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G3MOD: A Multi-Country Global Forecasting Model

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G3MOD: A Multi-Country Global Forecasting Model

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ABSTRACT: This paper develops G3MOD, a semi-structural gap-trend model designed for frequent external sector forecasts crucial in macroeconomic forecasting. Focused on the G3 economies (US, Euro Area, and China) and the rest of the world, G3MOD leverages insights from central banks' policy models, to consistently translate external forecasts such as the IMF's World Economic Outlook into a Quarterly Projection Model format. The model offers flexible simulations and policy assessments and is structured around trade and financial linkages. G3MOD supports model-based forecasts and risk evaluations, helping central banks integrate external forecasts and scenarios into their own forecasts, thus generating timely macroeconomic projections. Its calibration ensures alignment with historical data, economic coherence, and robust predictive capability, and it has been validated against major global projection models. The complete set of codes, calibrated parameter values, and supporting programs are posted with this working paper.

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WORKING PAPERS

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Prepared by Iaroslav Miller, Daniel Baksa, Philippe Karam, and Tugrul Vehbi[1]

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Contents

1. Introduction

Central banks—and increasingly ministries of finance—in emerging market and developing countries have found semi-structural gap-trend Quarterly Projection Models (QPMs) useful for supporting their policy-making processes. Analyzing external developments—such as changes in trading partner demand, financial markets, and commodity prices—is a critical component of this analysis. However, developing and systematically incorporating these external factors into baseline predictions and scenario analysis is challenging, particularly in institutions with nascent modeling capacity or limited staff resources. Many institutions prefer to use available global forecasts such as those of the IMF's World Economic Outlook (WEO). However, these projections are generally expressed in annual values and not in terms of gaps and trends, as is necessary for incorporation into many modeling frameworks.

This paper presents a straightforward variant of standard global projection models that can be quickly implemented to support the inclusion of global forecasts in countries' economic analysis and forecasting. To achieve this, G3MOD can regularly update external assumptions about foreign growth, commodity prices, and other factors based on external forecasts, such as those provided by the IMF's WEO and other available global models. This should ensure consistency and reliability of G3MOD in offering relevant economic projections. Additionally, the model and its code infrastructure facilitate the mapping of available global forecasts into quarterly gap-tend projections, as well as the production of user-defined scenarios, updates, and alternatives. We make G3MOD codes and infrastructure publicly available so it can be used by interested parties such and central banks and ministries of finance to prepare QPM-consistent external assumptions in-house independently.

G3MOD leverages a large body of global projection models, beyond the ones produced by the IMF's Research Department (RES). Therefore, there is no need to develop a novel model; instead, the goal is to present a streamlined and targeted global model while providing the associated codes and procedures to facilitate its use. G3MOD closely follows Carabenciov et al. (2008, 2013). Originating from single-country predecessors, Carabenciov et al. (2008) introduced a three-country semi-structural model covering the United States (US), Euro Area (EA), and Japan, which evolved into GPM6 (Carabenciov et al., 2013), spanning six regions and 85 percent of the global economy. For benchmarking and calibration purposes, we compare the behavior and performance of G3MOD with GPM6, RES's Flexible System of Global Models (FSGM) that covers each of the G20 countries (Andrle et al., 2015), ECB-Global (Dieppe et al. (2017),) and NiGEM (Hantzsche et al. (2018)).

G3MOD covers 80 percent of global GDP, including the US, EA, and China, referred to as the G3 economies, plus a 'rest of the world' (RW) block of ten large economies.[1] It is a calibrated semi-structural model where each economy features an IS curve, a decomposed Phillips curve with core and non-core (usually food and energy) components modeled separately, and linked by relative price gap terms,[2] an uncovered interest parity (UIP) condition, and a monetary policy rule. The model is flexible and accommodates various policy regimes. For instance, the US and EA blocks follow inflation targeting regimes, where a monetary policy rule sets the

[1] The ten countries included are Australia, Brazil, Canada, Indonesia, India, Japan, South Korea, Mexico, Russia, and the United Kingdom. Data for these economies are aggregated into a single "rest of the world" block, represented as a nominal GDP-weighted average series.

[2] Based on a "relative price" approach, core and non-core inflation rates are compared to overall headline inflation, capturing CPI dynamics and second-round spillover effects.

nominal interest rate based on inflation and output. For China, a managed exchange rate regime[3] reflects monetary policy with limited autonomy in interest rate policy, and exchange rate practices.

Largely based on Carabenciov et al. (2013), G3MOD integrates trade and financial linkages among the major economies and the rest of the world, offering a versatile framework for monitoring economic conditions, evaluating forecasts, assessing risks, and analyzing policy impacts. It examines key spillover channels, including financial spillovers, which gauge the impact of economic shifts in G3 economies on global markets through indicators like Bank Lending Tightening (BLT), and demand spillovers, which assess pressures from interconnected trade dynamics and shocks.[4] For instance, G3MOD can explain the prolonged inflation observed during the post-COVID-19 recovery phase.

G3MOD is a valuable tool for central banks with their own semi-structural gap-trend QPMs, providing a robust solution for external forecasting needs.[5] By focusing on the G3 economies and leveraging insights from central banks' policy models, G3MOD allows users to create baseline and alternative scenarios with flexibility and timeliness. Its quarterly projections and simulations, combined with a parsimonious design, make it ideal for policy simulations and economic analysis, especially for central banks with limited resources or capacity. Regular updates and an adaptable framework enable central banks and finance ministries to evaluate external developments and risks effectively, supporting informed decision-making. As these institutions develop skills to use G3MOD, the model will continue to evolve, integrating with broader models for comprehensive policy analysis.

The following sections delve into specifics. Section 2 outlines the model structure. Section 3 covers model calibration, parameter categorization, and the underlying iterative process. Section 4 analyzes impulse responses to stylized shocks, and compares G3MOD outcomes with other global projection models. Sections 5 and 6 explore the dynamic and empirical properties of G3MOD, using tools such as historical simulations and in-sample forecasting performance assessment. Section 7 describes the procedure of translating external forecasts into semi-structural gap-trend, henceforth "QPM", framework and use in G3MOD, using WEO-based forecasts as an example. Section 8 summarizes key findings and explores opportunities for future model enhancements. While the current version of G3MOD reflects the latest in theoretical and empirical knowledge, its dynamic nature allows for future enhancements to incorporate evolving insights from theory and empirical research.

2. Model Description[6]

Our model adopts a semi-structural open-economy New Keynesian framework, designed for practical policymaking and periodical (quarterly) forecasting. Semi-structural models offer several advantages: they are parsimonious and more flexible than usual DSGE models, which enhances their practicality. Their operational

[3] China's exchange rate arrangement is classified as a de-facto crawl-like arrangement and a de-jure arrangement managed floating as per China's Country Report (International Monetary Fund 2024).

[4] Fundamental shocks include changes in global interest rates, productivity, and commodity prices. Non-fundamental shocks include risk-on/off episodes triggered by changes in investor portfolio constraints not directly related to fundamentals (e.g., the Fed's taper tantrum episode in 2013).

[5] We have found it to be a useful tool for several recipients of IMF technical assistance, for example.

[6] The full set of model equations, calibrated coefficients, and codes are available in supplemental resources.

flexibility allows for adaptation to new environments and policy regimes while ensuring consistency with other models used in policymaking and academia. These models emphasize the core linkages among macroeconomic variables, describing economic agents' decisions and relationships through so-called behavioral equations in a reduced-form, facilitating adjustments and the inclusion of new channels, variables, and policy tools. They allow for theoretical consistency across behavioral equations, provide flexibility in calibration improving fit to time-series data, and readily accommodate policymakers' preferences.

Similar to the New Keynesian literature, G3MOD distinguishes between the short-term cyclical position and the long-term potential growth of the economy. In the long term, prices are fully flexible, and output is determined by the economy's supply side, with monetary policy being neutral. However, in the short term, sticky prices allow monetary policy to influence real interest rates, affecting GDP's cyclical position and inflationary pressures. The model incorporates hybrid expectations, blending rational (forward-looking) and adaptive (backward-looking) expectations in agents' economic decisions. Specifically, we use endogenously determined model-consistent expectations, encompassing both lagged and leading values of corresponding variables. This approach induces substantial inertia into the model.

The model expresses each variable in terms of deviation from non-inflationary trends,[7] using "gap" terms. As a simplification, trends are treated as primarily exogenous assumptions. Therefore, our framework does not analyze the determinants of equilibrium levels for output, the real exchange rate, or the real interest rate.

Each model region (US, EA, China, and RW) has its own block with key behavioral equations: (1) an aggregate demand (IS curve) relating the level of real activity to expected and past real activity, the real interest rate, the real exchange rate, activity in other economies (direct foreign demand channel and spillover demand channel), and financial impacts approximated by the BLT index; (2) a decomposed inflation equation (core and non-core Phillips curves) linking inflation to past and expected future inflation, the output gap, exchange rates, and commodity prices (food and oil), allowing also for spillovers between inflation components; (3) a UIP condition for the exchange rate, accommodating backward-looking expectations for the US, EA, and RW, and a policy-driven managed exchange rate regime for China; and (4) a policy interest rate rule based on the output gap and expected inflation.

The following subsections outline the model's behavioral equations (i.e., aggregated demand, aggregate supply, nominal exchange rate, and the monetary policy block), offering economic interpretations of coefficients[8] and interaction of variables. Specific country features, like China's monetary regime, are highlighted.

We adopt the following notation. Variables are expressed in log terms and decomposed into gap and trend components. The gaps, cyclical percentage deviation from the potential (trend) level, are described by reduced-form equations associated with the macroeconomic theory. We denote the gaps by a hat over the corresponding variable ($\widehat{\ }$), e.g., the output gap is written as $\hat{y}$. The trends are captured as autoregressive processes and are denoted by bar ($\bar{\ }$), e.g., potential GDP is denoted by $\bar{y}$.

[7] These trends can be aligned with the flexible price equilibrium; however, semi-structural models do not characterize the state of the economy without considering real and nominal rigidities.

[8] As a reference point, we used parameter estimates from Carabenciov et al. (2013). However, parameters in G3MOD were updated to more accurately reflect the economic changes that have occurred over the past decade.

2.1 Aggregate Demand

The aggregate demand equation describes the key determinants of the cyclical position of GDP (i.e., the output gap) in each country *i* ($\hat{y}_{i,t}$). The output gap is a function of the forward-looking (rational) expectation ($E_t\hat{y}_{i,t+1}$) and adaptive expectation ($\hat{y}_{i,t-1}$) terms, the real interest rate gap ($\widehat{rr}_{i,t}$), financial conditions proxied by a bank lending tightness (BLT) measure ($\eta_{i,t}$), an export-weighted real effective exchange rate gap ($\widehat{reer}^x_{i,t}$),[9] foreign demand gap ($\hat{y}^f_{i,t}$),[10] direct demand spillover channels ($ds^f_{i,t}$ and $\varepsilon^{ds}_{i,t}$), and a domestic demand shock ($\varepsilon^y_{i,t}$): [11]

$$\hat{y}_{i,t} = \beta_1 E_t\hat{y}_{i,t+1} + \beta_2\hat{y}_{i,t-1} - \beta_3\widehat{rr}_{i,t} + \eta_{i,t} + \beta_4\widehat{reer}^x_{i,t} + \beta_5\hat{y}^f_{i,t} + ds^f_{i,t} + \varepsilon^{ds}_{i,t} + \varepsilon^y_{i,t} \quad (1)$$

The real interest rate is derived by subtracting expected year-on-year core inflation from the nominal interest rate, with the gap indicating deviations from its trend. This interest rate measures both the monetary policy stance and its impact on cyclical variables. An increase in the nominal interest rate by the central bank, under sticky prices, leads to higher real interest rates, thereby dampening aggregate demand and widening the output gap.

The direct effect of bank lending conditions on the output gap is captured by $\eta_{i,t}$. Following GPM, BLT is assumed to reflect a hump-shaped weighted average of lagged shocks to financial conditions. Equation 2 outlines the assumption for BLT levels, which depend on medium-term lending conditions ($\overline{BLT}_{i,t}$), expected output gap four quarters ahead, and temporary shocks (ε^{blt}_t). The negative relationship with the expected output gap signifies easier access to credit during economic upswings. Idiosyncratic shocks to lending conditions account for regulatory impacts or financial market sentiment beyond the dynamic IS curve and direct output gap measurements. The weighted average of lagged financial shocks measures the delayed impact of financial shocks on the output gap, with weights derived from GPM, updated as needed, to capture the transmission effects through the credit channel:[12]

$$BLT_{i,t} = \overline{BLT}_{i,t} - k_i E_t y_{t+4} - \varepsilon^{blt}_t \quad (2)$$

$$\overline{BLT}_{i,t} = \overline{BLT}_{i,t-1} + \varepsilon^{\overline{blt}}_t \quad (3)$$

$$\eta_{i,t} = 0.04\varepsilon^{blt}_{t-1} + 0.08\varepsilon^{blt}_{t-2} + 0.12\varepsilon^{blt}_{t-3} + 0.16\varepsilon^{blt}_{t-4} + 0.20\varepsilon^{blt}_{t-5} + 0.16\varepsilon^{blt}_{t-6} + 0.12\varepsilon^{blt}_{t-7} + 0.08\varepsilon^{blt}_{t-8} + 0.04\varepsilon^{blt}_{t-9} \quad (4)$$

[9] The model is using the core inflation for deflating purposes and construction of the real effective exchange rate. This approach is chosen because the US, the EA, and China primarily trade non-food, non-energy items among themselves. Thus, fluctuations in food and energy prices should not directly affect their effective exchange rates. It represents the relative external competitive position of the economy vis-à-vis its trading partners in terms of core products.

[10] This reflects the weighted sum of the output gaps in trading partner economies. When the latter expand, wealthier domestic exporters will contribute to domestic demand pressures.

[11] Unless specified otherwise all four country blocks have similarly structured equations that only differ in terms of coefficients.

[12] Dakila et al. (2024) documents how credit demand and supply can be modeled within the QPM framework, highlighting the role of bank lending and macrofinancial linkages.

The real effective exchange rate, $reer_{i,t}$, is calculated as a weighted average of bilateral real exchange rates relative to the US dollar, $rer_{i,t}^{US}$, with weights determined by the export or import trade volumes of the respective country.[13]

$$reer_{i,t}^{j} \;=\; w_{i}^{US,j} rer_{i,t}^{US} + \sum_{-i\setminus\{US\}} w_{i}^{-i,j}(reer_{-i,j,t} + rer_{i,t}^{US}) \quad (5)$$

where the bilateral real exchange rate can be given as:

$$rer_{i,t}^{US} = s_{i,t}^{US} + p_{US,t}^{c} - p_{i,t}^{c} \quad (6)$$

which is the nominal exchange rate against the US dollar, less the US and domestic core price level differential. Both the real effective and bilateral real exchange rates can be decomposed into gap and trend components, where trends are exogenous. In the dynamic IS-curve, a positive the real exchange rate gap boosts domestic demand. This implies that an increasing (depreciating) real exchange rate leads to an improved trade balance, driven by enhanced competitiveness (domestic prices relative to foreign prices are decreasing), or increasing import prices (due to foreign inflation shocks or a depreciated nominal exchange rate), prompting consumers to switch expenditure toward domestic goods (the expenditure switching channel).

$ds_{i,t}^{f}$ represents a trade-weighted combination of foreign spillover demand shocks influencing the domestic economy. For example, in the case of the US, it is an average of spillovers from EA, China, and RW($\varepsilon_{ea,t}^{ds}, \varepsilon_{cn,t}^{ds}$ and $\varepsilon_{rw,t}^{ds}$, respectively), weighted by export and import trade matrices. $\varepsilon_{i,t}^{ds}$ denotes a domestic spillover demand shock originating from country *i*, directly impacting other countries through trade channels, including $\varepsilon_{us,t}^{ds}$ which explains fluctuations in other countries' foreign spillover demand shocks. This shock reflects both tangible real economic changes and intangible impacts on partner economies,[14] influencing the domestic economy rapidly and directly, sometimes faster than official trade statistics capture. For instance, adverse economic or financial news in the US can immediately affect global consumer and investor confidence, impacting other countries before the effects manifest through trade channels. $\varepsilon_{i,t}^{y}$ represents an idiosyncratic domestic demand shock affecting only the domestic economy. The key distinction between an idiosyncratic domestic shock and a spillover domestic shock lies in their representation in economic models: the former appears exclusively in the IS curve of the originating economy, whereas the latter manifests in both the originating economy's IS curve and those of its trading partners. Thus, while idiosyncratic shocks capture domestic demand pressures, spillover shocks reflect simultaneous global pressures irrespective of their origin economy.

[13] Real effective exchange rate can be calculated with export or import weights to capture distinct composition of export goods that reflect foreign trade and import goods that contribute to domestic inflation and production.

[14] The calibrated coefficients in the IS curve ensures stable solutions for the foreign spillover shock.

2.2 Aggregate Supply and Inflation

The aggregate supply block describes headline inflation ($\pi_{i,t}$) as decomposed into core ($\pi_{i,t}^{c}$) and non-core (food and energy primarily, $\pi_{i,t}^{nc}$) components.

$$\pi_{i,t} = w^{\pi,c}\pi_{i,t}^{c} + (1 - w^{\pi,c})\pi_{i,t}^{nc} + \varepsilon_{i,t}^{\pi} \tag{7}$$

where the shock, $\varepsilon_{i,t}^{\pi}$, accommodates the time-varying weight between core and non-core, each characterized separately by a New Keynesian Phillips curve. This distinction aligns with empirical observations: core inflation correlates with real economic fluctuations and underlying demand-side inflationary pressures, while non-core inflation is influenced more by commodity price volatility making it inherently more volatile.[15] However, this division does not imply independence; Philipps curves incorporate pass-through from non-core to core inflation and weaker linkages from core to non-core.

Core inflation meets the essential criteria of the open-economy version of the New Keynesian Phillips curve, shaping inflation dynamics through the interplay of expectations and production costs:

$$\pi_{i,t}^{c} = \alpha_1\pi_{i,t-1}^{c} + (1 - \alpha_1)E_t\pi_{i,t+1}^{c} + \alpha_2 rmc_{i,t}^{c} + \varepsilon_{i,t}^{\pi^c} \tag{8}$$

Quarter-on-quarter core inflation is driven by backward- and forward-looking expectations, real marginal costs ($rmc_{i,t}^{c}$), and the core cost-push inflation shock ($\varepsilon_{i,t}^{\pi^c}$). The expectations are endogenously determined by the series of real marginal costs and shocks. Core real marginal costs include the cyclical position of the real economy (output gap) as a proxy of demand-driven inflationary pressure, the inflationary pressure from non-core items with the pass-through expressed with the relative price gap ($\widehat{rp}_{i,t}$), and the import-weighted real effective exchange rate gap ($\widehat{reer}_{i,t}^{m}$) as a proxy of imported inflationary pressure.

$$rmc_{i,t}^{c} = \alpha_3\hat{y}_{i,t} + \alpha_4(1/(1 - w^{c}))\left(-\widehat{rp}_{i,t}\right) + (1 - \alpha_3 - \alpha_4)\widehat{reer}_{i,t}^{m} \tag{9}$$

The output gap in marginal cost reflects the cost of domestic producers, including the wage bill and capital costs; however, our semi-structural model does not formalize explicitly labor market and wage dynamics. The import-weighted real effective exchange rate gap is used as a proxy of the real marginal costs of importers. Imported inflationary pressures stem from two sources: the relative price differential in core foreign and domestic core price levels, and fluctuations in the nominal exchange rate. Increases in foreign prices and nominal depreciation shift the real exchange rate, heightening domestic inflationary pressures. Under floating exchange rate regimes, monetary policy can influence the nominal exchange rate's position, exposing core inflation to short-term exchange rate volatility. Finally, the relative price gap ($\widehat{rp}_{i,t}$) comprises trend and gap components: the trend is influenced by exogenous productivity factors, while the gap fluctuates in the short term due to changes in core and non-core inflation. It is calculated as core inflation divided by the total price level, linking core to non-core inflation and generating second-round effects driven by volatile commodity prices. A positive relative price gap indicates that core prices are rising faster than non-core prices, surpassing

[15] Non-core inflation comprises volatile commodity price inflation which is often worsened by exchange rate volatility as fuel has a high import component.

the headline index. To maintain headline inflation at target, the central bank must manage deceleration in core inflation.

Non-core inflation also adheres to the New Keynesian theory:

$$\pi_{i,t}^{nc} = \alpha_5 \pi_{i,t-1}^{nc} + (1-\alpha_5) E_t \pi_{i,t+1}^{nc} + \alpha_6 rmc_{i,t}^{nc} + \varepsilon_{i,t}^{\pi^{nc}} \quad (10)$$

The Phillips curve for period-t non-core inflation incorporates both adaptive and rational expectations, along the non-core real marginal cost ($rmc_{i,t}^{nc}$) and the shock to the non-core inflation ($\varepsilon_{i,t}^{\pi^{nc}}$). The real marginal cost follows a similar structure as in the case of the core inflation, but it is extended to include global commodity price effects expressed in local currency.

$$rmc_{i,t}^{nc} = \alpha_7 \hat{y}_{i,t} + \alpha_8 \widehat{qoil}_{i,t}^{nc} + \alpha_9 \widehat{qfood}_{i,t}^{nc} + \alpha_{10}(1/(1-w^c))\left(\widehat{rp}_{i,t}\right) + (1-\alpha_7-\alpha_8-\alpha_9-\alpha_{10})\widehat{reer}_{i,t}^{m} \quad (11)$$

Similarly, to the core inflation, the real marginal cost is also a function of the output gap, real effective exchange rate gap, relative price gaps reflecting the domestic demand, imported inflationary pressure, and the pass-through to domestic prices. However, non-core inflation is mostly determined by international food ($\widehat{qfood}_{i,t}^{nc}$) and oil ($\widehat{qoil}_{i,t}^{nc}$) prices, where q denotes real series (nominal series deflated by US CPI). Both global commodity prices are expressed in terms of domestic currency and deflated by the domestic non-core price level:[16]

$$\widehat{qcommodity}_{i,v,t}^{nc} = \widehat{qcommodity}_{v,t}^{usd} + \widehat{rer}_{i,t}^{usd} + (1/(1-w_i^{xfe})) * \widehat{rp}_{i,t}\ , \quad (11a)$$

where $\widehat{qcommodity}_{v,t}^{usd}$ is a gap in real price of commodities, ($\widehat{rer}_{i,t}^{usd}$) is a gap of real exchange rate of country currency vis-à-vis the US dollar and $(\widehat{rp}_{i,t})$ is a gap of relative prices (core vis-à-vis headline). All three components in equation 11a can be expanded to show that commodity prices that enter non-core inflation equations are converted into local currency and adjusted by non-core CPI as follows (equation 11b):

$$commodity_{i,t}^{nc} = (commodity_{i,t}^{usd} - cpi_t^{us}) + (s_{i,t} + cpi_t^{us} - cpi_{i,t}^{c}) + (1/(1-w_i^c)) * (cpi_{i,t}^{c} - cpi_{i,t}) = (commodity_{i,t}^{usd} - cpi_t^{us}) + (s_{i,t} + cpi_t^{us} - cpi_{i,t}^{c}) + (1/(1-w_i^c)) * (cpi_{i,t}^{c} - (w_i^c * cpi_{i,t}^{c} + (1-w_i^c) * cpi_{i,t}^{nc})) = (commodity_{i,t}^{usd} - cpi_t^{us}) + (s_{i,t} + cpi_t^{us} - cpi_{i,t}^{c}) + (1/(1-w_i^c)) * (1-w_i^c) * (cpi_{i,t}^{c} - cpi_{i,t}^{nc}) = commodity_{i,t}^{usd} + s_{i,t} - cpi_{i,t}^{nc} \quad (11b)$$

Global food and oil prices are modeled with trend and gap components to reflect fundamental long-term movement and cyclical fluctuations that influence global inflation dynamics. This structure is a simplification, as a more accurate forecasting methodology requires more sophisticated tools outside the scope of G3MOD. These forecasts serve as external assumptions for economists who wish to use G3MOD, facilitating analysis and projections for small open economies. In line with GPM, we adjust nominal US dollar commodity prices with US CPI to obtain real US dollar prices which is decomposed into trend and gap components (equation 11c).

[16] Adjusting global commodity prices by the non-core price level in marginal cost calculations highlights the significance of relative price differentials for non-core producers. In response to a commodity price shock, if commodities become relatively more expensive compared to non-core prices, producers will adjust domestic non-core prices to maintain profitability.

$$qcommodity_{i,t}^{usd} = commodity_{i,t}^{usd} - cpi_t^{us}$$

$$qcommodity_{i,t}^{usd} = \overline{qcommodity}_{i,t}^{usd} + q\widehat{commodity}_{i,t}^{usd} \tag{11c}$$

$$\overline{\Delta qcommodity}_{i,t}^{usd} = \rho * \Delta\overline{qcommodity}_{i,t-1}^{usd} + (1 - \rho) * \Delta\overline{qcommodity}_{i,t}^{usd,ss} + \varepsilon_{i,t}^{\overline{\Delta rcommodity}}$$

$$q\widehat{commodity}_{i,t}^{usd} = \theta * q\widehat{commodity}_{i,t-1}^{usd} + \iota * demand^{world}{}_t + \varepsilon_{i,t}^{q\widehat{commodity}l^{usd}}$$

In turn, cyclical movement in global commodity prices $q\widehat{commodity}_{i,t}^{usd}$ is influenced by world demand pressures $demand^{world}{}_t$. $demand^{world}{}_t$ is a weighted sum of all innovation terms in all country IS equations: BLT shock, spillover foreign and domestic shocks, and the idiosyncratic output gap shock (equation 11d).

$$demand^{world}{}_t = \sum_i^{EZ,US,CN,RC} w_i^{GDP} * \left(-\eta_{i,t} + ds_{i,t}^f + \varepsilon_{i,t}^{ds} + \varepsilon_{i,t}^y\right) \tag{11d}$$

2.3 Nominal Exchange Rate

The nominal exchange rate is measured vis-à-vis the US dollar, with specific equations governing its determination applicable only to EA, China, and RW.

For the floating exchange rate regimes with open capital accounts (EA and RW), the model assumes the uncovered interest rate parity (UIP) condition. This UIP condition describes the behavior of the spot exchange rate in response to changes in nominal interest rate differential, country risk premium and the expected level of nominal exchange rate.

$$s_{i,t} = s_{i,t}^e - (RS_{i,t} - RS_{i,t}^{us} - prem_{i,t})/4 + \varepsilon_{i,t}^{s,uip} \tag{12}$$

Where ($s_{i,t}$) and ($s_{i,t}^e$) are nominal and expected nominal exchange rate of country *i* vis-à-vis USD, $RS_{i,t}$ is a policy rate in country *i*, ($prem_{i,t}$) is a country risk and ($\varepsilon_{i,t}^s$) is a risk-on/off term capturing the willingness of foreign investors to supply financing to country *i*.

The conventional condition assumes forward-looking expectations, but empirical evidence suggests that nominal exchange rate determination also involves adaptive expectations. Incorporating lagged exchange rates with forward-looking terms introduces inertia, influencing the adjustment time to current and future expected interest rate differentials. The expected nominal exchange rate is expressed as follows:

$$s_{i,t}^e = c_1 E_t s_{i,t+1} + (1 - c_1)(s_{i,t-1} + 2 \cdot \Delta\bar{s}_{i,t}/4) \tag{13}$$

where the parameter c_1 defines the share of backward- and forward-looking expectations in the nominal UIP, and the $\Delta\bar{s}_{i,t}$ denotes the trend nominal depreciation calculated by the bilateral real exchange rate and core inflation differentials.

The model assumes that China operates under a managed exchange rate regime with the nominal exchange rate maintained to align the real effective exchange rate with country fundamentals, aiming to minimize deviations and prevent currency misalignments that could undermine real economic performance:

$$s_{CN,t} = s_{CN,t-1} + \Delta\bar{s}_{CN,t}/4 - c_2\widehat{reer}^x_{CN,t} + \varepsilon^s_{CN,t} \quad (14)$$

where $\Delta\bar{s}_{CN,t}$ is the same term as in equation (13) and denotes trend nominal depreciation reflecting country fundamentals and calculated by the bilateral real exchange rate and core inflation differentials. $\widehat{reer}^x_{CN,t}$ is the export-weighted real effective exchange rate gap used as a proxy of the price competitiveness, and $\varepsilon^s_{CN,t}$ is an exchange rate volatility smoothing shock that allows exchange rate deviation from the trajectory specified in equation (14).

2.4 Monetary Policy Response Function

In each country, monetary policy decisions are guided by an interest rate reaction function rule. The model assumes free floating nominal exchange rates and open capital accounts for the US, EA and the RW, ensuring fully independence of monetary policy. In the case of China, managed exchange rates and imperfect capital flows provide some restrictions on monetary policy.[17]

The central bank policy rule sets the short-term interest rate based forecasted inflation deviations from the target level, and also considers the cyclical position of the real economy:

$$RS_{i,t} = g_1 RS_{i,t-1} + (1 - g_1)(RS^{neutral}_{i,t} + g_2(E_t\pi^4_{i,t+k} - \pi^{tar}_{i,t+k}) + g_3\hat{y}_{i,t}) + \varepsilon^{RS}_{i,t} \quad (15)$$

where $RS_{i,t}$ is annualized short-term nominal interest rate; $RS^{neutral}_{i,t}$ is the desired neutral nominal interest rate given by the long-term country fundamentals and inflation target; $\pi^4_{i,t+k}$ is the year-on-year 4 quarters ahead core CPI inflation rate and $\pi^{tar}_{i,t+k}$ is the year-on-year inflation target. In the short term, the central bank primarily reacts to deviations of inflation from the target. Over time, monetary policy adjusts short-term rates gradually to mitigate volatility in financial markets. Therefore, the monetary policy rule includes a lagged term to accommodate these adjustments.

In response to global financial crises and later during the COVID-19 period, the United States Federal Reserve (US Fed) and the European Central Bank (ECB) reduced their interest rates to historically low levels, reaching an effective lower bound (ELB). [18]Once a central bank encounters the ELB constraint, it cannot lower interest rates further if inflation remains below target. To model this non-linear effect in monetary policy decisions, we introduce a modification to the interest rate rule in equation (16), incorporating a constraint function that prevents the central bank from reducing the policy rate below the ELB. When the monetary policy rule suggests a rate below the ELB, the central bank maintains it at the ELB level. This non-linear feature enhances the model's ability to capture the unique characteristics of these crisis periods in the data.

[17] The Taylor coefficient (g_2) in the China economy block is rather small as a result the monetary policy stance is not fully determined by Taylor principle.

[18] The model assumes an explicit ELB only for the US and Euro Area blocks. The China economy and the rest of the world blocks do not have ELB assumptions.

$$RS_{i,t} = \max(RS_{i,t}^{ELB}, RS_{i,t}^{Taylor}) \quad (16)$$

The neutral nominal interest rate is the sum of the natural real interest rate and the inflation target. The natural real interest rate sets the trend for real interest rates and is modeled as an exogenous process for the US. For the other countries, we assume the natural rate is determined by the real UIP condition. This condition can be calculated from the UIP equation under the assumption of targeted inflation levels, substituting the nominal exchange rate with the real exchange rate and inflation differentials. The modified real UIP condition is as follows:

$$\overline{rr}_{i,t} = f_1 \overline{rr}_{i,t-1} + (1 - f_1)(\overline{rr}_{US,t} + \Delta z_{i,t} + prem_{i,t}) + \varepsilon_{i,t}^{\overline{rr}} \quad (17)$$

Based on the real UIP condition, the US real interest rate reflects global monetary conditions, adjusted for country risk premia and trends in real exchange rate appreciation. Typically, the rest of the world economies are converging to the developed economies (their real exchange rates are appreciating) due to relatively higher productivity growth which offset their relatively higher country risk premiums. For China, which employs capital controls, additional adjustments are made based to its real UIP condition. The f_1 coefficient captures the extent of capital controls: a value closer to one indicates greater financial autarky, where the domestic natural rate is set exogenously by the government.[19] A zero value is typical for countries without capital controls, such as the US and EA.

3. Model Calibration

Model *calibration* is an iterative process involving three main stages, following Berg et al. (2023). Initially, dynamic properties such as impulse response functions, are aligned with economic theory under specific monetary regimes, cross-validated with similar shocks in other global models (e.g., ECB-Global, FRB's various global models, IMF's Flexible System of Global models (FSGM), GPM, NiGEM, OECD's Global Economic Model, Oxford Global Economic Model (OxGEM), and QUEST).[20] Subsequently, the model is confronted with the data using the Kalman filter, interpreting historical data through estimated unobserved variables (e.g., output gap or real-exchange rate gap) and economic shocks. This step verifies economic knowledge and refines model calibration or behavioral assumptions to ensure consistency with observed time-series. After reviewing the Kalman filtration, the model calibration is adjusted to improve the data fit and align historical interpretations with common economic understanding. In-sample simulations then assess forecasting performance, guiding parameter adjustments to enhance accuracy. Finally, we describe the procedure that translates other external forecasts into the QPM-language with a well-calibrated and validated semi-structural model.

[19] China's capital control measures and their tightness have been changing over time. To account for the time-varying aspects of the CFMs, the model uses the shock to the real UIP (real interest rate trend condition) $\varepsilon_{i,t}^{\overline{rr}}$ in the equation 17.

[20] G3MOD is later compared to the following four selected models: ECB-Global (Dieppe et al. (2017),); NiGEM Macroeconomic Model (Hantzsche et al. (2018)); The Flexible System of Global Models – FSGM (Andrle et al. (2015)), and GPM6 - The Global Projection Model with 6 Regions (Carabenciov et al. (2013)).

Since calibration for better data or forecasting performance can sometimes compromise theoretical consistency of impulse responses and vice versa,[21] the iterative calibration process aims to ensure the model achieves good results, including a good fit with data, accurate forecasting performance, theoretical coherence, and the capacity to substantiate historical narratives with model results.

The iterative calibration process also helps to optimize the model's likelihood, indirectly. We evaluate the goodness of fit by minimizing the Root Mean Squared Errors (RMSE) and comparing it to the RMSE of the Random Walk, as most macroeconomic variables follow a Random Walk or are highly autocorrelated.

Coefficients and parameters are classified in three groups:

a. *Steady-State parameters* reflect medium- and long-term historical averages of the data, such as potential growth or real effective exchange rate depreciation. They are consistent with medium-term policy objectives, such as inflation targets and are based on actual assessments or future expectations, such as assumptions about foreign sector variables.

b. *Trends and Gaps determining parameters* are crucial for the model's filtration and determining the gap-trend decomposition of variables. Typically, cycles are assumed to be more volatile than trends, reflected in a lower standard deviation for trends compared to cycles. Empirically, trends are more persistent than cycles, leading to higher autoregressive coefficients.[22]

c. *Transmission Mechanisms and Policy Response parameters* describe the economic linkages among variables, such as the strength of the interest rate channel, sacrifice ratio, steepness of Phillips curves, preference toward exchange rate smoothing or hawkishness of monetary policy to inflationary pressures.

Aggregate demand equations. They typically feature specific parameter ranges: the lagged gap term, β_2, often ranges from 0.40 to 0.90. The coefficient on the lead of the output gap, β_1, generally ranges from 0 to 0.30. Given significant lags in monetary policy transmission, β_3 and β_4 are expected to be relatively small compared to the lagged gap parameter. Experience suggests $\beta_3 + \beta_4$ typically ranges from 0.10 to 0.25 in quarterly models. For instance, a β_3 of 0.10 implies a one percentage point increase in interest rates leads to a 0.10 percentage point fall in the output gap the following quarter. β_4 is typically smaller than β_3 in industrial economies and varies with the degree of openness.[23] A sensitivity term added to trade volumes through the foreign activity variable, suggests β_3 is smaller in models capturing both scale and relative trade price effects. The last term reflects the external dependence of each economy. The coefficient on the foreign variable, β_5, represents the country's share of exports in output.

Phillips curves equations. Parameters α_1 and α_5 are positive, indicating that the central bank cannot systematically surprise people. A value of α_1 equal to one implies the central bank could indefinitely keep output above equilibrium through constant inflation surprises with higher-than-expected inflation. Values greater

[21] An alternative approach is Bayesian estimation, used to estimate DSGE models. However, in our case of a semi-structural model it is more efficient to calibrate reduced form equations than set prior assumptions for the non-deep coefficients.

[22] The COVID-19 shock can be understood as a one-off level shift of the GDP trend during which GDP trend volatility increased temporarily. Later, the estimated GDP trends returned to their long-term smoothed dynamic.

[23] The discussion of parameter values is based on experience with this type of model in several countries; see Berg et al. (2006), and other somewhat arbitrary examples, such as Abradu-Otoo et al. (2022), Szilágyi et al. (2013), and Marioli et al. (2020). In our pragmatic approach to parameterization, we also look at central banks' estimated macro models—i.e., Coenen and Wieland (2002) and Oda and Nagahata (2005) report small-scale estimated macroeconomic models.

than one may result from backward-looking expectations or intrinsic rigidities in price adjustments from indexation, or transaction costs. When inflation expectations are fully forward-looking ($\alpha_1 = 0$), inflation equals the sum of all *future* output and exchange rate gaps. A small but persistent increase in interest rates will have a large and immediate effect on current inflation. Sophisticated inflation targeting economies exhibit lower persistence parameters, reflecting credible inflation targeting regimes and well-anchored expectations. Monetary policy affects inflation through output and exchange rate gaps; thus, coefficients on these variables cannot all be zero for policy to influence inflation. Higher α_3 and α_7 values in core and non-core inflation equations indicate stronger impacts of domestic demand pressures compared to exchange rate volatility. Furthermore, larger parameters indicate a more closed economy. Typically, parameters such as α_4 and α_{10} are smaller compared to others, reflecting the weight of the real effective exchange rate. Their relative sizes depend on specific economic features. The weights of food and oil price gaps reflect the economy's relative dependence on food and oil imports.

Monetary policy rule (interest rate reaction function). Larger parameters g_2 and g_3 indicate a more aggressive policy response to inflation and output gaps, respectively. Models used at central banks typically incorporate smoothing of policy responses, gradually adjusting rates toward desired levels based on deviations of inflation and output from equilibrium. In semi-structural models, g_1 values typically exceed 0.6, reflecting substantial smoothing in policy adjustments.

4. Model Properties

Section 4 analyzes the model's structural adequacy through comparison with other global projection models and lays the foundation for model validation and comparative analysis in sections 5 and 6. It emphasizes the rationale for shock selection and their alignment with the model's framework.

To analyze the model properties of G3MOD, we focus on four significant shocks that have affected the global economy since 2020. Negative shocks to the US and Chinese demand during the COVID-19 pandemic had a profound adverse impact on global economic activity. Subsequently, increases in oil and other commodity prices, alongside tightening of US monetary policy, further stifled global economic growth. Additionally, a risk-off appetite shock offered insights into market sentiment and broader economic stability.[24] These shocks—US monetary policy tightening, reductions in US and Chinese demand, real oil price increases, and a negative shift in investor risk appetite—are all contractionary in nature. Given the critical importance for global policy decisions, these shocks have been extensively examined in major publications such as the IMF's World Economic Outlook (WEO) and IMF country reports.

Each discussed shock corresponds to the idiosyncratic shocks (ε terms) detailed in Section 2. A US monetary policy shock influences global financial conditions, negative demand shocks in the US and China affect global trade dynamics, a temporary increase in real oil prices impacts energy-dependent economies, and the shift in EA risk appetite provides insights into market sentiment and broader economic stability.

Furthermore, we recognize the potential impact of other traditional fiscal policies and additional Integrated Policy Framework (IPF)-related tools such as FXI, capital flow management measures (CFMs), and macroprudential measures (MPMs). These tools are addressed in modern international models as discussed

[24] This is a non-fundamental risk appetite shock, highlighted for example in Berg et al. (2023), and other research as in Adrian et al. (2021), and Basu et al. (2023).

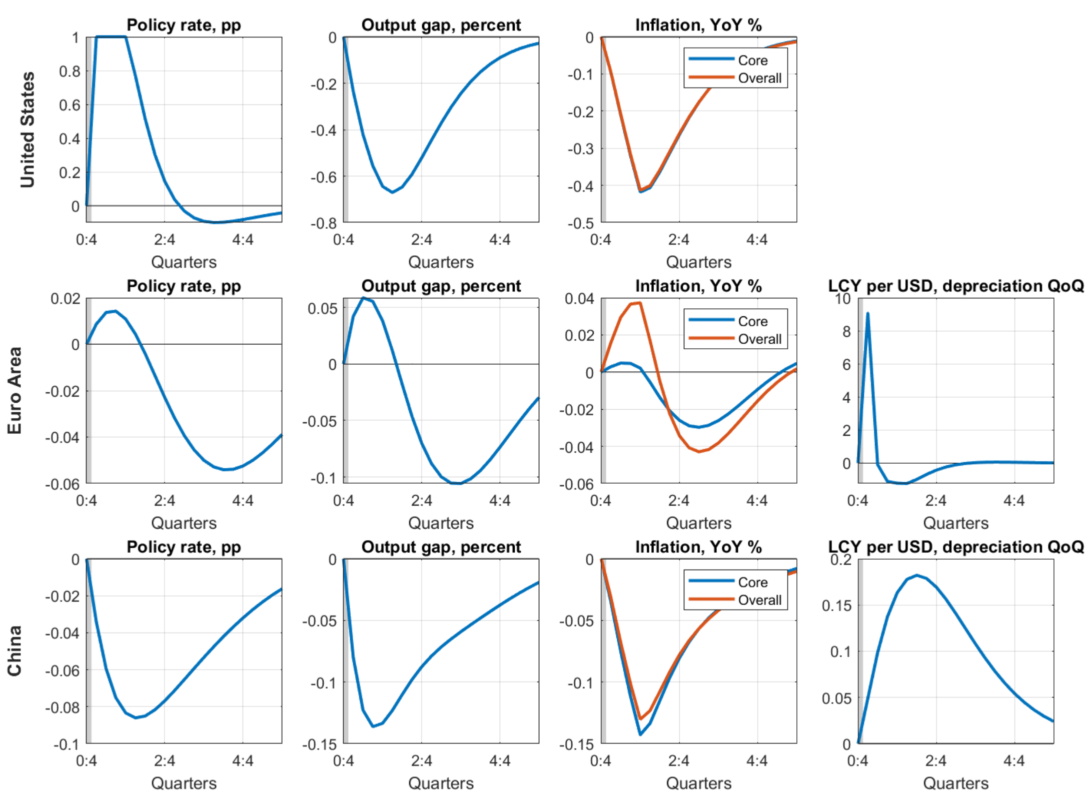
by Adrian et al. (2020, 2021), Basu et al. (2020, 2023) and Basu and Gopinath (2024). G3MOD leaves the IPF policy questions to other IMF models currently under development.

4.1 US Monetary Policy Shock

Figure 1 shows the effects of an unexpected one-year 100 basis point increase in the US policy rate by the central bank. First, the higher policy rate translates into an increase in real interest rates, dampening demand for domestically produced goods. Second, the appreciation of the US dollar in nominal and real terms shift consumption preferences towards imports, at the expense of domestic goods. These effects collectively tighten financial conditions, raising the cost and restricting the availability of credit for households and businesses.

As a result, the US output gap contracts by about 0.6 percent over five quarters, leading to a subsequent 0.4 percent decline in headline inflation. Furthermore, reduced domestic demand in the US lowers foreign product imports, which adversely impacts foreign economies and reduces imported inflationary pressures. The EA and China experience similar but small spillover effects, with their output gaps narrowing by about 0.1 percent. In response, the Euro depreciates, temporarily boosting competitiveness of European exporters and widening the output gap. However, the decline in foreign demand eventually dampens economic activity in Europe and China in medium term. Consequently, both the ECB and PBC implement expansionary monetary policies to mitigate economic losses.

Figure 1: US Monetary Policy Shock

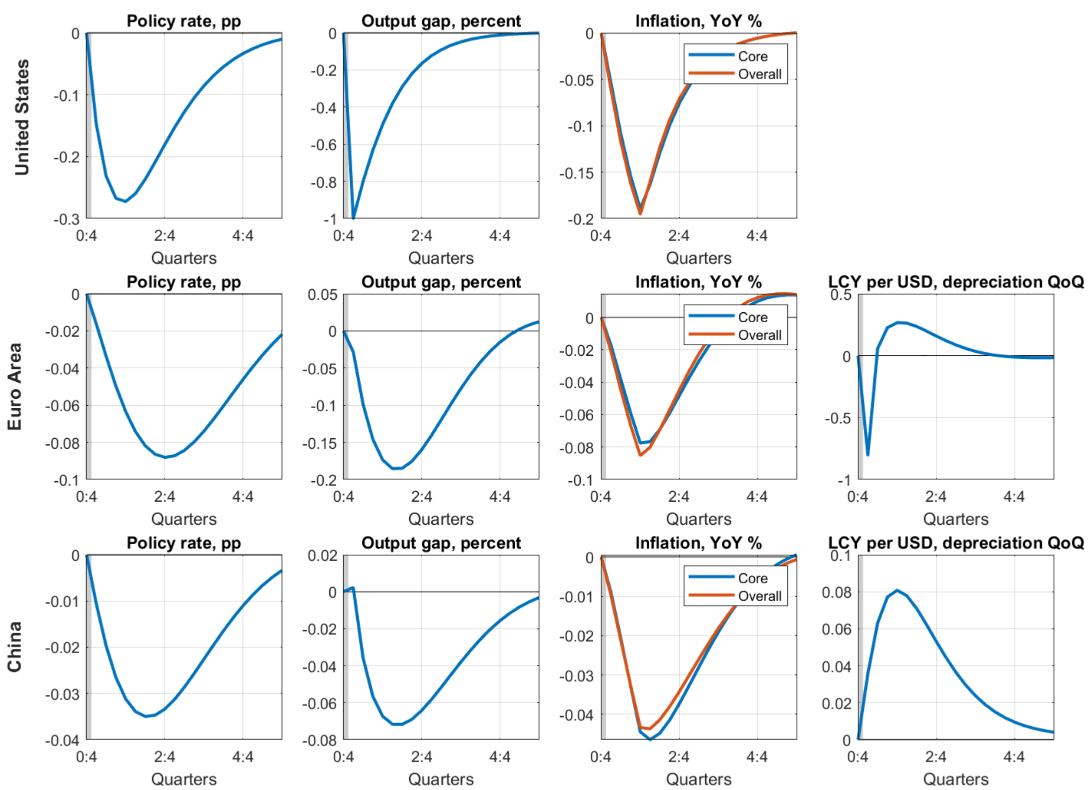


4.2 Temporary Decrease in US Domestic Demand

Figure 2 illustrates the effects of a one-quarter 1 percent reduction in the US output gap due to lower domestic demand. This exerts downward pressure on both producer and consumer prices, resulting in a 0.2 percent decrease in headline inflation. In response, the US Fed cuts interest rates by about 25 basis points stimulating demand and steering inflation back toward its target.

The slowdown in US demand ripples through the global economy, causing the EA and China to experience contractions in their output gaps by approximately 0.1 to 0.15 percent. This slowdown also leads to a deceleration in inflation of about 0.05 to 0.1 percent in both economies. Central banks in the EA and China respond by reducing their policy rates, albeit to a lesser extent than in the US.

Figure 2: Temporary Decrease in US Domestic Demand

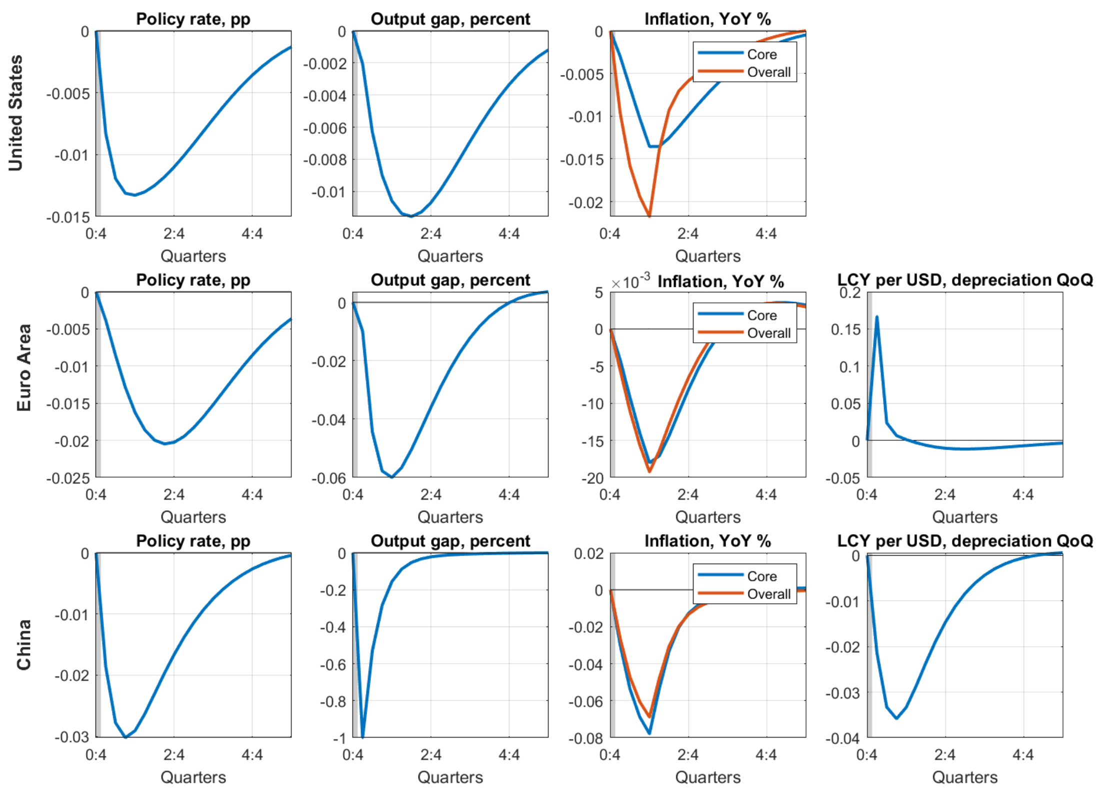


4.3 Temporary Decrease in China's Domestic Demand

Figure 3 depicts the effects of a one-quarter 1 percent reduction in China's output gap due to lower domestic demand. This decline leads to a 0.1 percent reduction in inflation. In response, the central bank eases monetary policy by approximately 3 basis points to mitigate the negative impact on domestic demand. [25]In addition, as inflation decline is more pronounced in China than in the US or EA, China experiences a weakening of its real effective exchange rate. This adjustment allows the PBC to intervene to strengthen its currency without sacrificing price competitiveness.

The trade linkages in the model are calibrated based on a trade matrix among the four economic blocks (including the rest of the world). Hence, despite China's growing significance in the global economy, the spillover effects from its slowdown are significantly smaller compared to those originating from the US.[26]

Figure 3: Temporary Decrease in China's Domestic Demand



[25] The PBC does not follow IT, therefore, the policy reaction via interest rate is limited.

[26] This is also in line with the findings of Osborn and Vehbi (2019) and Roache (2012) who report that global spillovers tend to be greater from the US than from China.

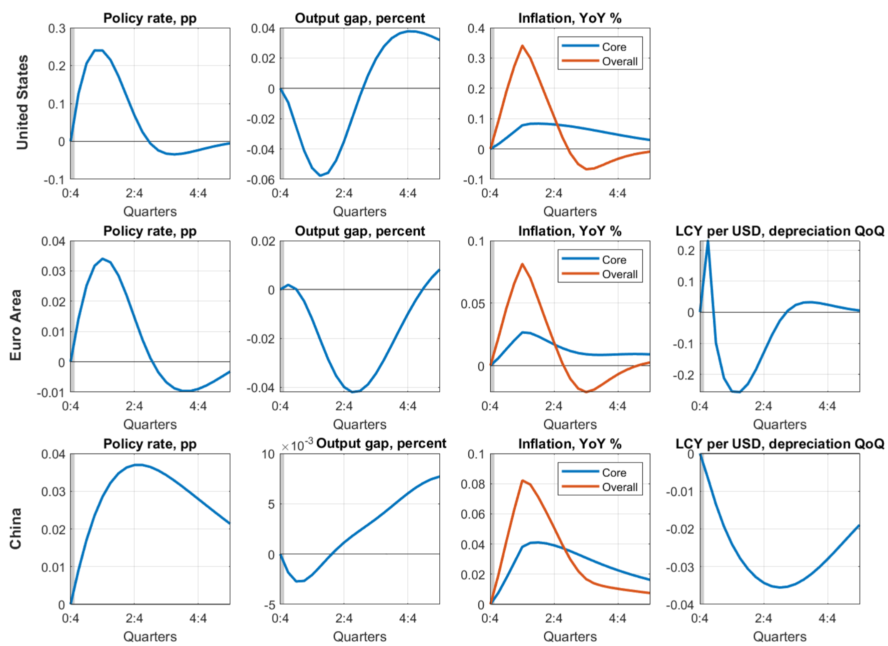
4.4 Temporary Increase in Global Oil Price

Figure 4 shows the effects of a 10 percent increase in the real price of oil, lasting for eight quarters. This shock impacts inflation and output across all countries/regions due to heightened production costs and reduced consumer spending. Globally, central banks respond by raising policy rates to curb the second-round effects on core inflation. The inflationary impact and the response of monetary policy are particularly pronounced in the US due to a combination of high energy consumption and a low fuel tax wedge.[27]

In the US, the sharp oil price hike increases headline inflation by 0.4 percent. The US Fed responds with an interest rate increase of over 25 basis points, which helps to contain inflationary pressures from rising beyond the first year. This tightening of monetary policy also reduces economic activity, narrowing the output gap by approximately 0.05 percent within eight quarters. Reduced domestic demand moderates second-round effects on core inflation, leading to a gradual decline in headline inflation after an initial peak in the first year.

The ECB reacts less aggressively, raising its policy rate rising by around 3 basis points due to the relatively lower pass-through of oil prices into prices.[28] Initially, the euro depreciates against the US dollar, driven by interest rate differentials, but this trend reverses due price level disparities between the two regions. Similarly, the PBC raises its policy rate, albeit to a lesser extent than the US Fed or ECB, to manage the inflationary impact of higher oil prices.

Figure 4: Temporary Increase in Global Oil Price



[27] The wedge is the gap between pre-tax gasoline prices and what consumers pay, including taxes. In economies like the US, where this gap is small, taxes are less effective in offsetting energy price changes to control inflation (see Robinson et al., 2000).

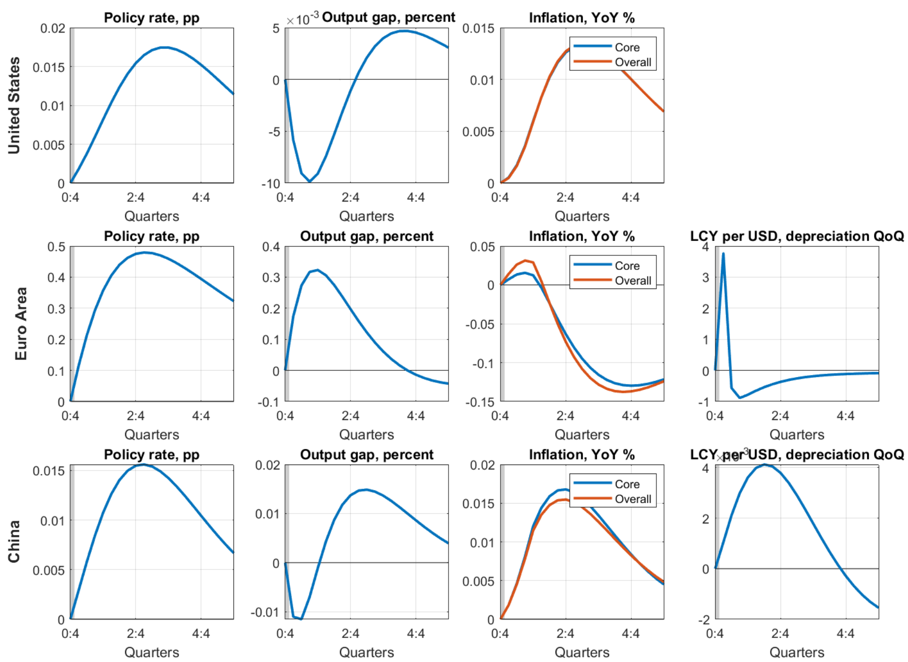
[28] This simulation is based on the model calibrated to reflect the average price sensitivity observed throughout the entire data sample (2004 – 2023), rather than focusing solely on recent post-COVID-19 price behavior in the US and EA.

4.5 Shift in Euro Area Risk Appetite

Figure 5 illustrates the impact of a one-quarter negative shock to the EA risk premium of 1 percentage point. Initially, this shock leads to the depreciation of the Euro against the US dollar and Renminbi, causing a rise in inflation. In this model, which lacks explicit macro-financial linkages between the real economy and banking sector stability, a temporary increase in the risk premium appears to stimulate EA economic activity due to enhanced price competitiveness.[29] In response to overheating, the ECB raises its policy rate by approximately 50 basis points and maintains it at elevated levels throughout the simulation period, leading to euro appreciation and a decline in EA inflation.

The medium-term appreciation of the euro mildly increases US inflation as imports become costlier, prompting the Fed to marginally raise its policy rate. The overall economic impact on the US remains modest due to the relatively small size of the premium shock in this scenario. The response of the Chinese economy mirrors that of the US, with adjustments to the renminbi. The initial depreciation of the euro adversely affects China's price competitiveness, prompting depreciation of the renminbi. As the ECB's tightening policy leads to euro appreciation and higher European export prices, inflation in China rises marginally, prompting a slight policy rate hike. Simultaneously, the gradual appreciation of the euro restores price competitiveness for Chinese goods, leading to a gradual, but very small, renminbi appreciation.

Figure 5: Temporary Decrease in Euro Area Risk Appetite



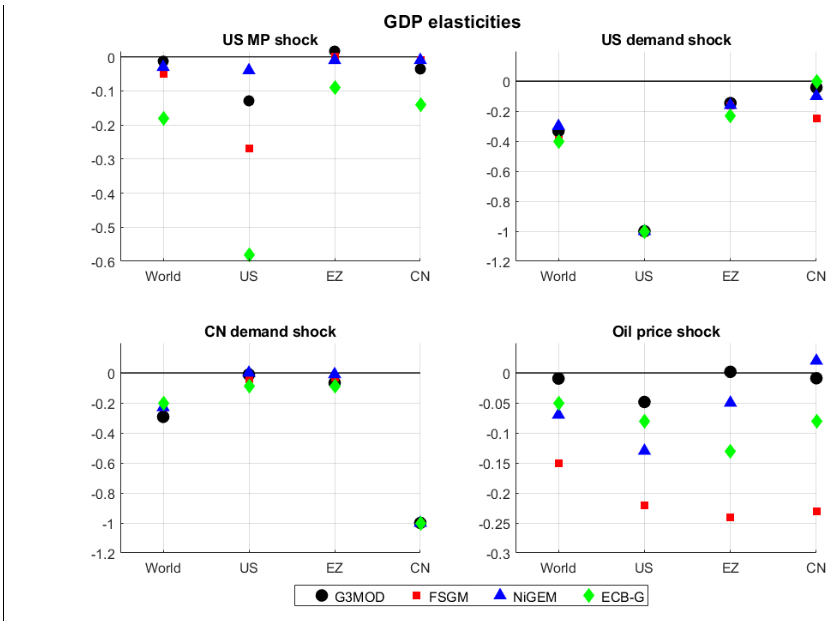
[29] In small models with less developed macro-financial linkages, combining multiple shocks (e.g., negative demand shock, increase in risk premium, supply shock) is often necessary to accurately simulate scenarios like sudden stops. Alternatively, broader models, including some DSGE-based ones, integrate macro-financial linkages and credit sectors internally to depict these transmission channels (Bokan et al., 2016, Coenen et al., 2019).

4.6 Comparison with Other Global Models

In this section, we compare G3MOD's output responses with three prominent global models: the ECB's global model (ECB-G), the IMF's annual FSGM, and the National Institute for Social and Economic Research's global model (NiGEM). These models are well-suited to analyzing how economic shocks propagate through the global economy via various channels (e.g., trade, private and public financial flows, migration, technological dispersion). To ensure consistency in comparison, we reproduce Figure 13 from Dieppe et al. (2017), illustrating the global and regional impacts of four economic shocks on GDP.

We simulate these shocks in G3MOD and present the results in Figure 6, depicting GDP responses as average percentage deviation in the first year following each shock. These shocks include a temporary 25 basis points increase in US monetary policy rates, a temporary 1 percent reduction in US GDP due to domestic demand, a temporary 1 percent reduction in China's GDP from domestic demand, and a temporary 10 percent rise in real oil prices. The markers in each panel represent the results from four model simulations, with the black circle indicating the G3MOD model. The countries/regions analyzed are the G3 economies.

Figure 6: GDP elasticities from different global models



The upper left panel of Figure 6 shows the impact of a temporary 25 basis points US monetary policy (MP) shock. This shock results in negative output effects across all models, with US GDP declining between 0.1 and 0.6 percent. G3MOD's responses for the EA, China, and the global economy closely align with FSGM and NiGEM, although there are slight variations in the US impact. ECB-G shows more pronounced responses across all regions, possibly due to its comprehensive consideration of financial spillovers.

The upper right panel presents the effects of a temporary 1 percent negative US demand shock, reducing real global GDP by between 0.3 and 0.4 percent. This highlights the significant influence of US demand on global economic activity, with impacts on global and regional GDP relatively consistent across all models, with a notable deviation in China from FSGM.

The lower left panel shows the effects of a temporary 1 percent negative Chinese demand shock, resulting in a slightly smaller negative impact on world GDP, compared to the US demand shock. The US and EA experience minor negative deviations, indicating that while China's economic movements are influential, the direct first-year impact on these economies is less significant than domestic US shocks.[30] The impacts observed across models demonstrate remarkable consistency.

In the lower right panel of Figure 6, the output effects of a temporary oil price shock are depicted. World GDP contracts by 0.02 to 0.15 percent in response, with effects on individual countries more varied compared to other shocks analyzed. Both the US and EA show negative output impacts, highlighting shared vulnerability to oil price fluctuations. G3MOD's elasticities are smaller than those estimated by other models, reflecting its calibration to a 20-year macroeconomic dataset to capture average historical behaviors. Overall, this analysis shows reasonable consistency among different models, despite their varying levels of detail.

5. Historical Interpretation

In the QPM suite of models, calibration and model performance are evaluated by interpreting historical data, including estimating unobserved variables and economic shocks. These assessments contribute to constructing a coherent economic narrative that reveals underlying inflation pressures and shocks.

Using the Kalman filter, unobserved variables (such as gaps and trends) and shocks are estimated based on observed time-series data. To assess the model's ability to interpret historical developments in the US, EA, and China, within a plausible economic narrative, we apply the Kalman filter to decompose data into shocks and gaps from 2006Q1 to 2023Q4. The analysis focuses on two pivotal events: the global financial crisis (GFC), and the COVID-19 pandemic. The resulting filtration provides a clear narrative to explain historical events and match macroeconomic shocks with corresponding developments. Furthermore, in regular forecast exercises, the filter estimates the initial conditions of the forecasts. This assessment is also crucial for decomposing other external forecasts, described in section 7, since the filter estimates the cyclical position of the economy based on observed inflationary pressure and monetary stance either for observed or forecasted data.

5.1 Historical Interpretation of the US Economy

Outside of the periods encompassing the GFC and COVID-19,[31] the US GDP growth rate fluctuated between 2 and 3 percent, with the model estimating stable potential growth (see Figure 7). The COVID-19 pandemic caused a downturn in both actual level and potential growth (the latter turned negative), but the economy has since rebounded.

[30] While the Chinese demand shock has a less pronounced impact on global economic activity compared to the US demand shock, this effect can be opposite for specific countries with close economic ties to China, especially in Asia (see FSGM-Asia).

[31] To capture potential GDP volatility during the COVID-19 pandemic, we introduce a large temporary multiplier to the standard deviation of the potential GDP shock. This adjustment helps the Kalman filter identify potential GDP shocks as the primary driver of GDP volatility associated with lockdowns, transportation bottlenecks and production disruptions.

Figure 7: US GDP and Potential Growth, YoY % (2006Q1 – 2023Q4)

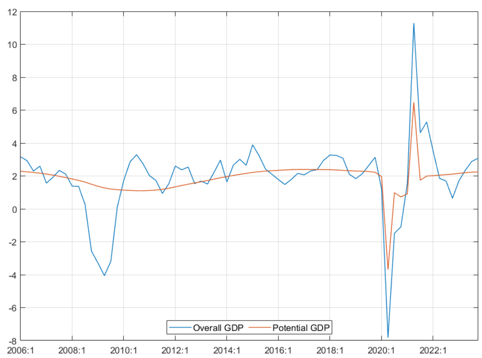


Figure 8: US Output Gap Decomposition, pp (2006Q1 – 2023Q4)

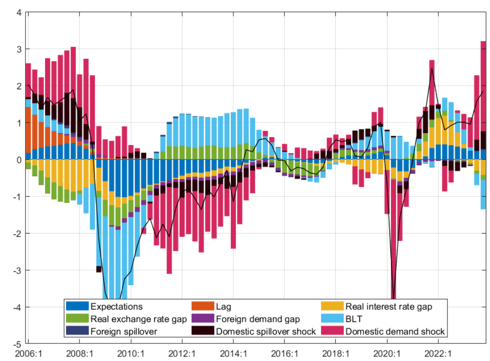


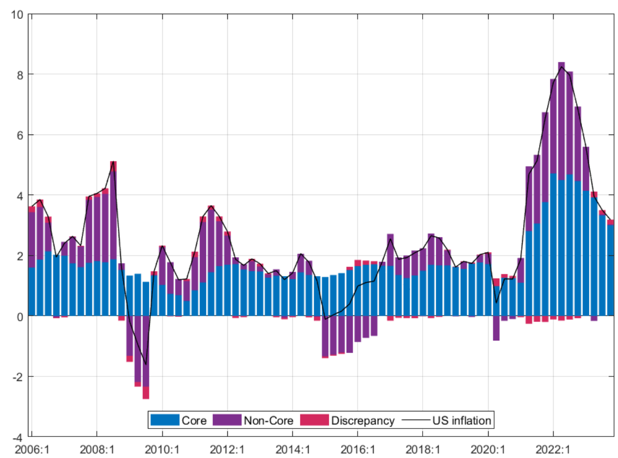
Figure 8 illustrates the decomposition of the US output gap into the contributions of the determinants specified in the US aggregate demand equation 1 above where the lagged element is decomposed into the fundamentals. The output gap shows an overheated cycle preceding the GFC, driven predominantly by positive domestic and spillover demand shocks, followed by a deep recession, and gradual recovery during and after the crisis. The recession was exacerbated by stringent lending conditions (negative BLT contribution) during the GFC, with recovery spurred by their subsequent easing. Conventional monetary policy remained somewhat contractionary due to the Fed's inability to lower rates below the zero lower bound. This was followed by a period of neutral output gap from 2014 to 2017, succeeded by an above-trend phase in the pre-COVID-19 period despite a restrictive monetary policy stance.

The COVID-19 downturn is characterized by a significant economic contraction caused by imposed restrictions, reflected in large negative domestic demand shocks in early 2020. The subsequent recovery was propelled by unprecedented fiscal stimulus[32] and monetary easing. Fiscal policy effects are indirectly represented by positive domestic demand shocks. Later, the US economy maintained an overheated state despite policy tightening, largely driven by accumulated savings and delayed consumption.[33]

[32] International Monetary Fund, 2022a. "United States: 2022 Article IV Consultation-Press Release; Staff Report; and Statement by the Executive Director for the United States." International Monetary Fund Country Report No. 2022/220.

[33] International Monetary Fund, 2021a. "World Economic Outlook: Recovery During a Pandemic—Health Concerns, Supply Disruptions, and Price Pressures." World Economic Outlook Reports, Washington, DC (October).

Figure 9. US headline inflation and its breakdown, inflation % yoy and contributions in p.p. (2006Q1 – 2023Q4)



With some exceptions, US inflation hovered around the target during the observed period (see Figure 9). Core inflation remained stable, with fluctuations in food and energy prices driving volatile non-core inflation. After the GFC, commodity price shocks, including those related to the Russia-Ukraine war, pushed headline inflation above the medium-term target. However, commodity price collapses following the GFC and in 2015-2016 led to significant deceleration in overall inflation.

US core inflation serves as a gauge of underlying inflationary pressures in the US economy. Figure 10 illustrates how core inflation is shaped by the real marginal cost, responding to factors like domestic demand pressures, exchange rate volatility, imported inflation, and second-round effects of commodity price fluctuations. The figure shows a clear correlation between major shifts in core inflation and changes in real marginal cost. Before the pandemic, core inflation was well anchored near the Fed's target. However, it accelerated rapidly after the pandemic due to significant disruptions in global economic production and logistics, leading to supply bottlenecks.

Figure 10: US decomposition of real marginal costs for core inflation, % (2006Q1 – 2023Q4)

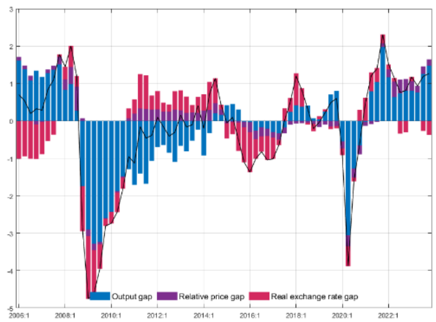
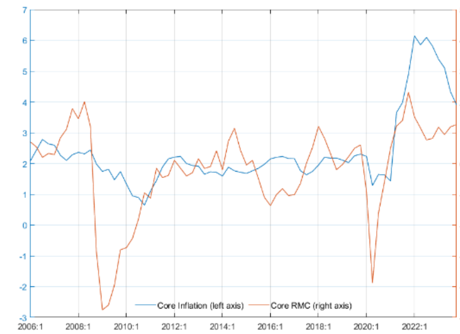


Figure 11. US core inflation (yoy %, left axis) and real marginal costs (% right axis) (2006Q1 – 2023Q4)



Secondly, As seen in Figure 10, core real marginal costs rose due to robust demand pressures and a tight labor market (reflected in the output gap). In addition, inflation was fueled by second-round effects from increases in non-core inflation, influenced by spikes in global oil and food prices (captured by the relative price gap). Temporary increases in inflation expectations might have also added to inflationary pressures during the post-COVID recovery.[34] Inflation began to decelerate more rapidly in 2023 as the Fed underscored its commitment to the inflation target by significantly tightening monetary stance.[35]

Figure 12: US Decomposition of real marginal costs for non-core inflation, % (2006Q1 – 2023Q4)

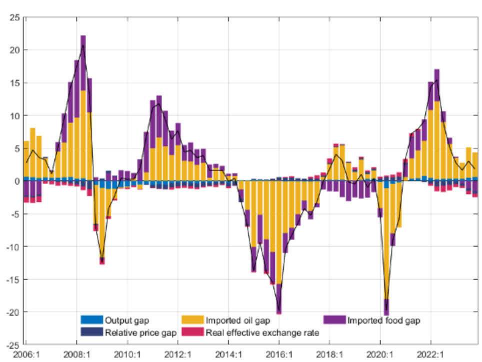
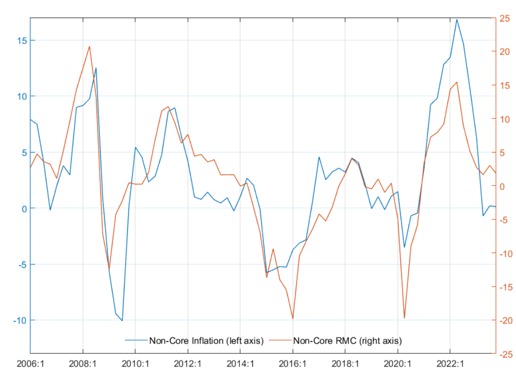


Figure 13. Non-core inflation (yoy %, left axis) and real marginal costs (% right axis) (2006Q1 – 2023Q4)



[34] Bae E., A. Hodge, and A. Weber (2024).

[35] International Monetary Fund. "Bringing the US Economy Back into Balance." Last modified February 16, 2023. https://www.imf.org/en/News/Articles/2023/02/15/cf-usa-bringing-the-us-economy-back-into-balance.

The non-core Phillips curve, encompassing food and energy items, exhibits significantly higher volatility than core inflation. Figure 13 demonstrates that this volatility stems from more pronounced fluctuations in real marginal costs, which includes the impacts of commodity price volatility reflected in the gaps for imported food and oil prices. During the GFC, non-core inflation temporarily decelerated due to the decline in global oil prices. Subsequently, from the GFC to the pandemic, it tracked global commodity cycles as indicated by the gaps in global oil and food prices. Non-core prices faced similar cost-push shocks as core prices, with acceleration later driven by a rebound in global commodity prices. However, non-core inflation proved less persistent than core inflation, decelerating swiftly once global oil and food inflation normalized.

5.2 Historical Interpretation of the Euro Area Economy

Besides the periods of the GFC and the COVID-19 pandemic, US GDP growth fluctuated around 2-3 percent, as shown in Figure 14, with stable potential growth estimated by the model. During the pandemic, both growth and potential growth turned negative, but the economy has since rebounded.

Figure 15 displays the decomposition of the EA output gap into the contributions specified in the EA aggregate demand equation (1). Similar to the US economy, the output gap trajectory suggested an overheated cycle before the GFC, primarily driven by positive domestic and foreign demand shocks, followed by a deep recession during and after the GFC, exacerbated by economic spillovers from the European sovereign debt crisis during 2012-2014. A gradual recovery ensued with loose bank lending conditions and a rebound in foreign demand. The pre-pandemic period during 2018– 2019 saw a slightly positive output gap driven by further rebounds in domestic and foreign demand.

Figure 14: Euro Area GDP and Potential Growth, YoY % (2006Q1 – 2023Q4)

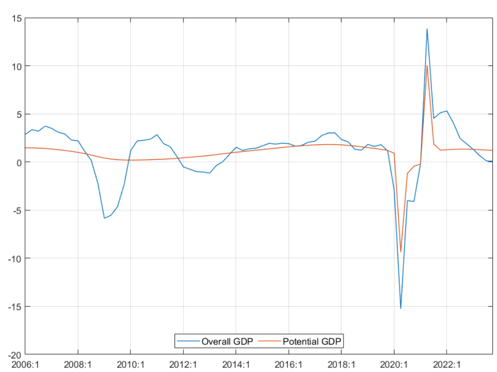
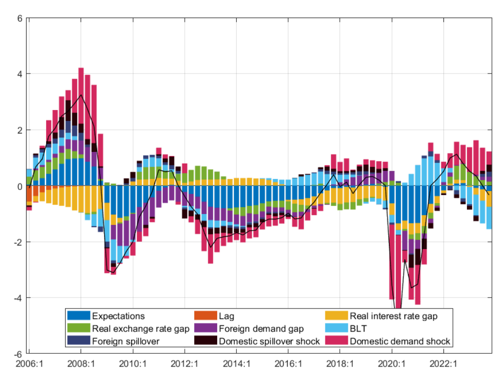


Figure 15. Euro Area Output Gap Decomposition, pp (2006Q1 – 2023Q4)

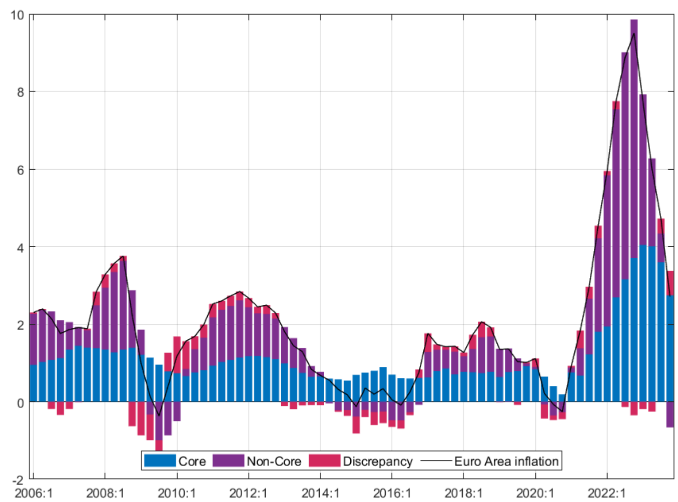


Similar to the US economy, the EA experienced a sharp decline in economic activity during the pandemic, characterized by stringent quarantine measures and travel restrictions. This led to substantial negative domestic demand shocks in early-2020, compounded by a decline in foreign demand. The subsequent recovery was slower compared to the US, primarily driven by the loosening of bank lending conditions. The positive effects of fiscal policy were indirectly captured through increased domestic demand shocks. From 2023, the unwinding of adverse supply shocks, moderating commodity price increases, and the launch of the

ECB's tightening cycle, turned monetary conditions contractionary, alleviating overheated demand pressures, anchoring inflation expectations, and contributing to disinflation over the forecast horizon.

Unlike US inflation, EA inflation historically exhibited more deviation from its medium-term target (see Figure 16). Economic challenges during the GFC and the European Debt Crisis subdued domestic inflationary pressures, notably affecting core prices. Similarly to US non-core inflation, fluctuations in global food and oil prices contributed to volatile non-core inflation in European countries. After the GFC, commodity price shocks stemming from events like the Russia-Ukraine war pushed headline inflation above the medium-term target, whereas the collapse of commodity prices following the GFC and in 2015-2016 led to a significant deceleration in overall inflation.

Figure 16: Euro Area headline inflation and its breakdown, inflation % yoy and contributions in p.p. (2006Q1 – 2023Q4)

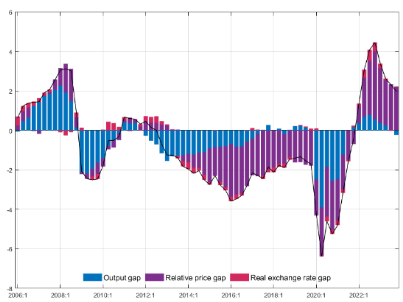
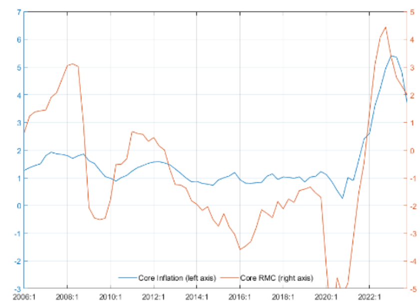


The co-movement of EA core inflation and core real marginal costs is shown in Figure 18. Before the post-COVID-19 recovery, EA core inflation fluctuated below the ECB's 2 percent inflation target. Supply chain disruptions during the pandemic caused significant adverse supply shocks in 2021. Furthermore, core inflation accelerated due to the depreciation of EUR and cost spillovers from non-core prices (Figure 16).[36] As real marginal costs decreased (Figure 17), core inflation began to decelerate in 2023 with the fading of adverse supply shocks and moderating commodity prices. The subdued cyclical position of real economic activity (Figure 15) also contributed to lower real marginal costs. Additionally, inflation expectations adjusted to the ECB tightening cycle, further contributing to the deceleration of core inflation.

Historically, non-core inflation dynamics in the EA have mostly mirrored global commodity cycles, particularly through movements in real marginal costs (Figure 19) and the impacts of global oil and food price gaps. These dynamics are also influenced by the cyclical position of real economic activity and the real exchange rate gap. At the onset of the post-pandemic period, European economies faced adverse supply shocks. Subsequently,

[36] The IMF notes that core price increases in the EA are largely driven by cost spillovers from energy prices, while in the US, core price acceleration is primarily attributed to tight labor market conditions (International Monetary Fund, 2023a).

inflation accelerated further due to the rebound in global commodity prices and the euro's depreciation. This acceleration was exacerbated by Russia halting natural gas exports to the EU in response to economic sanctions after its invasion of Ukraine in 2022. By the end of 2023, tighter monetary conditions, and a slightly negative cyclical position of real economic activity emerged. Additionally, real exchange rate appreciation significantly contributed to decreasing real marginal costs and the deceleration of non-core inflation.

Figure 17: Euro Area decomposition of real marginal costs for core inflation, % (2006Q1 – 2023Q4)	**Figure 18. Euro Area core inflation (yoy %, left axis) and real marginal costs (% right axis) (2006Q1 – 2023Q4)**
	

While oil prices and natural gas prices typically move in tandem, the surge in natural gas prices was notably more pronounced than that of oil prices.[37] Consequently, the global oil price gap does not fully capture the impact of the European energy crisis on its non-core inflation dynamics during 2022. Throughout 2023, European countries managed to lower non-core inflation by re-routing their energy imports.[38] This deceleration was reinforced by the normalization of commodity prices and the strengthening of the EUR following ECB tightening efforts.

[37] Natural gas price increased fifteenfold in European Union between January 2022 and its peak level in September 2022. Meanwhile, oil price increase was about 50 percent in the period between January 2022 and its peak in June 2022.

[38] According to the European Council to compensate for the reductions in Russian imports, the EU has increased imports from other sources, including Norway, the US, and the Middle East. The EU also reduced gas demand across the bloc, including voluntary 15 percent gas use reduction targets. For more information, see: Council of the European Union. "Energy Leap: How EU Countries Responded to the Russia Crisis." Last modified March 4, 2024. https://www.consilium.europa.eu/en/energy-leap-how-eu-countries-russia-crisis-supply/.

Figure 19: Euro Area decomposition of real marginal costs for non-core inflation, % (2006Q1 – 2023Q4)

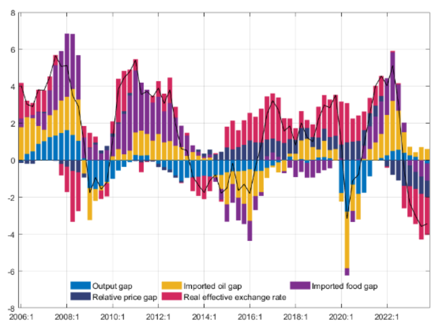
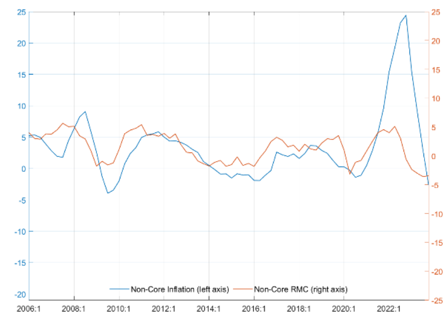


Figure 20: Euro Area non-core inflation (yoy %, left axis) and real marginal costs (% right axis) (2006Q1 – 2023Q4)



5.3 Historical Interpretation of the Chinese Economy

Figure 21: China GDP and Potential Growth, YoY % (2006Q1 – 2023Q4)

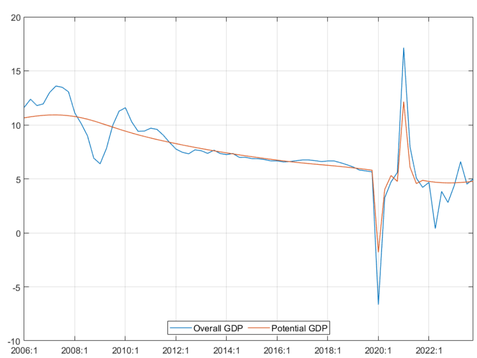
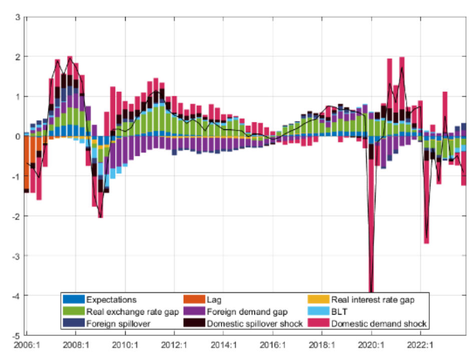


Figure 22: China Output Gap Decomposition, pp (2006Q1 – 2023Q4)



China experienced an unprecedented economic boom in the early 2000s. While the initial impact of the GFC was temporary, it reduced the long-term prospects of China's major trading partners, subsequently slowing China's average growth from above 10 percent before the GFC to just above 5 percent prior to the COVID-19 pandemic (see Figure 21). Similarly, while the immediate impact of COVID-19 on the Chinese economy was temporary, COVID-19 scarring, coupled with declining population and slowing productivity growth, have decelerated the country's potential growth to about 5 percent in near term.[39]

[39] International Monetary Fund (2023b) estimated that the potential growth of China might decline below 5 percent in the medium term.

Figure 22 displays the decomposition of China's output gap. Before the GFC, the output gap showed an overheated cycle driven mainly by a model-implied undervaluation of the exchange rate and robust foreign demand. A brief downturn below potential occurred due to weakening external demand, reflected in negative foreign demand and a model-implied strength of the exchange rate. The post-GFC recovery was broad based, bolstered by strong domestic demand and a relatively undervalued exchange rate. The impact of the COVID-19 pandemic was short lived in China, as authorities implemented larger quarantine measures compared to the rest of the world. The initial recovery was driven by robust domestic demand supported by financial relief and fiscal measures to aid affected firms. Demand for services surged after quarantine measures were lifted. In addition, the authorities implemented tax relief and waived part of social security contributions to safeguard employment. The PBC expanded re-lending facilities to provide targeted support to micro-, small- and medium-sized enterprises.[40]

While the central bank provided economic support, it did not include significant interest rate cuts; instead, the 1-year medium-term lending facility rate was lowered by 30 bps. This support is reflected in the positive demand shocks seen in the output gap decomposition. However, the post-pandemic recovery was short-lived due to frequent lockdowns under a zero-COVID-19 policy, which took a toll on the economy.[41] In 2022-23 period weak consumer confidence and domestic imbalances in real estate and financial sectors coupled with relative model implied strength of the exchange rate further accelerated the economic slowdown.[42] Although the model-based estimation of the cyclical position of the real effective exchange rate differs methodologically from the External Sector Assessment (ESA)[43] the model based estimate of the impact of the real exchange rate is consistent with the ESA results. In Figure 22, we show the cumulative impact of the real exchange rate on the output gap. The negative impact starts closing in 2023 remaining close to the neutral level afterwards as noted in the IMF 2024 China Article IV.

Figure 23 depicts the historical inflation behavior in China. Similar to its key trading partners, the US and EA, China experienced relatively stable core inflation dynamics and volatile non-core inflation linked to international commodity cycles before the pandemic. In 2023, unlike most of the world, China faced deflation driven by above mentioned sluggish economic activity depressing core prices and deflationary non-core supply shocks.

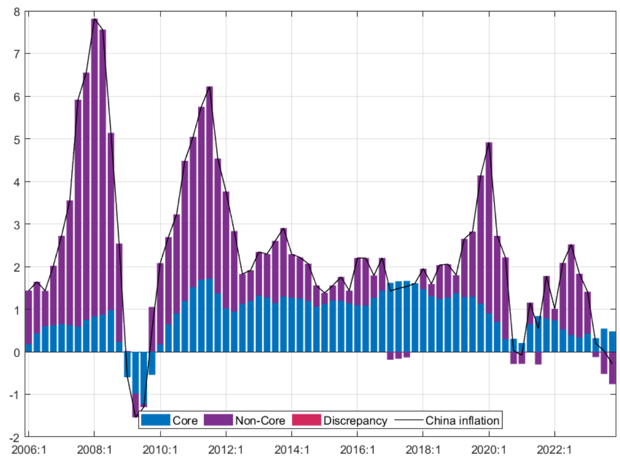
[40] International Monetary Fund, 2021b. "People's Republic of China: 2020 Article IV Consultation-Press Release; Staff Report; and Statement by the Executive Director for the People's Republic of China." International Monetary Fund Country Report No. 21/6.

[41] International Monetary, 2022b. "World Economic Outlook: Countering the Cost-of-Living Crisis." World Economic Outlook Reports, Washington, DC (October).

[42] International Monetary Fund (2023a) discusses several factors such as financial contagion in real estate market and problems with debt sustainability of local governments.

[43] See International Monetary Fund (2024), Appendix I.

Figure 23: Chinese headline inflation and its breakdown, inflation YOY % and pp contributions (2006Q1 – 2023Q4)



As shown in Figure 25, core inflation remained below 2 percent prior to the COVID-19 pandemic. Following the pandemic, core inflation decelerated due to weakened demand pressures, as depicted in the decomposition of real marginal costs (Figure 24). Meanwhile, according to Banque de France[44], China may have benefited in 2022 from increased energy imports that were re-routed from the EU. In addition, food prices also declined primarily due to the downturn of the pork price cycle. Hence, spillovers from non-core prices exacerbated disinflationary pressures, compounded by a sluggish economy in 2023. Furthermore, efforts to maintain a relatively stable exchange rate despite deflationary pressures have also contributed to inflation deceleration.

The Article IV published in 2024 highlighted two major sources of disinflationary pressures:[45] (i) heightened precautionary savings by households amid economic uncertainty dampened domestic demand; (ii) a real estate downturn weighed on rental costs and overall consumer prices. Moreover, elevated youth unemployment exerted additional disinflationary pressures through stagnant wage dynamics.

[44] Banque de France. “China Has Reduced Its Energy Bill Thanks to Russian Oil Discounts." Last modified July 25, 2024. https://www.banque-france.fr/en/publications-and-statistics/publications/china-has-reduced-its-energy-bill-thanks-russian-oil-discounts.

[45] See International Monetary Fund (2024).

Figure 24: Chinese decomposition of real marginal costs for core inflation, % (2006Q1 – 2023Q4)

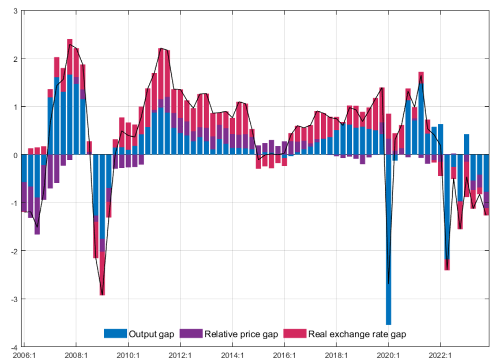
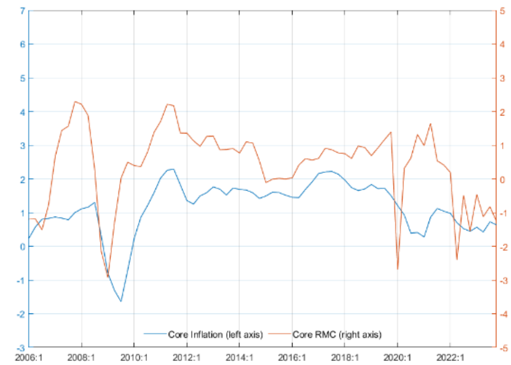


Figure 25. Chinese core inflation (yoy %, left axis) and real marginal costs (% right axis) (2006Q1 – 2023Q4)



China exhibits a history of volatile non-core prices influenced by domestic demand and reliance on volatile commodity imports, particularly food and oil, as depicted in the non-core real marginal cost decomposition (Figure 26). Historically, the premium between Brent oil prices (observed in the model) and Urals oil prices (reflecting Russian oil exports) has remained stable around USD 1 per barrel. However, in 2022, this premium jumped to an average of USD 23 per barrel. Consequently, the real marginal costs that would be projected by G3MOD for Chinese producers in 2022 are biased upwards, requiring the model to adjust with negative non-core supply shocks.

Figure 26: China decomposition of real marginal costs for core inflation, % (2006Q1 – 2023Q4)

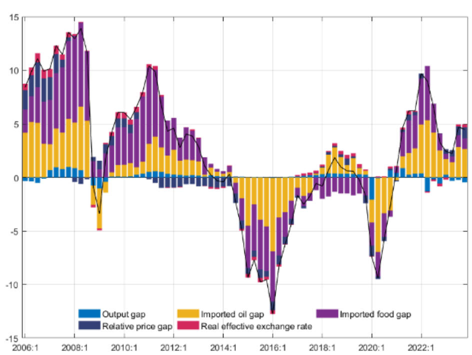
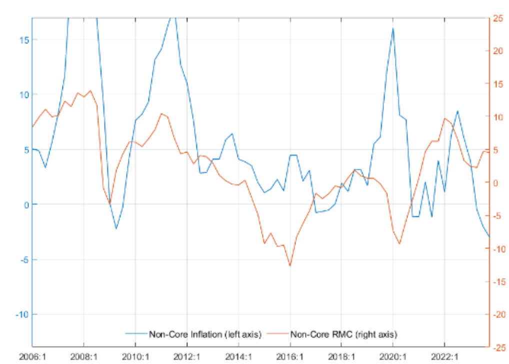


Figure 27: China core inflation (yoy %, left axis) and real marginal costs (% right axis) (2006Q1 – 2023Q4)



Overall, G3MOD-generated historical interpretation has helped to explain developments in the US, EA and Chinese economies over the last 20 years and build an economic narrative that is consistent with common views in the profession. The model correctly captures economic deceleration during GFC, anemic recovery with weak inflationary pressures, the abrupt drop in economic demand during COVID-19 pandemic and diverse inflationary pressures during the post-pandemic recovery. We next focus on G3MOD forecasting performance.

6. In-Sample Simulations and Forecasting Accuracy

To ensure that the G3MOD has good forecasting performance and is a reliable tool for interpreting other external forecasts, we conduct in-sample forecasts to empirically evaluate G3MOD's ability to predict core macroeconomic dynamics and capture critical turning points in the data of the three economies. Given that G3MOD operates as a simultaneous multi-country model without a distinct foreign sector to condition the in-sample model forecast, we do not assume prior knowledge of underlying variable trends such as real interest rate or real exchange rate. Therefore, we run recursive 8-quarter ahead conditional forecasts from 2002Q1 to 2023Q4, conditioning on inflation targets, potential growth, and commodity price developments. Figures 27 to 29 depict the resulting forecasts for selected observed variables, with model-based simulations shown in various colors, and actual data represented by solid black lines.

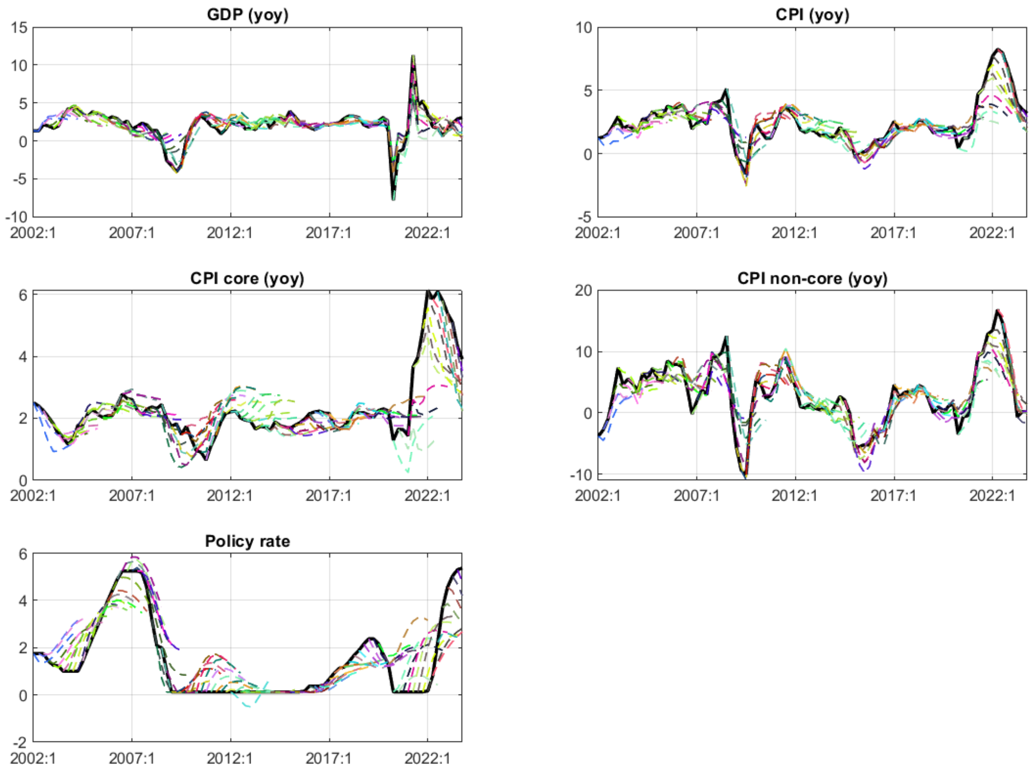
Calibrating G3MOD post-COVID-19 presented a major challenge due to shifts in elasticities of macroeconomic variables compared to the pre-COVID-19 era. Specifically, commodity price elasticity and core inflation persistence increased significantly during the post-COVID-19 recovery,[46] necessitating a careful trade-off in model calibration. The model must accurately reflect both pre-COVID-19 dynamics and generate plausible forecasts for the COVID-19 and post-COVID-19 periods. In addition, our analysis suggests a non-linear relationship between the output gap and inflation: positive gaps have a stronger inflationary impact than disinflationary impact stemming from a similarly sized negative output gaps, possibly due to downward price or wage rigidities.

6.1 In-Sample Simulations and Forecasting Accuracy for the US Economy

The model generally captures US macroeconomic dynamics, accurately identifying major turning points in most indicators. However, notable errors in inflation forecasts occurred during the GFC trough and the COVID-19 pandemic in 2020-21. These deviations can be attributed to the non-linear impact of the output gap on inflation. To improve the model's ability to explain post-COVID-19 inflation dynamics, we calibrated it with a stronger passthrough from the output gap to inflation (larger parameter values for α_3 in equation 9 and α_7 in equation 11). While this adjustment helps link rising inflation post-COVID-19 to a robust US economy, it also leads to an overestimation of disinflationary pressures following the post-GFC slack.

[46] For more details see Cascaldi-Garcia et al. (2023).

Figure 28: In-sample Simulations for the US Economy (2002Q1 – 2023Q4)



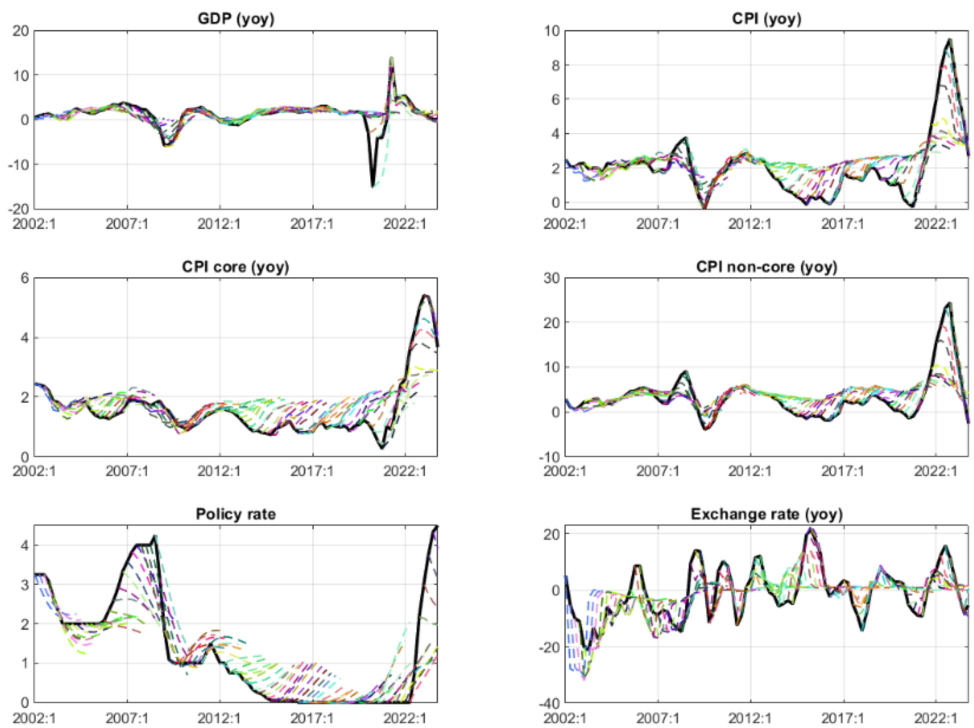
6.2 In-Sample Simulations and Forecasting Accuracy for the Euro Area Economy

The model generally captures EA macroeconomic dynamics well. It identifies major turning points in most indicators, similar to the US economy. However, significant and persistent errors arise during the post-GFC recovery. Despite predicting a gradual economic recovery that typically pressures inflation and prompts monetary policy tightening, actual inflation did not accelerate as expected. This discrepancy is attributed to larger inflation expectations persistence in the EA compared to the US, requiring a more prolonged economic acceleration to generate noticeable inflationary pressures.[47]

Adjusting the calibration of EA Phillips curves to be more backward-looking (i.e., increasing values of α_1 in equation 8 and α_5 in equation 10) could potentially improve fit during post-GFC recovery periods when inflation forecasts overshoot. However, such a change would exacerbate errors during the trough of the GFC and COVID-19, resulting in lower overall forecasting accuracy.

[47] Ciccarelli and Osbat (2017).

Figure 29: In-sample Simulations for the Euro Area Economy (2002Q1 – 2023Q4)



6.3 In-Sample Simulations and Forecasting Accuracy for the Chinese Economy

Similar to the US and EA, the model generally produces a reasonable forecast fit for macroeconomic variables in China, except during the recent disinflationary period. One potential explanation is that the model may not fully capture the extent of economic slack in China, thereby underestimating disinflationary pressures from weaknesses in the real estate sector weakness and high youth unemployment. Additionally, the model may overestimate the pass-through of commodity price shocks, particularly evident in the post-COVID oil price increases.

Figure 30: In-sample Simulations for the Chinese Economy (2002Q1 – 2023Q4)

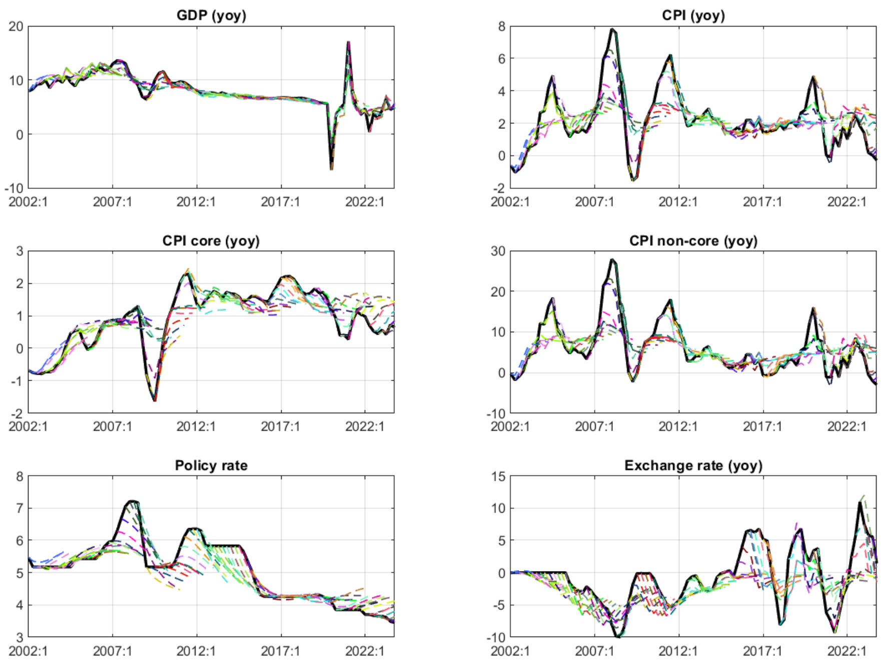


Table 1 presents a quantitative evaluation of the G3MOD's forecast performance by comparing root mean squared errors (RMSE) with those of the random walk (RW) benchmark.[48] We present ratios of G3MOD's RMSE to the RW benchmark for selected series over 8-quarter forecasting horizon, where a lower ratio delivers superior forecasts, outperforming the RW benchmark for the corresponding variables and forecasting horizon. Results show that G3MOD consistently outperforms the random walk model specially over longer time horizons, with exceptions observed in the first quarters for nominal interest rates and exchange rates.[49] This

[48] RMSE is calculated by taking the square root of the average of squared differences between predicted and actual values. It quantifies the average magnitude of prediction errors in the same units as the dependent variable.

[49] The endogenous monetary policies respond to all incoming information, even in the early periods of the in-sample forecast. However, during the Global Financial Crisis (GFC) and COVID-19 periods, the observed policy rates are notably smoothed. Subsequently, G3MOD effectively captures the medium-term dynamics of the time series and can outperform random walk forecasts for key monetary policy variables as well.

can be attributed to the model's calibration, which is optimized for the post-COVID-19 period of inflationary pickup and may not align well with the pre-COVID-19 period, spanning more than 20 years.

Table 1: Root Mean Square Forecast Errors Relative to Random Walk Model

	1q	2q	3q	4q	5q	6q	7q	8q
US Real Output (% YoY)	0.35	0.39	0.39	0.36	0.40	0.45	0.49	0.52
US Real Output (%)	0.95	0.89	0.84	0.79	0.75	0.73	0.70	0.68
US Headline CPI (% YoY)	0.58	0.56	0.54	0.56	0.56	0.59	0.61	0.64
US Core CPI (% YoY)	0.73	0.83	0.92	0.99	0.93	0.90	0.87	0.87
US Non-Core CPI (% YoY)	0.52	0.47	0.42	0.39	0.39	0.42	0.44	0.47
US Nominal Interest (% pa)	1.04	0.97	0.87	0.75	0.65	0.58	0.55	0.54
EZ Real Output (% YoY)	0.68	0.62	0.55	0.50	0.51	0.57	0.59	0.62
EZ Real Output (%)	0.90	0.83	0.77	0.71	0.67	0.66	0.65	0.65
EZ Headline CPI (% YoY)	0.62	0.68	0.71	0.77	0.75	0.73	0.72	0.72
EZ Core CPI (% YoY)	0.56	0.63	0.74	0.84	0.85	0.83	0.82	0.81
EZ Non-Core CPI (% YoY)	0.58	0.61	0.64	0.67	0.64	0.64	0.66	0.70
EZ Nominal Interest (% pa)	0.99	0.94	0.87	0.81	0.76	0.73	0.73	0.73
EZ Nominal Exchange (100*log)	1.84	1.11	0.82	0.68	0.60	0.57	0.55	0.52
CN Real Output (% YoY)	0.35	0.35	0.34	0.30	0.36	0.40	0.40	0.42
CN Real Output (%)	0.92	0.94	0.84	0.82	0.78	0.76	0.73	0.72
CN Headline CPI (% YoY)	0.55	0.54	0.55	0.56	0.54	0.53	0.55	0.57
CN Core CPI (% YoY)	0.53	0.57	0.62	0.68	0.69	0.69	0.68	0.68
CN Non-Core CPI (% YoY)	0.57	0.55	0.55	0.55	0.52	0.51	0.54	0.58
CN Nominal Interest (% pa)	0.89	0.83	0.80	0.78	0.78	0.78	0.79	0.80
CN Nominal Exchange (100*log)	1.00	0.94	0.91	0.89	0.85	0.82	0.79	0.77

Overall, Table 1 shows that the model achieves good forecasting performance despite significant challenges in calibration. These challenges stem from the need to comprehensively reflect economic behaviors over two decades marked by diverse shocks such as the GFC, European debt crisis, COVID-19 pandemic, and subsequent global inflation acceleration.

Achieving accurate forecasting and fitting historical data while maintaining theoretical coherence required an iterative calibration approach. Each adjustment aimed at improving forecasting performance was followed by a review of impulse responses to ensure consistency with economic theory and an assessment of changes in historical interpretation to align with common understanding of events.[50]

This approach has resulted in a model that effectively captures historical data and generates high-quality forecasts for the global economy. Recognizing the challenges faced by certain EMDE central banks in developing robust assumptions for the major global economies through ICD-provided macroframework TA, G3MOD plays a crucial role in supporting TA recipients. It enables them to focus on enhancing their capacity in learning and modeling their domestic economies until they can independently produce reliable assumptions for the major global economies.

[50] This is especially complicated in the multi-country model when changes in one block calibration can affect behavior of other blocks.

7. Translating External Forecast into QPM language

G3MOD is a suitable tool for manipulating and interpreting projections of key external variables, notably GDP growth, inflation, exchange rates, and commodity prices, within a QPM-consistent framework. This section outlines the procedures for using G3MOD to reproduce the headline values for a given external forecast, while decomposing these forecasts into their gap and trend components.[51] Additionally, it explains how to produce quarterly versions of these forecasts when they are originally provided on an annual, frequency. With the appropriate assumptions, as detailed below, this quarterly trend-gap decomposition can maintain the underlying narrative of the original external forecast. In the accompanying code and as described in this section, we use the IMF's published WEO forecasts as an example.

More specifically, in the example application demonstrated in this paper and in the accompanying code and infrastructure, the G3MOD can incorporate the annual values of institutional external forecasts (e.g., IMF WEO, FED and ECB forecasts, World Bank Global Economic Prospects, Asian Development Bank's Asian Development Outlook etc.) for the US, Euro Area, and China (CPI, GDP, exchange rates), and commodity prices (food, oil), and interpolates them into quarterly data, using the Kalman filter. In line with the institutional external forecasts and based on the structural assumptions of G3MOD, the filter estimates the gap and trend components of the real variables in accordance with projected monetary policy measures and inflationary pressures for the G3 economies. For instance, the procedure estimates the output gaps' underpinning the observed GDP projection for G3 economies by gaining information from the inflation outlook to help determine the strength of demand-side inflationary pressures over the forecast horizon. This also considers the expected inflationary impact of other factors including from commodity prices and exchange rate fluctuations. Furthermore, to include other considerations outside the scope of a parsimonious G3MOD in further enhancing consistent economic narratives, expert judgment based on a thorough review of country reports and market analyses can be used to fine-tune the trend-gap decomposition. Here for example, the unconditional G3MOD projection of the US policy rate may not be fully aligned with the Federal Reserve's expectations, in which case, the Fed dot plot can be exploited in fine-tuning the expected path of the medium-term interest rate path.

As for a typical G3MOD forecast preparation, this follows in spirit in the footsteps of typical forecast rounds inside central banks. Key procedural steps are followed—i.e., data collection and transformation; estimation of initial conditions; and forecasting.

G3MOD users start by collecting data for the US, Euro Area, and China as well as for the 10 other economies combined into the "rest of the world" block. An automated data transformation script will apply the necessary transformation procedures (e.g., frequency conversion, log-linearization) and additionally provides a single rest of the world block as a weighted average based on the nominal GDP sizes of these economies.

Next, the Kalman filter estimates the initial conditions of the economy, which are based on the observed data and the structural assumptions of the model, regardless of future information. Users can then apply additional judgment to reflect their assessment or overwrite the filter estimation. For example, during the COVID-19 period, expert judgments were used to inform the model about the level shift in the GDP trend, in light of negative demand shocks which on their own generate large negative output gaps and negative inflationary pressures.

[51] Along with the model, the code infrastructure used to carry out the exercises in this section is available in supplemental resources.

Moving into the forecasting stage, the G3MOD then considers the estimated initial conditions, imposes the annual frequency projections for the key GDP growth, inflation, and commodity prices from the WEO forecast,[52] and simultaneously estimates the forecast for the unobserved variables (gaps and trends) consistently with the forecast story including on inflation, while also relying on expert judgment in further helping guide a consistent narrative with the WEO forecast.[53]

In this example, the G3MOD does not deliver its own external forecast. Instead, it decomposes a given external forecast, such as the IMF WEO forecast in this example. However, other exercises are possible. For example, a pure model forecast known as an ‘unconditional’ forecast, can be generated to demonstrate the implications of estimated initial conditions and the underlying projected narrative of the model.[54]

Before imposing the external forecast onto the model, the unconditional forecast, and the external forecast (WEO) are compared. Significant discrepancies that cannot be rationalized or explained consistently with underlying changes in the economies, such as a surge in commodity prices, necessitate revisiting the estimation of initial conditions. This step ensures that when the WEO forecast is imposed, the model does not assume shocks with a low probability of occurrence, provided both forecasts share similar narratives.

G3MOD codes can follow these procedures to produce in-house QPM-consistent external assumptions.[55] Similarly, G3MOD output aligned with GAS assumptions can be used directly by Fund staff using QPM models in their external assumptions.

8. Conclusion

G3MOD represents an important contribution to meeting the external forecasting needs of central banks and other policy institutions, including IMF TA recipients. By focusing on the G3 economies and incorporating insights from central banks’ policy models, G3MOD enables users to generate baseline and alternative scenarios for the external environment with enhanced flexibility and timeliness. Available global projections, such as those of the IMF’s WEO are generally not expressed in gap-trend terms, and only available in annual values. G3MOD and its code infrastructure facilitate the mapping of these existing forecasts into quarterly gap-tend projections. It also facilitates user-defined scenarios. The structured approach of G3MOD, calibrated through rigorous testing, ensures alignment with global economic trends while providing a practical tool for monetary policy analysis and forecasting.

G3MOD is a small-scale, semi-structural model designed to assess trade and financial linkages across the G3 economies and the rest of the world. It is based on Carabenciov (2013), incorporating updates to reflect recent economic developments, particularly the inclusion of the differences in China’s monetary policy. G3MOD’s

[52] The published WEO forecast numbers are annual growth rates, these are interpolated to quarterly frequency by the Kalman filter.

[53] Under extraordinary circumstances, in case of an outdated WEO forecast or significant changes in the forecast story, expert judgments can be used. They can reflect an updated monetary policy decision, i.e., the revision of Fed dot plot pointing to a prolonged restrictive monetary policy, and adjusting the G3MOD forecast by new information from the Fed.

[54] An ‘unconditional’ forecast is derived from the estimated initial conditions and cyclical positions of the last key variable observations without any expert judgment or imposed forecast assumption.

[55] For example, IMF TA recipients can independently generate external assumptions for their regular forecasting activities, after a period of training and capacity building. TA recipients can use G3MOD results to build own external assumptions using relevant trade weights. For instance, the Bank of Mauritius may observe the foreign demand gap as 30 percent US and 70 percent Euro Area, while the Bank of Bangladesh would have a larger weight to China’s output gap.

parsimonious design enables focused policy simulations and economic interpretations, catering to central banks and others using semi-structural gap-trend-based frameworks, especially where resource or capacity constraints limit in-house multi-country projections.

Impulse response analysis in G3MOD interpreted successfully historical data, which can support policy-contingent forecasts and risk assessments. Its adaptability to diverse shocks, coupled with insights into G3 macroeconomics provided robust policy implications across various scenarios. Historical interpretation, aided by the Kalman filter, has been pivotal in constructing a coherent economic narrative, analyzing variable co-movement, and validating the alignment of economic interpretations with model outcomes. For instance, G3MOD facilitated a consistent explanation of pre- and post-COVID-19 demand-side pressures, monetary policy responses and escalating inflationary pressures. Furthermore, the G3MOD can support EMDE central banks during their regular forecasting exercise to prepare their own foreign assumptions based on external forecasts such as those of the IMF's WEO.

G3MOD's regular quarterly updates and adaptable framework are well-suited to support central banks in evaluating external developments and risks, thereby enhancing their capacity for informed decision-making. Increasingly, other institutions, such as ministries of finance are also using QPMs and may find this tool useful. In part because of its simplicity, G3MOD is poised for adaptation to a broad range of economic contexts, future economic developments, and policy new challenges.

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