Monetary Policy Regimes: A Global Assessment

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Monetary Policy Regimes: A Global Assessment* **

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Highlights

A GE model with money simulates multi-country choice amongst four alternative monetary targets.

Identified regional output shocks drive Monte Carlo simulations, yielding output and welfare risk.

Current *de facto* monetary policies yield less global economic volatility than *de jure* alternatives.

In Nash equilibria targets “nominal GDP” and inflation, in turn, cut real GDP and welfare volatility.

A fallacy of composition arises as the spread of IT raises welfare volatility in the advanced economies.

Monetary Policy Regimes: A Global Assessment[1]

Abstract

An eight-region, stochastic, general equilibrium model that incorporates global money and financial markets is used, first, to identify the distributions of regional supply side shocks in 1954-2016 from real GDP data. Second, in Monte Carlo simulations the model is subjected to random draws from these distributions in all regions simultaneously, under a range of combinations of monetary targets. These experiments begin with a comparison of the volatilities of output and welfare (defined as the purchasing power of disposable income at regional prices) under current *de facto* and *de jure* monetary targets. The results show the *de facto* targets offer significant improvement. A further analysis of targeting games suggests a Nash equilibrium on output risk is dominated by nominal GDP targeting, while the corresponding Nash equilibrium on welfare risk has predominant inflation targeting (IT). Notwithstanding IMF policy to convert developing country central banks to inflation targeting, a fallacy of composition is observed in the spread of IT internationally. This spread tends to raise the volatility of welfare in the established open economies. (170 words)

1. Introduction

A salient trend in the global economic architecture has been the deepening of monetary and financial integration. An associated rise in international spill-overs from monetary policy actions has triggered a revival of the "coordination" literature[2] and intensified the focus on performance outcomes at the global level (IMF 2013, Ostry and Ghosh 2013, IMF 2017). It is again debated as to whether international monetary policy coordination offers improvements over non-cooperative alternatives (Eichengreen 2013b; Mohan & Kapur 2014; Frankel 2018). Cooperation is seen as improving global outcomes by internalising the impacts of economic interdependence. Considering that the role of macroeconomic policy is to smooth growth, rather than to accelerate

[1] Data resources used are all publicly available:
The IMF-IFS global database, IMF Annual Report on Exchange Arrangements and Exchange Restrictions, Central Banks Annual Reports, including the Federal Open Market Committee (FOMC) meeting minutes and the IMF Direction of Trade Statistics database.

[2] See Taylor (2013) for a detailed review of this literature.

it, modern approaches to this issue require the explicit representation of risk and volatility, along with the strategic behaviour that enables central banks to minimise it (Diaz-Roldan 2004)[3].

Macroeconomic spill-overs from monetary policy actions depend on country characteristics, mainly including degrees of integration via trade and financial flows, monetary policy, and exchange rate regimes.[4] Mechanisms by which these spill-overs affect performance in other economies are suggested by financial indicators associated with investment flows, consumption, and the volumes and directions of trade (Chinn & Ito 2008; Boivin, Kiley & Mishkin 2010; Evgenidis & Siriopoulos 2015). The transmissions through each channel might be expected to change gradually over time due to structural changes in the economy and monetary policy transitions.

As the review of Borio (2014) indicates, very broad policy responses are required, with monetary policy inevitably at their centre.[5] Yet it is a popular view that global monetary policy interactions yield multiple Nash equilibria and, when national policy-makers follow only domestically focussed goals, those reached are less than the best available.[6] This suggests the potential importance of international monetary policy coordination (Coeure 2016), even while, at least before the Global Financial Crisis (GFC), it was *also* commonly viewed that domestically optimal policies could approximate globally optimal equilibria.[7]

Given the prominence of financial interdependencies and the centrality of monetary policy, it is not inconceivable that there are important externalities, both inter-country and global, from the commonality of monetary policies in response to the IMF's encouragement of near-universal inflation targeting (IT). A distant parallel is with the price-stabilizing elements of commodity trade policies, referred to as "market insulation" (Tyers 1991; Tyers & Anderson 1992). In this case, there is clearly a fallacy of composition in that, the more countries choosing to adopt insulating policies, the more volatile become global commodity markets. A similar fallacy of composition applies in the case of the rise of export manufacturing in developing countries in

[3] Early work by Hamada (1976) set the scene for studies of this type. He evaluated international policy coordination via a two-country model with governments seeking both price stability and external balance.
[4] The substantial literature on spillover effects includes Broda (2001); Frankel, Schmukler & Serven (2004); Calvo, Izquierdo & Mejia (2008); Cavallo & Frankel (2008); Milesi-Ferretti & Tille (2011); Forbes (2012); Shinagawa (2014) and Georgiadis (2016).
[5] Yet particular controversy remains over the role of monetary policy in stabilizing financial markets, or "leaning against the wind". See, for example, Svensson (2009). This issue is not addressed in the current paper.
[6] The extensive literature supporting this includes Clarida et al. (2002); Blanchard et al. (2013) and De Paoli & Paustian (2017).
[7] See Clarida et al. (2002) and Obstfeld & Rogoff (2000, 2002).

recent decades (Martin 1993), with increased export volume from these countries shifting their terms of trade adversely.

While the case of monetary policy is more complex than these, the stabilisation of the consumer price level facing agents within each economy screens consumers from shocks that would otherwise induce adjustment. A working hypothesis is that, in open economies, the wedge between consumer and producer price levels depends most importantly on nominal exchange rates. Fixed consumer price levels imply more volatile nominal exchange rates in a precise parallel with the commodity market story. When the nominal exchange rate appreciates and the consumer price level or rate of change is targeted, home prices of imports fall and so the monetary policy therefore causes a home producer price inflation relative to comparatively rigid wage costs. To the extent that this induces increased output and employment in the short run, economic welfare is also raised. The converse occurs when the exchange rate depreciates. The result is that, while consumer prices are stabilised, output and welfare are rendered more volatile.[8]

In this paper, these strategic monetary policy issues are explored through the use of a calibrated global general equilibrium model, with regional money and open financial and product markets, that is embedded in Monte Carlo simulations.[9] In the context of the literature specific to monetary spillovers, the method embodied in our modelling deviates in a number of ways from the more common approaches, such as that by Farhi and Maggiori (2018), who focus on the competition between large currency issuers for shares of global reserve currency demand. Important amongst these is that we do not use a "new Keynesian" behavioural structure, preferring to maintain nominal wage rigidity in the short run and to incorporate the consequent effects on employment and output. This assumption, we believe, better captures the output and welfare effects of negative shocks than the more common ruling out of involuntary unemployment.

A further embodied assumption is that functional, conventional monetary policy is applied in all regions and that risk levels are within bounds that allow the assumption of institutionally rigid money multipliers. Central banks therefore have complete control of their regional nominal money supplies.[10] While these particular assumptions limit our power to address issues associated

[8] Of course, this output volatility can feed back into potentially or partially offsetting pressure on underlying real exchange rates.
[9] The core macro model used is an adaptation of that by Tyers (2016) and Tyers and Zhou (2020), which is here restructured over more regional groupings, to accommodate shocks, and then embedded in a Monte Carlo simulation cycle.
[10] This parallels McCallum (1993).

with zero lower bounds (ZLBs) and panics that cause money multipliers to collapse, the resulting modelling offers a wider representation of economic behaviour and hence a useful assessment of pre-GFC patterns of monetary intervention, not to mention the implications of the hoped-for return to a post-pandemic world with conventional monetary policy.[11]

The model embodies a globe divided between eight regions with synthetic shocks originating in each. The domestic and global transmission of these shocks occurs via adjustments affecting each economy's domestic or external demand sides. For each region, four alternative monetary objectives are considered, seeking to reduce volatility in 1) the nominal effective exchange rate, 2) a domestic monetary aggregate, 3) nominal GDP and 4) the consumer price inflation rate (inflation targeting, or IT). Also included is an empirically based policy rule that combines changes in the consumer price level and output, reflecting average recent behaviour.

Multi-region, normal form games are constructed that allow each central bank, given the choices made by other central banks, to choose among these monetary targets so as to minimise risk, with objective functions that emphasise either real GDP or a more generally defined economic welfare measure (the purchasing power of disposable income at home consumer prices). Simulations are implemented with many global combinations of monetary targets to construct payoff matrices. The final step is to identify Nash equilibria in target selections under each of the two objective functions.

The results suggest, first, that *de facto* monetary policies are collectively more stabilising than *de jure* ones. Indeed, many of the strategic outcomes suggest currently adopted monetary policy regimes are close to global equilibria, suggesting that the need for central banks that do not already adopt IT to transition to it is weak. That said, the conventional result that nominal GDP targeting best stabilises output emerges clearly,[12] yet under the broader welfare criterion, IT regimes and the empirically based policy rules (that embody substantial inflation weights) perform best overall.[13] Finally, evidence does emerge for the fallacy of composition hypothesis in that economic welfare in the US, which is the most open global economy, contributing the bulk of

[11] The consequences of floating rates with the ZLB and unconventional monetary policy are addressed in forthcoming research using further augmented modelling.
[12] This finding is consistent with McKibbin & Singh (2003), Bhandari & Frankel (2015), Garín, Lester, & Sims (2016) and Frankel (2018), that nominal GDP targeting offers less volatility of output when shocks stem from the supply side.
[13] This result is not fully consistent with Schmitt-Grohe & Uribe (2007), who argue that output targeting rules subject to supply side shocks reduce the volatility of more broadly defined economic welfare. We have not considered real targets, however.

global financial exchanges, is made more risky the larger is the proportion of the global economy under IT.

The paper is organized as follows. Section 2 briefly reviews recent evidence as to the choice of monetary policy regimes. Section 3 outlines the global model employed. Section 4 describes the Monte Carlo analysis conducted using the model. Section 5 presents results regarding *de facto* and *de jure* monetary policies; Section 6 then offers normal form, multi-player games indicating global monetary policy equilibria and their consequences. Conclusions are outlined in the final section.

2. Monetary Policy Regimes

Monetary policy regimes "encompass the constraints or limits imposed by custom, institutions and nature on the ability of the monetary authorities to influence the evolution of macroeconomic aggregates" (Bordo & Schwartz, 1999; Stone & Bhundia 2004). Central banks have a fundamental responsibility to establish and maintain a nominal anchor, which is a publicly announced nominal variable that serves as a target for monetary policy, to guide monetary policy to stabilise economies around their long run growth paths (Mishkin, 1999; Mishkin & Savastano, 2001; Berg, Borensztein, & Mauro, 2002). Real targets do not achieve this because, when effective, they leave price levels and other nominal variables unbounded. Alternative nominal anchors include those based on convertibility into a commodity, such as gold or silver; the currency of another country; a common currency in a currency union or an exchange rate target; a money aggregate target and an inflation target (Bordo & Schwartz, 1999).

The distinction between fixed and floating exchange rate regimes is central, in that the former implies an exchange rate target, commonly adopted by central banks in smaller or less developed countries on the financial periphery and commonly combined with controls on financial flows. The liberalisation of those financial flows since the 1990s has been associated with the incentive facing emerging economies to attract investment from an increasingly mobile pool of global saving. Necessarily, then, the central banks in such economies have transitioned away from exchange rate targeting monetary policy (Mishkin & Savastano 2001; Gebregiorgis & Handa 2005; Paranavithana et al. 2020). Chosen targets range between pure IT (Mishkin 2004; Yamada

2013; McKibbin & Panton 2018) and policy rules with mixed weighted objectives (Moura & De Carvalho 2010; et al. 2015).

Some recent literature suggests that a further transition should be considered, to nominal GDP targeting. Though this is not employed explicitly as yet, it is seen as attractive as a stabiliser of output and employment when predominant shocks are from the domestic supply side (Jensen 2002; Mitra 2003; Bhandari & Frankel 2018; Garin et al. 2016). The lag between changes in the stance of monetary policy and their impact on inflation complicates the monitoring of the commitment under these regimes and thus requires a high degree of transparency, accountability and forecasting capability, though the global trend prior to the 2020 pandemic, toward central bank independence, was supportive (Van der Cruijsen, Eijffinger & Hoogduin 2010; Levin 2014).

In the course of monetary policy transitions dissimilarities have emerged between *de jure* and a *de facto* monetary policies, where the former is the officially announced policy of a national government and the latter is deduced by observation of its central bank behaviour. For a sample of countries relevant to our purpose the IMF *de facto* and *de jure* monetary policy classifications are listed in Table 1. Deviations between these turn out to be complex, with the taxonomies depending on domestic political economy and the size of the economy concerned.

[Table 1 here]

For some regions, our assumed *de facto* monetary policy differs from the IMF's *de facto* classification, most importantly for the US and the EU. While the regimes adopted by these large regions are classified by the IMF as in their "other" category, in practice their central banks appear to seek the stabilisation of both inflation and output gaps, with some attention to exchange rates. In these cases, we classify monetary regimes as adopting idiosyncratically weighted, empirically based, policy rules. This said, inflation is a focus in these cases, which have been referred to as "flexible inflation targeting" regimes (Clarida 2020). The "rest of the world" is a residual that produces 23 percent of global GDP. About half of the countries included in it have central banks that target nominal exchange rates.

3. Modelling the Global Macroeconomy with Endogenous Financial Flows

The model used has its roots in dynamic general equilibrium structures and solution techniques. Here we offer a brief, general description, followed by some relevant detail. Conventional elements of the model are then detailed in an accompanying appendix.

3.1 Micro Structure:

The financial products of each region are differentiated and portfolio managers assign new net savings across regions so as to maximise expected portfolio returns given this differentiation. Within each region the demand for money is driven by a cash in advance constraint. For any one collective regional household, home money is held in a portfolio with long maturity assets, which are claims over physical capital across the regions, and domestic government debt. The markets for short and long maturity assets are assumed to be segmented with that for short instruments being domestically focussed and driven by central banks that adjust money supplies to meet monetary targets. By contrast, the markets for long instruments are driven by transactions that lead to Wicksellian global financial equilibria.[14] The yields on long maturity assets therefore represent the opportunity cost of holding money in regional financial portfolios.

The eight regions identified in the model are the United States (US), the European Union (EU),[15] Japan, China, India, Sri Lanka, the Gulf states[16], and the rest of the world (RoW). Each region supplies a single product that is differentiated from the products of the other regions and consumption in each region is distributed across all global products consistent with national accounts and international trade data for 2016. Total consumption depends on current and expected future real disposable income and the real interest rate, via an extended Keynesian consumption equation.

3.2 The Short Run Micro Behaviour

In formulating the short run behaviour of the model's supply side we depart from the "new Keynesian" tradition and assume that it is the nominal wage that, amongst all prices, is the least responsive to shocks. Ample evidence of this is available, for example, from Bewley (2002) and Malley et al. (2005). Implicit is the recently uncommon assumption that there is involuntary unemployment.[17] The simulated economies are not in a collective steady state, and so the expected net rates of return that drive investments need not equal the long maturity yields that

[14] The market for short maturity instruments is suppressed here in favour of explicit representation in our modelling of the money supply. These instruments tend not to be held outside their issuing regions.
[15] The EU is modelled as the full 28 countries and it is assumed that this collective has a single central bank.
[16] Represents 6 countries, namely Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and United Arab Emirates, and it is also assumed that this collective has a single central bank.
[17] In a model with a single product this assumption is doubly valuable, in that, while negative shocks might not render marginal workers fully unemployed in reality, they cause them to move to jobs with lower marginal products and therefore to reduce output. In this respect, our assumption is as near to reality as is allowed in the confines of a model with single regional products.

bring together the supply of investable funds from saving and the demand for investment at the global level.

3.3 Monetary Policy

At the level of each region monetary policy is assumed to target a range of variables that are explicit in the model. These include consumer price inflation rates (IT), nominal GDP levels and nominal exchange rates. According to the IMF (2016), some of these are more commonly referred to as "monetary policy frameworks" or "monetary anchors", defined as "the main intermediate target the authorities pursue to achieve their policy goals". In our model applications the region-specific monetary bases are seen as the most basic monetary instrument. These these are either retained as exogenous ("targeted") or rendered endogenous and swapped with one of the other "anchor" variables so that the money supply adjusts to hold it constant.

3.4 The Supply Side in Detail

Region *i* output volume, y_i, is assumed to be Cobb-Douglas in the three primary factors and a TFP coefficient, A_i, so that local output is:

$$y_i = A_i\left(1+\nu_i\right)L_i^{\beta_i^L}\left(S_i^K\right)^{\beta_i^{S^K}}\left(K_i\right)^{\beta_i^K}\text{, where } \beta_i^L+\beta_i^{S^K}+\beta_i^K=1 \;\;\forall\, i,\;\; \nu_i \sim N\left(0,\sigma_i^2\right), \tag{1}$$

ν_i is an exogenous TFP shock in region *i*, with standard deviation σ_i. The marginal products are conventionally derived, that for capital contributing to the expected net rate of return on installed capital:

$$r_i^c = \left(\frac{P^P}{P^K}\right)MP_i^K - \delta \approx \beta_i^K\frac{y_i}{K_i} - \delta = \left[A_i\left(1+\nu_i\right)\beta_i^K\left(S_i^K\right)^{\beta_i^{S^K}}\left(K_i\right)^{\beta_i^K-1}\right]L_i^{\beta_i^L} - \delta\;, \tag{2}$$

Where P^P is the producer price level, P^K is the price of capital goods and δ the depreciation rate. The real volume of output, y_i, is distinct from nominal GDP, $Y_i = P_i^Y y_i$, where P_i^Y is the GDP price level (deflator), differing from the producer price level, P^P, by the proportion of GDP made up of indirect tax revenue less subsidies. As indicated in (2), in a single product economy with product and capital goods prices inflating together the ratio P^P/P^K is unity.

The real wages of low-skill, w_i, and high-skill, w_i^S, workers depend on the corresponding marginal products, evaluated at the producer price level, P_i^P.

$$w_i = \frac{W_i}{P_i^P} = MP_{L_i} = \beta_i^L \frac{Y_i}{L_i} \quad \text{and} \quad w_i^S = \frac{W_i^S}{P_i^P} = MP_{S_i^K} = \beta_i^{S^K} \frac{Y_i}{S_i^K} \; . \tag{3}$$

The unemployment rate (u) in region i is calculated for all workers, where the labour force is F.

$$u_i = \frac{F_i - S_i^K - L_i}{F_i} \tag{4}$$

3.5 Financial Markets

Here the modelling departs from convention by incorporating explicit regional portfolios comprising assets from all regions. Data on regional savings and investment for 2016 is combined with that on international financial flows to construct an initial matrix that allocates total savings to investment in each region. From this is derived a corresponding matrix of initial shares of region i's net domestic savings that are allocated to the local savings supply that finances investment in region j, i_{ij}^{S0}. When the model is shocked, the new shares are calculated so as to favour investment in regions, j, with comparatively high after tax yields, generally implying high expected real gross rates of return, r_i^{ce}, and/or low financing interest rates, r_i. The expected rate of return is calculated as:

$$r_i^{ce} = r_i^c + \hat{e}_i^e = \left(MP_i^K - \delta\right)\left(\frac{\varphi_i^O}{\varphi_i}\right) + \hat{e}_i^e \; , \tag{5}$$

where the exogenous expected proportional change in the real exchange rate is $\hat{e}_i^e$. Here a further adjustment is made using an interest premium factor, φ_i, that is defined relative to the US ($\varphi_{US} = 1$).[18] This permits consideration of the effect of any change in sovereign risk in association with the fiscal balance. Increments to regional sovereign risk cause investments in those regions to be less attractive.

[18] The φ_i^O are a set of initial values that are calibrated for consistency of starting investment levels with real rates of return across the regions represented in the model.

$$\varphi_i = \varphi_i^0 \left[\frac{G_i}{T_i} \Big/ \frac{G_{US}}{T_{US}} \right]^{\phi_i}, \quad \forall i \neq \text{“US”}, \tag{6}$$

where ϕ_i is an elasticity indicating sensitivity to sovereign risk and *G/T* is the government expenditure to revenue ratio.

In region *i*, then, the demand for investment financing depends on the ratio of the expected rate of return on installed capital, r_i^{ce} and a domestic market clearing bond yield or financing rate, r_i.

$$\frac{I_i^D}{I_i^0} = \frac{P_K}{P_K^0} \left(\frac{r_i^{ce}}{r_i} \right)^{\varepsilon_i^I}, \tag{7}$$

where ε_i^I is a positive elasticity enabling the relationship to reflect Tobin's Q-like behaviour. This investment demand is then matched in each region by a supply of saving that incorporates contributions from all regional households. Region *i*'s portfolio manager allocates the proportion i_{ij}^S of its annual domestic savings to new investment in regions *j*, such that $\sum_j i_{ij}^S = 1$. Because the newly issued equity is differentiated across regions based on un-modelled and unobserved region-specific properties, their services are combined via a CES function specific to each regional portfolio manager. Thus, region *i*'s household portfolio management problem is to choose the share, i_{ij}^S, of its private savings net of any government deficit, $S_i^D = S_i^P + T^D + T^I - G$, which are to be allocated to the assets of region *j* so as to maximise a CES composite representing the value of the services yielded by these assets:

$$\max_{i_{ij}^S} U_i^F = S_i^D \left[\sum_j \alpha_{ij} \left(i_{ij}^S \right)^{-\rho_i} \right]^{-\frac{1}{\rho_i}} \quad \text{so that} \quad \sum_j i_{ij}^S = 1 . \tag{8}$$

Here α_{ij} is a parameter that indicates the benefit to flow from region *i*'s investment in region *j*. The CES parameter, ρ_i, reflects the preparedness of region *i*'s household to substitute between the assets it holds. To induce rebalancing in response to changes in rates of return, α_{ij} is made dependent on ratios of after-tax yield in destination regions, *j*, and the home region, *i*, via:[19]

$$\alpha_{ij} = \beta_{ij}\left(\frac{r_j/\tau_j^K}{r_i/\tau_i^K}\right)^{\lambda_i}, \quad \forall i,j, \quad \lambda_i > 0 \quad \forall i,j \,. \tag{9}$$

Here, τ_i^K is the power of the capital income tax rate in region *i*. This relationship indicates the responsiveness of portfolio preferences to yields, via the (return-chasing) elasticity, λ_i. The allocation problem, thus augmented, is:

$$\max_{i_{ij}^S} U_i^F = S_i^D\left[\sum_j \beta_{ij}\left(\frac{r_j/\tau_j^K}{r_i/\tau_i^K}\right)^{\lambda_i}\left(i_{ij}^S\right)^{-\rho_i}\right]^{-\frac{1}{\rho_i}} \text{ such that } \sum_j i_{ij}^S = 1 \,. \tag{10}$$

Solving for the first order conditions we have, for region *i*'s investments in regions *j* and *k*:

$$\frac{i_{ij}^S}{i_{ik}^S} = \left(\frac{\beta_{ij}}{\beta_{ik}}\right)^{\frac{1}{(1+\rho_i)}}\left(\frac{r_j/\tau_j^K}{r_k/\tau_k^K}\right)^{\frac{\lambda_i}{(1+\rho_i)}} \tag{11}$$

This reveals that region *i*'s elasticity of substitution between the bonds of different regions is $\sigma_i^I = \lambda_i/(1+\rho_i) > 0$, which has two elements. The return-chasing behaviour of region *i*'s household, λ_i and the imperfect substitutability of regional bonds and therefore the sluggishness of portfolio rebalancing, ρ_i. For the purposes of this analysis, the values of σ_i^I are seen as indicating the extent of each region's integration with global financial markets.[20] The optimal share of the net domestic saving of region *i* that is allocated to assets in region *j* then follows from (11) and the normalisation condition, that $\sum_k i_{ik}^S = 1$:[21]

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[19] Note that region *i*'s market bond yield, r_i, is determined concurrently and indicates the replacement cost of capital in region *i* and therefore the opportunity cost for region *i*'s household of investment in region *j*.

[20] The values used therefore vary by region in ways that are consistent with such indices of financial openness as that by Chinn and Ito (2008). The values employed and their association with indices are are discussed in detail by Tyers and Zhou (2019). For the calibration used here, the return-chasing elasticity, λ_i, is set to unity.

[21] The key matrix for calibration is $\left[\beta_{ij}\right]$. These elements are readily available, first, by noting that only relative values are required, and hence, for each region of origin, *i*, one value can be set to unity, and second, by making the assumption that the initial database has the steady state property that the net rates of return in regions *j* are initially the

$$i_{ij}^{S} = \frac{1}{\sum_{k}\left(\frac{\beta_{ik}}{\beta_{ij}}\right)^{\frac{\sigma_i^I}{\lambda_i}}\left(\frac{r_k/\tau_k^K}{r_j/\tau_j^K}\right)^{\sigma_i^I}} \quad . \tag{12}$$

To complete the financial market specification, investment demand in each region is equated with the global supply of saving to that region. Total investment spending in region *i*, in *i*'s local currency, is then:

$$I_i^D = \sum_j \left[i_{ji}^S S_j^D \left(\frac{E_j}{E_i}\right)\right] \ \forall j \ , \tag{13}$$

where E_i is the nominal exchange rate of region *i* relative to the US$ (the number of US$ per unit of region *i*'s currency), which is the numeraire in the model ($E_{US} = 1$). The regional real bond yields (interest rates, r_j) emerge from this equality. Their convergence across regions is larger the larger are the elasticities of asset substitution, σ_j^I.

3.6 Regional Money Market Equilibrium

The opportunity cost of holding home money is set at the nominal after-tax yield on home long-term bonds. Real money balances (lower case *m*) are measured in terms of purchasing power over home products at GDP prices.

$$m_i^D = a_i^{MD} \left(y_i\right)^{\varepsilon_i^{MY}} \left[\frac{r_i\left(1+\pi_i^e\right)}{\tau_i^K}\right]^{-\varepsilon_i^{MR}} = \frac{M_i^S}{P_i^Y} = \frac{\mu_i M_i^B}{P_i^Y} \quad , \tag{14}$$

where ε^{MY} is the income elasticity of money demand, ε^{MR} is the interest elasticity of money demand and π_i^e is the expected inflation rate of the consumer price level, P_i^C, defined as a CES aggregate of home and imported consumer prices. M_i^B is the (nominal) monetary base, the primary monetary policy variable, and the money multiplier, μ_i, is assumed to be institutionally determined and held constant.[22] No endogenous changes are assumed to take place in the proportional holdings of cash reserves by institutions and households.

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same as the market bond yield, r_j. Then, since in the base data $r_{ij}^{e0} = r_j^0$, $r_{ij}^{e0} = r_k^0$, the $\beta_{ij}s$ is available from a modified (12).

Along with the conventional targets, or "anchors" of monetary policy mentioned earlier, a reduced form rule of the Taylor type is also included that is empirically based and offers dependence of the monetary base on both an output gap (represented by the unemployment rate) and the price level. It is notable here that our single year analysis does not require a distinction between the price level and its rate of change.[23]

$$M_i^B S_i^M = a_i^T u_i^{\varepsilon_i^U} \left[\frac{P_i^T}{P_i^C} \right]^{\varepsilon_i^P}, \qquad \varepsilon_i^U, \varepsilon_i^P > 0, \tag{15}$$

where S_i^M is a slack variable that has initial value unity, and which is set as exogenous when this rule is functional, and endogenous when there is a different target of monetary policy. The unemployment rate is u_i, which affects monetary policy via the elasticity ε_i^U, and P_i^T is a target consumer price level towards which P_i^C is drawn by changes in the monetary base. The extent of this attraction depends on the elasticity ε_i^P. The implied monetary policy rule, when it is active, uses elasticities that differ by region, as described in the accompanying appendix.

3.7 Economic Welfare

The welfare measure used is the purchasing power of disposable income at domestic consumer prices, W_i^E. It is defined as:

$$W_i^E = \frac{Y_i^D}{P_i^C} = \left(P_i^Y y_i + \sum_j N_{ji}^F \frac{E_j}{E_i} - T_i^D + G_i \right) \Big/ P_i^C, \tag{16}$$

where Y_i^D is nominal disposable income, P_i^Y is the GDP price level, N_{ji}^F is net nominal income from foreign region j, T_i^D is total direct taxation and G_i is government expenditure on goods and services, included to represent the supply of public goods.

Expressions for the variables not defined above are in the accompanying appendix.

[22] In its use of the monetary base as the central monetary policy variable this formulation follows McCallum (1993) and Orphanides (2010). It also reflects both transaction and portfolio demand, implying some natural variation in money velocity, which is low when portfolio holdings are high relative to transactions demand and yields are low.
[23] Dynamic analysis does require this distinction (Hatcher and Minford 2014) but here shocks generate wthin-year changes in price levels, which affect behaviour directly and which are reported as inflation beyond an underlying steady state.

3.8 Model Database and Implementation

Here we briefly review the data on which the model is based and discuss the means by which it is implemented, including closures chosen and the implications for expectation formation.

The data and its embodied structure:

The model database is built on national accounts as well as data on international trade and financial flows for 2016. The structures of the regional economies are as indicated in Table 2. They differ in important ways. The US, India, and Sri Lanka have high consumption shares of GDP, China and the Gulf states have comparatively low shares. Necessarily, then, the US, India and Sri Lanka contribute comparatively little net saving to global financial markets while China and the Gulf states make considerable contributions.

[Table 2 here]

Since, in several regions, indirect taxes fall heavily on consumption, changes in saving behaviour have strong implications for fiscal deficits and, therefore, indirectly, for interest premia. Investment contributes more to GDP in some economies than in others, and its contribution is extraordinarily large in China. Fiscal deficits, which are proportionally largest in the Gulf states but numerically largest in the US, are offset by the current account surpluses or financial account deficits of Japan and China. Interactions between these economies through trade are captured in the consumption expenditure matrix shown in Table 3. It is derived from the combination of national accounts with a matrix of trade flows. The flows are expenditures inclusive of indirect taxes, converted into the shares of total expenditure on goods and services by each country. Investment demand for capital goods and government spending on goods and services make demands on the markets for home products only.

[Table 3 here]

The financial interactions between the regions are indicated by the saving-to-investment flows in Table 4. These show the expected Feldstein-Horioka (1980) behaviour but also that there are substantial financial interactions between the US, the EU, Japan, and China in particular. The data suggest, however, that economies like Sri Lanka and the Gulf states are comparatively less integrated with the remainder of the global economy.

[Table 4 here]

The closures:

Closure choices dictate, in an *n*-equation model with *m*>*n* variables, which variables are chosen to be amongst the *m-n* that are defined as exogenous, to ensure that the system can be solved. The targets of monetary policy in the eight regions are closure choices in the modelling, in that they indicate that regional money supplies are endogenous to fixed target measures such as the nominal exchange rate or nominal GDP. Beyond monetary policy, closure choices apply to labour market clearance, fiscal balance, and expectations. The alternatives are detailed in Table 5.

[Tables 5 here]

Expectation formation:

Routinely, expectations are made model-consistent by iteration, usually converging within five iterations. As described in the section to follow, however, the model is here embedded in a Monte Carlo simulation structure. Model-consistency then applies to expectations over moments of the distributions of key variables, rather than periodic realisations. Importantly, expectations over price levels are anchored at mean values in all regions, so no short run consumer price inflation or deflation is anticipated, even where a region's monetary policy does not target consumer price inflation. In some cases, mean outcomes in response to shocks might be expected to drift slightly from initial values under Monte Carlo randomness, but we find this drift to be small. Our focus is on the stabilising role of monetary policy and hence on the variances of key variables.

4. Shock Formation and Monte Carlo Simulation

Since the model is global, regional supply side shocks permeate through it, resulting for each economy in a combination of domestic supply and demand side shocks, with the more open economies experiencing the strongest demand side shocks incident from abroad. The primary supply side shocks are applied simultaneously to the levels of TFP in all regions, via the vector $\underline{v} = [v_i]$ in (1). The problem that arises is that each region's TFP shocks are not readily identified from available macro data. So, we identify the TFP shocks from time series for real GDP, by using the model in reverse.

First, a time series of annual GDP growth rates is constructed for each region, from 1954 to 2016 from published data. In each year we then change the closure of the model, making TFP endogenous and real GDP exogenous and apply the real GDP shocks. This yields a vector across regions of proportional TFP shocks for that particular year. This process is then repeated for each year in the data series, yielding a set of regional time series for synthetic TFP shocks. We then examine departures from their means to capture shocks relative to underlying long run growth paths for each region. For each region we then have a series of proportional departures from growth trends over the years 1954 to 2016. From these we construct a variance-covariance matrix and an associated matrix of correlation coefficients, $R(\underline{v})$. This matrix is listed in Table 6. We find that the resulting synthetic TFP shocks are positively correlated across regions, with the strongest links to the US and Japan. This suggests that these shocks already embody some international interdependence, perhaps through trans-border climatic events or recent investment in new capital that embodies globally available new technology, both of which directly affecting supply sides.

[Table 6 here]

The calibrated correlation matrix, $R'(\underline{v})$, shown in Table 7, is then constructed. It includes only the statistically significant results emerging from the initial estimation. Insignificant correlations are ignored and so have zero values. From this calibrated correlation matrix we then reconstruct the variance-covariance matrix of these proportional departures from TFP growth trends in each region, $\Sigma(\underline{v})$. The delivery of shocks to the model in our Monte Carlo simulations then draws vectors of random variables from a multi-variate normal distribution with zero means and variance-covariance matrix $\Sigma(\underline{v})$. These shocks are introduced to all regions simultaneously and the model, with conventional closure (real GDP endogenous, TFP exogenous) is used to calculate proportional changes in the variables of interest.[24] The first and second moments of the distributions of these variables, and particularly the levels of real GDP and our welfare measure, are accumulated and seen to converge acceptably after 5000 model simulations.[25]

[Table 7 here]

[24] To check the normality of our TFP shocks, we use multivariate Jarque-Bera test and probability well exceed the 0.05 p-value. Therefore, the data follows a normal distribution.

[25] Convergence is acceptable when the first two moments of the simulated distribution of the TFP variables, $\underline{v}$ are accurate to within three significant figures. The model solutions are derived using the Gempack software, which is here embedded in a Python program that recycles the model and collects moments of the distributions of all endogenous variables.

Of particular interest are the emerging variances of output (real GDP, equation 1), and welfare (16), where the latter was defined previously as the purchasing power of disposable income at domestic consumer prices, adjusted to include government expenditure on public goods. These represent risks of particular interest to central banks, which can be evaluated in the form of regional risk premia. They are measures of the cost of volatility, which central banks are assumed to be committed to minimise. These risk premia (costs to be avoided), ρ_i^y and ρ_i^W, are defined as proportions of real GDP and the measured welfare level as follows:

$$\rho_i^y = 0.5\left(S_i^y\right)^2 R_i, \quad \rho_i^W = 0.5\left(S_i^W\right)^2 R_i, \tag{17}$$

where S_i^y and S_i^W are the standard deviations of proportional changes to real GDP and welfare in region *i*, respectively, that emerge from the Monte Carlo simulations. R_i is the Arrow-Pratt coefficient of relative risk aversion of region *i*'s central bank, defined as a unitless measure of the curvature of a twice-differentiable Bernoulli utility function in real GDP and real purchasing power of disposable income, as:

$$R_i^y = -y_i \frac{U''(y_i)}{U'(y_i)}, \quad R_i^W = -W_i^E \frac{U''(W_i^E)}{U'(W_i^E)} . \tag{18}$$

These measures are here calibrated based on the R_i values derived from central bank behaviour by Gandelman & Hernandez-Murillo (2015). They calculate Arrow-Pratt coefficients for selected countries' central banks based on the Gallup World Poll database. We apply the implied *R* values for the regions defined in this analysis. These are US: 1.39; EU (country average): 1.08; Japan: 0.44; China: 1.01; India: 0.92; Sri Lanka: 0.68; Gulf states (average): 0.70.

5. *De Jure* vs *De Facto* Monetary Policies

As a first application, we simulate the effects of shocks on the global economy, initially assuming monetary policies align with the *de jure* classification of Table 1. The hypothesis to be tested is that the *de facto* policies are implemented, at least in part, because they take better account of the effects of international spill-overs than the *de jure* ones and so deliver less risk to real GDP or economic welfare. The Monte Carlo simulation results for the assumed *de facto* and *de jure* cases are summarised in Table 8.

[Table 8 here]

The *de jure* targets of the US, the EU, Japan, and India are all IT. Sustaining price level stability in these economies in the face of TFP shocks can exacerbate volatility in output, so the accommodating changes in monetary policy suggested by the corresponding *de facto* classification are required in practice when such shocks occur. Yet, if stability in our welfare variable is the priority, the *de jure* targets of the US and the EU are more effective in controlling its volatility. Given spill-over effects, particularly from US policy, *de facto* targets uniformly yield less welfare volatility in smaller regions. In the EU, *de facto* targets are more stabilising of real GDP, without impairing the stability of economic welfare. In China, *de facto* targets are significantly more stabilising of both real GDP and welfare, as they are for the Gulf states. In other regions, the adoption of assumed *de facto* targets by all regions leads to marginally reduced real GDP and welfare risk levels. It would appear, therefore, that the empirically based US policy rule, while it is more stabilising of real GDP, and therefore domestic employment, than of domestic economic welfare, better serves the rest of the world than a strict IT regime.

6. Strategic Interactions

First we consider two-player games with other regions adopting their *de facto* monetary policies throughout. The two players interact and choose amongst the five alternative monetary policy targeting regimes – exchange rate targeting, E_i, money supply targeting, M_i^T, nominal GDP targeting, Y_i^N, an empirically based policy rule, T_i^R and inflation targeting, IT. The empirically based policy rules considered are characterised by their elasticities in (15). Estimation is based on monetary responses over the past 20 years, as described in the accompanying appendix. The IT regime is considered to stabilise the consumer price level, P^C, perfectly. Since there are eight regions the number of pair combinations that could interact strategically in such bilateral analysis is 8C2=28. But we will consider just two: the US vs Europe and the US vs China.

We then consider strategic interaction between seven of the regions, with the "rest of the world" maintaining its de facto policy. To further simplify the required enumeration we restrict the policy options to exclude money supply targeting.[26] The game with seven players (regions) and four

[26] To test the importance of this omission we conducted a preliminary analysis in a two-player context using different combinations of players (advanced country vs advanced country; advanced country vs emerging and developing

monetary policy actions still requires extensive enumeration, since it has 4^7=16,384 policy combinations. Clearly a selection is required. The combinations thus considered and the associated closures affecting labor market clearance, fiscal balance and monetary policy choices are summarised in Table 9.

[Table 9 here]

6.1 Two Player Game (US and EU)

As suggested by the analysis of *de jure* and *de facto* regimes, the monetary policy choices of the US and the EU have significant global macroeconomic impacts. For this reason, the strategic elements of regime choice for these two regions deserve closer analysis. Here we examine the implications of their choices amongst five alternative regimes, while other regions maintain their *de facto* regimes as per Table 1. In this normal form game, there are $\left(5^2 = 25\right)$ strategic combinations, each of which is simulated in the Monte Carlo model, with (inverse) pay-offs that are risk premia as proportions of real GDP and economic welfare measures. The results are illustrated in Table 10.

[Table 10 here]

When the criterion is GDP risk, both economies have strictly dominant strategies, to adopt nominal GDP targeting. This is because the nominal GDP targeting regime adjusts price levels in directions that stabilise output. Indeed, this equilibrium reduces the levels of real GDP volatility by more than half relative to IT. Yet the economic welfare criterion favours IT. From the figure it is clear that IT is the most favored strategy for the US, though the results for the EU are more complex. If the US were to select exchange rate targeting, the best response by the EU would be to select its empirically based policy rule. If, on the other hand, the US chooses money supply targeting, nominal GDP targeting or its empirical policy rule, the EU's best response is to select IT. The Nash equilibrium has the US choosing IT while the EU chooses its policy rule.

6.2 Two Player Game (US and China)

Recognising the rising significance of the Chinese economy, we consider an alternative simplification of the global monetary policy game, such that the active players are the US and

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country; emerging and developing country vs emerging and developing country) considering the full five monetary policy actions. None of the regions are shown to prefer money supply M_i^T targeting regimes under either of the real GDP or welfare stability criteria.

China. Given that the two regions choose from five alternative policy regimes, this scenario also has 25 strategic combinations. The normal form game payoffs are listed in Table 11. When the objectives are to stabilise real GDP, as in the case of the US–EU game, targeting nominal GDP is a dominant strategy for the US economy. However, the stability of China's real GDP depends on the US target. If the US were to select exchange rate targeting, People's Bank of China would prefer its policy rule, which assigns some weight to output stability. If, on the other hand, the US were to choose as its target a money supply aggregate, nominal GDP, its policy rule or IT, then China's best response stabilises its output by selecting nominal GDP targeting. In the end, the Nash equilibrium has both economies selecting nominal GDP targeting regimes.

[Table 11 here]

If welfare stability is the objective the choice by the US to target either its exchange rate, a monetary aggregate or its nominal GDP, would induce the People's Bank of China to adopt its empirical policy rule, which weights both output and price stability. On the other hand, if the US were to select its policy rule or an IT regime, the People's Bank of China's best response is to peg its nominal exchange rate to the US$. In the end, the Nash equilibrium has the US adopting an IT regime, and China targeting its exchange rate. This is a well-established equilibrium point. For the US the IT regime reduces volatility in its *effective* exchange rate and improves its exports. Exchange rate volatility is, however, a key issue for the stability of Chinese economic welfare, hence the Chinese adoption of the US$ peg.

6.3 Seven Player Game

The seven player game allows regime choice by advanced economies including the US, the EU and Japan, as well as by the emerging and developing economies including China, India, Sri Lanka, and the Gulf states. This game has 4^7 = 16,834 possible outcomes. Because full enumeration is impractical, we first consider the three largest economies, the US, the EU and China, holding all other regions at their *de facto* policies. We then sample combinations that allow variation in the policies of the other four regions. We find that the policies of the "big three" are robust to changes in the other four. As shown in Table 12, payoffs differ only slightly from the cases where the other four are assumed to adopt their de facto policies, but all play nominal GDP targeting under the real GDP criterion and, under the welfare criterion, the US plays IT, the EU plays its empirical policy rule and China pegs its exchange rate.

[Table 12 here]

For the remaining four regions, if the big three are constrained to adopt their equilibrium policies, there are 256 policy combinations. A guide to how these are enumerated is given in Figure 1. The results are summarised in Table 13. For parsimony, the table only shows risk premia for Japan, India, Sri Lanka and Gulf states, with primary interaction between India and Sri Lanka, while listing at the bottom the Nash equilibrium policy choices and premia for all seven regions. Generally, the regime choices of smaller economies have little effect on the larger ones. As before, when the stability of real GDP is the objective, nominal GDP targeting is a strictly dominant strategy for all regions. When the stability of economic welfare is the criterion, Japan chooses its empirical policy rule, India and Sri Lanka choose IT regimes, and the Gulf states choose exchange rate targeting regime (US$ pegs). In the Nash equilibrium, the US, India and Sri Lanka all choose IT regimes, the EU and Japan choose their empirical policy rules and China and the Gulf states choose exchange rate targeting regimes (US$ pegs).

[Figure 1 here]

[Table 13 here]

When the US selects an IT regime, the best strategy for other *large* economies is to choose either their empirical policy rules or exchange rate targeting regimes. The opposite applies for emerging and developing economies like India and Sri Lanka, which respond to the US choice of IT by implementing IT themselves. Idiosyncratically for these developing economies, their main partners for both trade and financial flows are other small economies, and so they are less than usually affected by the regimes chosen by the US and other large economies. This lends support to the IMF's encouragement of emerging and developing economies to change their monetary policy regimes toward IT (Nicolett et al. 2006). With unemployment less of a domestic consideration than in advanced economies, economic welfare is a policy priority. Their relative independence makes the benefits of the IT regimes accessible when larger economies adopt regimes that trend in the IT direction.

Finally, in Table 14 we compare the *de facto* policies with our seven player equilibrium results. Recognising that the inflation weights in most regions' empirical policy rules are considerable, the equilibrium policies are very close to the *de facto* policies in operation. This suggests existing policies are near "optimal" and that there is no need for further transitions toward IT.

6.4 The Fallacy of Composition

It is our working hypothesis is that the stabilisation of the price level facing agents within each economy screens them from shocks that would otherwise induce adjustment, thus externalising the effects of domestic supply side volatility and therefore increasing volatility abroad. One mechanism by which this might operate is via exchange rate volatility. When consumer price levels are fixed by IT and shocks cause variation in underlying *real* exchange rates (appropriately defined on home output prices, as indicated either by producer or GDP prices), *nominal* exchange rate volatility must increase. When consumer prices are fixed and nominal exchange rates fluctuate, producer prices must become more volatile. To see this it is constructive to reconsider the price levels represented in the model. Importantly, the consumer price, P^C, is the weighted average of the home producer price and the domestic currency price of foreign goods,[27] which is affected by import tariff levels and nominal exchange rates. While this relationship is more complex in the model due to its constant elasticity of substitution (CES) price index,[28] we can usefully simplify it, for any one region, to:

$$P^C = \tau_C \left[\alpha_H P^P + \left(1 - \alpha_H\right) \left(\frac{\tau^M P^*}{E} \right) \right], \tag{20}$$

where α_H is the home product share of consumption, τ^M is the power of the import tariff, P^* is the landed foreign currency price of foreign goods and E is the nominal exchange rate expressed as the purchasing power of the home currency over others.

If universal IT stabilizes both P^C and P^*, changes in underlying real exchange rates due to the introduced shocks cause nominal exchange rate volatility. When the nominal exchange rate, E, appreciates and P^C is constant, monetary policy must be expansionary, causing an inflation in the producer price level, P^P. When E depreciates, monetary policy must force a producer price deflation. The result is that, while IT stabilizes consumer prices, it destabilizes nominal producer prices, and this occurs to a greater extent the more open is the economy to trade. With the Keynesian assumption that nominal unit labor costs are fixed in the short run, there is greater volatility in employment and income. Of course, this primary effect is opposed in the model (and

[27] See the appendix for price definitions.
[28] See the accompanying appendix, (A10).

in reality) by adjustments in the share of the home product that is consumed (α_H), but these do not reverse the direction of price effects.

From our Monte Carlo simulations, we do find evidence of this in our measure of the US economic welfare. To see it, one approach would be to commence with a simulation of the global economy in which all central banks adopt their *de facto* policies. From this baseline, we wouild then construct a set of simulations in which regions switch their monetary policy regimes successively to IT. Because IT is frequently close to *de facto* policies, however, we differentiate monetary policies more starkly at the outset. Under our baseline simulation, the US and EU adopt IT while all other regions adopt exchange rate targeting. A subsequent seven simulations are then constructed by successively switching one region from exchange rate targeting to IT, until all regions in the global economy function under IT. As illustrated in Figure 1, the level of US economic welfare proves to be quite sensitive to price level volatility in other regions, suggesting the presence of the hypothesised relationship with the prevalence of IT. The spread of IT regimes raises the US welfare risk monotonically, with uniform, global adoption of IT raising welfare risk by at least a third.

[Figure 2 here]

7. Conclusion

This paper employs a new global general equilibrium model with open capital accounts, regional money and endogenous financial flows to analyse the effects of monetary policy spill-overs and their dependence on countries' choices of targeting regimes. Monte Carlo simulations are used to apply region-specific shocks that propagate through the global economy via both trade and financial flows, appearing in any region as combinations of demand and supply side shocks. Baseline monetary policy regimes are those identified as *de facto*, with a comparison of these with IMF-defined *de jure* policy frameworks suggesting the implemented policies are pragmatic in that they offer improved economic stability.

Choices amongst alternative targets of monetary policy are then examined strategically. Multiplayer non-cooperative, normal form games are constructed, with regional objectives to reduce risk premia on either real GDP or economic welfare, defined as the real purchasing power of disposable income at home consumer prices. Unique Nash equilibria are located, suggesting that "nominal GDP targeting" monetary policy regimes provide the most stable real GDP paths. On the other hand, when regions seek to reduce risk premia in the welfare measure, Nash equilibria show a mix of IT, empirical policy rules and exchange rate targets that tend to mirror the global pattern of *de facto* monetary policies. The results therefore suggest that *de facto* monetary regimes already in practice are close to a global equilibrium (Clarida et al. 2002 and Obstfeld and Rogoff 2000, 2002), casting doubt as to whether further "coordination" or the encouragement of developing country governments to consider IT is needed.

Evidence also emerges of a fallacy of composition as more of the world's GDP is managed under IT regimes. In particular, economic welfare is rendered more volatile in the largest, most open economy as larger developing regions transition from exchange rate targeting to IT. This suggests a potential downside from universal IT, which, while it stabilises consumer prices, tends to increase the volatility of producer prices and therefore of real output, employment and welfare.

The implications of our modelling apply to circumstances under which conventional monetary policy is unconstrained by "zero lower bounds" or deviations from our assumption that the range in levels of risk does not stray outside the bounds within which regional money multipliers can be considered constant. While this limits the scope with which our results can be interpreted, strong conclusions as to equilibrium sets of strategic monetary policy nonetheless emerge that suggest patterns comparable with those observed in recent times as well as to which convergence could recur in the future.

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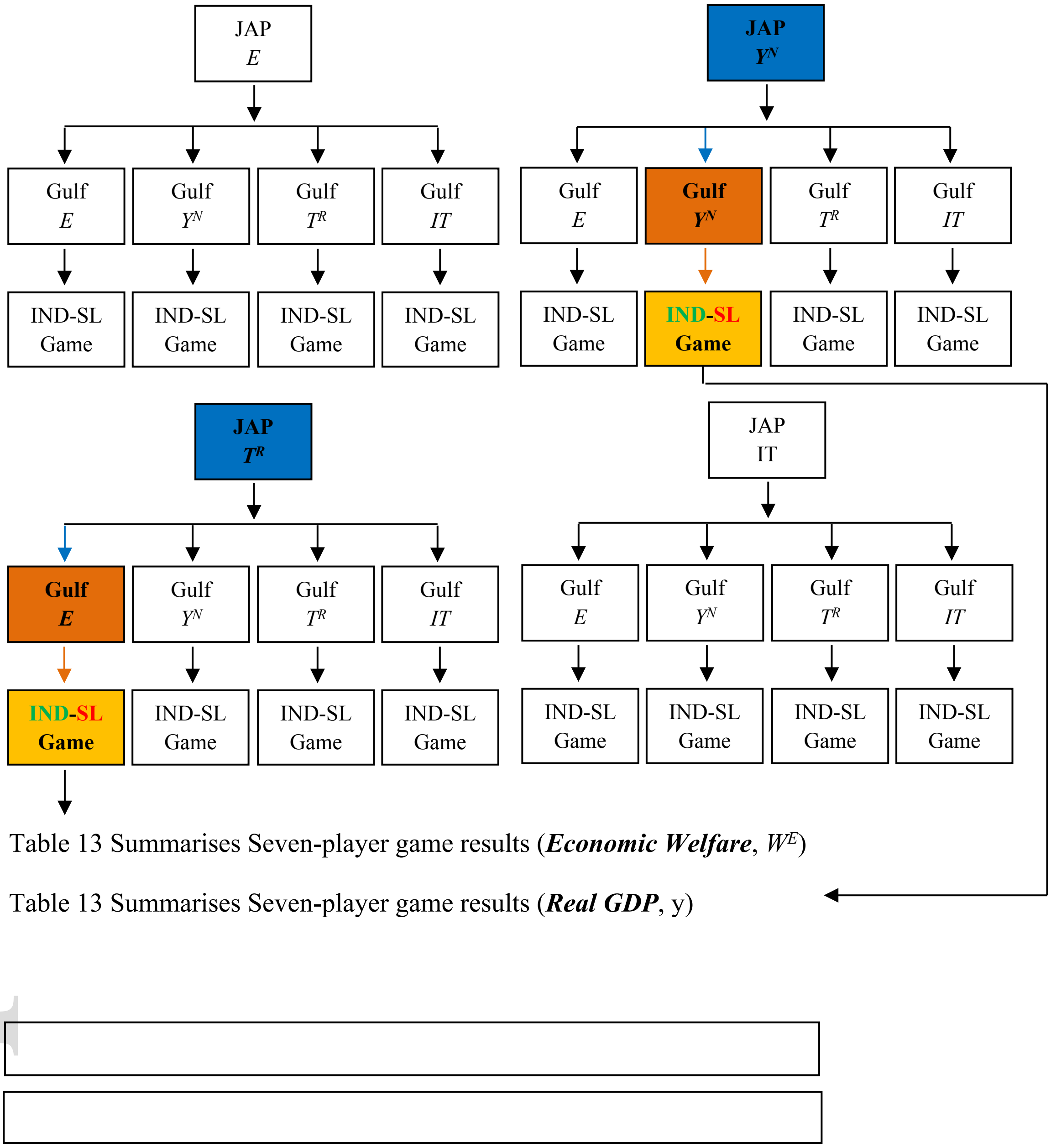
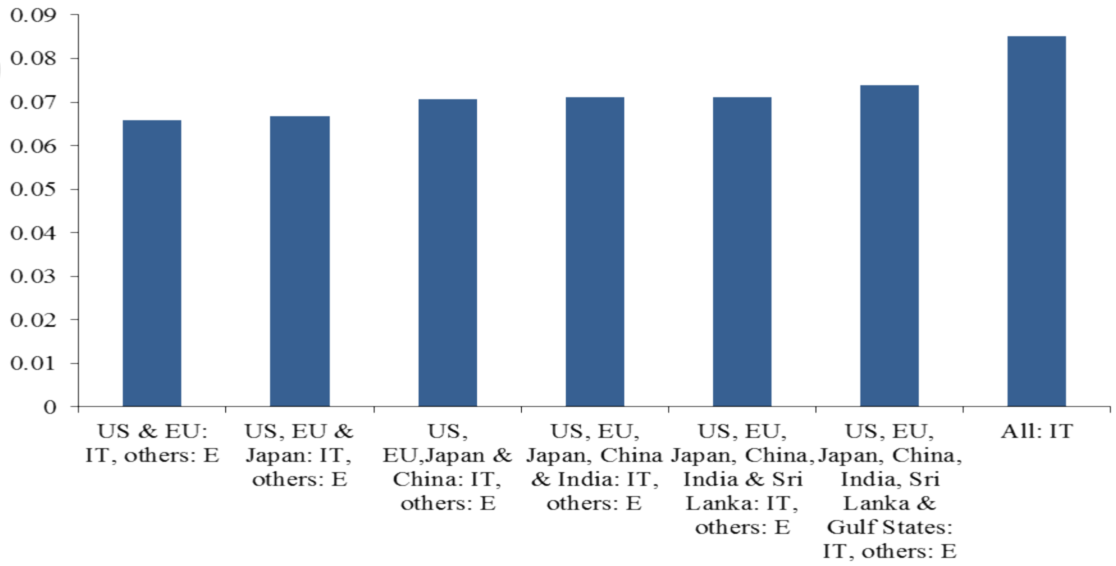
Figure 1: Enumerating the Seven Player Monetary Policy Game for Japan and the Emerging Economies[a]



a Here the three largest economies are excluded, playing their robust policies: the US plays IT, the EU plays its its empirical policy rule and China pegs its US exchange rate, *E*. This leaves 16 two-dimensional normal form payoff matrices, each with 16 cells representing combinations of policy choices across Japan and the emerging economies.

Figure 2: US Economic Welfare Risk Premium as Regions Transition from Exchange Rate Targeting to IT[a]

(Economic welfare risk premia as % of US base welfare, W^E)



a Here a series of Monte Carlo simulations are made over seven cases, commencing with the older advanced economies adopting IT while the rest of the world pegs to the US$ and allowing one region to transition to IT in each successive case.

Source: Authors' calculations based on Monte Carlo simulations of the model described in the text.

Table 1: Monetary Policy Classification

Region	Monetary Policy Regimes		
	de jure[a]	IMF *de facto*[b]	Nominated *de facto*
US	IT	*Other* [c]	T^R [d]
EU	IT	*Other* [c]	T^R [d]
Japan	IT	IT	IT
China	E	M^T	E
India	IT	IT	IT
Sri Lanka	IT[e]	M^T	IT
Gulf states	E	E	E
RoW[f]	E	E	E

a This taxonomy is based on countries' central bank annual reports and official statements.
b This is based on the IMF *Annual Report on Exchange Arrangements and Exchange Restrictions*.
c The most frequently chosen classification in the last three years is here adopted as the *de facto* regime.
d In practice, these economies follow policy mixed targeting strategies. Weights in empirical policy rules designed to reflect this are derived as per the Appendix. They differ by region and so represent average patterns of central bank intervention.
e In 2015, the Central Bank of Sri Lanka introduced both monetary targeting and flexible inflation targeting, working toward the establishment of an IT framework.
f The RoW is a residual with economies represented in this category contributing 23 per cent of global GDP. Of the included countries, 46 per cent follow exchange rate targeting regimes.

Source: IMF Annual Report on Exchange Arrangements and Exchange Restrictions Central Banks Annual Reports and the Federal Open Market Committee (FOMC) meeting minutes

Table 2: Regional Economic Structure – 2016[a]

% of GDP	US	EU	Japan	China	India	Sri Lanka	Gulf states	RoW
Consumption, C	69.48	57.40	57.95	43.72	60.29	66.92	47.55	59.10
Investment, I	18.28	19.94	21.59	40.16	27.12	28.39	25.82	25.93
Govnt. spending, G	16.10	21.64	19.85	13.37	15.12	16.26	17.51	17.05
Export, X	13.09	14.13	16.21	28.94	17.51	17.69	33.53	15.28
Import, M	16.95	13.11	15.61	26.18	20.04	29.26	24.42	17.36
Domestic savings, S^D	16.89	23.21	24.39	46.54	28.91	23.82	36.89	24.53
Total tax rev., T	10.52	19.37	11.53	9.59	11.28	12.36	1.37	15.15
Indirect tax rev., T^I	7.71	14.84	2.71	6.01	9.98	8.89	1.01	12.82
Monetary base, M^B	20.40	21.21	16.46	11.13	13.69	4.53	9.15	22.16

a National accounts data supply most of the elements though adjustments have been required to ensure that current accounts sum to zero globally, as do capital/financial accounts.

Sources: The IMF-IFS database is the major source, but there is a frequent resort to national statistical databases.

Table 3: Shares of Consumption by Region of Origin – 2016[a]

% of row cons. expenditure	US	EU	Japan	China	India	Sri Lanka	Gulf states	RoW
US	65.23	8.10	1.61	6.32	0.56	0.06	0.32	17.83
EU	6.10	72.89	1.05	5.73	0.62	0.04	0.60	12.96
Japan	4.15	4.35	68.48	7.13	0.16	0.01	1.80	13.93
China	6.12	7.53	4.32	40.11	0.57	0.01	1.46	39.88
India	1.38	2.73	0.66	4.55	66.76	0.04	3.42	20.45
Sri Lanka	1.01	3.41	1.78	9.82	7.17	56.28	2.44	18.08
Gulf states	7.89	14.90	3.56	8.61	4.38	0.06	28.07	32.53
RoW	9.36	4.83	3.94	10.44	1.98	0.05	3.21	66.19

a These shares sum to 100 horizontally. They are based on the 2016 matrix of trade flows combined with consumption expenditure data in each region. The resulting matrix is inconsistent as between data sources, and so a RAS algorithm is used to force consistency of bilateral elements with national accounts data.
Source: Implied trade flows are for 2016, drawn from the IMF Direction of Trade Statistics database.

Table 4: Shares of Total Domestic Saving Directed to Investment in Each Region– 2016

% of row total savings [a]	US	EU	Japan	China	India	Sri Lanka	Gulf states	RoW
US[b]	64.68	16.77	4.15	4.02	0.41	0.01	0.20	9.78
EU	10.95	75.89	2.26	2.15	0.23	0.01	0.25	8.25
Japan	9.91	11.62	63.05	3.43	0.26	0.00	0.10	11.62
China	7.04	6.54	1.65	78.07	0.17	0.03	0.09	6.42
India	3.66	5.37	1.57	2.25	79.50	0.55	0.50	6.60
Sri Lanka	0.57	2.47	0.18	0.36	1.53	81.95	0.02	12.91
Gulf states	4.72	2.98	0.69	1.86	0.52	0.09	84.63	4.51
RoW[c]	10.83	8.24	1.21	1.83	0.27	0.02	0.12	77.47

a These shares sum to 100 horizontally. They are based on 2016 investment flows. Elements are adjusted so that row and column sums are consistent with other data. The row sums of the flow matrix are total saving by region and the column sums are total investment by region. These sums are sourced from the IMF-IFS database and the World Bank database. Financial flows of each region identified base on each region International Investment Position. The direction of these flows estimated base on the IMF "Coordinated Direct Investment Survey" (CDIS) and "Coordinated Portfolio Investment Survey" (CPIS).
b Values for the US are concorded with official statistics from the Bureau of Economic Analysis (BEA).
c The RoW is a residual. Its saving is inferred from national accounts estimates and its investment abroad is determined to balance the matrix of financial flows.
Source: Authors' calculations.

Table 5: Closure Choices and Policy Regimes[a]

Closure		
Labour Market:	Exogenous nominal wage (W_i) with endogenous employment (L_i)	
Fiscal Policy:	Exogenous nominal government spending (G_i) and endogenous government revenue (S_i^G)	
Monetary Policy Targets[b]:	1. Exchange rate, E_i	2. Monetary aggregate, M_i^T
	3. Nominal GDP, Y_i^N	4. Empirical policy rule, T_i^R
	5. Consumer price level, $\pi = \hat{P}_i^C$, IT_i	

a Since the model is a system of non-linear simultaneous equations and more variables are specified than equations in the system, there is flexibility as to the choice of those to make exogenous. This choice mirrors assumptions about the behaviour of labour markets, fiscal deficits, and monetary policy targets.
b This lists the included range of alternative monetary policy regimes.
Source: Analysis and simulations of the model described in the text.

Table 6: Correlation Coefficients and Significance Level (TFP between Regions)[a]

Shock Regions	$R(\underline{v})$							
	v_{US}	v_{EU}	v_{Japan}	v_{China}	v_{India}	$v_{SriLanka}$	$v_{Gulfstates}$	v_{RoW}
v_{US}	1.00							
v_{EU}	0.12	1.00						
	(0.34)							
v_{Japan}	0.35***	-0.01	1.00					
	(0.00)	(0.94)						
v_{China}	-0.03	-0.01	0.03	1.00				
	(0.82)	(0.96)	(0.83)					
v_{India}	0.12	0.02	0.16	0.08	1.00			
	(0.34)	(0.87)	(0.21)	(0.55)				
$v_{SriLanka}$	0.04	-0.07	0.26*	-0.09	0.28**	1.00		
	(0.74)	(0.61)	(0.04)	(0.49)	(0.03)			
$v_{Gulfstates}$	0.24*	0.31***	0.19	0.24*	-0.03	0.12	1.00	
	(0.08)	(0.01)	(0.14)	(0.06)	(0.84)	(0.34)		
v_{RoW}	0.04	0.39***	-0.04	0.22*	-0.07	0.05	0.19	1.00
	(0.78)	(0.00)	(0.77)	(0.08)	(0.61)	(0.70)	(0.15)	

a As measures of significance, p values are in parentheses ***p<1% **p<5% *p<10%
Source: Authors' calculations.

Table 7: Calibrated Correlation and Covariance Matrixes

	v_{US}	v_{EU}	v_{Japan}	v_{China}	v_{India}	$v_{SriLanka}$	$v_{Gulfstates}$	v_{RoW}
				$R'(\underline{v})$				
v_{US}	1.00							
v_{EU}		1.00						
v_{Japan}	0.35		1.00					
v_{China}				1.00				
v_{India}					1.00			
$v_{SriLanka}$			0.26		0.28	1.00		
$v_{Gulfstates}$	0.24	0.31		0.24			1.00	
v_{RoW}	0.00	0.39		0.22				1.00
				$\Sigma(\underline{v})$				
v_{US}	0.0019							
v_{EU}		0.0012						
v_{Japan}	0.0004		0.0007					
v_{China}				0.0025				
v_{India}					0.0009			
$v_{SriLanka}$			0.0002		0.0003	0.0009		
$v_{Gulfstates}$	0.0004	0.0004		0.0005			0.0016	
v_{RoW}		0.0007		0.0006				0.0025

Source: Derived from Table 6 by eliminating insignificant estimates. Authors' calculations.

Table 8: Simulated Risk Premia under *de jure* and *de facto* Regimes[a]

(% of mean real GDP, y, or of welfare, W^E)

Region	*de jure*		Assumed *de facto*	
	Real GDP	**Welfare**	**Real GDP**	**Welfare**
US	0.260	**0.114**	**0.192**	0.186
EU	0.137	**0.119**	**0.092**	0.120
Japan	0.038	0.029	**0.034**	**0.020**
China	0.263	0.152	**0.153**	**0.109**
India	0.152	0.085	**0.142**	**0.081**
Sri Lanka	0.058	0.051	**0.056**	**0.047**
Gulf states	0.160	0.176	**0.110**	**0.130**
RoW	0.402	0.385	**0.353**	**0.314**

a Where empirical policy rules are the classified *de jure* or *de facto* policy, they are implemented based on historically estimated weights on employment and inflation. These weights and their estimation are discussed in the accompanying appendix.
Source: Authors' calculations.

Table 9: Game Scenarios and Closures[a]

Scenario	Closure
Two Player Game (US and EU)	Monetary policy closure [b,c]: *Exogenous*: either E, M^T, Y^N, T^R or IT *Endogenous*: Other monetary policy variables *Other economies*: Following *de facto* monetary policy Labour market closure: *Exogenous*: Nominal wage, W_i *Endogenous*: Employment, L_i Fiscal policy closure: *Exogenous*: Government expenditure, G_i *Endogenous*: Real government expenditure, G_i^R *Endogenous*: Government savings (surplus), S_i^G
Two Player Game (US and China)	Monetary policy closure [b,c]: *Exogenous*: either E, M^T, Y^N, T^R or IT *Endogenous*: Other monetary policy variables *Other economies*: Following *de facto* monetary policy Labour market closure: same as above Fiscal policy closure: same as above
Seven Player Game (US, EU, Japan, China, India, Sri Lanka and Gulf states)	Monetary policy closure [b,c]: *Exogenous*: either E, Y^N, T^R or IT *Endogenous*: Other monetary policy variables Labour market closure: same as above Fiscal policy closure: same as above

a The analysis represents short run departures from a steady state path. In this case there is no substantive difference between policies that target the *ex post* price level and IT.

b The empirically based monetary policy rules set the monetary base as dependent on both unemployment and inflation. IMF classifications in the "other" category are represented as policy rules, T^R, based on estimates of the parameters in (15) that are detailed in the Appendix.

c Though the model represents nominal and real effective exchange rates, the E targets are US$ pegs.

Source: Analysis and simulations of the model described in the text.

Table 10: Normal Form Two Player Game (US and EU)[a,b]

(Payoffs are risk premia in % of mean real GDP, y)

		EU				
		E	M^T	Y^N	T^R	IT
US	E	0.211 0.108	0.211 0.091	0.198 0.060	0.220 0.089	0.211 0.137
	M^T	0.179 0.113	0.172 0.076	0.162 0.061	0.172 0.097	0.167 0.131
	Y^N	0.088 0.129	0.095 0.098	**0.091 0.060**	0.093 0.093	0.089 0.127
	T^R	0.199 0.107	0.199 0.085	0.179 0.057	0.188 0.089	0.197 0.133
	IT	0.271 0.116	0.256 0.081	0.254 0.061	0.258 0.095	0.288 0.139

(Payoffs are risk premia in % of mean economic welfare, W^E)

		EU				
		E	M^T	Y^N	T^R	IT
US	E	0.108 0.070	0.110 0.072	0.111 0.075	0.113 0.068	0.101 0.069
	M^T	0.128 0.071	0.159 0.077	0.134 0.097	0.146 0.080	0.141 0.062
	Y^N	0.255 0.068	0.340 0.072	0.298 0.083	0.314 0.070	0.292 0.059
	T^R	0.085 0.070	0.091 0.078	0.072 0.085	0.083 0.072	0.090 0.063
	IT	0.084 0.074	0.078 0.079	0.077 0.091	**0.079 0.071**	0.087 0.080

a Nash equilibrium cases: ***Real GDP*** - both countries target Y^N, ***Economic welfare***: US: IT and EU: T^R

b Where monetary policy rules are implemented, they are based on historically estimated weights on employment and inflation. These weights and their estimation are discussed in the accompanying appendix.

Table 11: Normal Form Two Player Game (US and China)[a,b]

(Payoffs are risk premia in % of mean real GDP, y)

		China				
		E	M^T	Y^N	T^R	IT
US	E	0.221 0.236	0.205 0.229	0.219 0.235	0.213 0.226	0.216 0.265
	M^T	0.176 0.234	0.180 0.156	0.178 0.123	0.188 0.145	0.184 0.288
	Y^N	0.087 0.329	0.086 0.179	**0.089 0.117**	0.090 0.142	0.086 0.270
	T^R	0.191 0.251	0.178 0.157	0.195 0.120	0.203 0.142	0.189 0.286
	IT	0.259 0.255	0.257 0.156	0.262 0.113	0.259 0.142	0.247 0.289

(Payoffs are risk premia in % of mean economic welfare, W^E)

		China				
		E	M^T	Y^N	T^R	IT
US	E	0.111 0.138	0.105 0.130	0.119 0.137	0.106 0.133	0.096 0.154
	M^T	0.120 0.127	0.129 0.128	0.125 0.133	0.133 0.124	0.130 0.139
	Y^N	0.300 0.141	0.299 0.124	0.302 0.123	0.304 0.118	0.292 0.134
	T^R	0.082 0.117	0.077 0.128	0.085 0.122	0.092 0.120	0.084 0.137
	IT	**0.079 0.123**	0.079 0.134	0.079 0.127	0.078 0.126	0.076 0.148

a Nash equilibrium cases: ***Real GDP*** - both countries target Y^N, ***Economic welfare***: US: IT and EU: *E*.

b Where monetary policy rules are implemented, they are based on historically estimated elasticities to employment and inflation. These elasticities and their estimation are discussed in the accompanying appendix.

Table 12: "Big Three" Interaction in the Seven Player Game[a,b]

(Payoffs are risk premia in % of mean real GDP, *y*)

		EU: E		EU: Y^N		EU: T^R		EU: IT	
US	E	0.234	0.113	0.223	0.064	0.239	0.094	0.235	0.143
	Y^N	0.105	0.135	**0.117**	**0.061**	0.119	0.099	0.103	0.134
	T^R	0.216	0.112	0.204	0.059	0.218	0.096	0.218	0.139
	IT	0.287	0.118	0.264	0.065	0.271	0.102	0.294	0.144

(Payoffs are risk premia in % of mean economic welfare, W^E)

		EU: E		EU: Y^N		EU: T^R		EU: IT	
US	E	0.099	0.074	0.101	0.076	0.107	0.073	0.091	0.074
	Y^N	0.247	0.073	0.276	0.084	0.282	0.075	0.251	0.063
	T^R	0.076	0.075	0.064	0.089	0.075	0.076	0.082	0.069
	IT	0.075	0.080	0.066	0.097	**0.069**	**0.079**	0.080	0.088

(Payoffs are risk premia in % of mean real GDP, *y*)

		China: E		China: Y^N		China: T^R		China: IT	
US	E	0.245	0.231	0.244	0.223	0.235	0.223	0.235	0.264
	Y^N	0.113	0.227	**0.117**	**0.115**	0.119	0.142	0.111	0.267
	T^R	0.212	0.347	0.217	0.119	0.227	0.137	0.215	0.280
	IT	0.283	0.250	0.280	0.107	0.284	0.138	0.273	0.282

(Payoffs are risk premia in % of mean economic welfare, W^E)

		China: E		China: Y^N		China: T^R		China: IT	
US	E	0.105	0.149	0.112	0.143	0.101	0.147	0.093	0.163
	Y^N	0.220	0.155	0.291	0.134	0.293	0.126	0.281	0.145
	T^R	0.072	0.122	0.080	0.131	0.085	0.124	0.078	0.147
	IT	**0.069**	**0.131**	0.068	0.141	0.068	0.137	0.069	0.153

a Nash equilibrium - ***Real GDP***: All three target Y^N and for ***Economic welfare***: US: IT, EU: T^R and China *E*. The remaining four regions are playing their Nash equilibrium policies as indicated in Table 13.
b Where monetary policy rules are implemented, they are based on historically estimated elasticities to employment and inflation. These elasticities and their estimation are discussed in the accompanying appendix.
Source: Authors' calculations.

Table 13: Emerging Economies in the Seven Player Game[a]

(US, EU, Japan, China, India, Sri Lanka, and Gulf states)

(Payoffs are risk premia in % of mean real GDP, y)

Japan -Y^N

Gulf states -Y^N

		Sri Lanka							
		E		Y^N		T^R		IT	
India	E	0.114	0.085	0.117	0.027	0.110	0.048	0.115	0.085
		0.056	0.014	0.054	0.015	0.055	0.015	0.052	0.015
	Y^N	0.034	0.085	**0.036**	**0.027**	0.035	0.051	0.035	0.083
		0.057	0.015	**0.054**	**0.015**	0.055	0.016	0.053	0.015
	T^R	0.062	0.089	0.064	0.026	0.063	0.050	0.063	0.079
		0.053	0.016	0.055	0.015	0.056	0.015	0.055	0.015
	IT	0.116	0.088	0.114	0.027	0.124	0.050	0.113	0.086
		0.054	0.015	0.053	0.015	0.053	0.015	0.056	0.015

Nash equilibrium: US (Y^N 0.117); EU (Y^N 0.061); Japan (Y^N 0.015); China (Y^N 0.115); India (Y^N 0.036); SL (Y^N 0.027) and Gulf states (Y^N 0.054).

(Payoffs are risk premia in % of mean economic welfare, W^E)

Japan -T^R

Gulf states -E

		Sri Lanka							
		E		Y^N		T^R		IT	
India	E	0.087	0.049	0.085	0.051	0.086	0.050	0.087	0.045
		0.195	0.023	0.177	0.023	0.181	0.022	0.195	0.024
	Y^N	0.085	0.043	0.080	0.049	0.087	0.047	0.088	0.045
		0.194	0.023	0.197	0.021	0.206	0.023	0.204	0.023
	T^R	0.087	0.046	0.084	0.051	0.083	0.047	0.086	0.043
		0.201	0.023	0.184	0.022	0.185	0.021	0.192	0.022
	IT	0.082	0.049	0.087	0.053	0.086	0.049	**0.083**	**0.045**
		0.199	0.024	0.192	0.023	0.198	0.023	**0.199**	**0.022**

Nash equilibrium: US (IT 0.069); EU (T^R 0.079); Japan (T^R 0.022); China (E 0.147); India (IT 0.083); SL (IT 0.045) and Gulf states (E 0.199).

a Where monetary policy rules are implemented, they are based on historically estimated elasticities to employment and inflation. These elasticities and their estimation are discussed in the accompanying appendix.

Source: Authors' calculations.

Table 14: Nominated de facto and Nash Equilibrium Monetary Policies

Region	**Monetary Policy Regimes**		
	Nominated *de facto*[a]	**Equilibrium GDP criterion**	**Equilibium Welfare criterion**
US	T^{R} d	Y^{N}	IT
EU	T^{R} d	Y^{N}	T^{R}
Japan	IT	Y^{N}	T^{R}
China	E	Y^{N}	E
India	IT	Y^{N}	IT
Sri Lanka	IT	Y^{N}	IT
Gulf states	E	Y^{N}	E

a For the adopted set of *de facto* policies, see Table 1.

Source: IMF Annual Report on Exchange Arrangements and Exchange Restrictions Central Banks Annual Reports and the Federal Open Market Committee (FOMC) meeting minutes

Appendix

A1. Model Analytics–The Conventional Components and Parameters

Key supply side, and financial and monetary policy relationships are given in the main text. This appendix lists the remaining details of the demand side of the model specification.

Both direct and indirect tax revenues, T_i^D and T_i^I, respectively, play key roles in the formulation. GDP at factor cost (or producer prices), Y_i^{FC}, is the total of direct payments to the collective household in return for the use of its factors. Nominal GDP is then:

$$Y_i = Y_i^{FC} + T_i^I, \quad Y_i^{FC} = C_i + T_i^D + S_i^P \tag{A1}$$

This is the standard disposal identity for GDP, or the collective household budget, where C_i is the total value of final consumption expenditure at consumer prices, including indirect taxes paid, and S_i^P is private saving. The GDP price, P_i^Y, and the producer price, P_i^P, would be the same in the model were it not for indirect taxes. In their presence we have:

$$Y_i = P_i^Y y = Y_i^{FC} + T_i^I = P_i^P y_i + T_i^I \text{, so that } P_i^Y = P_i^P + \frac{T_i^I}{y_i} \tag{A2}$$

Conventionally, overall balance on expenditure is constrained by

$$Y_i = C_i + I_i + G_i + X_i - M_i \tag{A3}$$

where I_i is expenditure on investment, G_i is government spending on goods and services (net of transfers), X_i is export revenue (including export tax revenue), and M_i is the landed cost of imports (pre-tariff) in domestic currency.

A2. Direct Tax

A constant marginal direct tax rate, t_i^W, is assumed to apply to all labour income, while the marginal tax rate on capital income is t_i^K. The corresponding "powers" of these rates are $\tau_i^W = \left(1 + t_i^W\right)$ and $\tau_i^K = \left(1 + t_i^K\right)$ and these appear in the coding of the model. There is no distinction between home goods and capital and no consumption tax is assumed to be applied to capital goods, so the capital goods price is P_i^P.

$$T_i^D = t_i^W \left[W_i L_i + W_i^S S_i^K \right] + t_i^K r_i^C P_i^P K_i \tag{A4}$$

Capital income is taxed based on its measured net (of depreciation) rate of return, r_i^c, rather than the market interest rate, r_i. Indirect tax revenue, T^I, depends on consumption and trade and it will emerge later.

A3. Consumption

Aggregate consumption, here volume, c_i, corresponding with expenditure, C_i, depends negatively on the real after-tax return on savings and positively on disposable money income. This is nominal GDP, $Y_i = P_i^Y y_i$ combined with net factor income from abroad (adjusted from exchange rate in other regions, *j*), less direct tax:

$$Y_i^D = P_i^Y y_i + \sum_j N_{ji}^F \frac{E_j}{E_i} - T_i^D, \tag{A5}$$

where N_{ji}^F is nominal net factor income from foreign region *j*, which is set as constant in foreign currency and E_j is the nominal exchange rate in US$ per unit of region *j*'s currency. Real consumption volume, c_i, then depends positively on the present and expected future levels of disposable income, Y_i^D and Y_i^{De}, respectively, deflated by the corresponding consumer price level, P_i^C, which depends as indicated in Eq. (A8) below, on the home producer price and the import price, marked up by the ad valorem consumption tax.

$$c_i = \frac{C_i}{P_i^C} = A_i^C \left[\frac{r_i}{\tau_i^K} \right]^{-\varepsilon_i^{CR}} \left[\frac{Y_i^D}{P_i^C} \right]^{\varepsilon_i^{CY}} \left[\frac{Y_i^{D^e}}{P_i^C \left[1 + \pi_i^e \right]} \right]^{\varepsilon_i^{CY}} \tag{A6}$$

where the expected inflation rate of the consumer price level is π_i^e. To capture the home household's substitution between home and foreign products, real aggregate consumption in region *i* is a constant elasticity of substitution, α, composite of region *i*'s consumption products from all regions *j*;

$$c_i = \left(\sum_j \alpha_{ij} c_{ij}^{-\rho_i} \right)^{-\frac{1}{\rho_i}} \tag{A7}$$

The home household then chooses its mix of consumed to minimise consumption expenditure in a way that accounts for home indirect tax rates, foreign export tax rates and differing foreign product prices and exchange rates:

$$C_i = P_i^C c_i = P_i^P \tau_i^C c_{ii} + \sum_j \tau_i^C \tau_i^M \tau_j^X c_{ij} P_j^P \frac{E_j}{E_i} \tag{A8}$$

where τ_i^C, τ_i^M and τ_j^X are, respectively, the "powers" of region *i*'s consumption and import taxes and the region of region, *j*'s export tax. E_i is region *i*'s nominal exchange rate, measured as US$ per unit of home currency.[29]

Optimum consumption is consistent with an elasticity of substitution between home and foreign products of $\sigma_i = 1/(1+\rho_i)$ and the initial expenditure shares of each in the composite of consumption are $\alpha_{ii}^{\sigma_i}$ and $\alpha_{ij}^{\sigma_i}$. The volumes of the two product varieties consumed then depend on the "powers" of the consumption tax and import tariff and the prices:

$$c_{ii} = \alpha_{ii}^{\sigma_i} \left[\frac{C_i}{P_i^C} \right] \left[\frac{P_i^P \tau_i^C}{P_i^C} \right]^{-\sigma_i} \text{ and } c_{ij} = \alpha_{ij}^{\sigma_i} \left[\frac{C_i}{P_i^C} \right] \left[\frac{\tau_i^C \tau_i^M P_j^P \left(E_j / E_i \right)}{P_i^C} \right]^{-\sigma_i}, j \neq i \,. \tag{A9}$$

Given these consumption volumes, the composite price of all consumption emerges from the combination of Eqs. (A7) and (A9) in Eq. (A8) as:

$$P_i^C = r_i^C \left[\alpha_{ii}^{\sigma_i} \left(P_i^P \right)^{1-\sigma_i} + \tau_i^M \sum_{j \neq i} \alpha_{ij}^{\sigma_i} \left\{ \frac{P_j^P E_j}{E_i} \right\}^{1-\sigma_i} \right]^{\frac{1}{1-\sigma_i}} . \tag{A10}$$

A4. The Global Product Balance

Each region's product is differentiated from the others and so global product balance stems from a version of the expenditure identity in real volume terms:

[29] The US currency is the numeraire in the model.

$$y_i = \frac{I_i + G_i}{P_i^P} + \sum_j c_{ji}, \quad \forall i \tag{A11}$$

where the final term is the sum of real consumption and real exports (the consumption of *i*'s product in region *j*). Neither investors nor the government pay indirect taxes on their expenditure and so the price they face for the home product is the producer price, P_i^P. This equation solves indirectly for the producer prices.

A5. Private Savings

Households receive income amounting to GDP at factor cost, Y_i^{FC}. Their disposable nominal income is this sum less direct tax Eq. (A4), and private saving is what remains after consumption expenditure Eq. (A8) is further deducted.

$$S_i^P = Y_i^D - C_i \tag{A12}$$

A6. Indirect Tax Revenue

This includes revenue from consumption, import and export taxes.

$$T_i^C = t_i^C \left[P_i^P c_{ii} + \sum_j \tau_i^M \tau_j^X c_{ij} P_j^P \left(\frac{E_j}{E_i} \right) \right] \tag{A13}$$

$$T_i^M = t_i^M M_i, \quad M_i = \sum_{j \neq i} \tau_j^M c_{ij} P_j^P \left(\frac{E_j}{E_i} \right) \tag{A14}$$

$$T_i^X = t_i^X X_i, \quad X_i = P_i^P \sum_k c_{ki} \tag{A15}$$

$$T_i^I = T_i^C + T_i^M + T_i^X, \quad T_i = T_i^D + T_i^I \tag{A16}$$

A7. Government Savings

This is government revenue less government expenditure and the annual increment to the holding of official reserves.

$$S_i^G = T_i^D + T_i^C + T_i^M + T_i^X - P_i^P G - \Delta R \tag{A17}$$

To simplify the demand side, government spending is assumed to be directed only at home goods free of consumption tax, whose home price is P_i^P. Domestic savings, S_i^D, then depends on the (value) sum of private and government savings in the home economy.

A8. Balance of Payments

The sum of net inflows of payments on the current account and net inflows on the capital and financial accounts measured in a single (home) currency is zero:

$$X_i - M_i + \sum_{j \neq i} \left[i_{ji}^S S_j^D \frac{E_j}{E_i} \right] - \sum_{j \neq i} \left(i_{ij}^S S_i^D \right) = 0, \forall i \neq "US" \quad \text{(A18)}$$

A balance of payments in the United States is implied by balance in all the other regions. These equations determine the nominal exchange rates and, since these are defined relative to the US$, that for the US is always unity $\left(E_{US} = 1\right)$.

A9. Estimated Policy Rule Elasticities

To calibrate the model we estimate the elasticities of the chosen money supply to inflation, ε_i^P, and to unemployment, ε_i^U, as in Eq. (15), for each of the identified regions. For this, we regress the monetary base, M^B (dependent variable) on the consumer price level, P^C, and the unemployement rate, *u*, for each reagion using sample data from 1994 to 2016. Our object is to estimate these elasticity values using Autoregressive-Distributed Lag (ARDL) model framework, which allows us to identify short-run as well as long-run coefficient values. All estimating variables are in log form. Initially, each region's data series is tested for a unit root by using the Augmented Dickey-Fuller (ADF) test with a trend term. Both the levels, I(0), and the first differences, I(1), are tested and the results are shown in Table A1. We also tested a model constant and trend term, but the results were largely unchanged.

Table A1 – Unit Root Test

Variable	Level	First difference	Variable	Level	First difference
$ln\, M_{US}^B$	-1.648	-4.414***	$ln\, M_{India}^B$	-1.700	-10.914***
$ln\, P_{US}^C$	-1.214	-4.414***	$ln\, P_{India}^C$	-3.199*	

$\ln u_{US}$	-3.286*		$\ln u_{India}$	-3.804**	
$\ln M^{B}_{EU}$	-2.803	-8.573***	$\ln M^{B}_{SriLanka}$	-4.592***	
$\ln P^{C}_{EU}$	-2.094	-10.800***	$\ln P^{C}_{SriLanka}$	-2.731	-6.189***
$\ln u_{EU}$	-2.694	-3.295*	$\ln u_{SriLanka}$	-3.572**	
$\ln M^{B}_{Japan}$	-0.565	-6.944***	$\ln M^{B}_{Gulfstates}$	-2.264	-8.229***
$\ln P^{C}_{Japan}$	-5.623***		$\ln P^{C}_{Gulfstates}$	-1.859	-3.215*
$\ln u_{Japan}$	-1.808	-3.311*	$\ln u_{Gulfstates}$	-3.189*	
$\ln M^{B}_{China}$	-7.218***		$\ln M^{B}_{RoW}$	-1.640	-8.092***
$\ln P^{C}_{China}$	-1.389	-5.899***	$\ln P^{C}_{RoW}$	-3.365*	
$\ln u_{China}$	-3.269*		$\ln u_{RoW}$	-4.774***	

* p<0.1 **<0.05 ***<0.01

Source: Authors' calculations.

To identify co-integration between variables, there are two basic approaches, one is the Engle and Granger (1987) two-step process and the other is the Johansen (1988) maximum likelihood reduced-rank procedure. Both methods require all explanatory variables to be I(1). This is necessary because, according to DeVita and Abbott (2004), in the presence of a mixture of I(0) and I(1) regressors, standard statistical inference based on conventional co-integration tests is no longer valid. However, unlike the traditional methods, the ARDL bound testing technique (Pesaran and Shin 1999 and Pesaran et al. 2001), does not require that all the variables of interest to be integrated of the same order. Bound test results are shown in Table A2.

Table A2: Bound Test Results

Region	Co-integration	F-Stat[a]
US	No	2.213
EU	No	1.371
Japan	No	0.311
China	No	1.136
India	No	1.253
Sri Lanka	No	1.834
Gulf states	No	0.739
RoW	No	1.506

a. F-Stat corresponds to the statistic for the co-integration bound test and its critical values can be found in Pesaran, Shin, and Smith (2001).

Accordingly, none of the regions show long-run co-integration relationships between the monetary base, inflation and the unemployment rate. We therefore focus on a short-run ARDL model with the following specification:

$$\Delta ln M_t^B = \beta_0 + \sum_{i=1}^{p} \beta_1 \Delta ln M_{t-i}^B + \sum_{i=1}^{q} \beta_2 \Delta ln P_{t-i}^C + \sum_{i=1}^{q} \beta_3 \Delta ln u_{t-i} + \varepsilon_t \tag{A19}$$

where the variables are the logs of the monetary base, $ln M_t^B$, the price level, $ln P_t^C$, the unemployment rate, $ln u_t$, and, ε_t is the error term. β_1, β_2 and β_3 are the short-run dynamic coefficients. Table A3 displays estimation results, which we use to calibrate the inflation elasticity, ε_i^P, and the unemployment elasticity, ε_i^U values in Eq. (15).

Table A3 - Monetary Policy Rule Elasticities[a]

Region	Inflation	Unemployment rate
US	1.43**	0.85*
(3 2 2)	(0.77)	(0.49)
EU	1.61*	1.10*
(4 4 1)	(0.88)	(0.69)
Japan	1.12*	0.97
(2 1 1)	(0.71)	(0.72)
China	1.07	1.64**
(4 4 1)	(0.90)	(0.65)
India	1.19***	0.90***
(2 1 2)	(0.28)	(0.39)
Sri Lanka	1.30***	0.82
(1 3 2)	(0.11)	(0.59)
Gulf states	0.84*	1.70*
(3 2 1)	(0.45)	(0.87)
RoW	0.93	1.34
(3 3 1)	(0.77)	(0.74)

a These are parameters in equation (15) in the main text. They are elasticities of the monetary base to the inflation rate and the unemployment rate.

Lags in first column pranthesis.

Robust standard errors in second and third columns pranthesis - * p<0.1 **<0.05 ***<0.01.

Source: Authors' calculations.