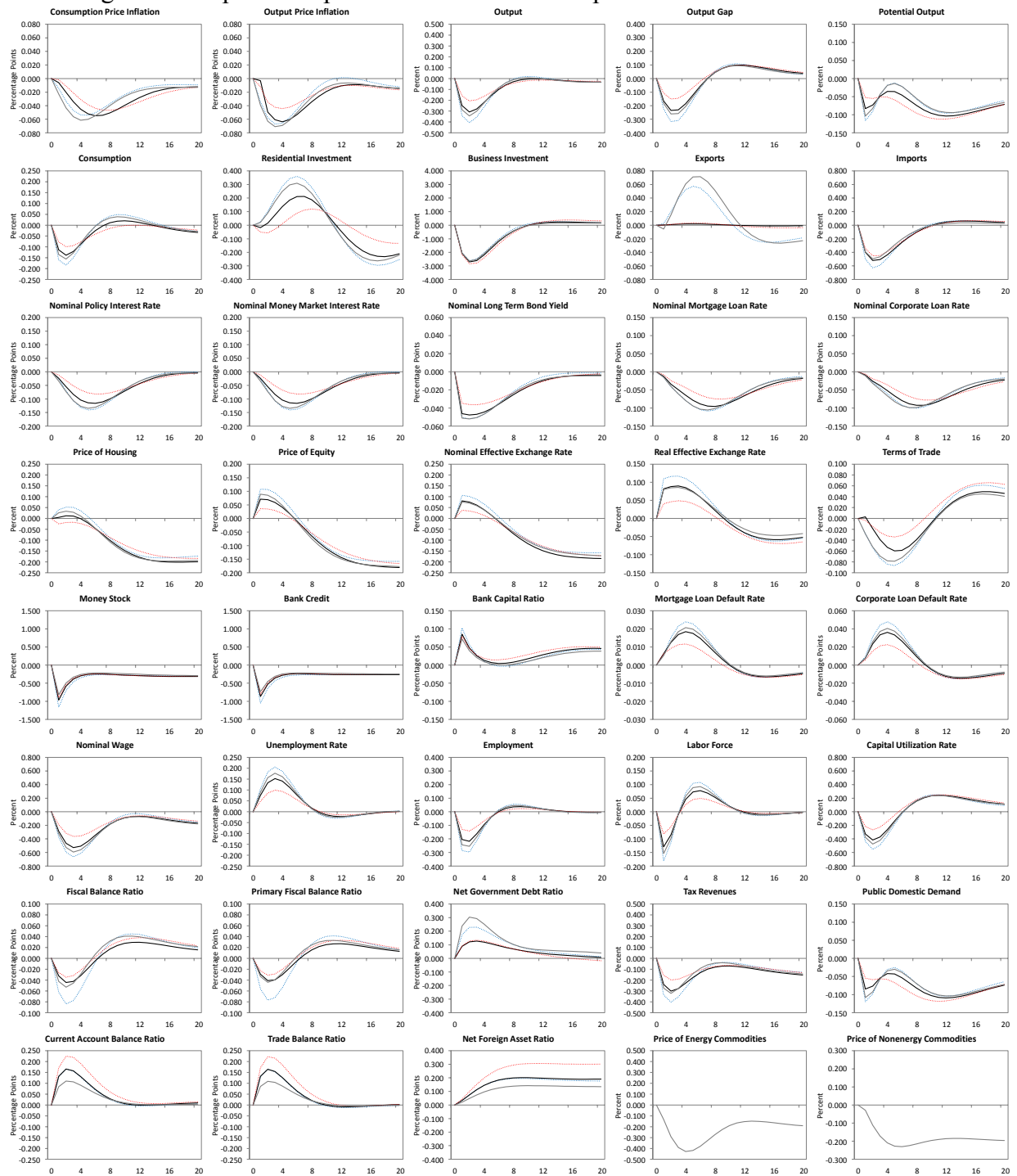
Note: Depicts impulse responses for the 2.5<sup>th</sup> percentile economy (China) ■, the median economy (Austria) ■, the 97.5<sup>th</sup> percentile economy (Malaysia) ■, and the reference economy (United States) ■ to mortgage loan to value limit shocks that reduce the mortgage loan to value ratio limit by one percentage point, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

Figure 39. Impulse Responses to a Foreign Mortgage Loan to Value Limit Shock



Note: Depicts impulse responses for the 2.5<sup>th</sup> percentile recipient economy (Mexico) ■, the median recipient economy (Italy) ■, the 97.5<sup>th</sup> percentile recipient economy (Poland) ■, and the source economy (United States) ■ to a mortgage loan to value limit shock that reduces the mortgage loan to value ratio limit by one percentage point, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

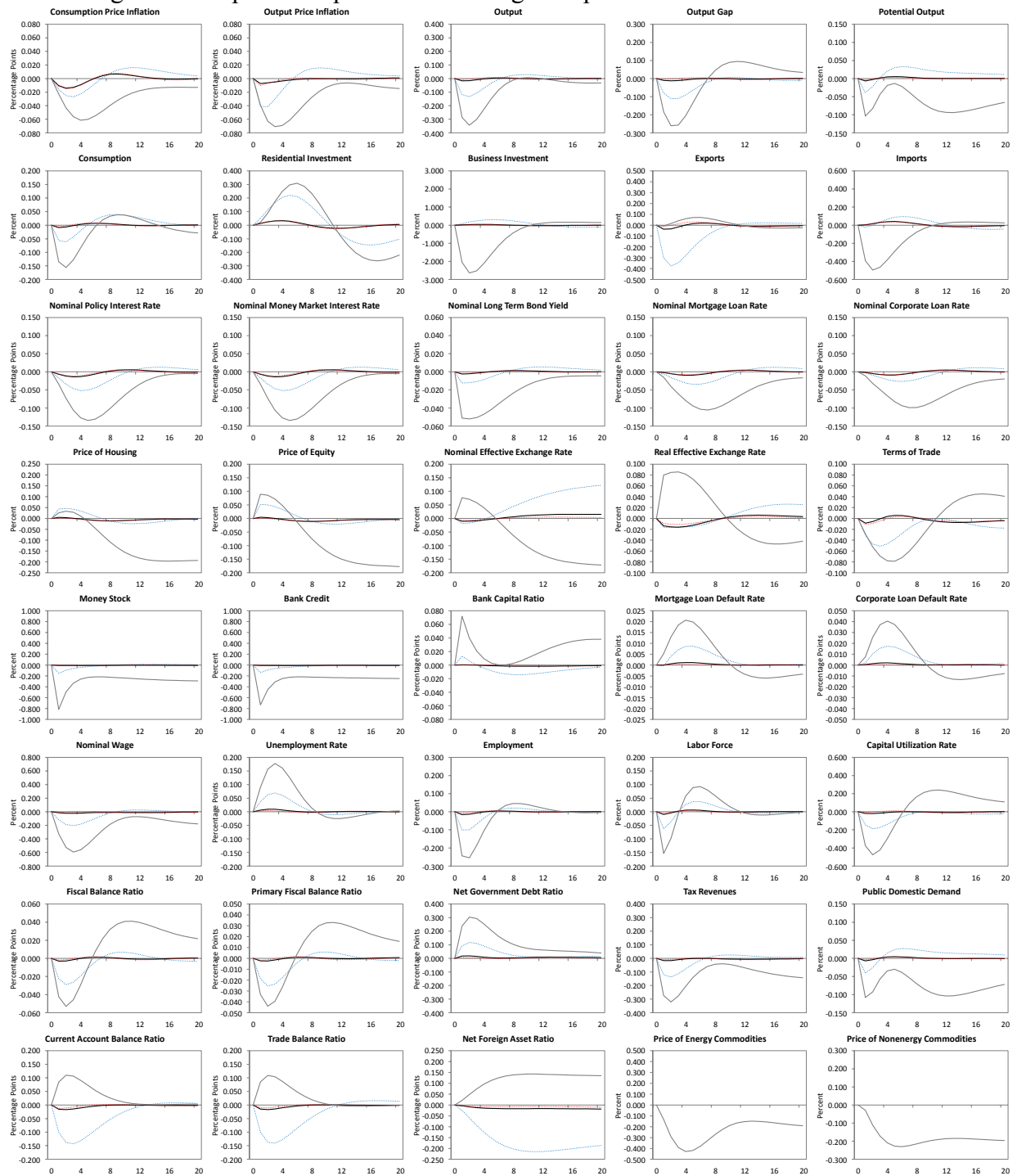
Figure 40. Impulse Responses to a Domestic Corporate Loan to Value Limit Shock



*Note:* Depicts impulse responses for the 2.5<sup>th</sup> percentile economy (China) ■, the median economy (Chile) ■, the 97.5<sup>th</sup> percentile economy (Malaysia) ■, and the reference economy (United States) ■ to corporate loan to value limit shocks that reduce the corporate loan to value ratio limit by one percentage point, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.



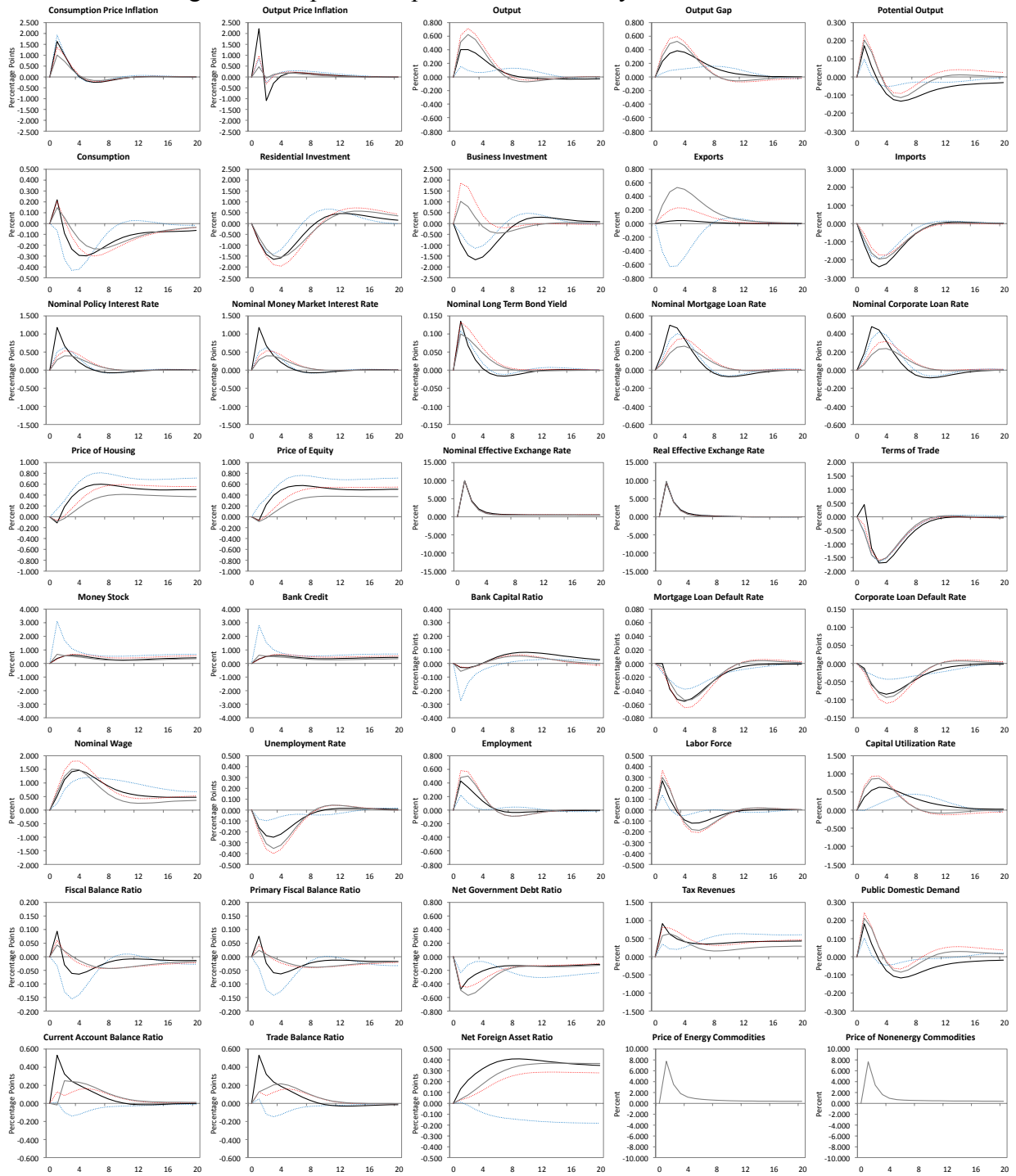
Figure 41. Impulse Responses to a Foreign Corporate Loan to Value Limit Shock



Note: Depicts impulse responses for the 2.5<sup>th</sup> percentile recipient economy (Canada) ■, the median recipient economy (Italy) ■, the 97.5<sup>th</sup> percentile recipient economy (Poland) ■, and the source economy (United States) ■ to a corporate loan to value limit shock that reduces the corporate loan to value ratio limit by one percentage point, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

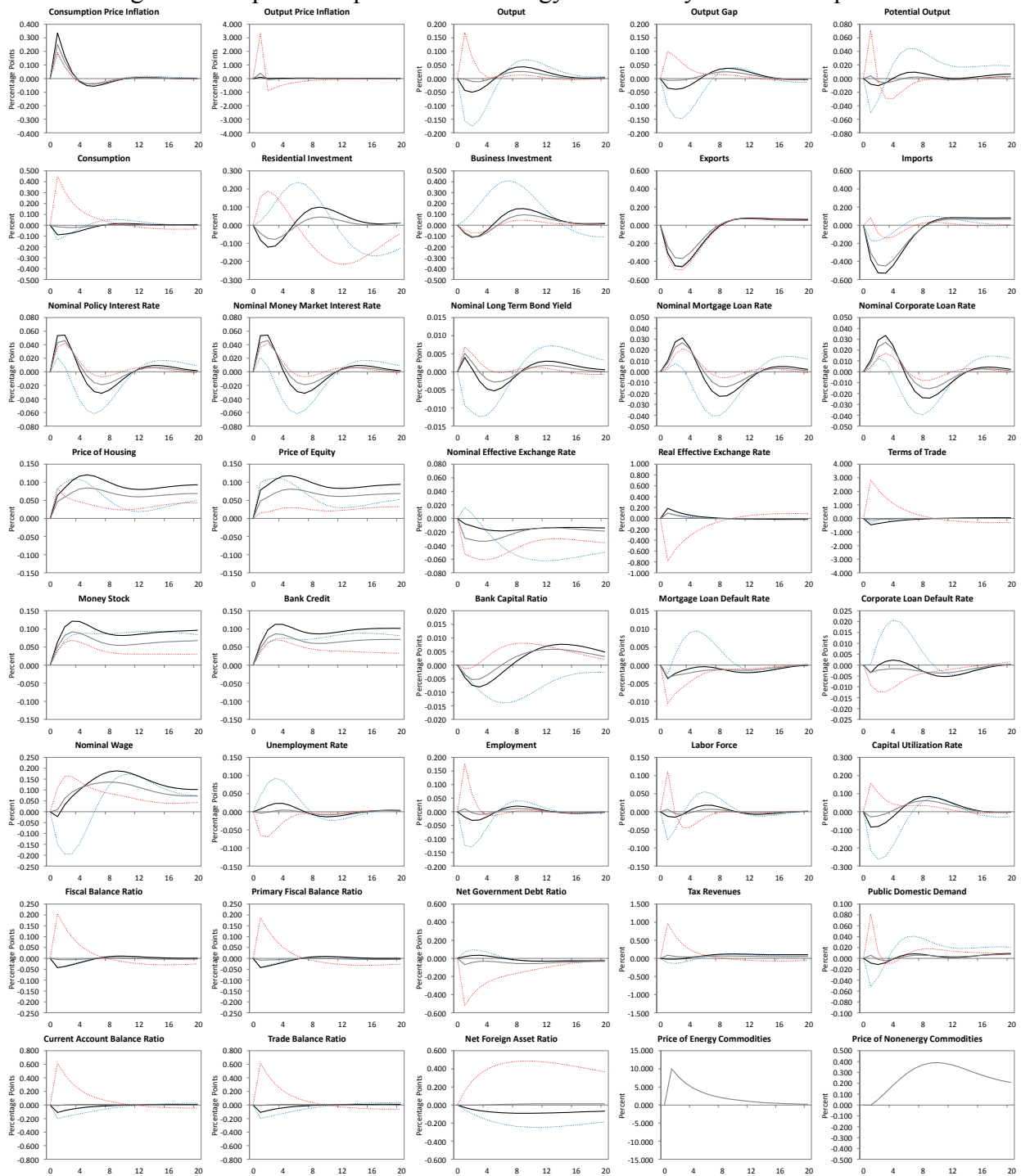


Figure 42. Impulse Responses to a Currency Risk Premium Shock



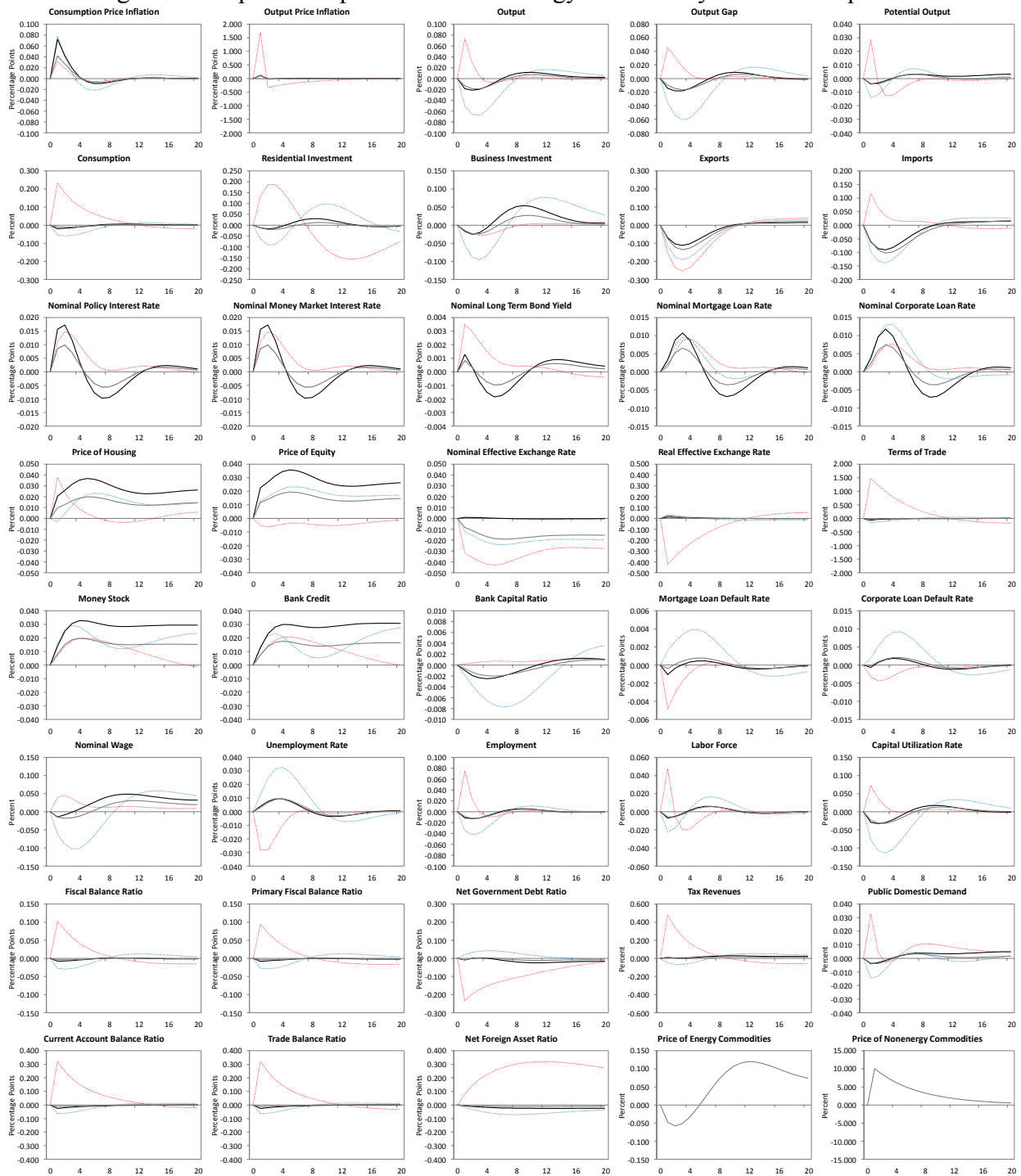
Note: Depicts impulse responses for the 2.5<sup>th</sup> percentile economy (Austria) ■, the median economy (South Africa) ■, the 97.5<sup>th</sup> percentile economy (Mexico) ■, and the reference economy (United States) ■ to currency risk premium shocks that depreciate the currency by ten percent in nominal effective terms, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

Figure 43. Impulse Responses to an Energy Commodity Price Markup Shock



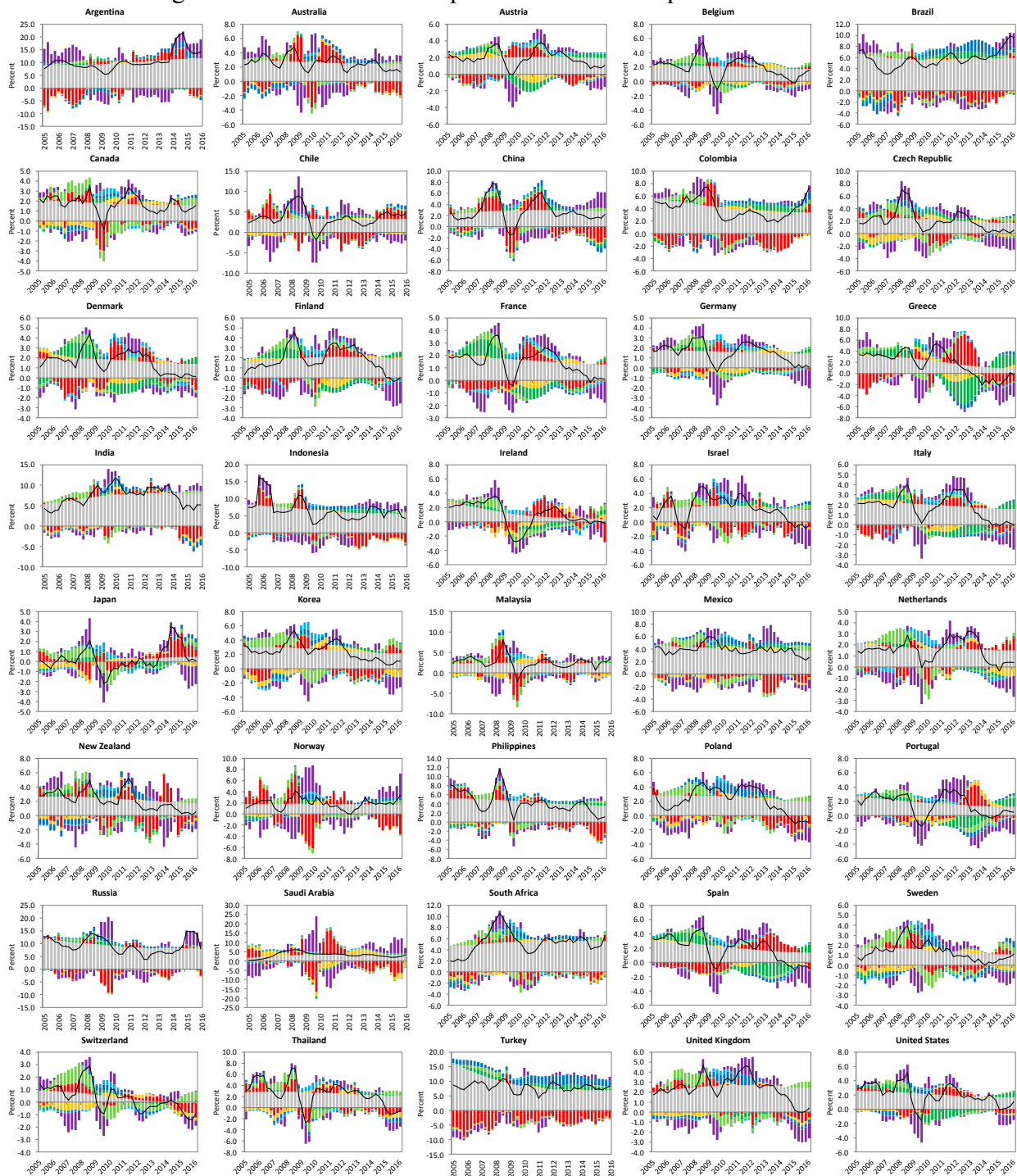
Note: Depicts impulse responses for the 2.5<sup>th</sup> percentile economy (Switzerland) ■, the median economy (China) ■, the 97.5<sup>th</sup> percentile economy (Colombia) ■, and the reference economy (United States) ■ to an energy commodity price markup shock that raises the price of energy commodities by ten percent, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

Figure 44. Impulse Responses to a Nonenergy Commodity Price Markup Shock



*Note:* Depicts impulse responses for the 2.5<sup>th</sup> percentile economy (Saudi Arabia) ■, the median economy (Portugal) ■, the 97.5<sup>th</sup> percentile economy (Australia) ■, and the reference economy (United States) ■ to a nonenergy commodity price markup shock that raises the price of nonenergy commodities by ten percent, ranked with respect to the peak impulse response of output. All variables are annualized, where applicable.

Figure 45. Historical Decompositions of Consumption Price Inflation



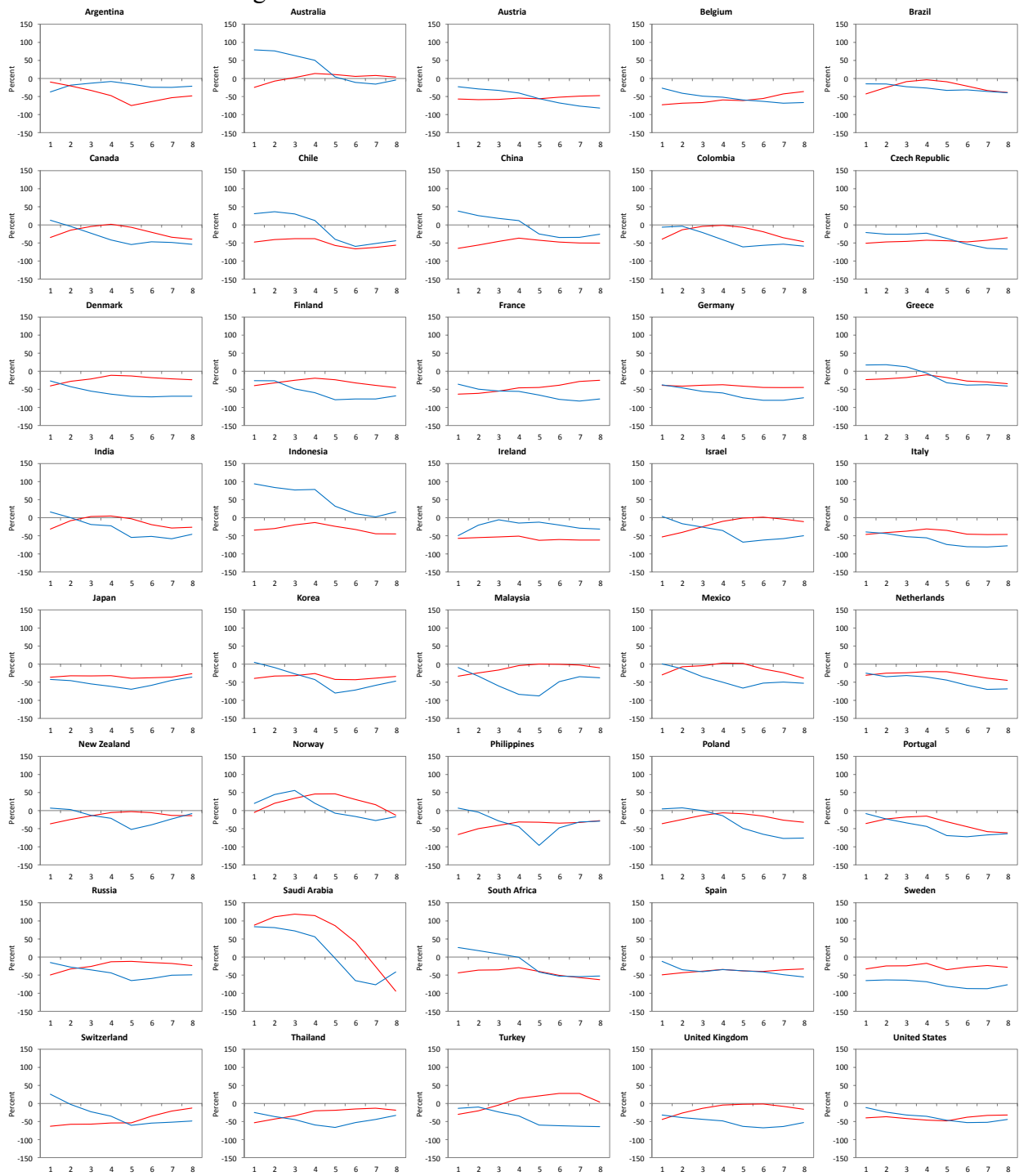
*Note:* Decomposes observed consumption price inflation ■ as measured by the seasonal logarithmic difference of the price of consumption into the sum of a trend component ■ and contributions from domestic macroeconomic ■, foreign macroeconomic ■, domestic financial ■, foreign financial ■, domestic policy ■, foreign policy ■, and world terms of trade ■ shocks.

Figure 46. Historical Decompositions of Output Growth



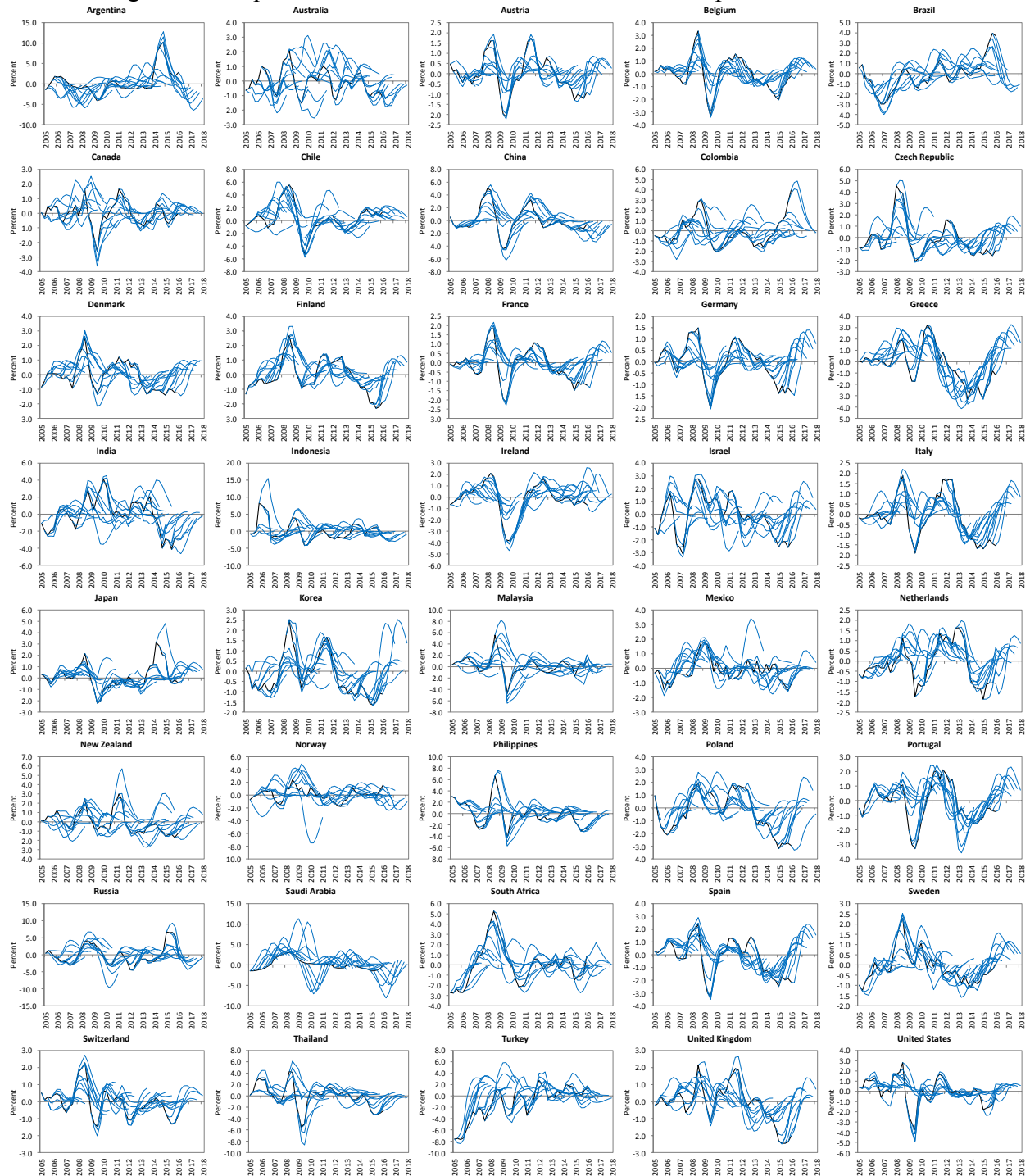
*Note:* Decomposes observed output growth ■ as measured by the seasonal logarithmic difference of output into the sum of a trend component ■ and contributions from domestic macroeconomic ■, foreign macroeconomic ■, domestic financial ■, foreign financial ■, domestic policy ■, foreign policy ■, and world terms of trade ■ shocks.

Figure 47. 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.

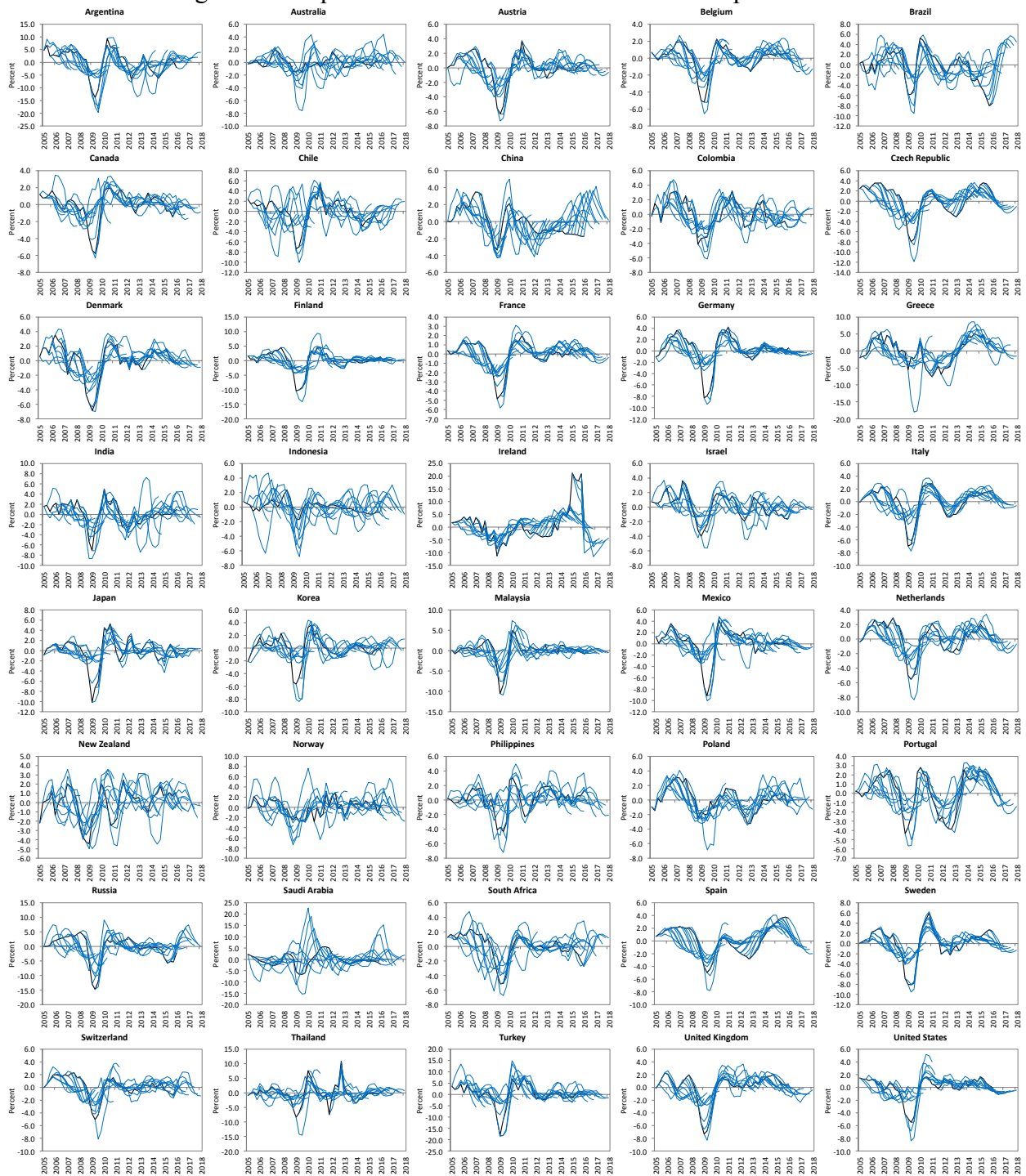
Figure 48. Sequential Unconditional Forecasts of Consumption Price Inflation



*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 unconditional forecasts ■.



Figure 49. 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 unconditional forecasts ■.



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