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Abstract

We extend the Global Projection Model (GPM) to include a separate block for China. China plays an important role in shaping global economic outcomes, given its sheer size and trade integration with other key economies, its demand for commodities, and its policies. Also, the Chinese economy has several unique features which differentiate it from the rest of emerging Asia. These features (the use of multiple monetary-policy instruments and a managed-floating exchange-rate policy) mean that a separate treatment of China allows for a better consideration of China, as well as how the rest of emerging Asia behaves.

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I. INTRODUCTION

As documented in prior papers, the Global Projection Model (GPM) project has developed a series of multi-country models designed to generate coherent global forecasts and conduct policy analysis in a comprehensive manner.[2] The underlying model-building strategy seeks to strike a balance between two popular approaches to macro modeling: highly structured dynamic stochastic general equilibrium (DSGE) models whose primary focus is theoretical consistency (often at the cost of empirical accuracy), and purely statistical models, whose primary focus is accuracy (often at the cost of theoretical consistency). The GPM modeling strategy features a core macro structure consisting of a few behavioral equations, based on conventional linkages familiar to most macro modelers and policy makers. This ensures some theoretical consistency and desirable model properties. The estimation/calibration methodology for the GPM's parameters is implemented in a manner that ensures the simulation properties are sensible and broadly consistent with modelers' priors and the data. This facilitates interpretation of forecasts and policy-analysis exercises.

This paper extends the existing GPM framework to include China. This extension is amply motivated by the emergence of China as an important driver of global economic outcomes in recent years. Indeed, China is a large and open economy (representing the world's second largest GDP in PPP terms), is a major source of demand for commodities, particularly oil and industrial metals, and is heavily integrated into global supply chains, particularly for manufactured goods. Despite the obvious importance of understanding the Chinese economy and its interactions with the rest of the world, there is a paucity of modeling work that considers China's role in the global economy. Although several models do exist which consider China, they generally fall into (at least) one of three categories: (i) those using statistical models, which are concerned only with short-term forecasting (such as Maier, 2011); (ii) those focused on domestic issues, which do not feature a well-developed external sector (such as Zhang, 2009); and (iii) those which treat China much like any other economy, overlooking many of its idiosyncratic features, for instance by treating the exchange rate regime as a pure peg, or by including only the policy rate as the key instrument used by monetary policy makers. Each of these classes of models serves a purpose, but none of them is particularly well attuned to conducting policy analyses, particularly if one wants to consider the consequences of shocks to the Chinese economy for the rest of the global economy. As demonstrated by the strong interconnections observed during the 2008 financial crisis, the lack of a structured global modeling framework is a problem for policymakers seeking to evaluate the global outlook. This paper seeks to fill that void by extending the existing GPM model to include China.

The current paper differs from earlier work on China using the GPM framework (Bailliu and Blagrave, 2010 – hereafter BB) in several important ways. First, we integrate China into a

[2] See Carabenciov and others (2008; 2013) among others.

richer global model (GPM6), which includes 6 other regional blocks (as opposed to just the G-3 in BB), and commodities (oil, food, and metals), which are critical to understanding China's role in the global economy. In addition, changes have been made to how monetary policy is conducted in the model. In particular, this paper uses the reserve-requirement ratio as an additional policy variable, where BB used a money–growth targeting rule. The decision to include the reserve-requirement ratio is motivated by its use as an instrument for sterilizing the inflationary impact of capital inflows associated with the exchange-rate regime, particularly in recent years (Ma, Xiandong, and Xi, 2011). And finally, this paper assigns a more fundamental role to exchange-rate policy in China.

The remainder of the paper proceeds as follows – the next section outlines the basic structure of GPM, emphasizing the treatment of monetary policy and exchange rates in a standard country block. The third section contrasts our modeling of China with this benchmark by presenting the equations added to suit China. The fourth section shows the properties of the new model with China, including impulse-response functions, and an examination of model fit. The fifth and final section concludes, with discussion of possible future modeling projects.

II. An Overview of GPM6

This section provides a brief overview of the structure of GPM6. The focus here is on how monetary policy and the exchange rate are modeled, given that these are the equations of the model that will need to be adapted to capture the behavior of the Chinese economy. For readers familiar with the GPM project, this section presents no new information. For a more detailed overview of the GPM model, see Carabenciov and others (2013).

Core Equation Structure

Each of the six countries/regions in GPM6 has a core set of behavioral equations specified to capture linkages between key macro variables, namely output, inflation, interest rates and exchange rates. Output, inflation and real interest rates are specified with reference to their steady-state equilibrium values. Leads and lags of selected variables are specified to capture the dynamic adjustment process. There is also a broad distinction between the modeling of G-3 and non-G-3 economies in the model, particularly with respect to the treatment of financial conditions – output in G-3 economies can be effected by episodes of domestic financial tightening/easing, whereas output in non-G-3 economies is not modeled to incorporate such a *domestic* channel (foreign financial shocks do have an effect on non-G-3 growth, however).

The output gap (y_t) in each of the G3 countries is affected by deviations of the medium-term real interest rate (RR_{t-1}) from its equilibrium value $\left(\overline{RR}_{t-1}\right)$, the four-quarter moving average of deviations of the real effective exchange rate $(REER_{t-1})$ from its equilibrium value ($\overline{REER}_{t-1}$), foreign demand (Ω_t),[3] financial conditions (θ_t, known in the GPM as 'bank lending tightening (BLT)'), commodity prices (κ_t) and two disturbance terms (ε_t^{yy} and ε_t^{y}):

(1) $$y_t = \beta_1 y_{t-1} + \beta_2 y_{t+1} - \beta_3\left(RR_{t-1} - \overline{RR}_{t-1}\right) + \beta_4 \Sigma_{i=t-1}^{t-4}\left(REER_i - \overline{REER}_i\right)/4 + \Omega_t + \theta_t + \kappa_t + \varepsilon_t^{yy} + \varepsilon_t^{y}$$

Next, the inflation process (π_t) in the model is affected by the output gap, the four-quarter moving average of the real effective exchange rate *gap* $\left(REER_t - \overline{REER}_t\right)$ and a disturbance term (ε_t^{π}) as is the case elsewhere in GPM. Inflation dynamics are determined by a combination of backward- and forward-looking components which implicitly captures the underlying expectations-formation mechanism, together with rigidities in the price-setting process:

(2) $$\pi_t = \lambda_1 \pi_{t+4} + (1-\lambda_1)\,\pi_{t-1} + \lambda_2 y_{t-1} + \lambda_3 \Sigma_{i=t-1}^{t-4}\left(REER_i - \overline{REER}_i\right)/4 + \varepsilon_t^{\pi}$$

The monetary authority in a 'standard' block of the model adjusts the nominal short-term interest rate to ensure that inflation reverts to its target rate over time. The monetary policy reaction function is specified using an inflation-forecast-based rule that has an interest-rate smoothing component:

(3) $$RS_t = (1-\gamma_1)\left[\,\overline{RR}_t + \pi 4_{t+3} + \gamma_2\left(\pi 4_{t+3} - \pi_{target}\right) + \gamma_4 y_t\,\right] + \gamma_1 RS_{t-1} + \varepsilon_t^{RS},$$

where RS_t is the short-term nominal interest rate, $\overline{RR}_t$ is the equilibrium short-term real interest rate, $\pi 4_{t+3}$ is expected inflation (in year-on-year terms), π_{target} is the inflation target, y_t is the output gap, and ε_t^{RS} is a disturbance term.[4]

Turning to the exchange rate, uncovered interest-rate parity (UIP) links deviations in domestic and foreign interest rates to the expected change in the exchange rate. For all countries in the existing GPM6 model, the expected change in the exchange rate is determined by the forward solution of the model. This ensures that interest-rate differentials are consistent with exchange-rate changes projected by the model. The expected change in the exchange rate is determined by a combination of backward- and forward-looking components:

[3] Spillovers from foreign demand occur via foreign output gaps, and shocks to foreign ε_t^{yy} terms. This structure is presented in Carabenciov and others (2013).

[4] For a discussion of Inflation-Forecast based (IFB) rules, see Laxton, Rose, and Tetlow (1993), and Amano, Coletti, and Macklem (1998).

(4) $$RR_t = RR_t^{US} + 4(LZ_{t+1}^e - LZ_t) + \overline{RR}_t - \overline{RR}_t^{US} + \varepsilon_t^{UIP},$$

where (LZ) is the real bilateral exchange rate (viz. the USD), ε_t^{UIP} is a disturbance term, and LZ^e is a blend of the model-consistent expectation of LZ, and a lag:[5]

(5) $$LZ_{t+1}^e = \varphi LZ_{t+1} + (1-\varphi)LZ_{t-1}$$

This hybrid approach in modeling exchange-rate expectations in GPM allows us to capture better the dynamics of how exchange rates adjust empirically.

III. Adding China to the GPM6

In this section we describe the modeling approach taken in adding China to the existing GPM6 framework. There are several challenges in specifying a model for China. First, there is the exchange-rate regime – China maintained a peg to the US dollar until mid-2005. Since then, the currency has been allowed to appreciate gradually against a basket of currencies, with the exception of the Great-Recession period during which time it returned to a strict peg (see Figure A in Appendix I). However, complications run deeper than this – the second wrinkle is that the existence of capital controls in China has enabled the authorities to pursue a somewhat independent monetary-policy agenda, despite the managed exchange-rate regime.[6] The third issue is that other policy instruments are used in smoothing out fluctuations in Chinese demand, including directed lending and changes in the reserve-requirement ratio. The final issue that we seek to capture in this model of China is the role that a large surplus pool or rural labor has played in limiting inflationary pressures over much of the sample period (see Dooley, Folkerts-Landau, and Garber (2004), and Das and N'Diaye (2013)). The remainder of the section presents the changes we have made to the benchmark GPM model in order to address these key features of the Chinese economy.

Modeling the Exchange-rate Regime

Beginning with the treatment of the exchange rate, we model the choice of exchange-rate regime as a policy variable in the following way:

(6) $$LS_t^{CH} = \eta^{CH}\left(LS_{p,t}^{CH}\right) + (1-\eta^{CH})LS_{UIP,t}^{CH}$$

[5] The estimation/calibration methodology for all parameters in GPM6 is described in Carabenciov and others (2013).

[6] Typically, in the presence of an open capital account, a pegged exchange rate will limit the ability of the central bank to control both the exchange and interest rates simultaneously, since any deviation in rates from those in the country to which the exchange rate is pegged would result in capital in/out flows thereby putting pressure on the exchange rate and undermining the peg.

Where LS_{UIP}^{CH} is defined by:

(7) $$LS_{UIP,t}^{CH} = LZ_{UIP,t}^{CH} - LCPI_t^{US} + LCPI_t^{CH}$$

(8) $$LZ_{UIP,t}^{CH} = LZ_{t+1}^{e} - \left(\left(RR^{CH} - \overline{RR}_t^{CH}\right) - \left(RR^{US} - \overline{RR}_t^{US}\right) + \Delta\overline{LZ}_t^{CH}\right)/4$$

So, LS_{UIP}^{CH} is the nominal bilateral exchange rate that would prevail in order for uncovered interest-rate parity to hold at time *t*. Thus, policymakers can allow the nominal exchange rate (LS_t^{CH}) to float freely, in which case they follow the UIP condition (η^{CH} set equal to 0) as is the case elsewhere in the GPM, or can opt to manage the nominal exchange rate (η^{CH} non-zero). At present, η^{CH} is set equal to $^2/_3$, thereby assigning a relatively large weight to exchange-rate management, while still allowing some fluctuations/pressures due to UIP.[7]

The path for the desired exchange rate ($LS_{p,t}^{CH}$) is assumed to be determined by the following equation:

(9) $$LS_{p,t}^{CH} = LS_{t-1}^{CH} + \left[\Delta\overline{LZ}_{t+1}^{CH} + \pi_{target}^{CH} - \pi_{target}^{US}\right] - \zeta_{CH} y_t^{CH} + \varepsilon_t^{LS_p^{CH}},$$

This equation states that policymakers adjust the appreciation/depreciation of their desired nominal rate ($LS_{p,t}^{CH}$) according to two factors – first, they would allow any change in the bilateral equilibrium real exchange rate, $\Delta\overline{LZ}_{t+1}^{CH}$ (adjusted for differences in the inflation target), to be passed through into the nominal rate. Secondly, they could accelerate (slow) the amount of appreciation if the output gap were to be positive (negative) according to the term $\zeta_{CH} y_t^{CH}$. In the current version of the model, we calibrate this term to be 0.2, which implies that the exchange-rate response to the output gap is modest.

Modeling Monetary Policy

In addition to treating the exchange rate as a policy lever, we also need to consider other mechanisms employed by policy makers in China. As in other blocks of the GPM, nominal interest-rates are one such mechanism. However, in the China block of the model nominal rates are not set in the same manner as elsewhere in the model (solely in response to inflation and output); this is done in order to alleviate pressure on the exchange rate coming through the UIP channel. More specifically, we begin with a similar rule as we have for the exchange rate, in which interest-rate policy can be chosen according to the following equation:[8]

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[7] In calibrating this parameter, the main objective was to ensure that the nominal exchange rate in the model adjusted slowly in the face of shocks, as was the case throughout the historical sample period.

[8] The approach taken here, which includes a modified interest rate rule where authorities cannot perfectly control interest rates, in tandem with the modified exchange-rate equation presented earlier, requires modifications to the UIP condition in the model. For a more detailed review of modifications to the UIP condition in New Keynesian models, see Benes, Hurnik, and Vavra (2008).

(10) $RS_t^{CH} = \upsilon^{CH}\left(RS_{p,t}^{CH}\right) + (1-\upsilon^{CH})RS_{UIP,t}^{CH} + \ \varepsilon_t^{RS^{CH}}$

As we saw in the previous subsection, the UIP condition has been modified somewhat from the specification in other work on the GPM:

(11) $RR_t^{UIP^{CH}} = RR_t^{US} + \ 4(LZ_{t+1}^{e} - \ LZ_t) + \overline{RR}_t - \overline{RR}_t^{US} - \ \Delta\overline{LZ}_t^{CH}$

(12) $RS_{UIP,t}^{CH} = RR_t^{UIP^{CH}} + \pi_{t+1}^{x,CH}$

In particular, there is no longer a shock term associated with this equation (ε_t^{UIP}). Instead, shocks enter the LS_p^{CH} and RS_p^{CH} equations directly.

Returning to equation (10), interest rates can: (i) respond freely so as to allow UIP to hold, which can be thought of as alleviating pressure on capital flows (υ^{CH} = 0); (ii) be set completely independent from what would be dictated by UIP and the exchange-rate policy (υ^{CH} = 1); or (iii) be set using some combination of the two approaches. In the present calibration of the model, we set υ^{CH} = 0.8, thereby allowing considerable autonomy in setting interest rates in response to domestic factors without great concern for the implications for the exchange rate. This parameter value yields sensible model properties, which broadly capture the recent dynamics of monetary policy decisions in China. Notionally, this equation can be thought of as suggesting that capital controls bind in China, but not completely, and so policy rates are set with some deference to the implications of exchange-rate policy for capital inflows. In fact, in recent years sterilization measures have been quite effective at curbing inflationary pressures associated with capital inflows (Ma, Xiandong, and Xi 2011). This has allowed interest rates to be set in response to domestic inflation and output, without too much concern for the implications for the managed exchange rate, and thus tends to support the calibrated value for υ^{CH} adopted here.

The policy-rate decision rule is similar to what appears elsewhere in GPM:

(13) $$RS_{p,t}^{CH} = (1-\gamma_1^{CH})\left[\,\overline{RR}_t^{CH} + \ \pi4_{t+3}^{CH} + \ \gamma_2^{CH}\left(\pi4_{t+3}^{CH} - \pi_{target}^{CH}\right) + \gamma_3^{CH} y_t^{CH}\,\right]$$

$$+ \gamma_4^{CH}\left(\varepsilon_t^{REQR_t^{CH}}\right) + \gamma_1 RS_{p,t-1}^{CH} + \ \varepsilon_t^{RS_{p,t}^{CH}}$$

As in the other blocks, rates respond to deviations of expected inflation from some target and the output gap, and display some inertia. The calibrated parameter values in this equation (presented in the appendix) are meant to reflect the notion that: i) rates are somewhat less inert in China than in the G-3 countries; ii) the policy response to inflation is somewhat weaker than in the EU, but slightly above that in the US and Japan; and iii) the response to the output gap is also slightly weaker than in other blocks of the model. This last point partly reflects the fact that China is modeled as having multiple monetary-policy instruments at its disposal to smooth out fluctuations in its economy.

Unlike other economies in the GPM, monetary policy in China does not rely as heavily on the setting of nominal interest rates. As documented in Liu and Zhang (2010), and Laurens and Maino (2007), authorities in China rely on a mix of instruments when setting policy, including benchmark lending and deposit rates (proxied in our model by the nominal interest rate equation documented above), open-market operations, moral suasion, and the reserve-requirement ratio (REQR). In recent years, the REQR has gained favor as an instrument to sterilize the domestic money base from inflows associated with the exchange-rate regime, as discussed in Ma, Xiandong, and Xi (2011) and elsewhere. Indeed, as shown in Figure B (Appendix I), reserve requirements have been adjusted at much higher frequencies since 2005 or so in response to policy objectives. With this instrument playing an increasingly important role in describing the stance of policy in recent years, we include the following decision rule for the reserve-requirement ratio in this model:[9]

(14) $$REQR_t^{CH} = \nu_1 REQR_{t-1}^{CH} + (1-\nu_1^{CH})\overline{REQR}_{t+1}^{CH} + \nu_2^{CH} y_t^{CH} + \nu_3^{CH}\left(\pi 4_{t+3}^{CH} - \pi_{target}^{CH}\right) + \nu_4^{CH}\left(\varepsilon_t^{RS_{p,t}^{CH}} + \varepsilon_t^{RS^{CH}}\right) + \varepsilon_t^{REQR_t^{CH}}$$

As with the interest-rate rule, $REQR_t^{CH}$ responds to expected inflation, the output gap, and it is a somewhat inert process. In addition, shocks to the interest rate will be accommodated by the REQR, to some degree, according to $\nu_4^{CH}\left(\varepsilon_t^{RS_{p,t}^{CH}} + \varepsilon_t^{RS^{CH}}\right)$. The calibrated parameter values in this version of the model place equal weights on the output gap and inflation deviations from target, and REQR is modeled as being slightly less inert than the interest rate.

Modeling Output and Inflation

Ultimately, the three policy measures described above affect output in the following way:

(15) $$y_t^{CH} = \beta_1^{CH} y_{t-1}^{CH} + \beta_2^{CH} y_{t+1}^{CH} - \beta_3^{CH}\left(RR_{t-1}^{CH} - \overline{RR}_{t-1}^{CH}\right) + \beta_4^{CH}\Sigma_{i=t-1}^{t-4}\left(REER_i - \overline{REER}_i\right)/4 + \Omega_t^{CH} + \kappa_t^{CH} - \beta_8^{CH}\left(REQR_{t-1}^{CH} - \overline{REQR}_{t-1}^{CH}\right) + \varepsilon_t^{yy^{CH}} + \varepsilon_t^{y^{CH}}$$

[9] Given that this is a reduced-form model, which does explicitly treat capital flows, money, and other such variables, the reserve-requirement ratio enters the model in a more stylized manner. It is understood that movements in the REQR would impact GDP only indirectly, through changes in the growth rate of money, but that channel is not explicitly modeled.

Where,

(16) $\kappa_t^{CH} = \beta_5^{CH}(oil_{\mathrm{t}}^{\mathrm{GAP^{CH}}} + \Delta\, \overline{oil}_{t,t-1}^{World} + \varepsilon_t^{\overline{LZ}})$

(17) $\Omega_t^{CH} = \beta_{fact}^{CH} \Sigma_{j=1}^{n}\left(\omega_{CH,j} * y_{\mathrm{t-1}}^{\mathrm{j}}\right) + \beta_{fact_{res}}^{CH} \Sigma_{j=1}^{n}(\omega_{CH,j} * \varepsilon_t^{yy^j})$

So, the output gap in China is driven by a host of factors similar to those found elsewhere in the GPM, including oil prices (represented by κ_t^{CH}),[10] the real effective exchange-rate gap, spillovers from foreign demand ($\Omega_{\mathrm{t}}^{\mathrm{CH}}$), own leads and lags meant to capture expectations, habit persistence, etc. However, unlike in other country blocks, there are two policy variables that influence output – interest rates, and the reserve-requirement ratio. As in other emerging market economy blocks in the GPM, output is calibrated to display less inertia (lower value for β_1^{CH}), and there is a relatively important role for movements in the real exchange rate (higher value for β_4^{CH}) given that China is an open economy. The role of oil prices is similar to what is found in other GPM models – higher prices depress activity in the short run, given the relatively price inelastic nature of demand for oil by both producers and consumers. Foreign demand impacts China's output gap in the same way as in GPM6 (through both the foreign output gap, and also foreign shocks (ε_t^{yy})). However, although the structure of how spillovers work in the model is the same as in previous versions of the GPM, the calculation of the spillover coefficients ($\omega_{i,j}$) has been changed slightly, for all countries in the model. The new spillover-calibration methodology is presented in Appendix VI.

The inflation process in the China block of the model also differs from the GPM6 setup (equation (2) above) in several ways. First, we model three components of inflation, namely core inflation π_t^x, domestic gasoline inflation π_t^g, and consumer food inflation π_t^{cf}.[11] Because of a lack of time series data on the weights of gasoline and food on the CPI basket, the respective weights are constant over time and calibrated to be 3 percent for gasoline (λ_2^s) and 32 percent for domestic food $(1 - \lambda_1^s - \lambda_2^s)$.[12] A shock to headline inflation (ε_t^{π}) was added to capture measurement errors associated with these constant weights.

(18) $\pi_t = \lambda_1^s \pi_t^x + \lambda_2^s \pi_t^g + (1 - \lambda_1^s - \lambda_2^s)\pi_t^{cf} + \varepsilon_t^{\pi}$

[10] More details on the addition of commodities to the GPM will be presented in a forthcoming IMF WP.

[11] This is not a China-specific feature. Rather, it is a feature that is being integrated into the entire GPM6 model (Carabenciov and others, 2013), and will be described in a forthcoming working paper.

[12] These values correspond to the most recent estimated basket weights in the Chinese CPI.

Second, we model the Phillips curve for core inflation as follows:

(19) $\pi_t^x = (\lambda_1 - \lambda_4)\pi_{t+4}^x + (1-\lambda_1)\pi_{t-1}^x + \lambda_2 y_{t-1} + \lambda_3 \Delta\left(REER_t - \overline{REER}_t\right) + \lambda_4 \pi_t^T + \lambda_5 \Sigma_{i=t-1}^{t-4}\left(REER_i - \overline{REER}_i\right)/4 - \varepsilon_t^{\pi}$

The most notable departure from the standard GPM setup is that we include the inflation target (π_t^T) on the right-hand side of the equation. This allows us to replicate better the inflation dynamics observed over the sample period (inflation has been remarkably well anchored throughout the sample period in China, despite some variation on other determinant variables). In our assessment, the behavior of core inflation over the sample period is at least partly a product of China's large pool of surplus rural labor, which has likely held down industrial wages for much of the past decade (Das and N'Diaye, 2013). The other feature of the Phillips Curve equation in the China block of the model that is unique is the inclusion of both the four-quarter moving average of the real exchange-rate gap (as done elsewhere in the model), and the *change* in that gap. This last term was added to capture better the core inflation dynamics observed in the data.

Third, we assume that the domestic prices for gasoline and consumer food follow a simple structure: in the long run, those prices depend on crude oil costs, international food prices, taxes and other factor input costs as well as markups. Domestic prices for gasoline (π_t^g) and consumer food (π_t^{cf}) depend on movements in international prices ($\pi_t^{oil\_d}$; $\pi_t^{cf\_d}$) , measured in domestic currency and other inputs costs such as labor, which we assume move in tandem with the inflation target (π_t^T).

(20) $\pi_t^g = \iota_1^g \, \pi_{t-1}^g + \left(1 - \iota_1^g\right)\pi_t^T\left\{\iota_2^g \pi_t^{oil\_d} + \left(1 - \iota_2^g\right)\pi_t^T\right\} - \varepsilon_t^{\pi^g}$

(21) $\pi_t^{cf} = \iota_1^{cf} \, \pi_{t-1}^{cf} + \left(1 - \iota_1^{cf}\right)\pi_t^T\left\{\iota_2^{cf} \pi_t^{cf\_d} + \left(1 - \iota_2^{cf}\right)\pi_t^T\right\} - \varepsilon_t^{\pi^{cf}}$

We also allow for shocks to these prices ($\varepsilon_t^{\pi^g}$; $\varepsilon_t^{\pi^{cf}}$), which enter the equation with a negative sign, to better capture the intuition that a positive supply shock reduces gasoline/food prices and is good for economic activity. The parameter ι_2^g for gasoline is calibrated to be lower in China than in advanced economies, which is meant to capture the small pass-through from crude oil prices due to the regulatory structure of domestic gasoline prices in China. Domestic food prices, however, are assumed to follow international food prices more closely, with an important role for domestic shocks.

Modeling Commodity Prices in a Global Setting

Given China's significant demand for commodities (in particular, oil and metals), this block of the model warrants further explanation. The block of real commodity prices for a generic commodity named Q, representing oil prices, food prices or metals, is defined by the following structure:[13]

The price at the world level of commodity, Q_t^w (in logarithms and measured in US Dollars), is equal to the sum of the equilibrium level of its real commodity price, $\overline{Q_t^w}$, and the gap between the level of real prices and its equilibrium value, q^w.

(22) $Q_t^w = \overline{Q_t^w} + q_t^w$

Then, the equilibrium value follows a simple stochastic process equal to its lagged value, the growth rate and a disturbance term representing shocks to the level of oil prices, $\varepsilon_t^{\overline{Q^w}}$.

(23) $Q_t^w = \overline{Q_{t-1}^w} + g_t^{\overline{Q^w}} + \varepsilon_t^{\overline{Q^w}}$

The growth rate is equal to lagged growth plus a term that links real commodity prices to potential GDP growth in the world, $\iota_4^Q gspill_t$, and a disturbance term representing shocks to the growth rate.

(24) $g_t^{\overline{Q^w}} = \left(1 - \iota_3^Q\right) g_{t-1}^{\overline{Q^w}} + \iota_4^Q gspill_t + \varepsilon_t^{g^{\overline{Q^w}}}$

The gap in commodity prices is equal to its lagged value plus the effect of world output gap plus and a disturbance term.

(25) $q_t^w = \iota_1^Q q_{t-1}^w + \iota_2^Q y_t^{world} + \varepsilon_t^{q^w}$

In the case of oil, the calibration of ι_2^Q follows empirical studies which indicate that a one percent permanent decrease in the level of global output would reduce the world price of oil by about 9 percent in the short run and 3 percent in the long run.[14] The price response is tempered over the longer term as firms cut back investment in oil production over time and consumers and firms substitute to less expensive energy options. For the cases of world metal and food prices, the calibration reflects the fact that these prices tend to be much less sensitive to changes in demand, and thus ι_2^Q is considerably lower. In the baseline calibration

[13] As was the case when considering the inflation equations for gasoline and food, the commodities block of the model is not unique to China, and will be documented in a separate forthcoming working paper which augments the basic version of the GPM6 model.

[14] Average of estimates reported in OECD (2004), Hamilton (2008), and IMF (2011).

of GPM the price elasticity for oil is three times the magnitude of that for metals and nine times that for food.[15]

Stochastic Processes

As is done elsewhere in the GPM, we specify stochastic processes that govern the path of the unobservable variables in the model. The most important processes (those for potential output, the equilibrium real interest rate, the equilibrium reserve-requirement ratio, and the equilibrium real exchange rate) are largely the same as those used in previous GPM work (Carabenciov and others, 2008). These are presented in Appendix IV.

IV. MODEL PROPERTIES

Impulse-Response Functions

When constructing a model to be used for policy analysis, arguably the most important consideration is the model's properties, in particular the response of the model to shocks applied around the steady state. These responses are critical, since the behavior of the model in a projection or simulation environment will simply reflect the combined effect of the shocks applied to the model. If the results from simple simulations around the steady state are not intuitive, the model is of no use to policy makers since one cannot understand the channels through which a change in the outlook/scenario has come to pass. To ensure that our model is sensible, we scrutinize a set of impulse-response functions (IRFs) for the major shocks in the new China block of the model.

First, we consider a simple (one quarter) positive Chinese demand shock. Shown in Figure 1 (Appendix II), the shock increases demand by about one percent on impact – since this is a pure demand shock, and there is no response of supply/potential, the impact on the level of GDP and the output gap is also one percent. In response to this shock, and its impact on the output gap, inflation rises by slightly under ½ a percentage point. Given the deviations of output and inflation from their equilibrium and target levels, respectively, policy tightens to restore equilibrium. In China, this entails the use of several instruments simultaneously: first, the policy rate increases, by about 100 basis points. Second, the reserve-requirement ratio also rises, and also by about 100 basis points. Finally, the nominal exchange rate is allowed to appreciate slightly, though this happens only gradually over several quarters, which is consistent with the observed behavior of policy makers in China, who allow only sluggish changes in this rate. In the quarters following the shock, as the output gap returns to target and inflationary pressures subside, policies return to neutral.

[15] The price elasticities for food are based on empirical estimates reported by Seale, Regmi, and Bernstein (2003).

Also of interest is the response of oil prices – this positive demand shock in China entails increased demand for commodities, which pushes up the real oil price. The demand shock, and subsequent impact on commodity prices, also has implications for growth in other regions of the model. Figure 2 shows the impact of this same Chinese demand shock on growth in the other regions of the model. Not surprisingly, the largest effect is on the Emerging Asia block, given the important trade linkages between these countries and China. The next most important recipient of spillovers is Japan, given its integration in the region. Also of note are the small responses of the US, and euro area. Given that Chinese demand for US/EU exports is fairly limited, and both the US and EU are relatively large, relatively closed economies, this result appears sensible.

As for the response of demand in Latin America, there is a modest positive impact of the increase in Chinese demand, despite limited trade linkages between these two economies – this result comes from the increase in commodity prices associated with higher Chinese demand, which is a favorable development for the commodity-exporting countries in the Latin America block of the model.

Next, we examine a core-inflation shock in the China block of the model in Figure 3. Here, the shock is negative, with quarter-on-quarter inflation falling by one percentage point on impact. Given the relatively mild persistence in this process specified in the Phillips curve equation, inflation returns to target relatively quickly. Of course, policy also plays a role here, acting quickly to provide stimulus (lower policy rate and reserve-requirement ratio) thereby opening up a very slight positive output gap which aids the smooth transition of inflation back to target. As in the previous IRF, the slight increase in demand (this time generated endogenously as a result of looser policy, rather than by an exogenous shock) boosts oil prices slightly.

Although the role of monetary policy in the model (interest rates and reserve-requirement ratio) can largely be understood from examining the first two simple IRFs, we nevertheless proceed to examine an exogenous shock to each of these in turn. Beginning with the interest-rate IRF, in Figure 4 we see that for a 100 basis point exogenous increase in interest rates, the output gap is depressed by about 1/3 pp, at the trough. Note that it takes several quarters for the increase in the interest rate to have a noteworthy effect on output, which is consistent with the well-established concept that there is a lag in the transmission of monetary policy to the real economy. This policy shock also dies out somewhat slowly due to the inertia in the policy rate equation. The rest of the results in this Figure are as described in the previous IRFs: lower output (and hence output gap, given that supply is not responding in this scenario) depressed inflation and oil prices. Following the shock, policy rates actually reverse the initial shock by easing for a period of time, providing stimulus to boost activity and close the output gap.

Turning to the response of the model to a shock to the reserve-requirement ratio, in Figure 5 we see that an exogenous 100 basis point increase in this ratio (which is not attributable to equilibrium/trend developments, and is not accompanied or offset by policy rates) has a fairly limited impact on output, depressing the output gap by only 0.1pp, with a subsequent muted effect on inflation. Exchange rates are essentially held constant.

Finally, we turn to the effect of a policy-induced, exogenous, nominal exchange-rate shock in the model in Figure 6. If policy makers force the nominal rate to depreciate by about 1 percent relative to baseline, output in the model rises gradually, peaking at 0.2 percent above baseline. Counteracting the impetus from the nominal exchange rate depreciation are the responses of the interest rate and reserve-requirement ratio, which increase to return output to equilibrium. In addition, note that the nominal exchange rate is permanently lower, but that this is offset by a higher price level (increase in inflation rates with no subsequent payback) leaving the *real* exchange rate unchanged once the shock has run its course.

Empirical Fit

Although theoretical coherence is the most important criterion in assessing the validity of a policy model, once this is achieved empirical fit is of paramount importance. To investigate the empirical validity of the changes we have introduced in this version of the model, we compare the model for China documented in this paper with a 'naïve' specification for China. More specifically, this naïve specification for China uses the same equations as found elsewhere in the GPM6. As such, a comparison of empirical fit between this benchmark model and the one we have specified in this paper will provide insights on whether the modeling innovations introduced here (changes to the exchange-rate process, addition of reserve-requirement ratio, and additional anchoring of inflation associated with excess labor supply) do a better job of fitting the data than would the 'standard' equations used in the other blocks of the model.

We begin by showing a comparison of the goodness of fit (using root-mean-squared errors) between the two models, over several different forecast horizons (one, four, eight, and twelve quarters ahead), for the key variables in the model (real GDP growth, inflation, interest rates, and the exchange rate) in Table 1 of Appendix III. On balance, the results are quite favorable for the innovations adopted in this paper. In particular, the short-term (one quarter ahead) fit of real GDP growth is dramatically better ('current' model's RMSEs are 0.76 of the 'naïve' model's errors), without any notable deterioration in the forecast performance at longer horizons. The fit of the inflation equation is considerably better across all forecast horizons, and the fit of the exchange-rate forecast is remarkably better at all horizons. The lone area in which the model's forecast performance has deteriorated is for policy rates at longer time horizons.

Figures I-III of Appendix III present the China model's unconstrained forecasts of real GDP growth, inflation, the exchange rate, and policy rates, beginning in three different time periods: 2009q1, 2010q1, and 2011q1. These plots show how the model would have projected these variables, subject to the information available at the beginning of each time period (in other words, assuming no further 'shocks' over the forecast period).

Beginning with the first projection period (2009q1 onwards) in Figure I we see that growth had fallen sharply in China as the global financial crisis was in full swing. In response to this weak growth environment, the model would have suggested that policy rates should be lowered to provide stimulus – in fact, interest rates would have been projected to trough quite near the level at which they ultimately did trough (actual realization of data shown in with a dashed line). The easing in policy conditions would have been expected to generate firmer growth, though the model was unable to predict how rapid the ultimate recovery would end up being – massive fiscal stimulus measures undertaken by policymakers in response to the crisis boosted China's growth to well over 15 percent (q/q saar – staff calculations) by 2009q2. Given that the model does not include equations to capture fiscal policy, this information was 'missed,' thereby preventing the model from capturing the sharpness of the recovery. In light of the model's expectation that the output gap would take about a year to close, inflation was projected to remain muted. Regarding the exchange rate, the model does not capture the fact that policy makers returned to pursuing a strict peg during the crisis period.

Proceeding to the next forecast period (2010q1 – Figure II), we see that the model would have performed very well on several fronts. First, as a result of a return to solid growth and some gradual improvement in external demand conditions, the exchange-rate peg was once again abandoned in early 2010, and the model's projection for the exchange rate over the two-year forecast period considered here was quite accurate. Next, the model would have expected policymakers to tighten rates starting in early 2010 in response to strong growth conditions, and this would have been expected to slow activity somewhat in coming years. However, in reality policy was not tightened in China, as authorities chose to allow growth to proceed at a more rapid pace. Although the model struggles to capture the precise dynamics of inflation over the forecast period (a very standard result in projection models, given the volatile nature of this variable), it does capture the broad evolution of inflation over the 2010-12 period very well.

Finally, we consider the forecast period starting in 2011q1 (Figure III). At this point, the property market was expanding rapidly, and authorities were beginning to take measures to cool the economy (raising policy rates and reserve requirements, as well as implementing policies to restrict investment in real estate) and would continue to do so throughout 2011. As we saw in Figure II, the model for China was already calling for moderately tighter policy in early 2010, and so by 2011q1 the model saw the need for *much* more tightening, given that policy had remained essentially unchanged for much of 2010. Examining Figure III, we can see that the model would have projected somewhat more tightening in policy rates, and somewhat less tightening in reserve requirements than what actually ended up occurring, but the net amount of tightening projected by the model between the two measures seems to have been fairly accurate. As a result of this projected, necessary tightening in policy conditions, growth would have been expected to slow, and inflation would have been expected to ease – the model's projections over the next two years were quite accurate for both of these variables. As in the forecast that began in 2010q1, the model's projection of exchange rates over the 2011q1 to 2013q1 period was also quite prescient.

V. Conclusion

Given China's increasingly important role in shaping global economic outcomes in recent years, its addition to the Global Projection Model is an important enhancement to the existing framework. This extension of the model is meant to allow for a richer understanding of the shocks driving growth outcomes across countries, as well as commodity-price fluctuations.

In addition, the treatment of China presented here captures several of the basic intricacies of the Chinese economy that are absent from many other such models. Perhaps most important among these intricacies is the approach to modeling China's exchange-rate policy. As shown earlier in the paper, and as is widely known by most China observers, the approach of policy makers has changed frequently in recent years, with a strict peg prevailing up until July of 2005, and a mix of a quasi-floating and full exchange-rate peg prevailing thereafter. The approach taken in this paper is flexible enough to accommodate each of these regimes through different parameterizations of a select few equations. Meanwhile, our preferred parameterization for the China block of the model replicates many of the key features of the current regime in China – impulse response functions show that exchange rates are very slow to adjust in the face of shocks (though, they are not strictly fixed), while domestic monetary policy remains effectively free to respond in the face of shocks. Monetary policy in the model is conducted by the joint use of interest rates (as in other blocks of the model), exchange-rate policy, and the reserve-requirement ratio. The addition of this ratio is more in line with recent work on understanding monetary policy in China.

Future research will focus on constructing a version of the model that will split out the other (ex. China) major countries in the emerging Asia block (India, Thailand, South Korea, and Indonesia) to allow for deeper analysis on the economies within the region (Blagrave and others, forthcoming IMF WP).

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Appendix I. Figures and Data Definitions

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Figure A:

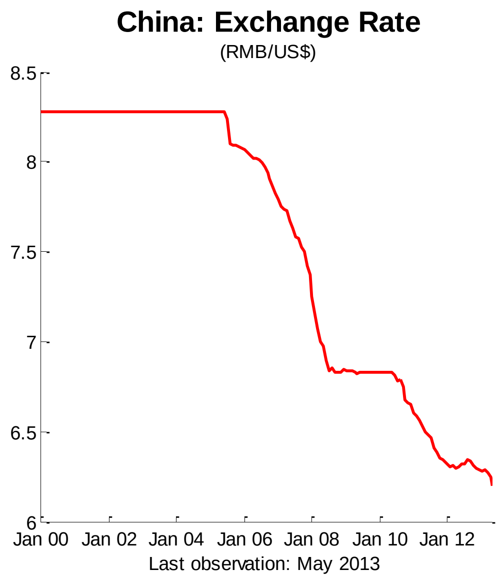


Figure B:

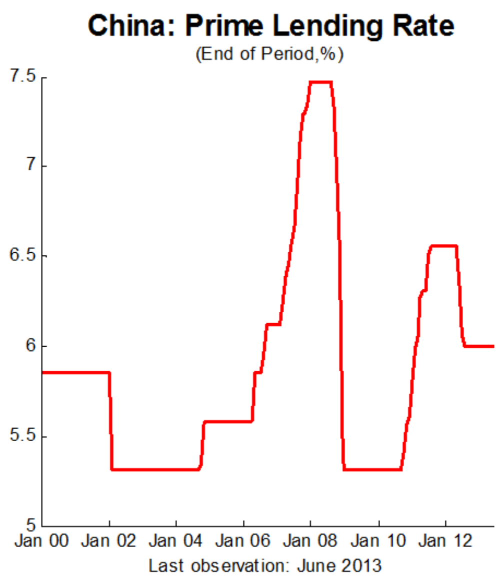
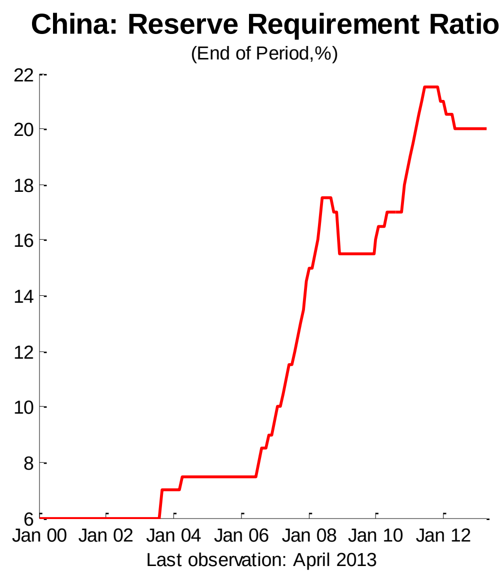


Figure C:



Data sources and definitions

Variable	**Original Description**	**Original Source**
Real GDP	Gross Domestic Product (SA, Bil.2000.Yuan)	China National Bureau of Statistics/Haver Analytics
Consumer Price Index	Consumer Price Index (SA, 2005=100)	China National Bureau of Statistics/Haver Analytics
Policy Rate	Prime Lending Rate: 1-Year (% per annum)(avg)	People's Bank of China
Nominal Exchange Rate	Exchange Rate: U.S. (National currency per USD)	State Administration of Foreign Exchange
Reserve Requirement Ratio	Deposits in Yuan: Large Depository Inst(EOP,%)	People's Bank of China

Appendix II. Impulse-Response Functions

Figure 1 – 1 percent positive shock to demand in China (1 quarter)

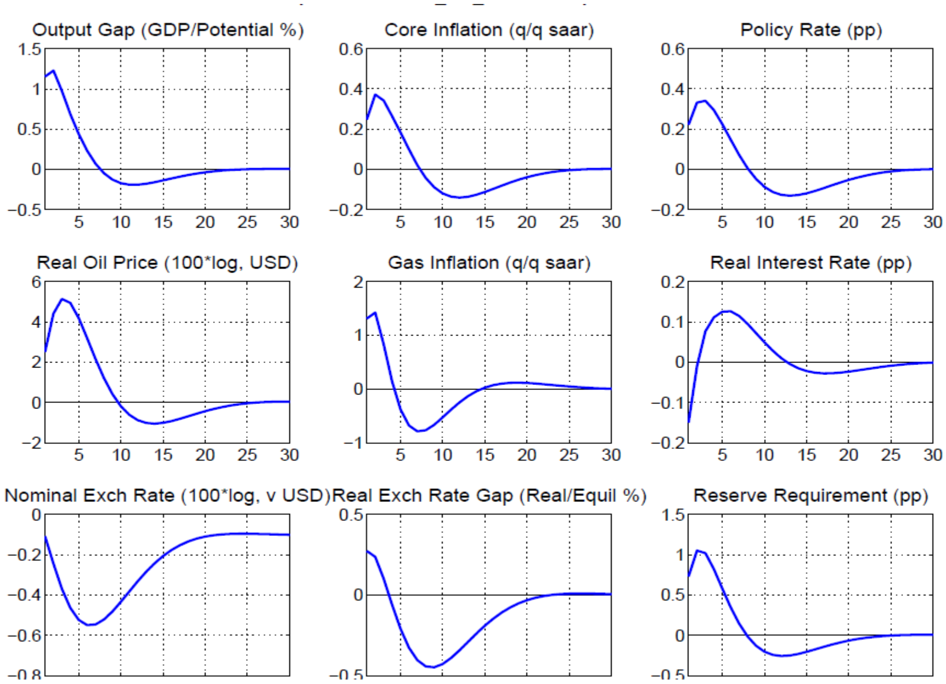


Figure 2 – Spillovers from 1 percent positive shock to demand in China (1 quarter; Y =output gap)

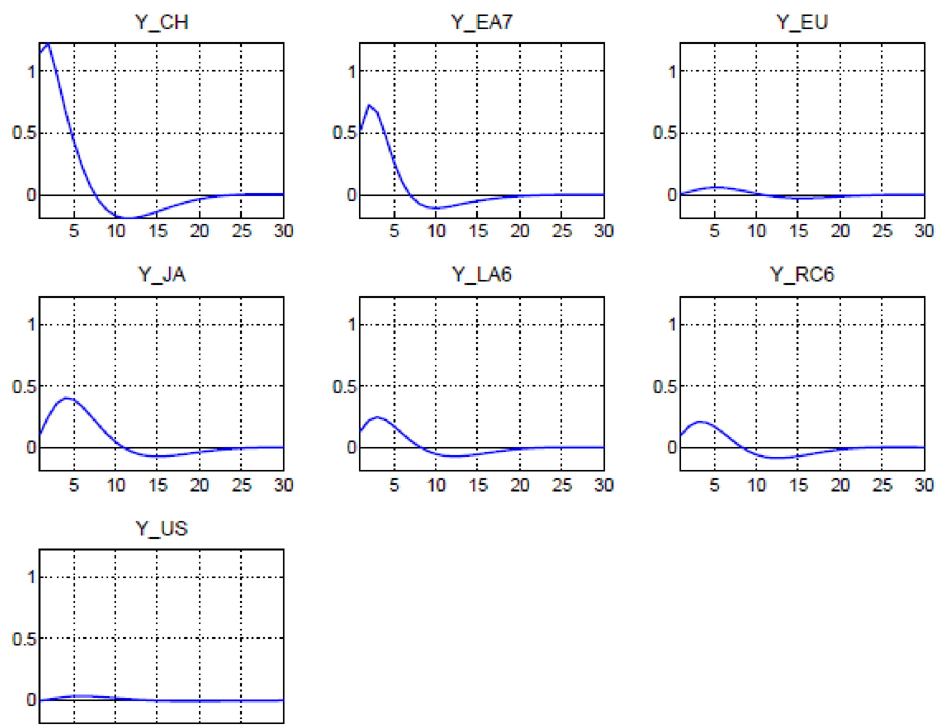


Figure 3 – 1 percent negative shock to core inflation in China (1 quarter)

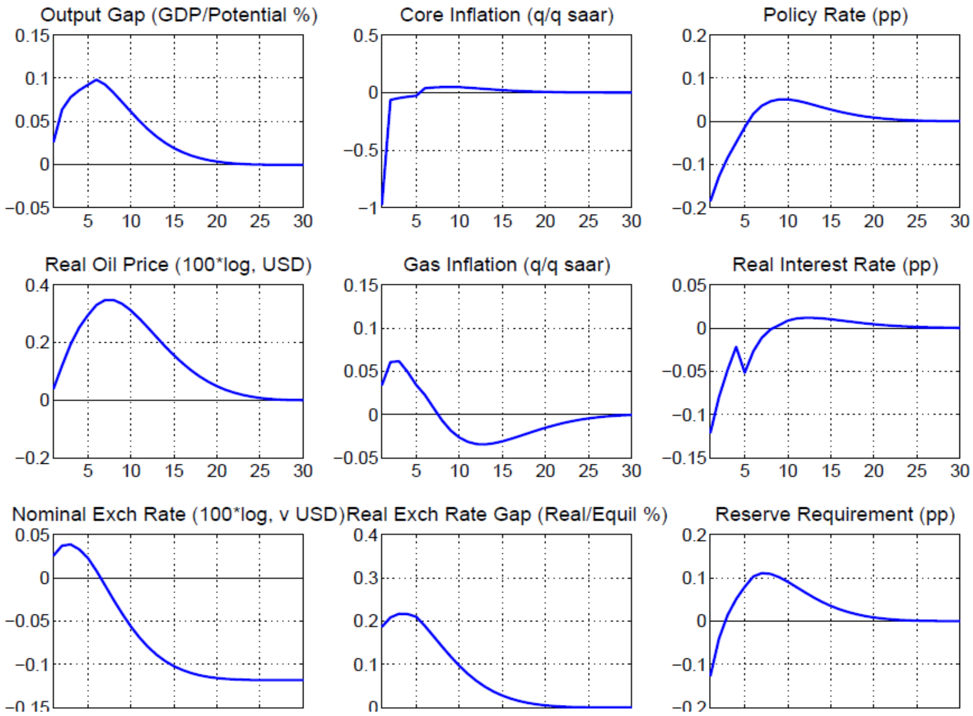


Figure 4 – 100bp positive shock to nominal interest rate in China (1 quarter)

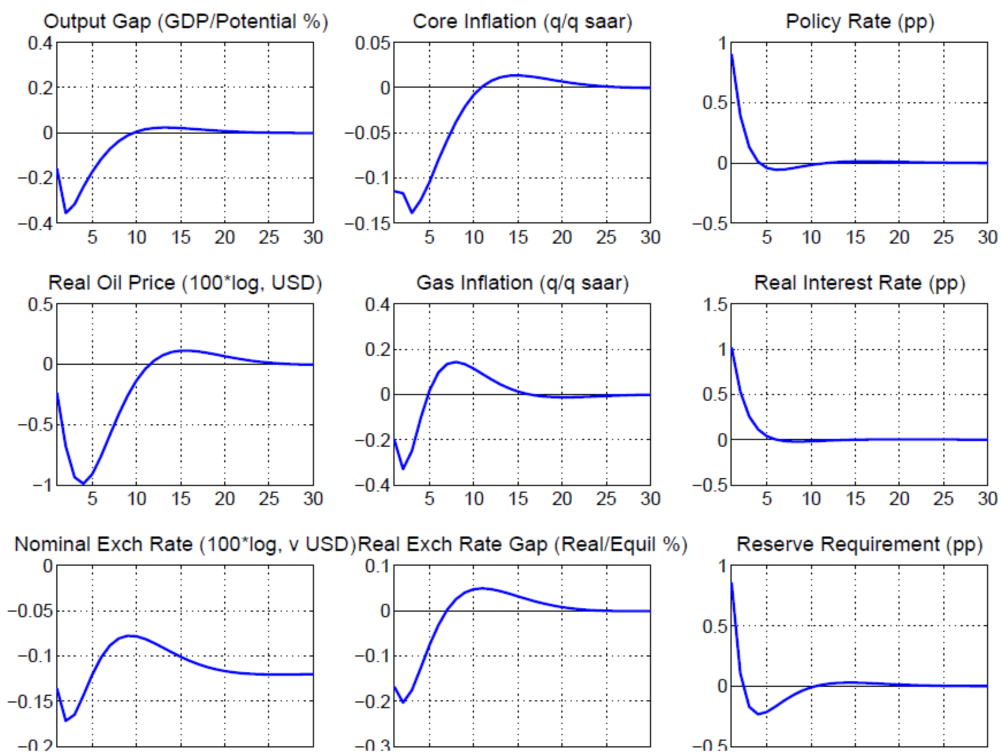


Figure 5 – 100bps positive shock to reserve-requirement ratio in China (1 quarter), with no response of policy rates (for 4 quarters)

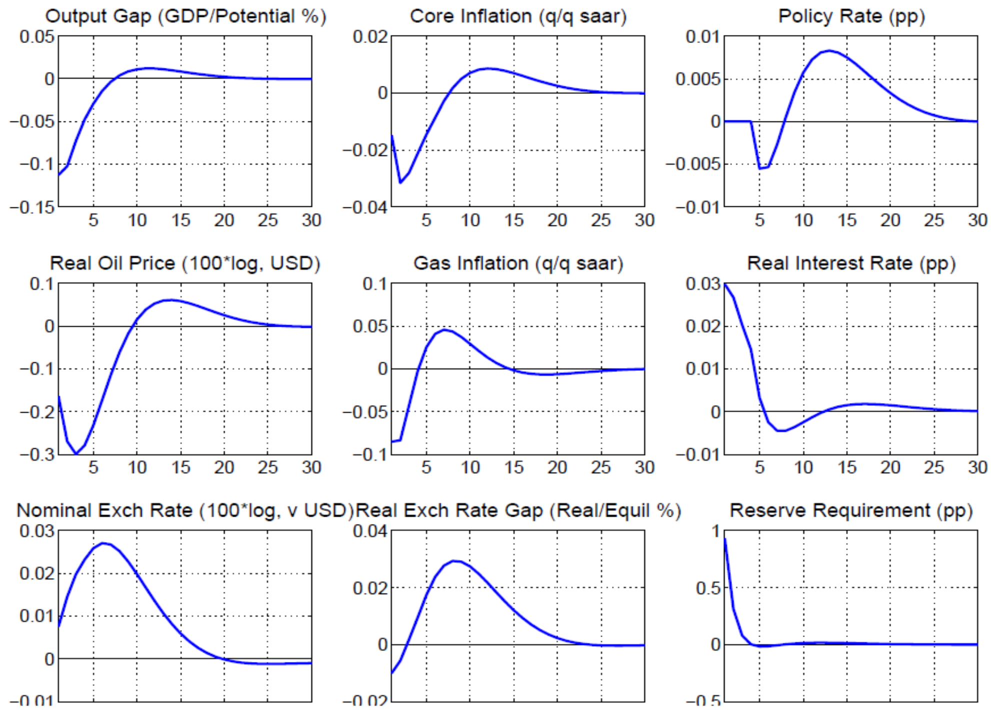
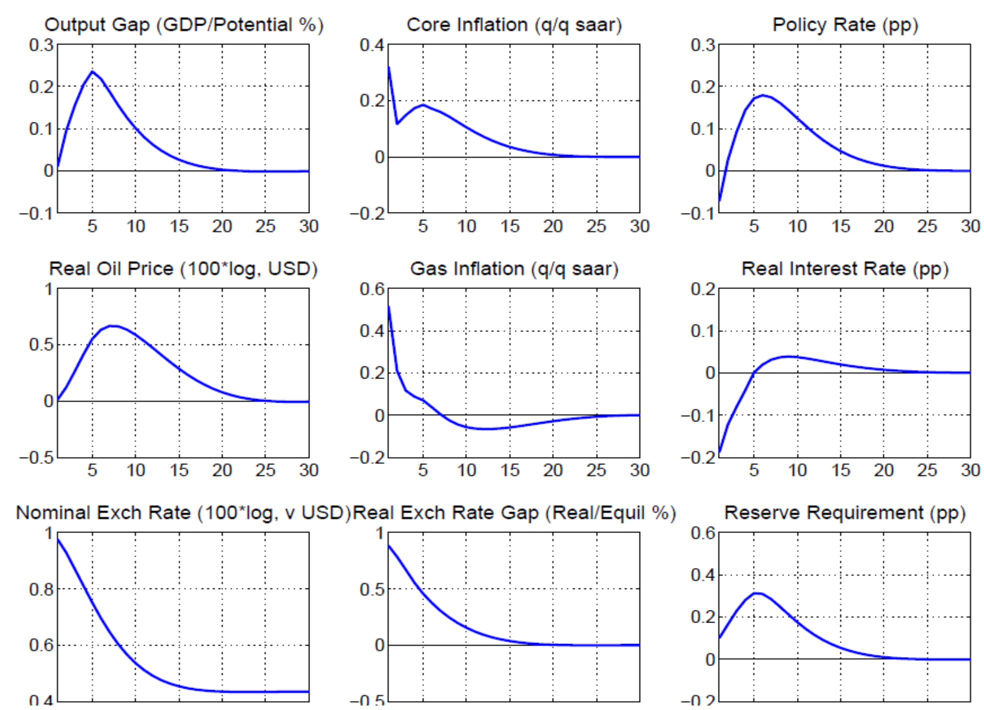


Figure 6 – Policy-induced 1 percent depreciation of the bilateral RMB/USD exchange rate



Appendix III. Evaluation of Model Fit

Root Mean-Squared Errors (RMSE)[16]

GPM7 China - Current Specification (2005Q1:2012Q4)

	1Q Ahead	4Q Ahead	8Q Ahead	12Q Ahead
Real GDP Growth (q/q saar)	2.90	3.08	2.65	2.67
Headline Inflation (q/q saar)	2.06	2.61	2.36	3.07
Short-term Interest Rate	0.69	1.57	1.64	1.50
Nominal Bilateral Exchange Rate	0.71	3.35	5.91	7.20

GPM7 China - Naive Specification (2005Q1:2012Q4)

	1Q Ahead	4Q Ahead	8Q Ahead	12Q Ahead
Real GDP Growth (q/q saar)	3.65	2.82	2.43	2.54
Headline Inflation (q/q saar)	3.29	4.72	3.98	3.83
Short-term Interest Rate	0.73	1.24	0.96	1.05
Nominal Bilateral Exchange Rate	2.12	10.57	18.67	22.98

Difference (Current/Naive)

	1Q Ahead	4Q Ahead	8Q Ahead	12Q Ahead
Real GDP Growth (q/q saar)	0.79	1.09	1.09	1.05
Headline Inflation (q/q saar)	0.63	0.55	0.59	0.80
Short-term Interest Rate	0.93	1.26	1.71	1.43
Nominal Bilateral Exchange Rate	0.34	0.32	0.32	0.31

[16] 'Current' specification refers to the version of the model outlined in this paper. 'Naïve' refers to a specification where China is treated precisely as any other block in the GPM model (with no augmentations to the GPM6 equations), and the difference is calculated as the ratio of the 'current' specification's RMSEs to those of the 'naïve' specification. RMSEs are calculated using in-sample forecasts.

Unconditional (zero shock) projection exercise

Figure I – Projection beginning in 2009q1

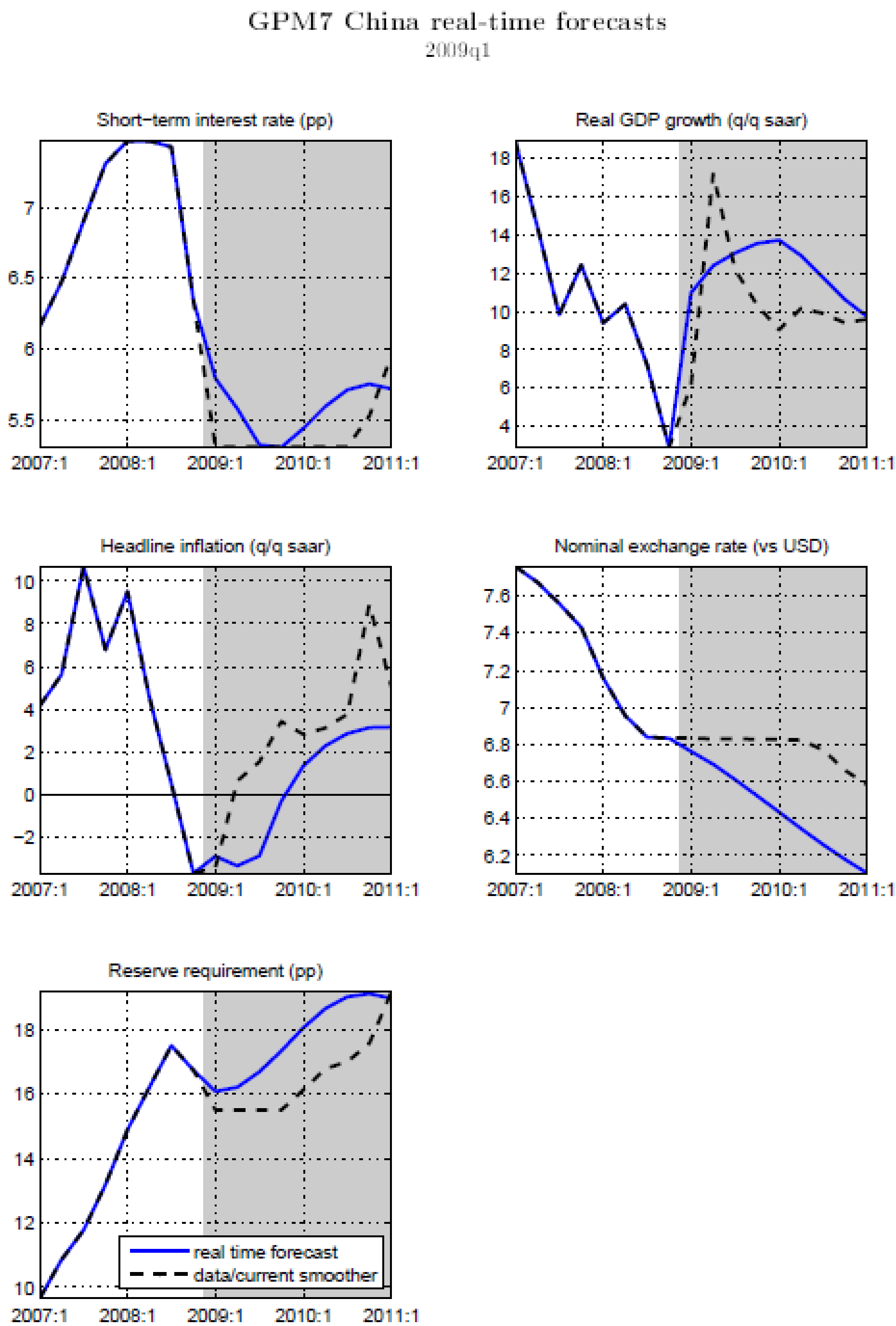


Figure II – Projection beginning in 2010q1

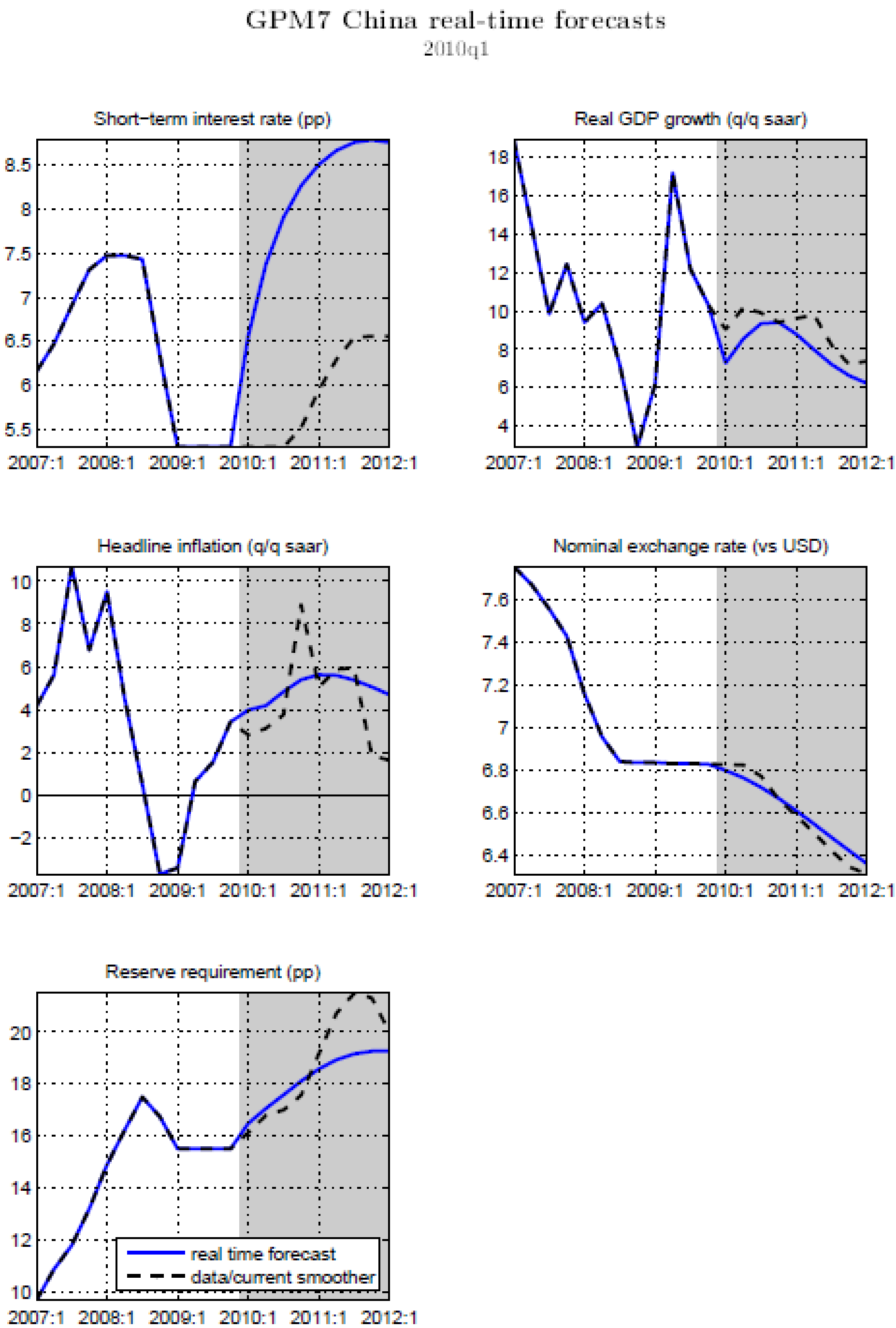
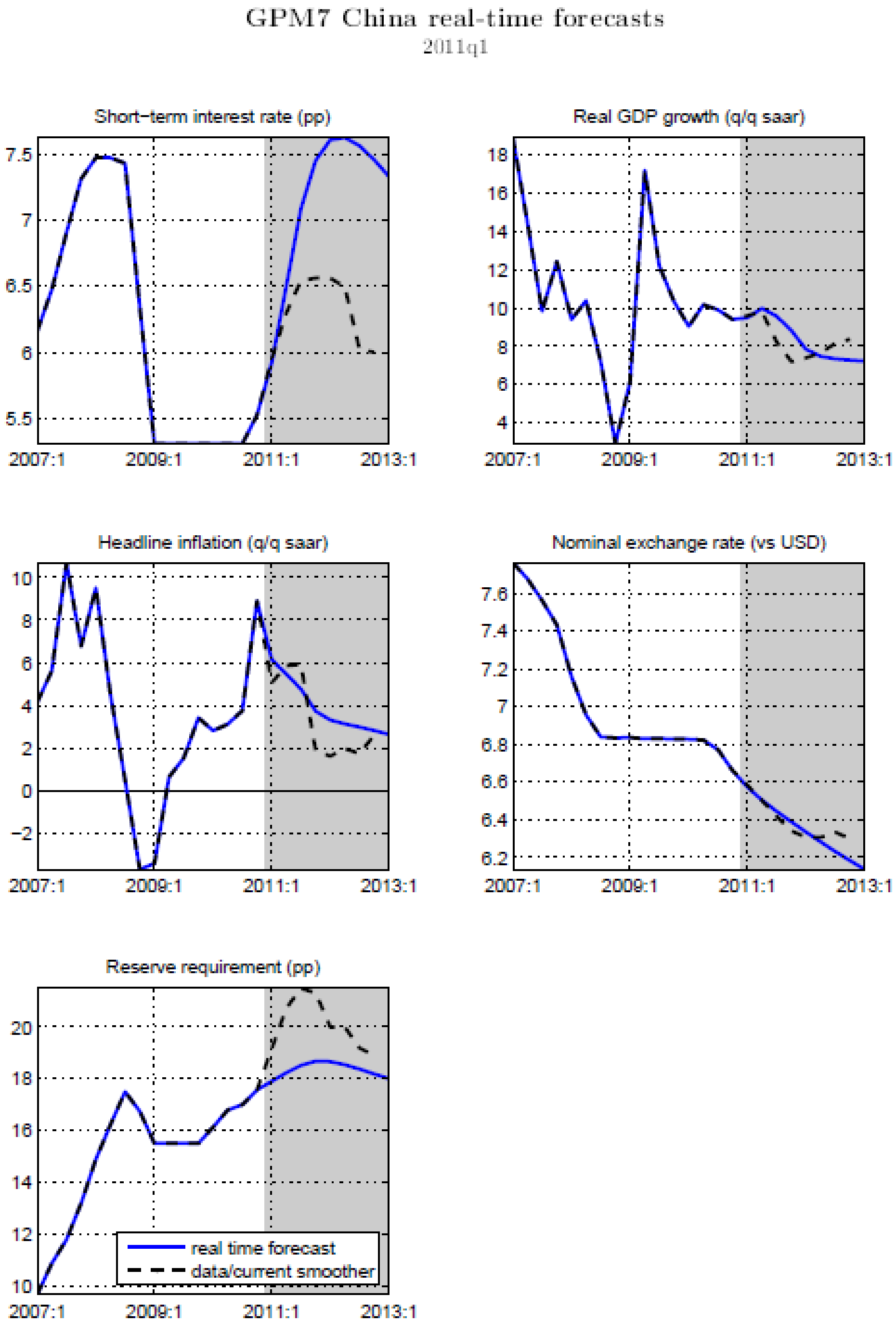


Figure III – Projection beginning in 2011q1



Appendix IV. Stochastic Processes and Definitions

Potential Output

$$\overline{Y}_t^{\ CH} = \overline{Y}_{t-1}^{CH} + \frac{g_t^{\overline{Y}^{CH}}}{4} + \varepsilon_t^{\overline{Y}^{CH}}$$

$$g_t^{\overline{Y}^{CH}} = \tau_{CH}\, g_t^{\overline{Y}_{ss}^{CH}} + (1-\tau_{CH})g_{t-1}^{\overline{Y}^{CH}} + \ \varepsilon_t^{g^{\overline{Y}}}$$

Equilibrium Real Interest Rate

$$\overline{RR}_t^{\ CH} = \rho_{CH}\overline{RR}_t^{\ CH,SS} + (1-\rho_{CH})\overline{RR}_{t-1}^{\ CH} + \ \varepsilon_t^{\overline{RR}}$$

Equilibrium Real Exchange Rate

$$\overline{LZ}_t^{\ CH} = \overline{LZ}_{t-1}^{CH} + \frac{\Delta\overline{LZ}_t^{\ CH}}{4} + \ \varepsilon_t^{\overline{LZ}}$$

$$\Delta\overline{LZ}_t^{\ CH} = \chi^{CH}\Delta\overline{LZ}_{t-1}^{CH^{SS}} + (1-\chi^{CH})\Delta\overline{LZ}_{t-1}^{CH} + \varepsilon_t^{\Delta\overline{LZ}}$$

Real Exchange Rate Expectation

$$LZ_t^e = \phi LZ_{t+1} + \ (1-\phi)(LZ_{t-1} + \frac{2\Delta\overline{LZ}_t^{CH}}{4}),$$

Equilibrium Reserve Requirement Ratio

$$\overline{REQR}_t^{\ CH} = \overline{REQR}_{t-1}^{CH} + \varepsilon_t^{\overline{REQR}}$$

Appendix V. Parameter Values

China parameter values

parameter	value
$\beta_{1,CH}$	0.47
$\beta_{2,CH}$	0.21
$\beta_{3,CH}$	0.20
$\beta_{4,CH}$	0.17
$\beta_{5,CH}$	-0.02
$\beta_{8,CH}$	0.10
χ_{CH}	0.05
$\Delta\overline{LZ}^{ss}_{CH}$	0.00
$\iota^{food}_{1,CH}$	0.52
$\iota^{food}_{2,CH}$	0.47
$\iota^{gas}_{1,CH}$	0.34
$\iota^{gas}_{2,CH}$	0.20
$\lambda_{1,CH}$	0.72
$\lambda_{2,CH}$	0.20
$\lambda_{3,CH}$	0.25
$\lambda_{4,CH}$	0.15

parameter	value
$\lambda_{5,CH}$	0.05
η_{CH}	0.66
ζ_{CH}	0.20
ϕ_{CH}	0.80
$\nu_{1,CH}$	0.40
$\nu_{2,CH}$	0.50
$\nu_{3,CH}$	0.50
$\nu_{4,CH}$	1.00
ρ_{CH}	0.20
$\overline{rr}^{ss}_{CH}$	4.00
υ_{CH}	0.80
$\gamma_{1,CH}$	0.67
$\gamma_{2,CH}$	1.11
$\gamma_{3,CH}$	0.17
$\gamma_{4,CH}$	1.00
τ_{CH}	0.03

.Global Commodity parameter values

parameter	value
ι^{oil}_{1}	0.50
ι^{oil}_{2}	9.00
ι^{oil}_{3}	0.10
ι^{oil}_{4}	1.50
ι^{food}_{1}	0.70
ι^{food}_{2}	0.80

parameter	value
ι^{food}_{3}	0.10
ι^{food}_{4}	0.15
ι^{metal}_{1}	0.50
ι^{metal}_{2}	3.00
ι^{metal}_{3}	0.10
ι^{metal}_{4}	0.50

Appendix VI. Calibration of Spillover Coefficients in GPM7

We are considering the effect of a demand shock in country *j* (the shock emitter) on output in country *i* (the shock receiver):

$$\Delta Y_i = \omega \Delta Y_j$$

We refer to the parameter ω as the spillover coefficient – that is, for a given change in the growth rate of output in country *j*, this coefficient will stipulate the corresponding change in growth in country *i*. Stated differently, this parameter can be interpreted as comprising three terms:

$$\omega = \frac{\Delta Y_i}{\Delta X_{ij}} * \frac{\Delta X_{ij}}{\Delta M_{ji}} * \frac{\Delta M_{ji}}{\Delta Y_j}$$

Beginning with the third term, these can be thought of as: (iii) the change in the growth of imports by country *j* from country *i*, for a given shock to demand growth in country *j*; (ii) the change in country *i*'s export growth to country *j*, for a given change in import demand growth by country *j* from country *i*; and (i) the change in output growth in country *i*, for a given change in country *i*'s export growth to country *j*. We can then decompose each of these terms in the following way:

$$\text{(i)} \quad \frac{\Delta Y_i}{\Delta X_{ij}} = \frac{\Delta Y_i}{\Delta VA_i} * \frac{\Delta VA_i}{\Delta X_i} * \frac{\Delta X_i}{\Delta X_{ij}}$$

$$\text{(ii)} \quad \frac{\Delta X_{ij}}{\Delta M_{ji}} = 1 \quad \text{by assumption}$$

$$\text{(iii)} \quad \frac{\Delta M_{ji}}{\Delta Y_j} = \frac{\Delta M_j}{\Delta Y_j} * \frac{\Delta M_{ji}}{\Delta M_j}$$

Beginning with term (iii), we see that it involves two calculations: the elasticity of imports by country *j* in response to a given change in demand growth ($\frac{\Delta M_j}{\Delta Y_j}$); and, the relationship between the change in *total* import-demand growth in country *j*, and import-demand growth from country *i* ($\frac{\Delta M_{ji}}{\Delta M_j}$). Regarding the latter calculation, we assume that all changes in import-demand growth are distributed uniformly across all trade partners (that is, for an X percentage-point increase in country *j*'s total import demand growth, the increase in import growth from all trade-partner countries will also be X p.p.) – so, this term is equal to one, by assumption. As for the elasticity of imports for a given change in demand growth, we base our calibrations on the results of simple econometric analysis.[17]

[17] More specifically, we ran pooled regressions (for both EMs and AEs) with imports (both in growth, and 'gap' terms) as a left-hand side variable, and GDP (both in growth, and 'gap' terms) as the right-hand variable. We then use the *average* coefficient on GDP in the AE regressions (2.16), and the *average* coefficient in the EM

(continued…)

Turning to term (ii), we make the simplifying assumption that bilateral exports and imports are reported without error by both reporting economies *i* and *j* (that is, country *i*'s reported exports to *j* are equal to country *j*'s reported imports from country *i*). In reality, bilateral trade data are generally not perfectly symmetric, but we abstract from this issue in calibrating spillovers. So, this term is unity, by assumption.

Finally, term (i) involves determining the impact of a change in the growth rate of country *i*'s exports to country *j* on country *i*'s GDP growth. Starting with the last element of (i), we must scale the size of the increase in exports from *i* to *j* in order to express it in terms of *total* exports from country *i*.[18] We approximate this impact ($\frac{\Delta X_i}{\Delta X_{ij}}$) by using historical data on the ratio of exports from *i* to *j* as a share of total exports from *i*.[19] Next, ($\frac{\Delta VA_i}{\Delta X_i}$) relates the change in the growth rate of total exports from *i* to the change in the growth rate of total economy-wide value added for country *i*. This relationship can be thought of as comprising two elements:

$$\frac{\Delta VA_i}{\Delta X_i} = \frac{\Delta VA_i}{\Delta VA_i^{x\ sector}} * \frac{\Delta VA_i^{x\ sector}}{\Delta X_i}$$

Thus, we must consider the impact of a change in exports of value added, *in the export sector*, and then consider the impact of this change in export-sector VA on total economy-wide value added. In calibrating, we take the impact of a given change in export growth on export-sector value added from a study by Koopman and others (2010); then, to relate this sectoral change to economy-wide value added ($\frac{\Delta VA_i}{\Delta VA_i^{x\ sector}}$) we simply use the ratio of exports-to-GDP in country *i*. The last element of term (i) is a Keynesian-type multiplier, relating a given change in value added to total output ($\frac{\Delta Y_i}{\Delta VA_i}$). At present, this multiplier term is assumed to be 1, though one could think of altering it based on the portion of liquidity-constrained agents in the economy, as well as other factors.

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regressions (2.61). The Remaining Countries block of the GPM is treated as a mix between AE and EM, and is assigned a marginal propensity to import of 2.39.

[18] A given z percent increase in the growth rate of exports from country *i* to country *j* will correspond to a smaller increase in country *i*'s *total* exports (in growth-rate space). As an example, if country *i*'s exports to country j increase by 10 percent, and country *i*'s imports to country *j* represent 50 percent of its total exports, then *total* exports have only increased by 5 percent.

[19] The current version of these calculations uses data from 2007 (pre-crisis).

After some manipulation of the preceding equations, the spillover coefficient ω can be computed using:

$$\omega_{ij} = \frac{\Delta M_j}{\Delta Y_j} * \frac{\Delta VA_i^{x\ sector}}{\Delta X_i} * \frac{X_{ij}}{Y_i} * \frac{\Delta Y_i}{\Delta VA_i} * \frac{\Delta M_{ji}}{\Delta M_j}$$

The final two terms are currently assumed to be = 1. The elasticity of import growth w.r.t. demand growth is taken from simple statistical analysis of the data (2.16 for advanced economies, 2.61 for emerging economies); the change in (export-sector) value added for a given change in exports is taken from Koopman and others (2010); and the share of exports (from *i* to *j*) in total GDP of country *i* is computed using direction of trade statistics (DOTS) data from 2007.