Special Feature B

A Multi-Country Quarterly Projection Model for MAS

Global Projection Model Network[1]

1 Introduction

Over the past decade, Quarterly Projection Models (QPMs)[2] have established their place in the forecasting toolkits of central banks due to their ability to strike an adequate balance between the theoretical consistency embodied in highly-structured DSGE models, and the empirical accuracy obtainable from statistical models.

QPMs are typically built from a relatively small number of key equations, such as an IS curve, a Phillips Curve, an uncovered interest rate parity (UIP) condition, and a Taylor-type monetary policy rule. A specific category in the family of these models are multi-country QPMs, which are created as a group of smaller interlinked country-specific QPMs. The Global Projection Model (GPM) is an example of a multi-country QPM. Its history dates back to 2008[3], when the GPM for the largest advanced economies was developed.

The family of GPM models has grown substantially over the years. Besides the broader advantages of QPMs adduced above, GPMs allow the modeller to configure the regions within the inbuilt model infrastructure. The modelling of interlinkages among the countries makes GPMs well-suited for analysing the propagation and transmission of global shocks.

Currently, the Global Projection Model Network (GPMN) maintains and regularly updates the GPM++ model, which consists of ten individual countries and a "Rest of the Countries" block.[4] GPM-MAS is a customised version of the GPM++, developed for MAS in 2019. The model covers some 80% of world GDP and comprises eight individual economies (China, Eurozone, India, Indonesia, Japan, Malaysia, UK, US), and three regions (Northeast Asia, Thailand/Philippines, and "Rest of the Countries").[5] With this specially selected set of economies, GPM-MAS can be used to forecast or simulate macroeconomic outcomes for Singapore's main trading partners. The results can then be used as an input to the MAS' suite of models of the Singapore economy. Specifically, the individual country blocks' output gaps and inflation obtained from the GPM-MAS serve as exogenous inputs into the Satellite Model

[1] The Global Projection Model Network (GPMN) is a non-profit research institute providing regular global macroeconomic forecasts and risk scenarios. The authors collaborated with EPG, MAS to construct the new model described in this Special Feature. However, the views in this article are solely those of the authors and should not be attributed to MAS.

[2] Behind the QPM is a New Keynesian semi-structural model. Benes *et al.* (2008) can be used as an introductory exposition.

[3] A background on QPMs can be found in Carabenciov *et al.* (2008a, b, c).

[4] The GPMN makes use of the original IMF Global Projection Model (GPM) as the main tool in its forecasting kit, with additional inputs from other more structural models, such as the IMF's Global Integrated Monetary and Fiscal Model (GIMF). In addition, the institute organises workshops, provides training and technical assistance related to the suite of models used by the team, and develops macroeconomic models and software solutions that support the forecasting environment. For more information, including the full model description, visit www.igpmn.org.

[5] Besides country blocks, the GPM++ also models the prices of eight types of commodities (coal, cobalt, cocoa, copper, food, gold, iron and oil).

of Singapore (SMS)[6], which then allows for more detailed analysis of the effects of global shocks on the Singapore economy.

The aim of this Special Feature is to describe the main features of the GPM-MAS and illustrate how this model is used for simulating alternative scenarios to address policy-relevant questions. Specifically, the impact of a vaccine-resilient mutation of the COVID-19 virus on the global economy is estimated, and the differing impacts on various regions illustrated.

2 Theoretical Overview

Similar to the GPM++, the GPM-MAS is a multi-country QPM that groups multiple open-economy New Keynesian semi-structural country models, and forms a global model via linkages among them. Each of these country models has four key equations:

- an aggregate demand or IS curve that relates real activity to the real interest rate and the real exchange rate;
- a price-setting or Phillips Curve that relates inflation to the output gap and the exchange rate;
- a UIP condition relating the exchange rate to domestic and foreign interest rates, with some allowance for backward-looking expectations or exchange rate management;
- a monetary policy rule for setting the policy instrument as a function of the output gap and expected inflation.

The individual country/region models are linked to ensure internal consistency of the model projections. These linkages are one of the most important features of the GPM model framework. The model structure accounts for three types of linkages, namely:

- a financial channel between the advanced economies and other countries;
- traditional trade links;
- confidence spillovers, which help to capture observed cross-correlation and covariance among countries that cannot be fully explained by traditional trade links.

Model Equations

In order to ensure an acceptable empirical fit and capture country-specific features, the GPM-MAS introduces several modifications of traditional textbook open-economy New Keynesian model equations (e.g., Walsh, 2010; Clarida *et al.*, 1999). The GPM-MAS is fundamentally a "gap model", in which the deviations of the variables from their equilibrium values play a crucial role in modelling the dynamics of the economy. The equilibrium values themselves are determined by stochastic processes that converge to calibrated steady-state values, as described below.

[6] Details of the SMS can be found in MAS (2011).

The IS curve accounts for expectations, persistence, the effect of monetary policy, foreign demand (including cross-border trade and confidence spillovers), lending conditions, and idiosyncratic demand shocks.

$$\hat{y}_t = \beta_1 \hat{y}_{t+1} + \beta_2 \hat{y}_{t-1} - \beta_3 \widehat{lr}_{t-1} + \beta_4 \widehat{reer}^{x}_{t-1} + \beta_5 fact^{y}_t + fact^{sp}_t - \eta^{blt}_t + \varepsilon^{\hat{y}}_t + \varepsilon^{sp}_t \qquad (1)$$

where $\widehat{y_t}$ represents the output gap, $\widehat{lr_t}$ is the gap in the long-term real interest rate and $\widehat{reer}^{x}_t$ is the gap in the real effective exchange rate calculated using export weights. The term $fact^{sp}_t$ captures confidence spillovers from other countries and the term $fact^{y}_t$ traditional trade linkages.

The bank lending spillovers term, η^{blt}_t, contains extra information on whether banks in advanced economies ease or tighten lending conditions beyond the usual fluctuations induced by the business cycle. For example, a positive η^{blt}_t implies that banks tighten their lending standards by more than would be expected given an anticipated worsening of economic conditions.

Core inflation, an inflation measure without the volatile components of the headline CPI, is the key price variable in the model. Real exchange rates and real interest rates are both defined in terms of core inflation. The equation for core inflation is based on the New Keynesian Phillips Curve with the underlying assumption that a proportion of firms do not set their prices optimally and will index their prices according to observed inflation in the preceding period, thus resulting in a Phillips Curve with forward- and backward-looking elements (Christiano *et al.*, 2005):

$$\pi_t = a_1 E_t \pi^{(4)}_{t+1} + (1 + a_1)\pi^{(4)}_{t-1} + a_2(\widehat{reer}^{m}_t - \widehat{reer}^{m}_{t-4}) + a_3 \widehat{reer}^{m}_t + a_4\big(\widehat{rpoilw}_t + \hat{z}_t\big) + a_5\big(\widehat{rpfoodw}_t + \hat{z}_t\big) + a_6 f(\hat{y}_{t-1}) + \varepsilon^{\pi}_t \qquad (2)$$

where π_t represents annualised q-o-q core inflation, $E_t\pi^{(4)}_{t+1}$ denotes the model-consistent rational inflation expectation on a year-ago basis, $\widehat{reer}^{m}_t$ is the gap in the real effective exchange rate (calculated based on import weights), $\widehat{rpoilw}_t$ is the gap in the real world price of oil, $\widehat{rpfoodw}_t$ is the gap in the real world price of food, and $\hat{z}_t$ is the gap of the bilateral real exchange rate against the US dollar.

Foreign prices enter the Phillips Curve via three different channels. The first channel is through indirect effects from world oil and food prices. The second channel, $\widehat{reer}^{m}_t$, captures indirect pass-through of foreign prices of imported intermediate goods. The final channel, $(\widehat{reer}^{m}_t - \widehat{reer}^{m}_{t-4})$, is the direct transmission of the prices of imported goods that enter the consumer basket. The parameters of the Phillips Curve may differ across country blocks depending on the availability of inflation components. For countries where only headline and core inflation rates are available, core inflation is modelled using the Phillips Curve. Core inflation rate forecasts are then taken together with an estimate of the relative ratio of headline to core prices to obtain projections of headline inflation. For countries where more detailed inflation components (energy and food inflation) are available, the components are individually modelled.

Central banks in the GPM-MAS follow an inflation-forecast-based reaction function (IFBRF), when deciding on an appropriate policy path:

$$i_t^* = \gamma_1 i_{t-1} + (1-\gamma_1)(\bar{\imath}_t + \gamma_2 \pi_t^{dev} + \gamma_3 \hat{y}_t) + \varepsilon_t^i \qquad (3)$$
$$i_t = \max\{i_t^*, 0\}$$

where ${\pi_t}^{dev}$ is the deviation of expected inflation from the inflation target and $\bar{\imath}_t$ represents the nominal neutral interest rate. The monetary policy rule has been modified for the US block to include an additional price level gap term in order to reflect the Fed's long-run policy framework articulated in August 2020 of achieving an average inflation target of 2% over time.

Since the GFC, some central banks have been using various non-standard monetary tools (e.g., bond purchases, yield curve control) to stimulate the economy. However, the lack of consensus in the literature on the transmission channel of unconventional policies or the magnitude of their effects makes it challenging to model them. Such measures are therefore not currently modelled in GPM-MAS.

The model uses nominal exchange rates vis-à-vis the US dollar for all countries. The central bank is assumed not to intervene in the foreign exchange market. Under the assumption that there are no capital account restrictions, the nominal exchange rate satisfies the UIP condition:

$$s_t = s_{t+1}^e + (i_t^{US} - i_t + prem_t) + \varepsilon_t^s \qquad (4)$$

where exchange rate expectations s_{t+1}^e are modelled with both forward- and backward-looking components in order to account for a group of agents that uses a "rule of thumb" formula and another group which rationally expects the nominal exchange rate to adjust in line with movements in the equilibrium real exchange rate and the average inflation differential implied by inflation targets.[7] There are alternative rules to equation (4) which recognise that some countries might have varying degrees of friction on their financial account.

Besides cyclical equations, the model defines several country block-specific domestic equilibrium and trend variables, of which the most important are: a) equilibrium output, b) equilibrium bilateral real exchange rate, c) country risk premium, d) equilibrium unemployment (i.e., NAIRU), e) equilibrium lending conditions, f) equilibrium ratio of headline to core prices, and g) the headline inflation target.

Equilibrium output $\bar{y}_t$ is given as the sum of a level shock $\varepsilon_t^{\bar{y}}$ and its growth rate, $\Delta\bar{y}_t$, which follows an AR(1) random walk process with drift, around the steady-state value $\Delta\bar{y}_{ss}$.

$$\bar{y}_t = \bar{y}_{t-1} + \Delta\bar{y}_t + \varepsilon_t^{\bar{y}} \qquad (5)$$
$$\Delta\bar{y}_t = \rho^{\Delta\bar{y}}\Delta\bar{y}_{t-1} + (1-\rho^{\Delta\bar{y}})\Delta\bar{y}_{ss} + \varepsilon_t^{\Delta\bar{y}} \qquad (6)$$

The equilibrium real exchange rate $\bar{z}_t$ is modelled in a similar fashion to equilibrium output. The NAIRU is defined by an AR(1) process. In the case of the equilibrium real interest rate $\bar{r}_t$, the model distinguishes between the US equilibrium real interest rate, which serves as

7 Specifically, $s_{t+1}^e = \alpha E_t s_{t+1} + (1-\alpha)[s_{t-1} + \frac{1}{2}(\pi_t^T - \pi_t^{T^{US}} + \Delta\bar{z}_t)]$, where $E_t s_{t+1}$ denotes the model-consistent rational expectation, π_t^T is the inflation target and $\Delta\bar{z}_t$ represents the change in the bilateral equilibrium real exchange rate.

a proxy for the global rate, and equilibrium real interest rates for other countries, which are derived as

$$\bar{r}_t = \bar{r}_t^{US} + \Delta\bar{z}_{t+1} + prem_t \tag{7}$$

where $prem_t$ is a country risk premium which follows an independent AR(1) process around a calibrated steady-state value.

Additionally, GPM-MAS takes into account heterogeneity among the countries in the model by introducing equations for groups of countries to capture country-specific traits. GPM-MAS includes five such groups of equations to account for the following types of heterogeneity:

- real-financial linkages through bank lending tightening measures available for the G3 economies to explain movements in real activity during the GFC;
- susceptibility to natural disasters or commodity cycles, which improves the model's ability to capture the unusually high volatility in GDP data for some countries;
- term premiums embedded in long-term interest rates (e.g., Japan, UK), allowing the model to be used to explore such shocks;
- the US monetary policy objective function places weights on both a price level target and an inflation target, to incorporate the Fed's new average inflation targeting framework;
- for some countries (where data is available), food and energy inflation are also modelled separately from core inflation (e.g., G3 economies), allowing commodity price shocks to be explored in more detail.

3 Confronting the Model with the Data

Similar to other variants of GPMs, GPM-MAS is estimated using a Bayesian technique. The Bayesian approach[8] provides a middle ground between conventional estimation and model calibration. An important benefit of this method is the flexibility it gives to strike an optimal balance between theoretical consistency (embodied in priors) and statistical fit, by adjusting the relative weights placed on priors and data. Further, the GPM-MAS includes a few countries with atypical policy regimes (e.g., inflation targeting with an exchange rate anchor). This calls for a more structural approach (based on knowledge of the conduct of monetary policy in these economies) rather than pure statistical inference when assigning appropriate values to model parameters. In such cases, parameters are calibrated with priors based on impulse response functions and conditional distributions.

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8 Carabenciov *et al.* (2008b, c) provides a more detailed explanation of the Bayesian technique adopted in Global Projection Models; Berg *et al.* (2006) introduces a manual on implementing and working with Bayesian estimation in macroeconomic models.

Special Model Features

The GPM-MAS benefits from recent developments in economic theory and modelling by incorporating non-linear features in order to account for the empirically-suggested convexity of the Phillips Curve and the zero lower bound problem. Both of these have become important policy-relevant issues after the GFC.

Further, the GPM-MAS allows simulations using both anticipated and surprise (unanticipated) shocks. Anticipated shocks are used in specific cases such as a VAT hike announced in advance (e.g., in Japan) and in policy actions of central banks communicated via forward guidance. Since the GFC, numerous central banks have been using forward guidance as a tool to indicate future policy steps. More recently, central banks (mostly in advanced economies) have communicated their intentions to maintain policy interest rates at zero/sub-zero levels for longer (and sometimes beyond the policy-relevant forecast horizon). In order to impose such assumptions in the model, policy actions of central banks are treated as anticipated policy actions.

4 Exploring Scenarios Using the GPM-MAS: An Illustrative Exercise

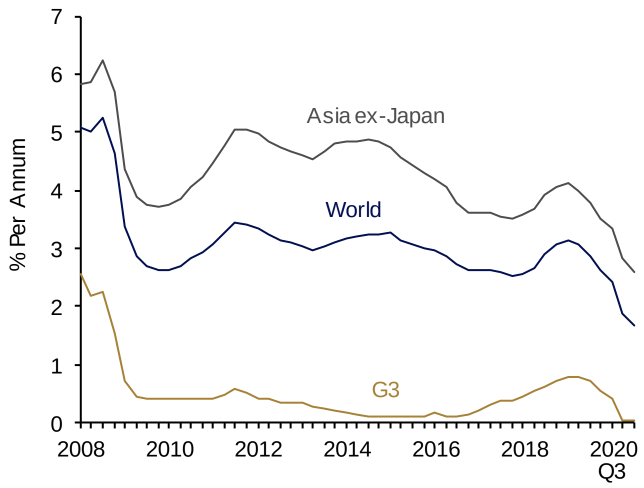
The GPM-MAS can be used for various purposes, ranging from regular quarterly projection updates to simulation of various hypothetical and policy-relevant scenarios. The modelling of interlinkages makes the GPM-MAS a particularly useful tool for the analysis of scenarios involving shocks that affect many countries. For this Special Feature, the purpose is to illustrate how the GPM-MAS is used to simulate the global macroeconomic effects of a scenario in which a new vaccine-resistant COVID-19 strain spreads globally.

Scenario Description

This scenario is built on the following narrative. A second global COVID-19 outbreak occurs in Q1 2022, involving the spread of a new virus strain with resistance to currently-available vaccines. Countries experiencing widespread COVID-19 infections may be more likely origins for such a new strain. To facilitate comparison with the first COVID-19 pandemic, it is assumed that the virus outbreak originates from within the region itself. Based on the time taken to develop the first crop of vaccines, it is assumed to take about a year to develop, test and approve a vaccine that is effective against the new strain. Meanwhile, global travel (assumed to have resumed in the meantime) will lead to a swift spread of the virus to other parts of the world. To contain infections and prevent healthcare systems from collapsing, countries close their borders and impose domestic movement restrictions. Accordingly, contact-intensive sectors will stop operations.

It is assumed that the policy responses of governments and central banks will be much more constrained compared to their reactions to the 2020 pandemic, owing to reductions in policy space. In particular, central banks have less or no remaining room to lower interest rates **(Chart 1)**. Fiscal space is also assumed to be limited given the unprecedented size of fiscal packages passed in response to the outbreak last year.

Chart 1 Nominal interest rates



Source: GPMN

Additionally, lending conditions are assumed to tighten by significantly more than during the COVID-19 crisis in 2020, as both borrowers' credit quality and banks' loss absorption capacity are assumed to still be suffering from the adverse effects of the initial pandemic; this in turn makes banks even more risk-averse than would be expected given the deterioration in the economic outlook.

Based on the narrative described above, the following assumptions were imposed in order to construct the scenario in the GPM-MAS:

- In terms of policy reactions of central banks, the effective lower bound condition is assumed to be binding for the advanced economies (G3 and the UK) and policy rates do not change from current levels. Central banks in other countries with remaining policy space have discretion to reduce policy rates.

- Unanticipated shocks are applied to domestic demand and potential output to reflect the closure of borders, movement restrictions as well as the shutdown of contact-intensive sectors to prevent the spread of the new strain, and the subsequent reopening once a new vaccine becomes available. The magnitudes of the imposed shocks are inspired by the COVID-19 crisis in 2020 but scaled down by about a half. This is based on the premise that the previous COVID-19 crisis had enhanced the readiness and responsiveness of governments and also improved contingency planning and crisis-management of businesses.[9] In other words, lockdowns of a given level of severity are assumed to be less economically damaging.

    - Sources of the demand shock are divided between the domestic and spillover effects, as lockdowns restrict domestic activities and impair global trade chains.

[9] While there is no fiscal block in GPM-type models, the specification of the shock took into account the magnitude and economic impact of additional stimulus measures.

    - On the supply side, lockdowns will lower both the level and growth of potential GDP on the assumption that the shock will inflict some permanent scarring on potential output.

- Regional heterogeneity needs to be accounted for when assessing the magnitude of shocks. In the 2020 crisis, the closure of non-essential businesses and limitations on cross-border travel affected mostly the contact-intensive services sectors. In some countries, these represent more than 60% of value added (e.g., the Euro Area or the UK), but less than 50% in others (e.g., India or Indonesia). Moreover, the types of restrictions imposed varied—some countries introduced hard lockdowns, while others adopted softer recommendations. These factors help to explain the differences in the size of shocks in each country.

- The timing of these shocks is allowed to differ between countries. The virus outbreak is assumed to occur in Q1 2022. The other countries will see negative effects with a delay, depending on the speed at which the virus spreads and the responsiveness of governments.

5 Results

The monetary policy responses and the macroeconomic impact from taking the scenario described above into the GPM-MAS are illustrated in this section, with a particular focus on the G3 and the Asian (ex-Japan) economies as blocs.[10] Results are presented relative to a baseline scenario in which the second virus outbreak does not occur.

Monetary Policy Response

The onset of a vaccine-resistant strain of the virus leads to the re-imposition of public health measures, reducing output and therefore, widening the output gap and reducing inflation. Central banks react by easing monetary policy, where they have space to do so. In the baseline, central banks in the G3 economies are expected to keep policy rates at their effective lower bounds until Q2 2023, and then gradually raise them. As a result, these central banks only acquire room to run easier policy than in the baseline around five quarters after the initial shock.[11] In comparison, some of the Asian central banks have more policy room available; on average, Asian central banks are able to lower policy rates by 0.5% point below baseline over a period of two years.

Real GDP

In GPMN's baseline, world GDP is expected to return to its pre-COVID level by end-2021. However, with the new virus outbreak in Q1 2022, the recovery is interrupted by a renewed deterioration in activity. World GDP reaches a trough of 3.1% below pre-shock levels (i.e., Q4 2021) by Q3 2022 **(Chart 2a)**. This is a much smaller decline than that inflicted by the 2020 pandemic, when GDP was 10.4% below Q4 2019 levels at its lowest point in Q2 2020. The smaller impact of the shock is largely due to the assumption in the scenario that the public health response will cause less disruption to economic activity. The reduced impact on activity reflects governments' improved ability to implement targeted lockdowns and efficient

10 The G3 refers to the Eurozone, Japan and the US, while the Asia ex-Japan bloc comprises China, Hong Kong, India, Indonesia, Malaysia, the Philippines, South Korea, Taiwan and Thailand. All aggregates are weighted by GDP PPP shares.

11 As noted above, the GPM-MAS does not incorporate unconventional monetary policies.

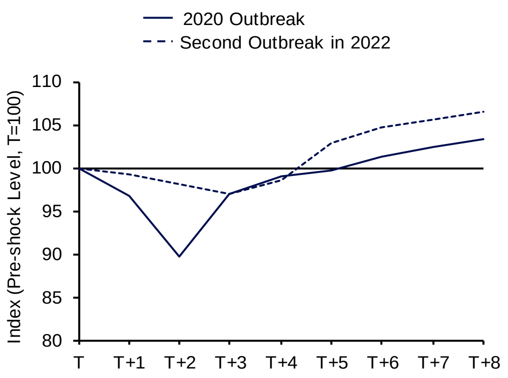
contact tracing systems without tightening mobility restrictions as much as in the first pandemic.

While the absolute magnitude of the shock's impact is estimated to be smaller, the dynamics of the recovery are broadly similar. The world economy is estimated to recapture its pre-shock (Q4 2021) level of GDP in five quarters, a quarter faster than GPMN's projected recovery from the initial COVID-19 outbreak. The Asian economies regain their pre-shock GDP levels by Q4 2022, more than a quarter earlier than the G3. This partly reflects greater room for monetary policy to respond in these countries **(Chart 2b)**.

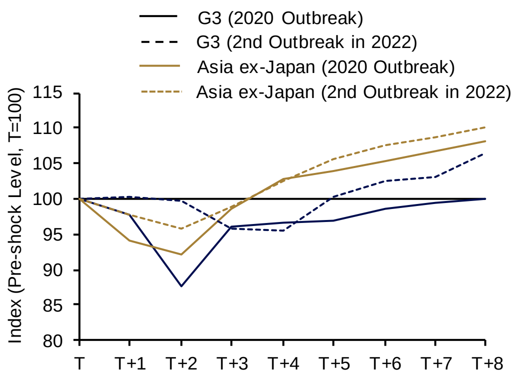
The simulations indicate the global economy recovers more strongly from the second pandemic than from the first. By Q4 2023, global output reaches 6.5% above its level in Q4 2021, before the onset of the second pandemic. The level of global output in Q4 2023, eight quarters after the shock, compares with global output at some 3.3% above the corresponding pre-shock levels for the first pandemic, partly due to the assumption that the new outbreak is less economically disruptive than its predecessor. It also reflects the point that the global economy will still be running a negative output gap as a consequence of the first pandemic by the time the second one hits. The negative output gap lowers the base from which the dynamics of the second pandemic shock progress. The lower base makes the second recovery phase more vigorous, as the model generates sufficient growth, via equilibrating forces including through price changes, to close off the residual output gap from the first pandemic, as well as to recoup output losses from the second.

Chart 2 Real GDP level

a. World



b. G3 and Asia ex-Japan



Source: GPMN

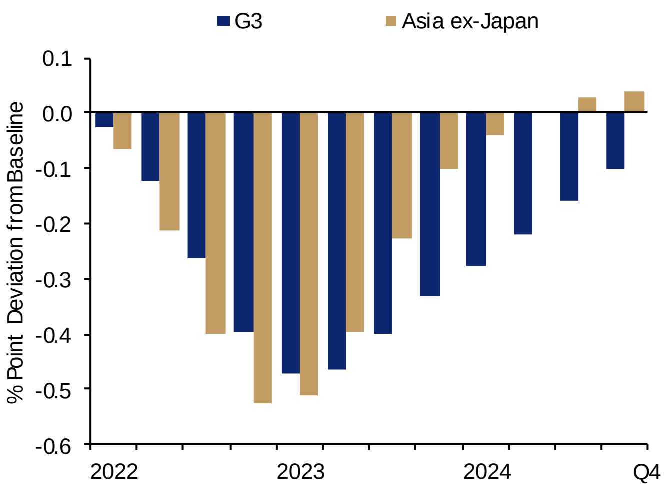
Note: The series are indexed to their respective pre-shock levels of T=Q4 2019 for the 2020 outbreak, and T=Q4 2021 for the second outbreak in 2022.

Prices

In this scenario, governments and businesses are assumed to be more adept in adjusting to the virus shock. Partly as a consequence, the impact of supply disruptions is outweighed by the decline in demand. The lower level of demand in turn explains why core inflation rates are expected to undershoot the baseline for at least two years after the onset of the shock **(Chart 3)**. Given lags in price transmissions, captured by the Phillips Curve in each of the country blocks, the impact on world headline inflation is the strongest in Q4 2022, at −0.7% point below baseline, two quarters after world output troughs. Central banks with policy rates at their effective lower bounds will take longer to see their core inflation rates return to baseline. Meanwhile, inflation rates in Asia ex-Japan, where there is still monetary policy room, are expected to return to baseline ahead of the G3 economies.

Given the fall in world demand, oil prices are projected to decline to US$11 below baseline in Q2 and Q3 2022. However, were a negative global shock to eventuate, the decline in oil prices may be smaller than the model projects if oil-producing nations decide to limit their production.

Chart 3 Core inflation



Source: GPMN

6 Sum-up

The GPM-MAS represents one of many collaborative efforts of central banks with the GPMN to create customised variants of the GPM++ to suit their modelling requirements. The inclusion of Singapore's key trading partners in the set of country blocks allows MAS to use the GPM-MAS to perform and analyse simulations that capture a richer set of interactions among the economies of greatest relevance for domestic economic outcomes. Moreover, similarities in structure allow the GPM-MAS to interface readily with the SMS. Used together, the models enhance MAS' capability to assess the effects of external shocks on the Singapore economy and to identify the attendant transmission mechanisms.

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