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Modelling the G20

CAMA Working Paper 17/2018
April 2018

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World leaders have declared the G20 to be the premier forum for economic cooperation. But as its influence and policy agenda has grown, so too has the need to be able to effectively model the G20 and the implications of its policy agenda. The paper introduces the G-Cubed (G20) model: a multi-country, multi-sector, intertemporal general equilibrium model of the G20. The paper gives an overview of the model and highlights its key features through four simulated shocks, all of which relate to the G20's goal of reducing global current account imbalances: a fiscal shock (reducing the fiscal deficit in the United States), a productivity/fiscal shock (increasing infrastructure investment in Germany), a consumption shock (increasing domestic consumption in China) and the collective impact of all three shocks occurring simultaneously. The results demonstrate that, to be effective, any model of the G20 must reflect the complex trade and financial linkages between countries, the structural differences across G20 economies and the short-term rigidities observed empirically in the data, as well as a high level of disaggregation across economies, markets and sectors. The simulations show that reducing current account imbalances through these policies often comes with a real economic cost. The results also explain some of the shifts in global current account balances observed since 2007.

Keywords

macroeconomic policy coordination, intertemporal general equilibrium models, econometric modelling, Group of 20, fiscal policy, structural reform

JEL Classification

F4, C68, C5, C02, E17, D9, D58, E62

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ISSN 2206-0332

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Modelling the G20[1]

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23 April 2018

Abstract

World leaders have declared the G20 to be the premier forum for economic cooperation. But as its influence and policy agenda has grown, so too has the need to be able to effectively model the G20 and the implications of its policy agenda. The paper introduces the G-Cubed (G20) model: a multi-country, multi-sector, intertemporal general equilibrium model of the G20. The paper gives an overview of the model and highlights its key features through four simulated shocks, all of which relate to the G20's goal of reducing global current account imbalances: a fiscal shock (reducing the fiscal deficit in the United States), a productivity/fiscal shock (increasing infrastructure investment in Germany), a consumption shock (increasing domestic consumption in China) and the collective impact of all three shocks occurring simultaneously. The results demonstrate that, to be effective, any model of the G20 must reflect the complex trade and financial linkages between countries, the structural differences across G20 economies and the short-term rigidities observed empirically in the data, as well as a high level of disaggregation across economies, markets and sectors. The simulations show that reducing current account imbalances through these policies often comes with a real economic cost. The results also explain some of the shifts in global current account balances observed since 2007.

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[1] We thank Peter Wilcoxen for his substantial and ongoing contributions to the modelling research on which this paper is built and Larry Liu for support with data, advice and helpful comments on a draft of this paper.
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1. Introduction

In June 2010, the leaders of the G20 economies made an extraordinary declaration when they met in Toronto. In the aftermath of the global financial crisis, facing an escalating debt crisis in Europe, ballooning debt and deficits, spillovers from unconventional monetary policies, rising unemployment, slowing trade and investment and a host of global governance challenges, the leaders declared the G20 to be the premier forum for global economic cooperation (G20, 2010).

This was a significant announcement. The G20 includes all seven members of the G7. It includes all five permanent members of the UN Security Council, all five BRICS countries, most of APEC and a quorum of the IMF and the World Bank. Declaring the G20 to be the premier forum for economic cooperation was a political recognition of an economic reality: that changes in the global economy meant these other forums were not capable, or no longer sufficiently capable, of economic leadership (Figures 1 and 2).

The premier status of the G20 has been matched by its growing and important policy agenda since 2008: Coordinating fiscal and monetary stimulus in response to the crisis; bolstering the IMF and the global financial safety net; moving towards market determined exchange rates and resisting protectionism; reducing global imbalances in trade and current accounts; coordinating cuts to debt and deficits; coordinating structural reforms of labour, product and capital markets in pursuit of a collective growth target; strengthening financial regulation; coordinating policies on multinational tax avoidance; promoting development; and the list goes on.

Figure 1: The relevance of the G20, G7, APEC and BRICS: shares of global aggregates (PPP)

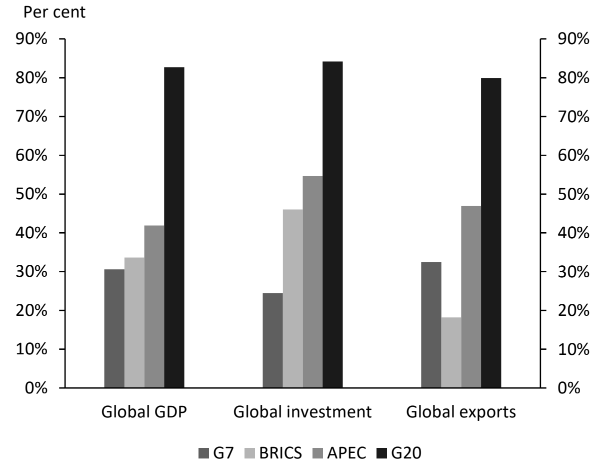
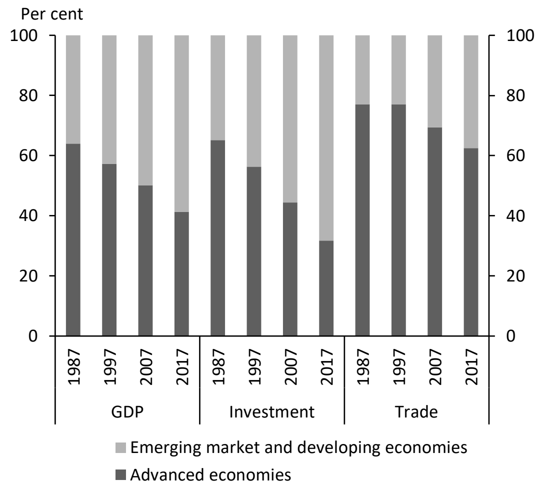


Figure 2: Changing of the Guard: shares of global GDP (PPP), investment and trade



Source: IMF World Economic Outlook database, October 2017

The G20's growing economic and political importance means that it is increasingly important to be able to effectively model the G20 and the implications of its policy agenda.

But modelling the G20 is a complex task. Any model must reflect the significant relative differences between G20 economies if it is to have any real-world application. G20 economies vary in their natural resource endowments, such as energy, agriculture and mining. They differ in their stocks of physical and human capital, and how specific and fixed they are. They vary significantly in their relative productivity and the size of their populations. The G20 includes economies which are advanced, developing, large, small, commodity exporting and commodity importing. Some are net importers of capital, goods or services and others are net exporters.

A model of the G20 must also reflect the high-level of integration between G20 economies. In a globalised world, we are interested not only in how a shock in one economy impacts that economy, but also how these shocks spillover into other economies through trade and financial linkages, and spillback onto the originating economy from the rest of the world. The level, direction, and composition of trade and capital flows will depend on transaction costs (tariffs, subsidies, transport cost, other taxes), comparative advantage, asset market arbitrage conditions and a host of other country-specific characteristics.

The depth of the G20's policy focus means that any model of the G20 requires a high level of disaggregation. The G20's policy agenda covers not only broad macroeconomic commitments in fiscal and monetary policy settings but also detailed reforms in financial, labour, capital and energy markets and the sectors for agriculture, mining, resources, manufacturing and services. Nearly every shock of interest will affect different sectors differently, generate changes in relative prices and affect the flows of trade and capital. Models that cannot account for distributional and relative effects from policy changes are of increasingly limited use in policymaking.

Finally, for real-world policy analysis, a model of the G20 must also reflect the economic rigidities that are observed empirically. McKibbin and Vines (2000) showed that large structural models that incorporated both intertemporal optimisation and stickiness were critical to understanding real-world economic developments. Inter-temporal budget constraints are needed, given their role in determining asset prices, along with short-term stickiness in wages, adjustment costs in investment and rule-of thumb behaviour by consumers and producers. McKibbin and Stoeckel (2018) stress the importance of modelling relative price shocks in understanding macroeconomic adjustment.

In short, an effective model of the G20 must incorporate a range of real-world complexities within a general equilibrium framework. It should reflect the critical asymmetries and differences between G20 countries that shape economic and financial outcomes. It needs to reflect the complex trade and financial linkages between countries. It requires a high level of disaggregation across economies, markets and sectors and it must reflect the rigidities that we observe empirically in the data.

The G-Cubed (G20) model, presented in this paper, seeks to provide such a framework. It is an extension of the multi-country, multi-sector, intertemporal general equilibrium model developed by Warwick McKibbin and Peter Wilcoxen (2009, 2013). It is designed to bridge the gaps between three areas of research – econometric general equilibrium modelling, international trade theory and modern macroeconomics – by incorporating the best features of each. Several versions of the model have been developed, which have been incrementally improved and built-on over many years. The version presented in this paper is the newest, and largest, version of the G-Cubed model, designed specifically to study the G20 and the implications of its policy agenda.

Previous versions of G-Cubed have been used to study a range of policy areas, including macroeconomic cooperation, international trade, monetary policy, fiscal policy, tax reform and environmental regulation. Studies have shown the effectiveness of G-Cubed in explaining the adjustment process in a number of historical episodes, including Reagonomics, German reunification, European fiscal consolidation in the 1990s, the formation of NAFTA and the Asian financial crisis.[4] G-Cubed has also proven successful in helping to explain the 'six major puzzles in international macroeconomics' highlighted in Obstfeld and Rogoff in a 2000 paper.[5] It has also proven useful in understanding the 2009 Global Financial Crisis[6].

We consider four policy shocks to highlight the key features of the model, all of which relate to the G20's goal of reducing global current account imbalances: a fiscal shock (reducing the fiscal deficit in the United States), a productivity/fiscal shock (increasing infrastructure investment in Germany), a consumption shock (increasing domestic consumption in China) and the collective impact of all three shocks occurring simultaneously. These have been the

[4] See McKibbin and Vines (2000), and, for the global financial crisis, see McKibbin and Stoeckel (2009).

[5] See Mckibbin and Vines (2000). Those six puzzles were: (1) the bias in trade towards consuming home goods; (2) the own-country bias in ownership of financial assets; (3) the Feldstein-Horioka result that there is a high correlation between national saving and national investment spending; (4) the international consumption-correlations puzzle – the low correlation between growth in consumption across countries - which is also expressed as the puzzle that output growth seems to be more highly correlated than consumption growth across countries; (5) the apparent breakdown of purchasing power parity in the short to medium-term or the persistence of changes in real exchange rates; and (6) the 'exchange rate disconnect puzzle' – shown by the apparent disconnect between exchange rates and underlying macroeconomic variables.

[6] See McKibbin and Stoeckel (2018).

primary policies advocated by the G20 in reducing global current account balances (see G20, 2010).

Using the dynamic trade and financial cross-country linkages in G-Cubed, we can show there are a variety of unintended consequences which would flow from the G20's policy agenda. In some scenarios, we show that global current account imbalances are in fact worsened, not improved, by these policies. In other scenarios, current account imbalances are reduced, but this comes at a significant cost. The ability of G-Cubed to reflect the important role of capital flows, savings and investment decisions is critical to these results.

G-Cubed's high-level of disaggregation allows us to show important sectoral differences that shape many of these outcomes. Because G-Cubed reflects critical asymmetries and differences between economies we can also illustrate how G20 economies are impacted differently by different shocks, particularly because of alternative monetary policy and exchange rate frameworks, but also through differences in production and consumption functions and endowments in resources and the factors of production.

By bringing together the real and financial sectors of the global economy, G-Cubed allows us to provide an explanation for why the significant narrowing of China's current account surplus since 2007 has been accompanied by a large widening of the current account surplus in Germany. Finally, the inertia that is built-in to the investment and consumption decisions of firms and households allows us to show the rich, dynamic pathways of short- and long-term effects from these policies. We argue this is critical to understanding both the economic and political dimensions of the G20's policy agenda.

Section 2 of this paper begins with an overview of the G-Cubed (G20) model. Section 3 analyses the four policy shocks and concluding remarks are contained in Section 4.

2. An overview of the G-Cubed (G20) model

While the main equations of the model are extracted to Appendix A, this section gives a non-technical overview of the G-Cubed (G20) model. It details the overall composition of the model between countries, sectors and economic agents. It then details the role of its key economic agents - firms, households and the government - and the operation of money and financial assets, capital and investment, wages and the labour market and, finally, trade and financial linkages between countries.

By way of summary, some of the key features of the G-Cubed (G20) model are as follows:

- Specification of the demand and supply sides of economies.
- Integration of real and financial markets of these economies with explicit arbitrage linking real and financial rates of return.
- Inter-temporal accounting of stocks and flows of real resources and financial assets.
- Imposition of inter-temporal budget constrains so that agents and countries cannot borrow or lend forever without undertaking the required resource transfers necessary to service outstanding liabilities.
- Short-run behaviour is a weighted average of neoclassical optimising behaviour based on expected future income streams and Keynesian current income.
- The real side of the model is disaggregated to allow for production of multiple goods and services within economies.
- International trade in goods, services and financial assets.
- Full short-run and long-run macroeconomic closure with macro dynamics at an annual frequency around a long-run Solow-Swan-Ramsey neoclassical growth model.
- The model is solved for a full rational-expectations equilibrium (consisting of a mix of rational and rule of thumb agents) at an annual frequency from 2015 to 2100.

2.1 Composition of the G-Cubed (G20) model

Each country/region in G-Cubed is represented by its own multi-sector econometric general equilibrium model with highly disaggregated, multi-sectoral flows of goods and assets between them. It represents the world as 24 autonomous blocks: one for each G20 economy (including the rest of the euro zone) and four regions which represent the world's non-G20 economies. These are: the other economies of the OECD, the other economies of Asia, the other oil-producing economies and a catch-all 'rest of the world' (Table 1).

Each country/region has six industries, which correspond to the production of six goods: energy, mining, agriculture (including fishing and hunting), durable manufacturing, non-durable manufacturing and services. Each good in a country/region is an imperfect substitute for goods from other regions. Thus, there are effectively 144 goods. Each country/region consists of 6 representative firms, a representative household and a government. The model also includes markets for goods and services, factors of production, money and financial assets (bonds, equities and foreign exchange). Finally, each country/region is linked through the flows of goods and assets.

Table 1: Overview of the G-Cubed (G20) model

Countries (20)	**Regions (4)**
Argentina	Rest of the OECD
Australia	Rest of Asia
Brazil	Other oil producing countries
Canada	Rest of the world
China	
Rest of Euro zone	**Sectors (6)**
France	Energy
Germany	Mining
Indonesia	Agriculture (including fishing and hunting)
India	Durable manufacturing
Italy	Non-durable manufacturing
Japan	Services
Korea	
Mexico	**Economic Agents in each Country (3)**
Russia	A representative household
Saudi Arabia	A representative firm (in each of the 6 production sectors)
South Africa	Government
Turkey	
United Kingdom	
United States	

2.2 Economic agents

Each country/region consists of a representative household, representative firms (in each of the above 6 production sectors) and a government.

Firms choose their production inputs (labour, capital, energy and materials) and make investment decisions to maximise their stock market value (represented by the present value of the future stream of dividends). They are assumed to be price-taking.

Households maximise an intertemporal utility function subject to a lifetime budget constraint that the present value of their consumption equals the present value of their future stream of after-tax labour income (plus transfers from the government) and their initial financial assets.

The model is based on explicit optimisation by firms and households. But the behaviour of firms and households is modified to allow for short-run deviations from optimal behaviour. This could be interpreted as near-sightedness in their decision-making or be due to liquidity constraints on the ability of some firms and households to borrow. These deviations take the form of rules of thumb, which are consistent with an optimising agent that does not update predictions based on new information about future events.

As the below simulations will highlight, these rules of thumb generate the same steady-state behaviour as optimising agents so that, in the long-run, there is only a single intertemporal optimising equilibrium of the model. Short-run behaviour, however, is assumed to be a weighted average of the optimising agents and the rule-of-thumb agents. This allows the model to reflect the inertia observed empirically in investment and consumption decisions (see McKibbin and Sachs, 1991).

For households, aggregate consumption is therefore a weighted average of consumption based on wealth (current asset valuation and expected future after-tax labour income) and consumption based on current disposable income. For firms, aggregate investment is therefore a weighted average of investment which, in turn, is based on Tobin's q (market valuation of the expected future change in the marginal product of capital relative to the cost) and is based on a gradually learning Tobin's q which partially adjusts to the forward-looking Tobin's q (for rule-of-thumb firms).

Finally, the government spends money on goods and services, interest payments on government debt, investment tax credits and transfers to households. It receives revenue from sales taxes, capital and labour taxes, tariffs and from the sale of new government bonds. As mentioned in the dot points above, a closure rule prevents governments from borrowing or lending forever without undertaking the required resource transfers necessary to service outstanding liabilities. This closure rule is important since, otherwise, agents would be unwilling to hold government debt. The government, through its central bank, is also responsible for monetary policy, which is discussed immediately below.

2.3 Money and financial assets

Money is introduced into the model as a constraint on transactions. To purchase goods and services, households require money. Unlike other financial assets in the model, money bears no interest. On the supply-side, central banks operate according to a Henderson-McKibbin-Taylor rule where interest rates evolve as a function of actual inflation, actual output growth and actual exchange rates (where there is a partial exchange rate peg) relative to their respective targets. The supply of money then clears the money market. This allows the model to differentiate between the monetary policy regimes of different G20 countries which, as the simulations below show, can significantly affect how shocks are transmitted.

Financial assets (bonds, equities and foreign exchange) are treated as imperfect substitutes, both within economies and internationally. Due to mobile financial capital, discussed below, asset prices adjust to equate rates of return on all assets adjusted by exogenous risk premia, both within economies and across countries.

2.4 Capital and investment

In the long-run equilibrium, the accumulation of capital takes place along a Swan-Solow-Ramsey neoclassical growth model path. But the model distinguishes between financial capital and physical capital. Financial capital flows freely between sectors and between countries to where expected returns are the highest (subject to any institutional constraints). Physical capital, however, is immobile once it has been installed: it cannot be moved from one sector to another or from one country/region to another, but it can be reduced by depreciation or increased through investment.

The distinction between financial and physical capital means that, any point in time, there is a critical difference between the quantity of physical capital that is available to produce goods and services and the valuation of that capital as a result of decisions about the allocation of financial capital. The model also includes explicit arbitrage which links real and financial rates of return and measures of risk in the model.

2.5 The labour market

Labour is assumed to be perfectly mobile among sectors in each country/region but immobile between countries/regions. As a result, nominal wages will be equal across sectors within each country/region, but there is no reason for them to be equal between countries/regions or for real wages by sector to be equal.

In the long run, labour supply is completely inelastic and is determined by the exogenous rate of labour supply growth. Long run nominal wages adjust to move each country/region to full employment. In the short run, however, nominal wages are assumed to adjust slowly. This can lead to significant periods of unemployment, depending on the labour-market institutions in each country. Similarly, employment can temporarily exceed its long-run level if unexpected events cause the real wage to be below its long run equilibrium.

2.6 Trade and financial linkages

While countries/regions are not linked through the endogenous flow of labour, they are linked through the endogenous flows of goods and assets. The flows of goods between countries are determined by the import demands from households, firms and the government. The goods produced in different countries are assumed to be imperfect substitutes and all agents in an economy are assumed to have identical preferences over foreign and domestic goods, but this can differ across countries.

Asset markets are assumed to be perfectly integrated across countries and countries/regions except where there are explicit capital controls. Perfect arbitrage is prevented by the existence of risk premia although, at the margin, this means financial capital moves seamlessly across borders in response to arbitrage opportunities while physical capital does not.

Trade imbalances are financed by flows of assets between countries. Explored in detail in the following simulations, current account deficits are matched by capital account surpluses and vice versa. In addition, intertemporal budget constraints are imposed on each country/region such that all trade deficits must eventually be repaid by future trade surpluses. The real exchange rate path is tied down by this constraint over time.

Exchange rates between countries are determined through uncovered interest parity equations (adjusted by risk premia) linking the rate of exchange-rate change to the difference between home and foreign interest rates and risk premia. This means that, eventually, the differences between asset returns must converge to amounts equal to exogenous risk premia.

3. Model simulations: reducing global current account imbalances

In 2010, the US Treasury Secretary Timothy Geithner wrote a letter to G20 finance ministers. Concerned about the doubling of current account imbalances between 2000 and 2007, he recommended a radical approach: that each G20 country pledge to keep current account surpluses and deficits within four per cent of GDP (Davies, 2010).

Geithner's idea was politely rejected. But what he tried to do highlighted the level of concern among politicians and officials over sustained imbalances in current accounts (Figures 3 and 4). These political concerns, particularly on global trade imbalances, have intensified since the election of Donald Trump (see Donnan, 2017).

The current account measures the difference between the level of domestic savings and investment in an economy. Many East Asian and European economies have large current account surpluses because they generate more savings than investment opportunities, the former in periods of exceptional growth, the latter as countries age. This surplus of savings goes overseas and finances investment in economies which are in the opposite situation: economies which have more investment opportunities than they have domestic savings to finance them. These economies, such as the United States, United Kingdom and Australia, have current account deficits.

Having a current account deficit or surplus is not necessarily a bad thing. A country might have a deficit because it has strong future growth prospects, encouraging forward-looking households to smooth consumption by borrowing today in anticipation of a prosperous tomorrow. Conversely, a country might run a current account surplus because it has an ageing population saving for retirement, or because it has a mature economy with fewer investment opportunities so its savers explore opportunities offshore.

But economists such as Maurice Obstfeld,[7] Kenneth Rogoff,[8] Ben Bernanke[9] and Mervyn King[10] argue that the rise in global imbalances was intimately linked, if not a key cause of, the global financial crisis by fuelling unsustainable booms in credit and asset prices. More recently, Brad Sester from the Council on Foreign Relations has suggested that global imbalances might be a critical contributor to depressed global interest rates, with implications for long-run

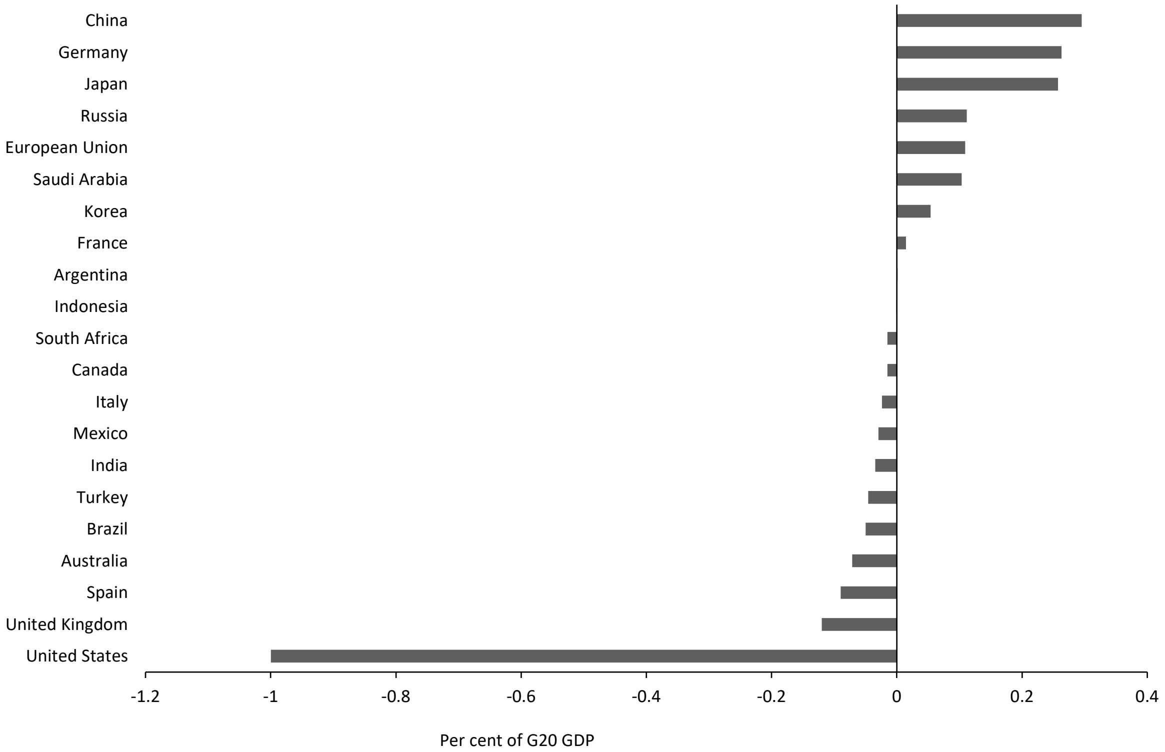
[7] See Obstfeld and Rogoff (2009).
[8] See Obstfeld and Rogoff (2009).
[9] See Bernanke (2009).
[10] See King (2016).

stability (Sester, 2016).

Similarly, Olivier Blanchard and Gian Maria Milesi-Ferretti (2011) have warned that current account imbalances are, in many instances, not benign because they are being driven by domestic distortions. For deficit economies, these distortions can include poorly regulated financial systems that fuel asset price bubbles or irresponsible fiscal authorities reducing national savings through excessive spending. For surplus countries, distortions can take the form of a lack of social insurance driving up precautionary saving or inefficient financial intermediation leading to low investment.

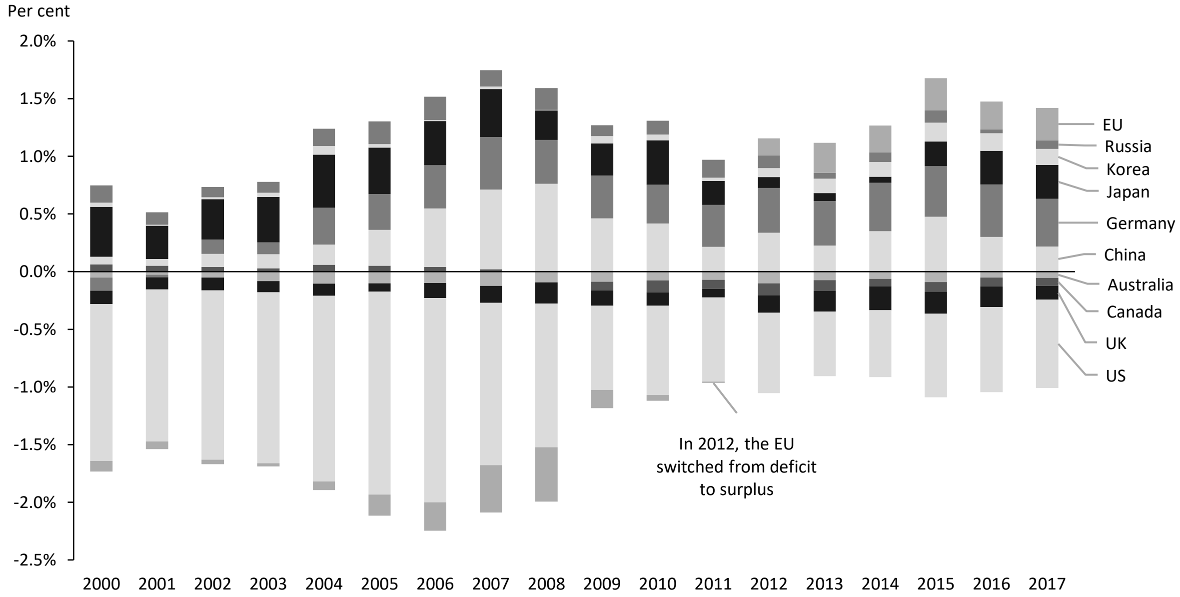
Concerns around global current account imbalances have been prominent in international forums since 2000 and, most recently, in the G20. In 2008, G20 leaders identified "unsustainable global macroeconomic outcomes" as a root cause of the crisis (G20, 2008). But discussions in the G20 have focused on three countries and three issues in particular (see G20, 2010).

Figure 3: Average current account balance from 2000 to 2016 as a per cent of G20 GDP



Source: IMF World Economic Outlook database, October 2017

Figure 4: G20 countries with the 10 largest current account surpluses or deficits (per cent of G20 GDP)



Source: IMF world economic outlook database, October 2017

The first is the United States. Its growing fiscal deficit has acted to reduce national savings and worsen its large current account deficit. The recent fiscal expansion from the Trump Administration, discussed below, is forecast to exacerbate these effects.

The second is Germany. The IMF argues that the German Government is spending too little, particularly on infrastructure, which means higher national savings, lower investment and a larger current account surplus (many have also argued that increased spending in Germany would help economies in the Euro Zone periphery – see Krugman, 2017).

The third is China. While China's current account surplus has narrowed significantly since 2007 (see Figure 4), the G20 and the Chinese government remain focused on rebalancing the Chinese economy to increase domestic consumption and reduce savings which, in turn, means a smaller current account surplus.

The sections below use the G-Cubed model to simulate each of these policies – first individually and then collectively.

3.1 The United States: A reduction in the fiscal deficit

The tax cuts and proposed infrastructure plan from the Trump administration in 2017 and 2018 has brought the US fiscal deficit into sharp focus. Although the fiscal deficit is forecast to worsen (see Congressional Budget Office, 2017), fiscal sustainability in the United States has been an issue and concern for many years. It has also been a consistent focus of the G20, particularly on the issue of reducing global imbalances (G20, 2010).

This section simulates the implications of having the United States reduce its deficit.[11] It is assumed that the smaller deficit is achieved by a 5 per cent reduction in government spending, rather than tax increases. It is assumed that spending is reduced on goods and services, rather than infrastructure and that the cut to spending is both immediate and permanent. The implications of these assumptions are discussed below.

Figures 5 to 16 highlight the key results. As would be expected, the reduction in government spending has a significant effect in reducing the size of the United States fiscal deficit, which is 4.5 per cent below the baseline or the 'business-as-usual' case (Figure 5). However, there are significant short-term and long-term effects from this policy for the United States economy.

Investment contracts by 1 per cent in the first year as firms respond to weaker aggregate demand caused by the sudden fiscal withdrawal (Figure 6). But the long-term implication of this policy is a more favourable, lower-tax environment for business into the future. Forward-looking firms respond by increasing investment above the baseline by the third year, with investment 1.5 per cent higher in the longer-term. Lower real interest rates (Figure 7) also boost investment as savings previously locked-up in government debt are now available to finance the supply-side of the economy.

Consumption is higher because of reduced government spending: by 0.75 per cent in the second year and up to 2.5 per cent by 2030 (Figure 8). Forward-looking households anticipate higher wealth in the future due to lower future taxes and a stronger economy. They adjust their intertemporal consumption decisions and bring forward future-consumption, facilitated by lower real interest-rates which encourages higher consumption today.[12]

Since consumption and investment are its largest components, the response of United States GDP is not surprising. Figure 9 shows a familiar Keynesian response from reduced government spending. GDP initially contracts by 1.75 per cent as government spending is withdrawn from the economy. But as savings are released from government debt to finance the supply-side of the economy, GDP is 1 per cent larger in the longer-term relative to the baseline, with a

[11] By changing the sign of the shocks the results can also be used to evaluate further expansion of US fiscal deficits – excluding any changes in US country risk that might occur due to further fiscal deterioration.
[12] An important assumption here is that the government is only reducing spending on goods and services, not on transfers to households.

permanently larger capital stock.

Much of the transition from this policy, particularly the impact on other countries, can be explained by what happens to interest rates, capital flows and exchange rates. Permanently lower interest rates in the United States results in financial capital flowing out of the United States to obtain higher returns overseas. This helps explain the fall in United States investment, but also acts to depreciate the United States exchange rate.

For the United States, because its exports are now relatively cheaper to those of other countries, a depreciated exchange rate means an improved trade and current account balance of 4.5 per cent in the first year (Figure 10). The current account is the key focus of the G20, which we will come back to shortly. However, for other countries, a weaker United States exchange rate means a weakened trade and current account balance since these countries now have a relatively appreciated currency against the United States.

Figure 5: US fiscal deficit

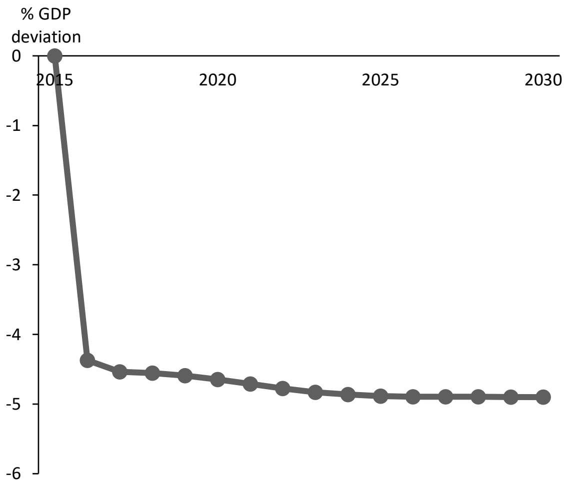


Figure 6: US investment

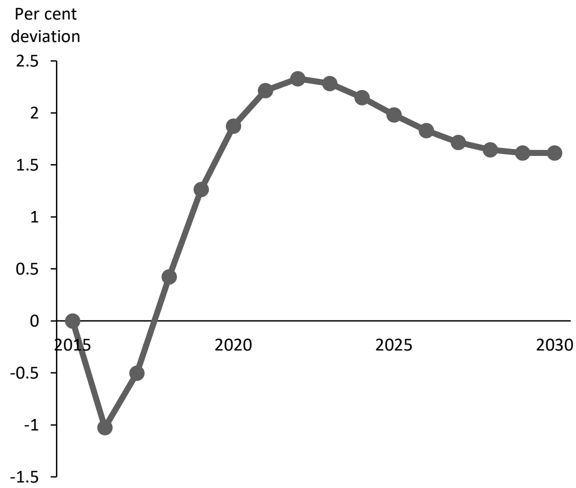


Figure 7: US real interest rates, short-run

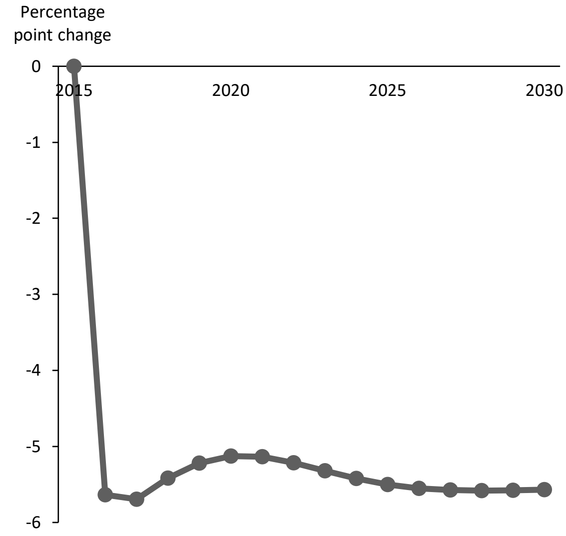


Figure 8: US consumption

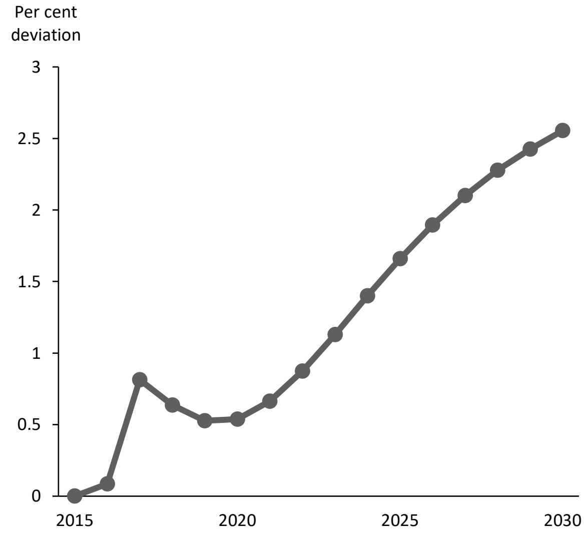


Figure 9: US real GDP

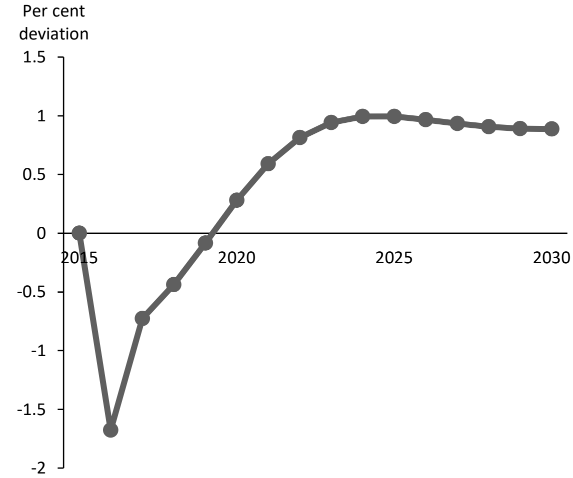
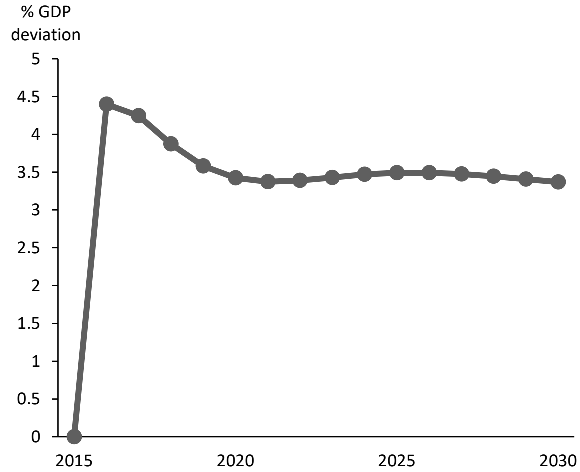


Figure 10: US current account balance



The results for other G20 economies are similar to what you would expect from a gravity model: the countries which trade the most with the United States tend to be the most significantly impacted. The exchange rates of Canada and Mexico, for example, appreciate by 3.5 per cent in the first year (Figure 11). As a result, their trade balances worsen by between 1 and 2 per cent (Figure 12).

The effects for China, the largest trading partner of the United States, are more muted because of its exchange rate policy. This is where G-Cubed is particularly useful in understanding differentiated impacts on economies based on their relative differences. China manages its exchange rate against a basket of currencies, which is reflected in the Henderson-McKibbin-Taylor rule for China in G-Cubed. As the United States dollar depreciates, Chinese authorities loosen monetary policy to achieve their exchange rate target which, in turn, stimulates investment in China through lower interest rates and boosts GDP more than other countries, (see Figure 15).

For countries negatively affected by a weaker United States currency, some of the negative impacts on their trade balance is offset by improvements in investment (Figure 13). Investment in Germany, Canada and Mexico increase by 0.9, 1 and 1.4 per cent, respectively, as capital flows into these economies from the United States to enjoy higher returns and as the firms in these countries respond to lower global interest rates.

The overall impact on other countries' GDP is generally similar to that of the United States, but for different reasons (Figure 14). There is an initial drop in GDP for most G20 economies which is driven by a weakened trade balance, but the increase in investment from capital inflows and lower real interest rates means a permanently larger capital stock which boosts GDP in the long-run.

Of key importance for the G20's agenda is what happens to current accounts, particularly for Germany and China. The current account balances of both China and Germany decline from the United States reducing its deficit. For Germany, it declines by 0.4 per cent in the first year and steadily declines thereafter: it is up to 0.7 per cent below the baseline by 2030. China sees a 1 per cent reduction in the first year, which rebounds through exchange rate and investment effects, but then settles back to be 1 per cent below the baseline in 2030 (Figure 16).

Several important insights flow from this analysis. The first is that the United States fiscal deficit plays a critical role in both the size of the United States trade deficit and global current account imbalances. This is an important consideration in the current political climate where the Trump Administration is undertaking fiscal stimulus while simultaneously lamenting the size of the United States trade deficit. This analysis highlights the links between these two variables: that increasing the size of the United States fiscal deficit will not only increase the size of the United States trade deficit but will also increase the size of the trade surpluses in Germany and China.

The second insight, which flows logically from the first, is that the United States can do a lot to reduce its trade and current account imbalances with Germany and China by acting unilaterally. Although these imbalances are referred to as being 'global', the United States could do much to reduce its contribution to them, as well as the contributions of Germany and China, by reducing its fiscal deficit. The ability of G-Cubed to reflect both the real and financial side of these economies is critical to this result.

Figure 11: Real effective exchange rates

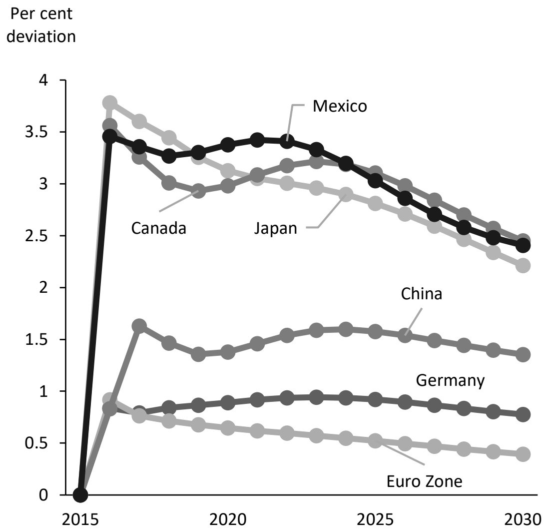


Figure 12: Trade balance

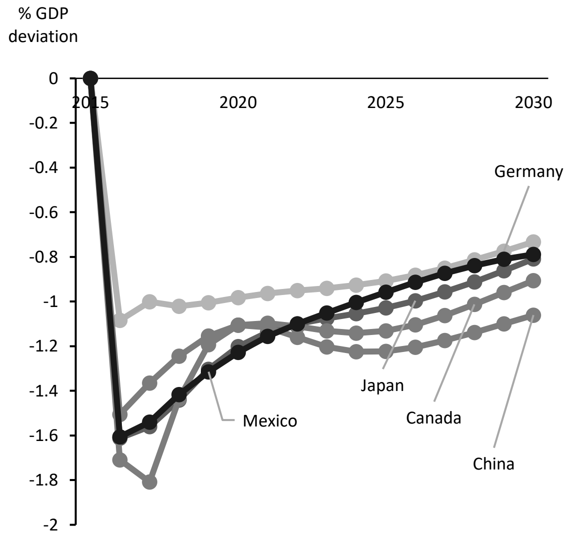


Figure 13: Investment

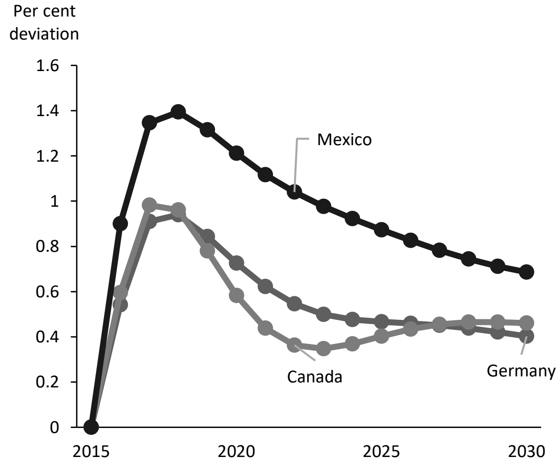


Figure 14: Real GDP

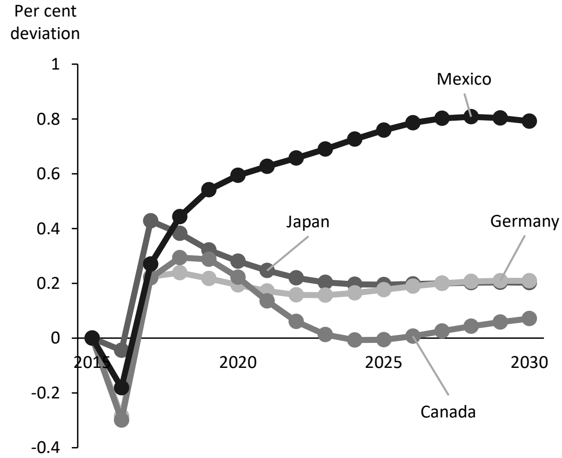


Figure 15: China GDP

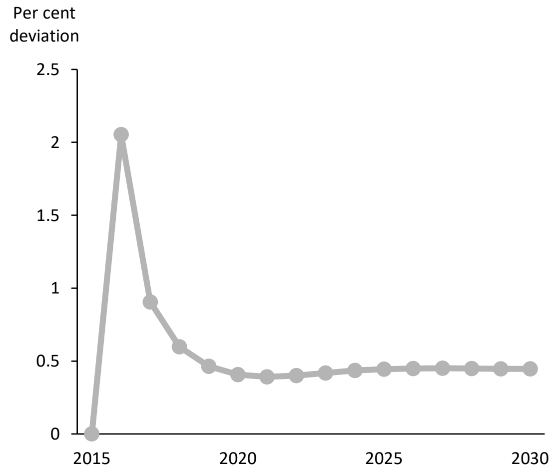
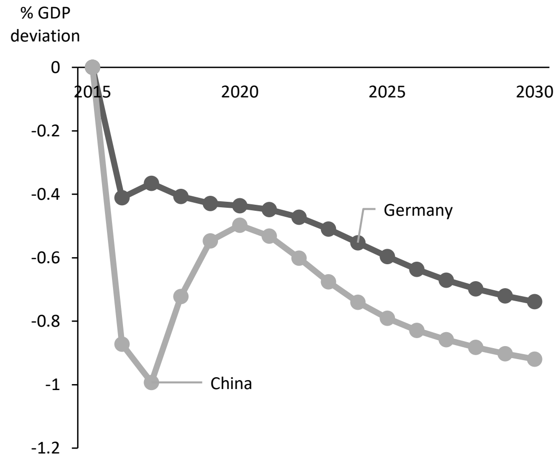


Figure 16: Germany and China current accounts



3.2 Germany: An increase in public investment

Figure 4 showed that Germany has the largest current account surplus in the G20. This has prompted many, particularly the IMF (2017), to recommend that Germany increase its public investment in infrastructure to boost growth, raise productivity and help reduce global current account imbalances.

The empirical evidence suggests that increasing the stock of quality infrastructure increases the marginal product of inputs into private sector production (see McKibbin et al, 2012). In the G-Cubed model, an increase in infrastructure investment would show up as an increase in labour augmenting technical change, coupled with a commensurate increase in government spending (assuming the infrastructure is publicly financed) to pay for it. While an increase in government spending is, to a large extent, the reverse of the fiscal consolidation scenario discussed above, simulating an increase in infrastructure investment is an opportunity to see how the G-Cubed model represents a simultaneous productivity shock.

The simulation below is based on an econometric finding from Calderon, Moral-Benito and Serven (2011). They found that for every 10 per cent increase in the stock of infrastructure capital, productivity in private sector output rises by 0.8 per cent. We use the IMF's Investment and Capital Stock database to calculate the size of Germany's infrastructure capital stock as well as the fiscal implications of increasing it. We then model a scenario where Germany increases the size of its infrastructure capital stock by 10 per cent over 15 years. For simplicity, we assume the 0.8 per cent improvement in productivity and the fiscal cost incurred by the government occur simultaneously. This means that, in each year for 15 years, productivity is immediately 0.8 per cent higher than the baseline and that government spending as a per cent of GDP is 1.4 per cent higher than the baseline (such that, after 15 years, the infrastructure has been completely paid-off and government spending returns to normal).

The results for Germany from this productivity and spending shock are illustrated in Figures 17 to 20. The most notable impact is the increase in private sector investment, which does not include the increase in government investment (Figure 17). Investment increases by over 3 per cent in the second year and, in the longer-term, is around 0.5 per cent higher than the baseline.

It is useful to break-down this shock into its two components. The effect of an increase in government spending, alone, would see a temporary increase in investment as firms respond to higher growth in the short-term but, in the longer-term, would see investment below the baseline due to a less favourable future business environment and higher taxes to fund the increase in spending (essentially the reverse of the US fiscal consolidation scenario discussed above). But this is not the case when the increase in government spending also boosts productivity. Higher productivity means firms can now produce more with less, are more profitable and more internationally competitive. This means the short-term increase in investment is larger, but investment also remains above the baseline into the longer-term.

As the demand for investment rises, so too does demand for workers which, along with higher productivity, results in higher real wages. Both backward-looking (rule of thumb) and forward-looking households respond to higher wages by increasing consumption, and forward-looking consumers bring-forward more consumption from the future to the present. Consumption is 0.7 per cent higher in the first year and permanently higher in the longer-run (Figure 18).

But the savings to finance this increase in investment must come from somewhere. Perfectly mobile financial capital means savings flow in from overseas. But the inflow of this capital appreciates Germany's real exchange rate by 0.7 per cent in the first year and Germany's overall trade balance declines by 2.5 per cent of GDP, steadily returning to around 0.5 per cent of GDP below the baseline (Figure 19). Hence the boost in investment in Germany is partially offset by the weakening trade balance.

The overall effect on Germany's GDP is, unsurprisingly, positive given productivity is permanently higher (Figure 20). GDP is 2.5 per cent larger in the third year and 1.75 per cent larger than the baseline in the longer term. Had this been only a fiscal stimulus shock, GDP would have looked more like the inverse of the United States case discussed above: a short-term sugar-hit for increased government spending but a longer-term negative effect as savings are taken from the supply-side of the economy to finance government debt. But because the increased spending boosts productivity, longer-run GDP remains above the baseline.

Figure 17: German investment

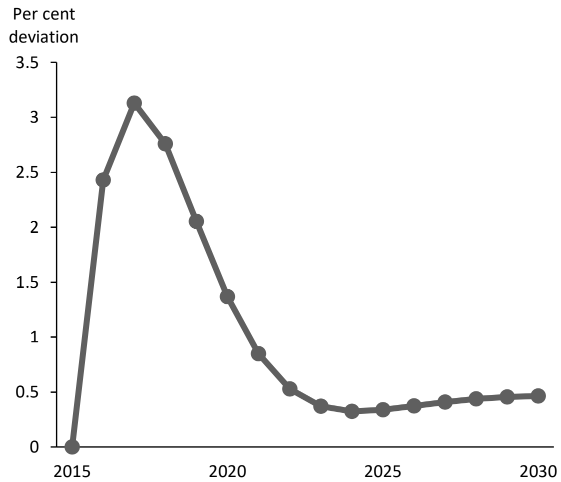


Figure 18: German consumption

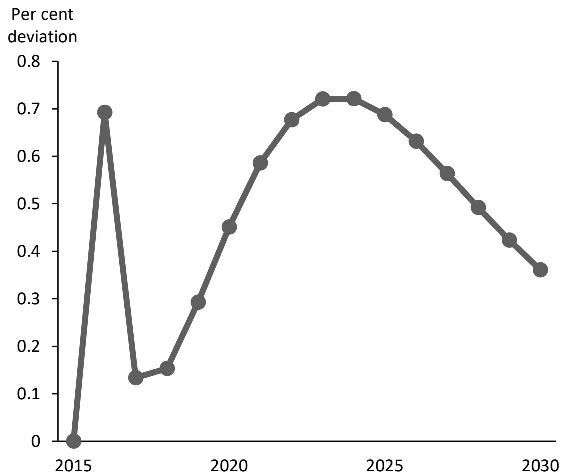


Figure 19: German trade balance

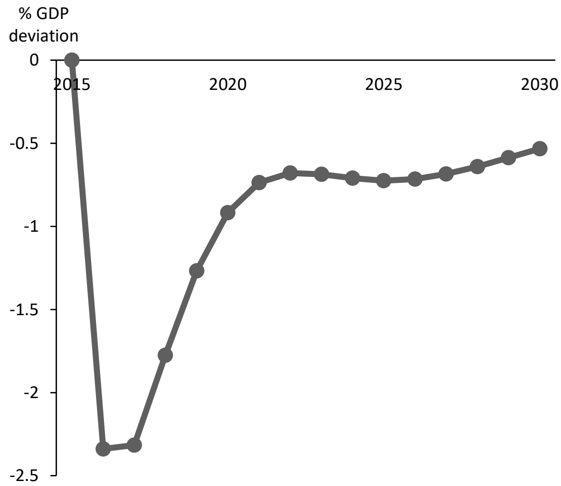
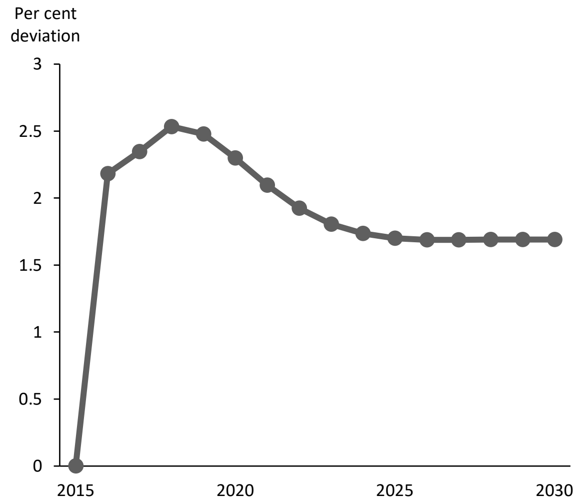


Figure 20: German real GDP



G-Cubed's high-level of sectoral disaggregation lets us explore critical sectoral and relative price effects, particularly given Germany's position as a dominant exporter of durable goods and services. The productivity shock sees a large increase in Germany's production of durable goods and services, diverting resources away from its other sectors which experience relatively smaller increases in output. This also shifts relative prices – pushing down the price of durables and services relative to those of other sectors.

But the critical question is what effect this policy has on other countries and on global imbalances. The immediate effect is through the exchange rate. An appreciated euro means relatively weaker currencies for Germany's trading partners which, as a result, enjoy a boost to their trade balance (Figure 21).

But the consequence of savings flowing out of their economies and into Germany means higher real interest rates and a contraction in investment (Figure 22). The overall effect on GDP for other countries is mostly negative (Figure 23). The negative effect on GDP is particularly pronounced for France, Italy and the rest of the Euro Zone (Figure 24). Due to the common currency they share with Germany, these countries also experience an appreciated exchange rate and a sharper outflow of capital but, unlike Germany, do not receive the benefits of higher productivity and fiscal stimulus (Figure 24).

The story for global current account imbalances is one in which Germany's current account balance worsens by more than 2 per cent of GDP in the near-term and is permanently 1 per cent of GDP below the baseline in the long-term (Figure 25). While the current account balance of the United States improves, it does so only marginally, and so does China's (Figure 26).

Figure 21: Trade balance

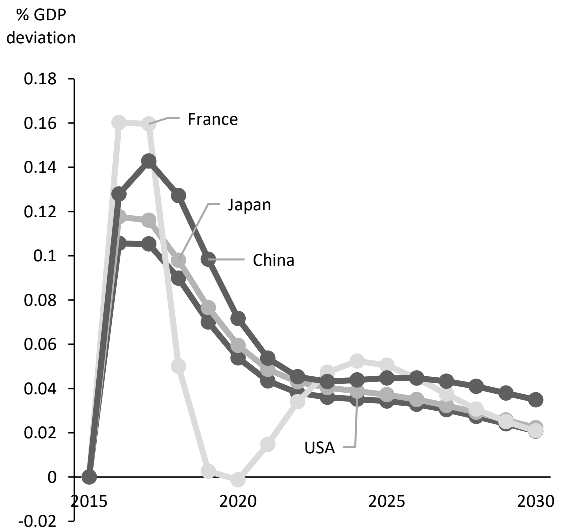


Figure 22: Investment

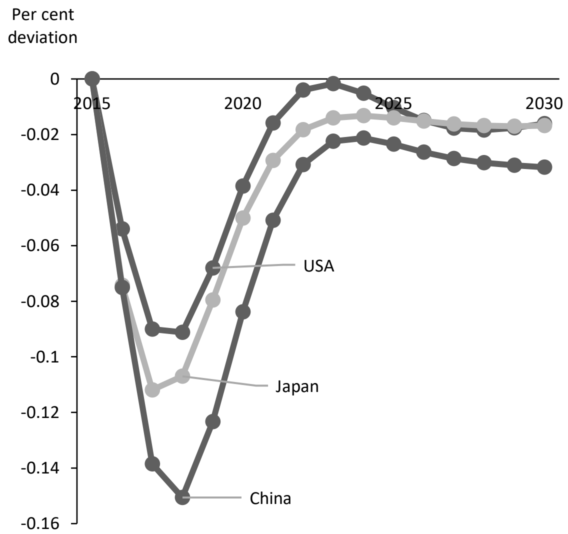


Figure 23: Real GDP

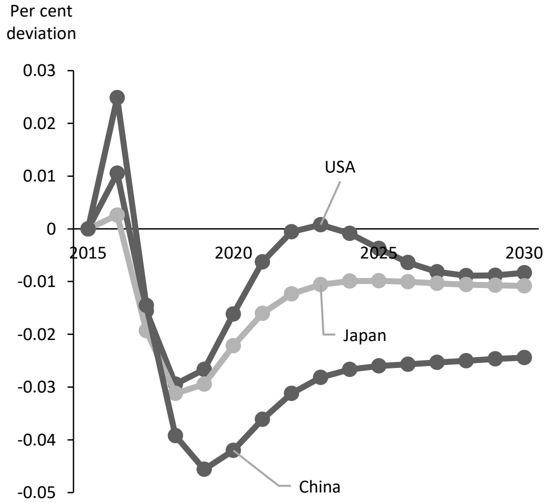


Figure 24: France, Italy, Euro Zone GDP

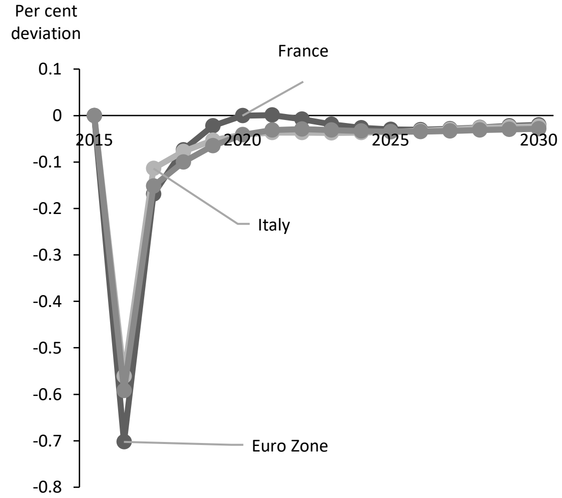


Figure 25: German current account

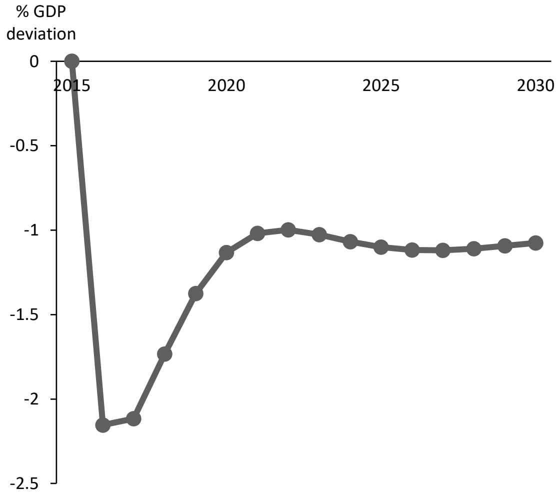
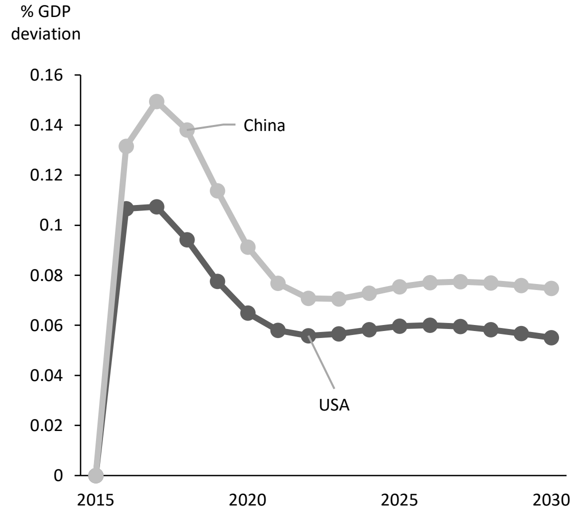


Figure 26: Current account: US and China



The critical insight which flows from this analysis is that, while Germany's current account surplus may be successfully reduced by this policy, this reduction has not come at the benefit of the United States – a key advocate for this policy in the G20. Not only is the benefit to the United States current account marginal, United States GDP, investment and consumption contract because of this policy. While the United States may celebrate a political victory for a reduced German current account balance, it does so at the cost of the United States economy. This insight flows from the general equilibrium nature of the G-Cubed model in which there are 'no free lunches'. When resources are reallocated from one part of an economy to another, there are financial and real economic consequences which tend to be ignored by partial equilibrium analysis or models that do not reflect both the real and financial sectors of the economy.

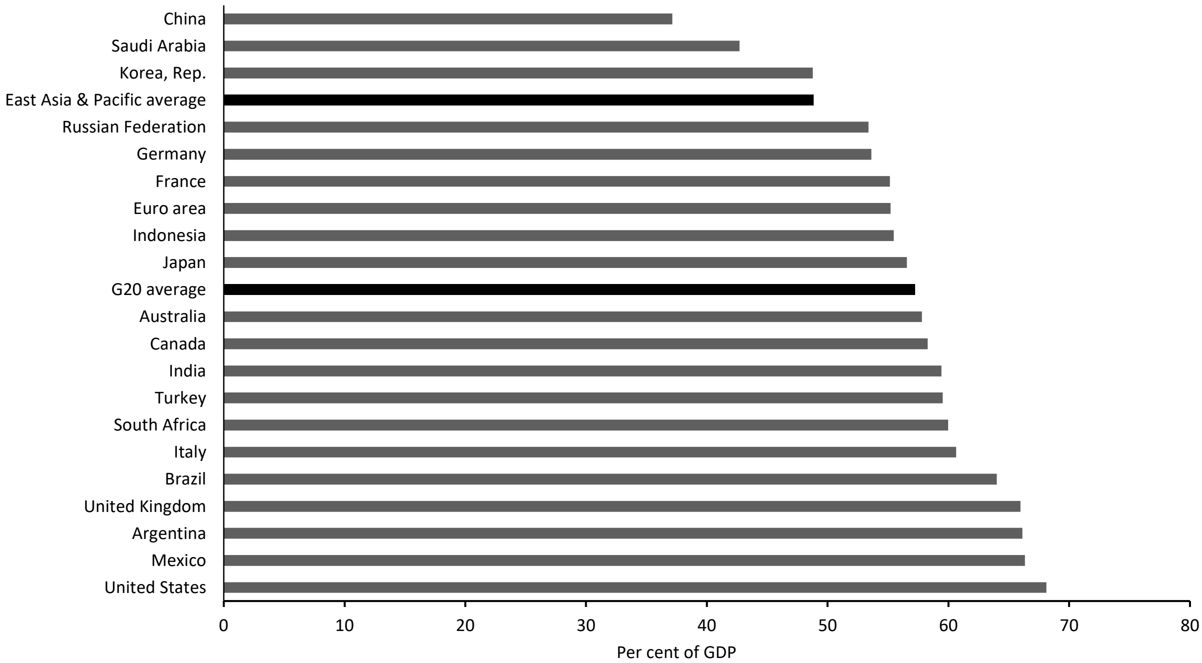
3.3 Increased domestic consumption in China

Now consider the final reform often advocated by the G20 to reduce global current account imbalances: increasing domestic consumption in China.

Consumption as a per cent of GDP is lower in China than any other G20 country (Figure 27). Given China is a full 15 percentage points below the G20 average, in this section we simulate a less dramatic policy shock where consumption in China increases to the average level among East Asian and Pacific countries (implying a 10 percentage point increase).

This is modelled as an exogenous shock to consumption which can be thought of as the result of some undefined policy in China. This allows us to explore how consumption shocks are reflected in the G-Cubed model as well as the pertinent question of whether this achieves the G20's objective of reducing current account imbalances. It also allows us to explore what unintended consequences might flow from such a policy.

Figure 27: Consumption as a per cent of GDP for G20 countries



Source: IMF world economic outlook database, October 2017

The results of this consumption shock for China are shown in Figures 28 to 31. An increase in consumption necessarily implies a decrease in savings – up to 10 per cent by 2022 (Figure 28). The increased demand for goods and services because of higher consumption sees an increase in investment in the short-term as firms expand to meet demand. But the increased demand placed on savings and the reduction in savings that follows from higher consumption means higher interest rates which, in turn, act to reduce investment in the longer-term (Figure 29). As capital flows into China to enjoy these higher interest rates and finance increased investment, China's real effective exchange rate appreciates by a substantial 16 per cent. Among other things, this sees a weakening of China's trade balance by 11 per cent of GDP in the first year (Figure 30). This effect, of course, is muted by China's managed exchange rate and capital controls framework.

The overall effect for China's GDP is significant, increasing by 4.1 per cent above the baseline in the first year. But as higher interest rates, weaker investment and a weaker trade balance start to bite, longer-run GDP is below the baseline after 2026 (Figure 31).

Figure 28: Chinese savings

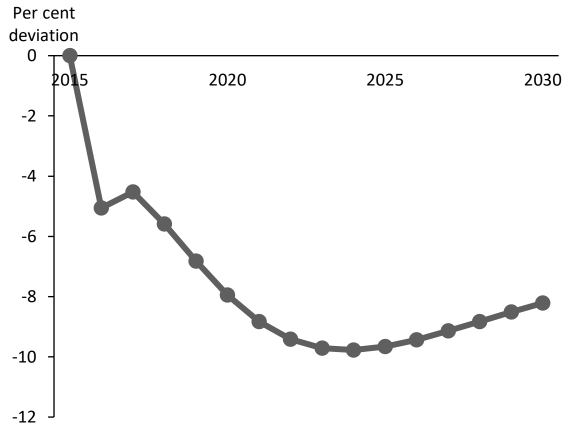


Figure 29: Chinese investment

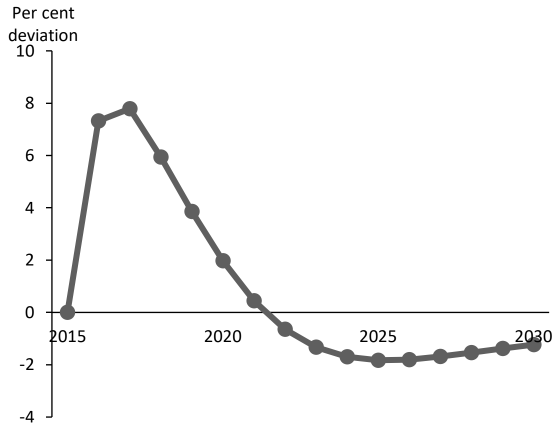


Figure 30: Chinese trade balance

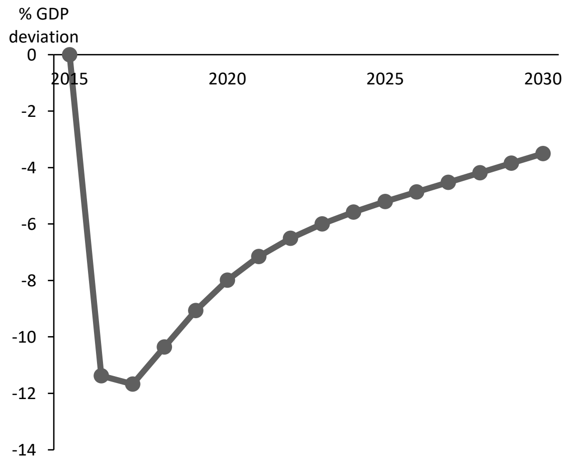
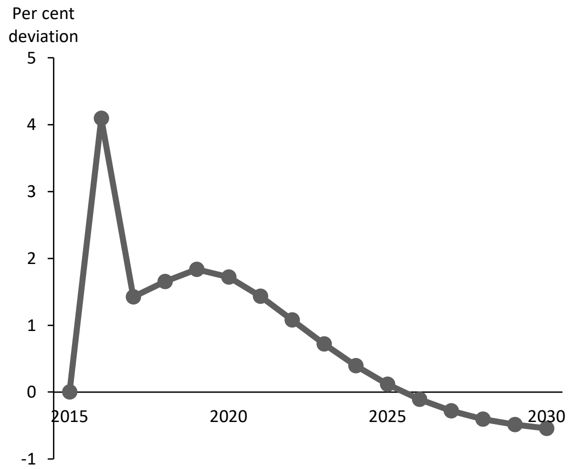


Figure 31: Chinese GDP



As in the previous scenario, an appreciated real effective exchange rate in the shocked economy means a relatively depreciated exchange rate for its trading partners. The United States and Japan both see their real effective exchange rates depreciate by around 5 per cent, boosting the trade balances for most advanced and emerging market economies by around 1.4 per cent (Figure 32).

This export-boost, however, is offset by a sharp decline in investment in most economies (Figure 33). Investment falls by 1.5 per cent in the United States and 1.6 per cent in Japan below the baseline in years two and three. Consumption also falls as the price of imports from China increases. Consumption falls by up to 0.6 per cent in the first year in the United States, Japan and the Euro Zone in the first year (Figure 34).

The overall GDP effect is negative for most G20 countries (Figure 35). Japan's GDP, for example, is 0.4 per cent smaller in the third year after the shock. Australia's and Germany's GDP are initially boosted by the trade balance but the reduced investment in the long-run means below-baseline GDP after the second-year.

This is a striking conclusion given it is often assumed that increased domestic consumption in China would be a benefit to its trading partners. By bringing together the real and financial sectors of the economy, G-Cubed shows that while countries do benefit through the trade balance, the impact of investment and capital flows produces a more complex story over the longer-term.

But does the G20 achieve its goal of reduced global imbalances? China's current account deteriorates by 11 per cent in the first year and is around 7 per cent below the baseline in the longer-term which is, indeed, a significant reduction. The current account also improves for the United States (by 1.6 per cent in the first year and 1.2 per cent in the longer-term – Figure 36) which helps further reduce global imbalances.

But Germany's current account surplus also increases because of this shock – by around 1.6 per cent in the second year (Figure 37). It follows that, to some extent, progress in reducing the current account surplus in China might merely transfer that surplus across to Germany.

Figure 32: Trade balance

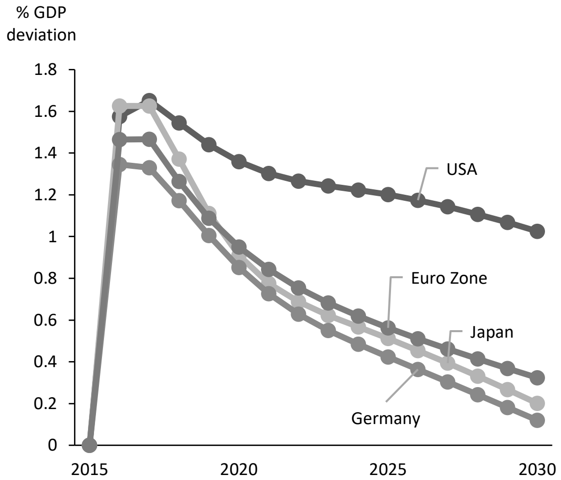


Figure 33: Investment

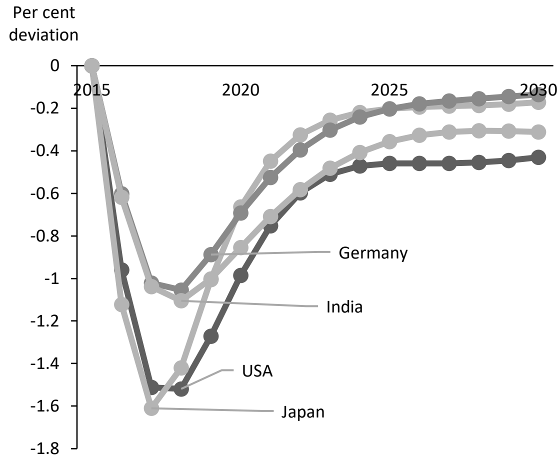


Figure 34: Consumption

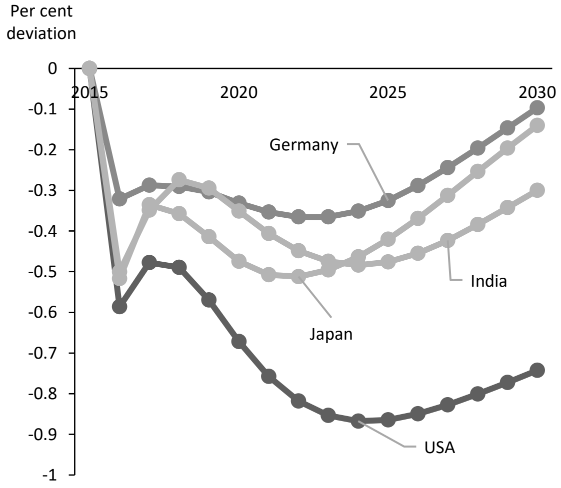


Figure 35: Real GDP

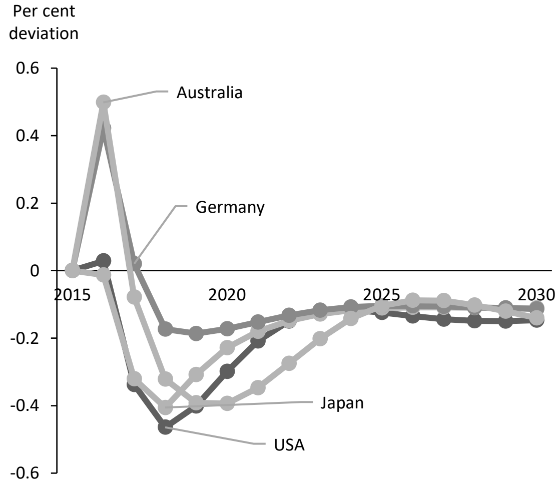


Figure 36: US current account

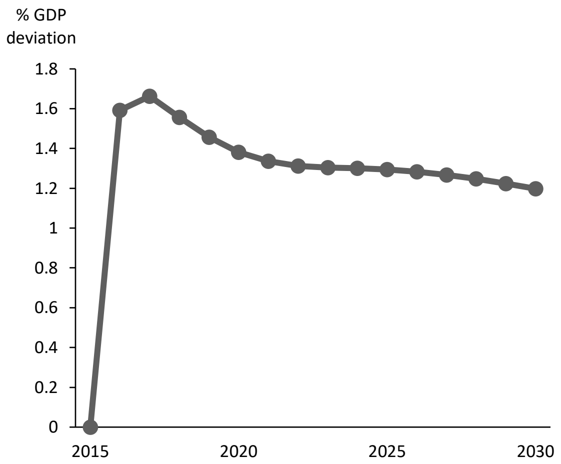
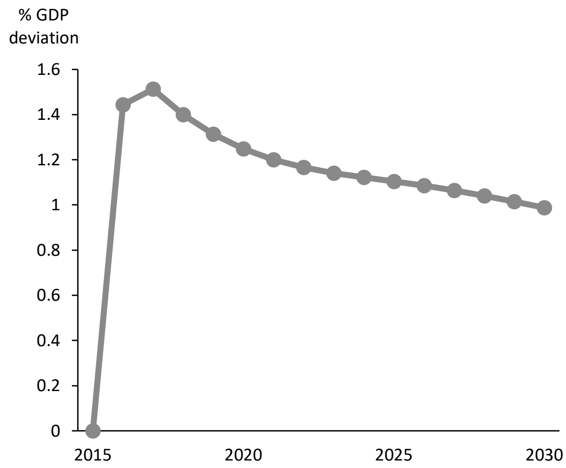


Figure 37: German current account



The first insight from this simulation is similar to that from the German simulation: these policies can reduce global current account imbalances, but they come at a cost to the real economies of most G20 countries. In the case of increased consumption in China, while countries benefit through their trade accounts, these benefits do not necessarily outweigh the cost to their economies of weaker investment and reduced purchasing power which ultimately sees their GDP lower than it otherwise would have been.

The second insight is that, while China's contribution to global imbalances can be reduced by increased Chinese consumption, it also increases the current account surpluses of some of its trading partners, notably Germany. This is discussed further in the final section, below, which considers the collective impact of these reforms.

3.4 The collective impact of all three reforms implemented simultaneously

The G20's focus and commitments on global imbalances envisages a 'grand bargain'. In return for the United States reducing its fiscal deficit, China would increase domestic consumption and Germany would increase public investment. This section considers the collective impact of this grand bargain, should it be implemented.

Consider the perspective of the United States first. In terms of investment, consumption and GDP, Figures 38 to 40 show that the United States is better off undertaking its policy reform (fiscal consolidation) alone. Fiscal consolidation boosts consumption and, despite contracting in the first three years relative to the baseline, investment and GDP are higher when the United States undertakes fiscal consolidation without simultaneous reforms from Germany or China. When Germany and China undertake their reforms at the same time, the United States is worse off in terms of investment, consumption and GDP.

However, the United States does enjoy a larger boost to its current account balance if all countries act together. If an improved current account is the only objective of the United States then it will prefer the 'grand bargain' cooperative outcome. However, as highlighted above, this improvement in the current account comes at the cost of the real economy. Furthermore, almost two-thirds of this improvement in the current account can be obtained by the United States from acting alone anyway. The key message for the United States, therefore, is that this grand bargain will give it an improved current account balance but will come at the cost of its real economy, with lower investment, consumption and GDP as a consequence.

Figure 38: United States investment

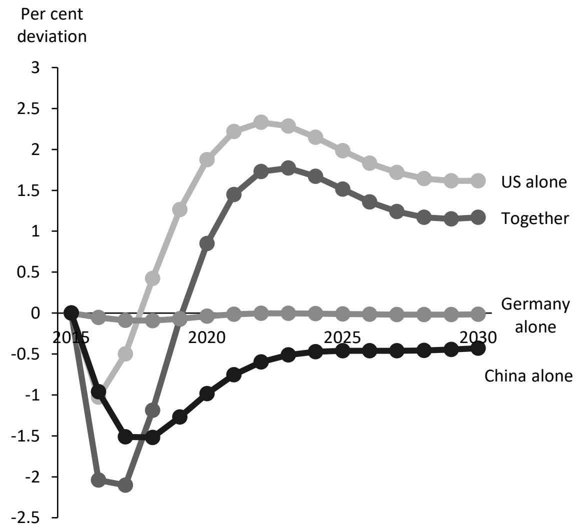


Figure 39: United States consumption

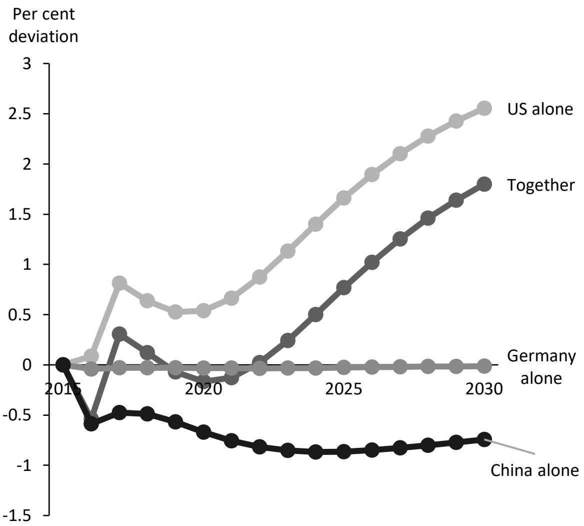


Figure 40: United States GDP

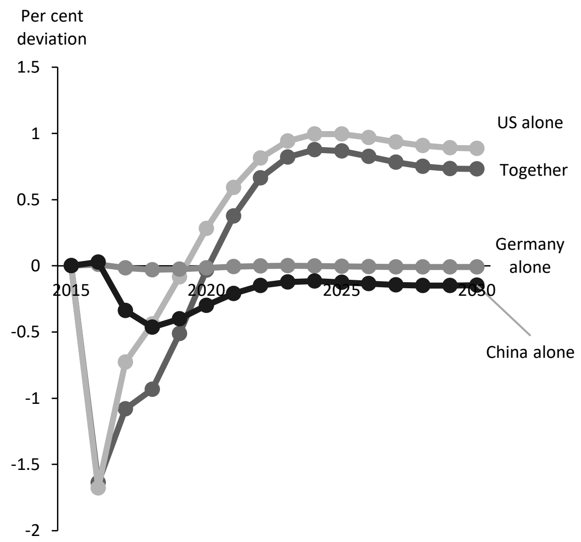
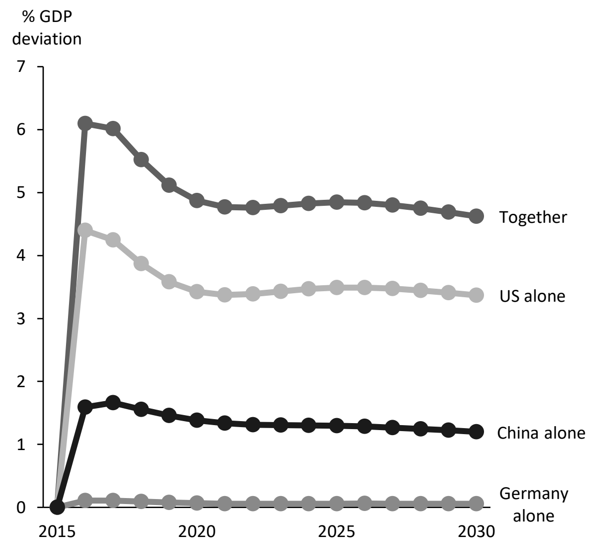


Figure 41: United States current account



Now consider Germany (Figures 42 to 45). In terms of investment and GDP, Germany is marginally better off undertaking reforms together rather than alone, but not significantly so. German consumption is higher if it acts together with the United States and China, but only in the longer-term.

In terms of reducing Germany's contribution to global imbalances, Germany, unlike the United States, is better off acting alone. Reforming alone has a larger effect in reducing Germany's current account surplus than reforming along with the United States and China. The key message for Germany, therefore, is generally one of relative indifference between acting together and acting alone.

Figure 42: German investment

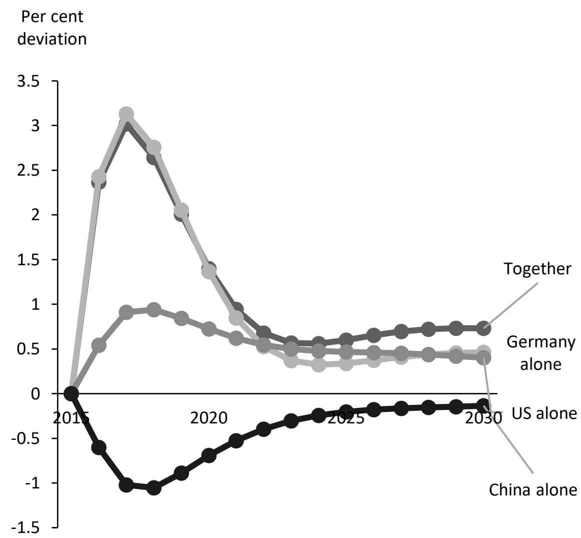


Figure 43: German consumption

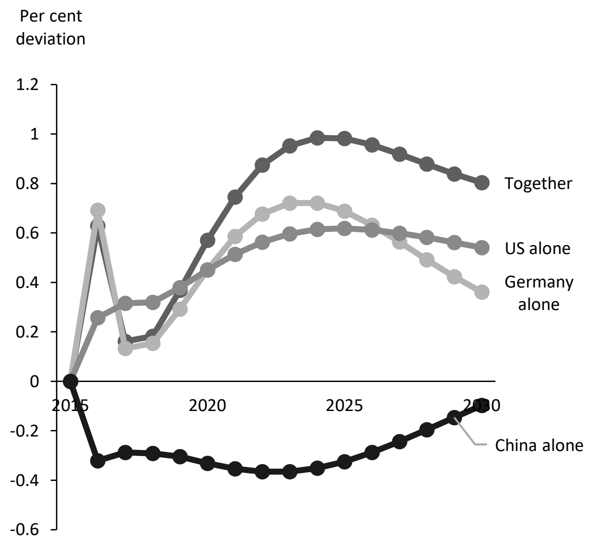


Figure 44: German GDP

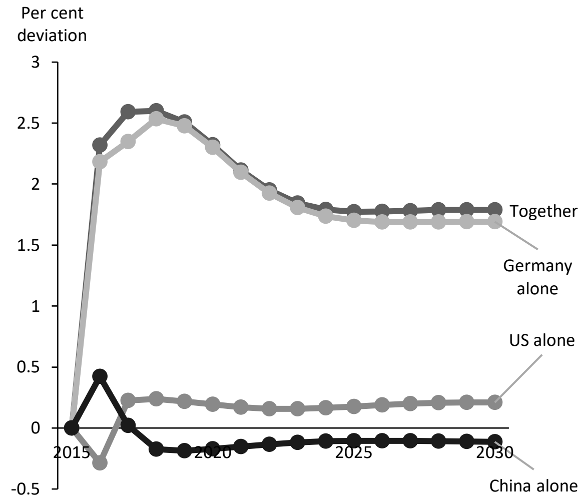
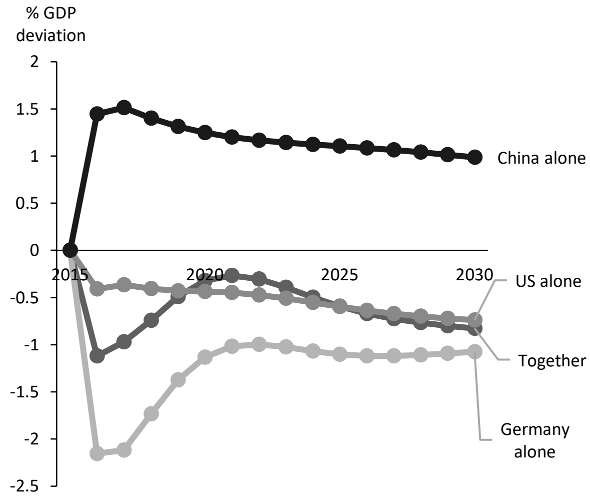


Figure 45: German current account



The most interesting result, however, is for China (Figures 46 to 49). In terms of investment, consumption and GDP in the near term, China is better off implementing its policies (increasing domestic consumption) together with Germany and the United States, rather than alone. And in terms of reducing its contribution to global current account imbalances, China is also better off acting together with the other countries.

However, there is an important observation when it comes to the impact of China acting alone for other countries. China's policies, if implemented alone, would have a significant effect in reducing China's current account surplus. But, as discussed earlier, it would also make Germany's current account surplus larger, thus worsening global current account balances. This finding is perhaps instructive as to what we have witnessed in the global economy since 2007. Illustrated earlier in Figure 4, the narrowing of China's current account surplus has occurred while Germany's current account surplus has widened considerably. This is precisely what the G-Cubed model would predict to happen as China continues its efforts to rebalance its economy towards higher domestic consumption.

Overall, the key message for China is that it is better off implementing its policies together with the United States and Germany. The key message for the United States and Germany is that, if they are primarily interested in reducing current account imbalances, they will also want to ensure they work together since, if China acts alone, global current account imbalances will worsen. This cooperation, however, comes at a cost for the United States in terms of lower investment, lower consumption and lower GDP.

Figure 46: Chinese investment

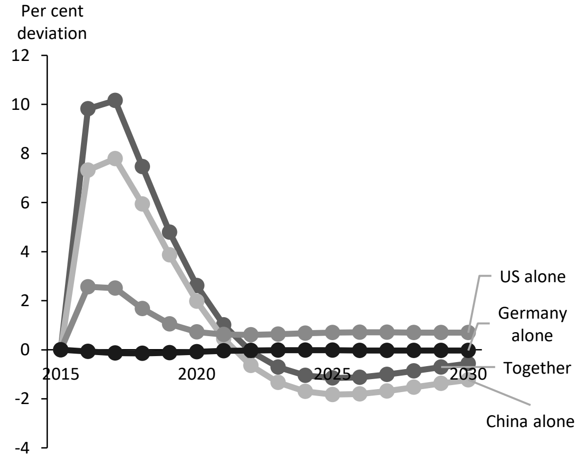


Figure 47: Chinese consumption

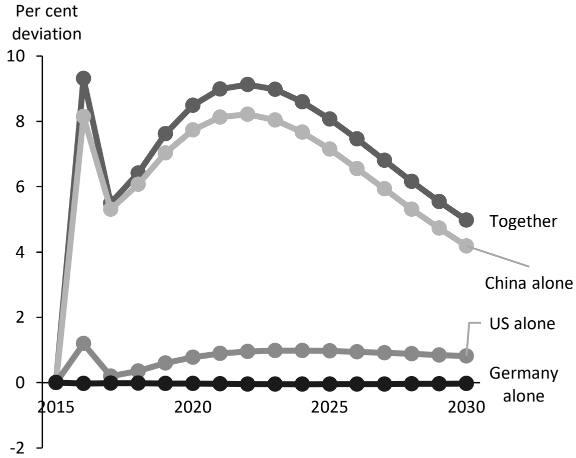


Figure 48: Chinese GDP

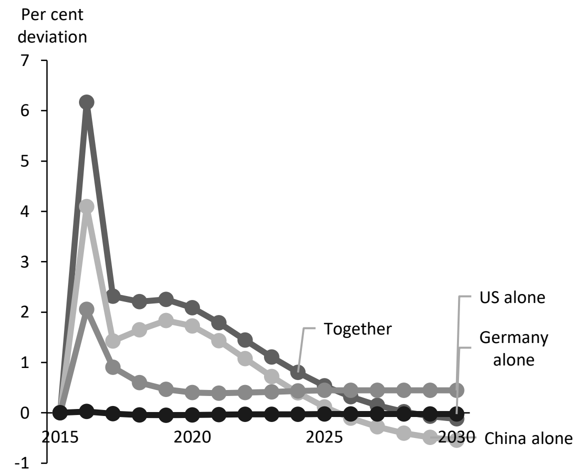
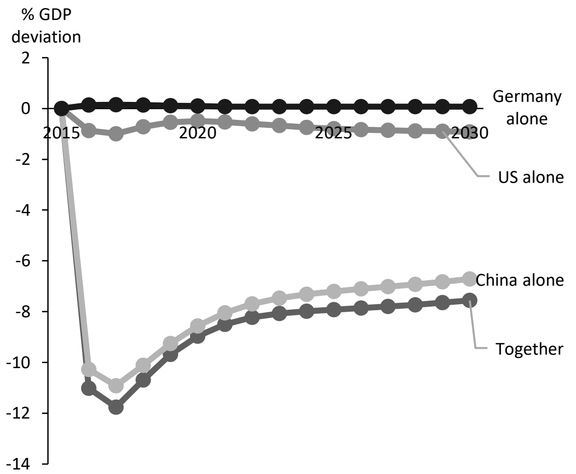


Figure 49: Chinese current account



4. Conclusion

The importance of being able to effectively model the G20 has increased as the G20 has become more influential in global economic decision making, with a broader and deeper policy agenda.

This paper introduced the G-Cubed (G20) model: a multi-country, multi-sector, intertemporal general equilibrium model. The paper gave an overview of the model and, to highlight its key features and functions, presented the results from four simulated shocks using the G-Cubed model which relate to the G20's longstanding goal of reducing global current account imbalances. These were: a fiscal shock (reducing the fiscal deficit in the United States), a productivity/fiscal shock (increasing infrastructure investment in Germany), a consumption shock (increasing domestic consumption in China) and the collective impact of all three shocks when they occur simultaneously.

The results highlighted several critical features of the G-Cubed model and showed how important these features are to understanding the impacts of these shocks for different economies and how those impacts differ depending on a variety of economy-specific characteristics.

Through econometric estimation and calibration, the G-Cubed model reflects the complex trade and financial linkages between countries and brings together the real and financial sectors into a single model. The simulations highlighted the critical role that savings, investment and global capital flows play in explaining the impacts of different shocks. While the United States, for example, benefits from an improved trade balance from policy reforms that reduce the current account surpluses in Germany and China, this comes at a cost to the real economy which is brought about by shifts in interest rates, exchange rates and capital flows. A model which focuses solely on trade and real economic variables misses these crucial impacts which, for the United States, produces a net-negative outcome for GDP. The same is true for Australia which, perhaps counterintuitively given its substantial trading relationship with China, sees GDP contract from an increase in Chinese domestic consumption (although GNP rises due to higher returns from investing in China) which, again, highlights the importance of bringing trade and financial flows into a single model.

The G-Cubed model also reflects the critical asymmetries and differences between G20 countries. In the above simulations, this allowed us to illustrate how economies are impacted differently by different shocks, particularly through their alternative monetary policy and exchange rate frameworks, but also through differences in production and consumption functions and endowments in resources and the factors of production. China is a significant example. In many of the above simulations, but particularly fiscal consolidation in the United States, China's managed exchange rate and system of capital controls meant a differentiated impact for the Chinese economy and financial system.

The G-Cubed model's high-level of disaggregation in terms of countries, sectors and markets also played an important role. This was highlighted through the significantly different sectoral effects that flows from increased productivity through infrastructure investment in Germany – a dominant exporter of durables and services. Similarly, this disaggregation allowed us to provide a compelling explanation for why the significant narrowing of China's current account surplus since 2007 has been accompanied by a large widening of that in Germany.

The model's reflection of the short-term rigidities we observe in the data was key to differentiating the impacts of shocks over different time horizons. The inertia that is built-in to the investment and consumption decisions of firms and households allowed us to show a rich, dynamic pathway of short- and long-term effects. When a country like Germany experiences a productivity shock, the sectors in which it is a dominant exporter (durables and services) are disproportionately affected, with critical implications for relative prices, capital flows and global trade patterns.

On the overall topic of global imbalances, the contribution of this paper to the G20 discussion is a simple warning: there is no such thing as a free lunch. For the United States, a lowering of current account imbalances from Germany and China comes at a cost of the real economy and, in any event, the United States could do much to improve its trade balance (and reduce those of Germany and China) through policies to reduce the size of its fiscal deficit. While the same is broadly true for Germany, the critical issue is around Chinese reform. If domestic consumption in China increases without action from the United States and Germany, not only is China worse off than if countries worked together but the current account surplus of Germany in fact increases.

This provides a critical warning to the G20. The direction the G20 is currently heading is one in which China continues to rebalance its economy, Germany does little to increase infrastructure investment and the United States fiscal deficit worsens rather than improves under the Trump Administration. The G-Cubed model would suggest that, with this combination of policies, the G20 had best get used to a world of with large global current account imbalances.

References

Abel, A.B. (1979). Investment and the Value of Capital. Garland, New York.

Bernanke, B. (2009). Financial Reform to Address Systemic Risk. Speech at the Council on Foreign Relations, Washington D.C. March 10. https://www.federalreserve.gov/newsevents/speech/bernanke20090310a.htm.

Blanchard, O. and Milesi-Ferretti, G.M. (2011). (Why) Should Current Account Balances Be Reduced? International Monetary Fund. Staff Discussion Note: SDN/11/03. March. https://www.imf.org/external/pubs/ft/sdn/2011/sdn1103.pdf.

Calderón, C., Moral-Benito, E. and Servén, L. (2009). Is infrastructure capital productive? A dynamic heterogeneous approach. Mimeo. The World Bank and CEMFI, December. http://onlinelibrary.wiley.com/doi/10.1002/jae.2373/abstract.

Campbell, J. and Mankiw, N.G. (1990). Permanent income, current income and consumption. J. Bus. Econ. Stat. 8, 265e279.

Congressional Budget Office (2017). Summary of deficit effects. Washington D.C. December. https://www.cbo.gov/system/files/115th-congress-2017-2018/costestimate/53362-summarysenatereconciliation.pdf.

Davies, G. (2010). A novel G20 proposal from Tim Geithner. Financial Times. 23 October. Retrieved from https:// www.ft.com/content/4d1d4be8-76d1-34eb-ab00-4d1df9357cbd.

Donnan, J. (2017). Donald Trump's war on trade deficit backfires. Financial Times. October. https://www.ft.com/content/33138fda-a20f-11e7-b797-b61809486fe2.

G20 (2008). Leaders communique. Washington D.C. November. Available at: http://www.g20.utoronto.ca/summits/2008washington.html.

G20 (2010). Leaders communique. Toronto. June. Available at: http://www.g20.utoronto.ca/summits/2010toronto.html.

Hayashi, F. (1982). The permanent income hypothesis: Estimation and testing by instrumental variables. J. Polit. Econ. 90, 895e916.

IMF (2017). Germany: 2017 Article IV Consultation-Press Release; Staff Report; and Statement by the Executive Director for Germany. International Monetary Fund. Washington D.C. July. https://www.imf.org/en/Publications/CR/Issues/2017/07/07/Germany-2017-Article-IV-Consultation-Press-Release-Staff-Report-and-Statement-by-the-45048.

King, M. (2016). The end of alchemy: Money, banking and the future of the global economy. London, UK: Little Brown.

Krugman, P. (2017). On The US-Germany Imbalance. New York Times. May. https://krugman.blogs.nytimes.com/2017/05/31/on-the-us-germany-imbalance/.

McKibbin, W. (1986). The International Coordination of Macroeconomic Policies. PhD Dissertation. Harvard University, Cambridge, MA.

McKibbin, W. and Sachs, J. (1991). Global Linkages: Macroeconomic Interdependence and Cooperation in the World Economy. Brookings Institution. Washington D.C. June. https://www.brookings.edu/book/global-linkages/.

McKibbin, W. and Stoeckel, A. (2009). Modelling the global financial crisis. Brookings Institution. Washington D.C. September. https://www.brookings.edu/wp-content/uploads/2016/06/0928_modelling_mckibbin_stoeckel.pdf.

McKibbin, W. and Stoeckel, A. (2018). Modeling a Complex World: Improving Macro Models. Oxford Review of Economic Policy. Vol. 34, 1-2, 2018, pp 329-347.

McKibbin, W. and Vines J. (2000). Modelling reality: The need for both inter-temporal and optimisation and stickiness in models for policymaking. Oxford Review of Economic Policy. Volume 16. No. 4. pp. 106 to 137. https://ora.ox.ac.uk/objects/uuid:72cdf8f6-df6a-4c8a-be49-60e72810006f.

McKibbin, W. and Wilcoxen, P. (1999). The theoretical and empirical structure of the G-Cubed model. Econ. Model. 16, 123e148.

McKibbin, W. and Wilcoxen, P. (2009). Uncertainty and climate change policy design. J. Pol. Model 31, pp. 463-477.

McKibbin, W. and Wilcoxen, P. (2013). A Global Approach to Energy and the Environment: The G-Cubed model. Handbook of CGE Modeling. Vol. 1, 2013, pp. 995-1068. https://www.sciencedirect.com/science/article/pii/B9780444595683000158?via%3Dihub.

McKibbin, W., Stoeckel, A. and Lu, Y. (2012). Global fiscal adjustment and trade rebalancing. Lowy Institute. Working Papers in International Economics. March 2012. No. 1.12. https://www.lowyinstitute.org/publications/global-fiscal-adjustment-and-trade-rebalancing.

Obstfeld, M. and Rogoff, K. (2000). The six major puzzles in international macroeconomics. NBER Working Paper 7777, Cambridge, MA. National Bureau of Economic Research. http://www.nber.org/chapters/c11059.pdf.

Obstfeld, M. and Rogoff, K. (2009). Global Imbalances and the Financial Crisis: Products of Common Causes. Paper prepared for the Federal Reserve Bank of San Francisco Asia Economic Policy Conference, Santa Barbara, CA, October 18-20. https://eml.berkeley.edu/~obstfeld/santabarbara.pdf.

Sester, B. (2016). The return of the East Asian Savings Glut. Council on Foreign Relations. Greenberg Center for Geoeconomic Studies. 18 October. https://www.cfr.org/report/return-east-asian-savings-glut.

Uzawa, H. (1969). Time preference and the Penrose effect in a two class model of economic growth. J. Polit. Econ. 77, 628e652.

Appendix A – Further information on the G-Cubed (G20) model[13]

1. Firms

The objective of firms is to choose their production inputs (labour, capital, energy and materials) and make investment decisions to maximise their stock market value (represented by the present value of the future stream of dividends). Firms are assumed to be price-taking. Each firm's production technology is represented by a tier-structured constant elasticity of substitution (CES) function. At the top tier, output is a function of capital, labour, energy and materials:

$$Q_i = A_i^O \left(\sum_{j=K,L,E,M} (\delta_{ij}^O)^{\frac{1}{\sigma_i^O}} X_{ij}^{\frac{\sigma_i^O - 1}{\sigma_i^O}} \right)^{\frac{\sigma_i^O}{\sigma_i^O - 1}} \qquad (1)$$

where Qi is the output of industry i, X_{ij} is industry i's use of input j, and A_i^O, $\delta^O{}_{ij}$ and σ_i^O are parameters. A_i^O reflects the level of technology, σ_i^O is the elasticity of substitution and the $\delta^O{}_{ij}$ parameters reflect the weights of different inputs in production; the superscript 'O' indicates that the parameters apply to the top, or 'output', tier. Without loss of generality, we constrain the δ's to sum to one.

At the second tier, the input of materials (X_{iM}) is itself a CES aggregate of agriculture, durable manufacturing, non-durable manufacturing and services. The functional form used for these tiers is identical to (1) except that the parameters are A_i^M, $\delta^M{}_{ij}$ and σ_i^M.

The goods and services purchased by firms are aggregates of imported and domestic commodities, which are assumed to be imperfect substitutes. All agents in the economy are assumed to have identical preferences over foreign and domestic varieties of each commodity. Preferences are represented by defining 6 composite commodities that are produced from imported and domestic goods. Each of these commodities, Y_i, is a CES function of domestic output, Qi, and imported goods, M_i. Constraining all agents in the model to have the same preferences over the origin of goods requires that, for example, the agricultural and service sectors have the identical preferences over domestic energy goods and energy goods imported from Saudi Arabia. This accords with the input-output data we

[13] This Appendix is an extract from McKibbin and Wilcoxen (2013)

use and allows a very convenient nesting of production, investment and consumption decisions.

The capital stock in each sector increases with the rate of investment (fixed capital formation: J_i) and decreases with the rate of geometric depreciation (δ_i) such that the capital stock in industry i is given by:

$$\dot{K}_i = J_i - \delta_i K_i \qquad (2)$$

We assume that investment is subject to rising marginal costs of installation such that, to install additional J units of capital, a firm must buy a larger quantity, I, that depends on its rate of investment (J/K) (see Uzawa, 1969):

$$I_i = \left(1 + \frac{\phi_i}{2}\frac{J_i}{K_i}\right)J_i \qquad (3)$$

where Φ is a non-negative parameter. The difference between J and I can be interpreted various ways, such as installation services provided by the capital-goods vendor.

Discussed earlier, the model assumes that the goal of each firm is to maximise inter-temporal risk-adjusted profits (net of tax):

$$\int_t^{\infty} (1-\tau_2)\pi_i e^{-(R(s)+\mu_{ei}-n)(s-t)} ds \qquad (4)$$

where μ_{ei} is a sector- and country/region -specific equity risk premium, τ_2 is the effective tax rate on capital income, and variables are implicitly subscripted by time. The firm's profits, π, are given by:

$$\pi_i = P_i^* Q_i - W_{iL_i} - P_i^{\mathrm{E}} X_{i\mathrm{E}} - P_i^{\mathrm{M}} X_{i\mathrm{M}} - (1-\tau_4)P^{\mathrm{I}} I_i \qquad (5)$$

where τ_4 is an investment tax credit and P^* is the producer price of the firm's output. R(s) is the long-term interest rate between periods t and s such that:

$$R(s) = \frac{1}{s-t}\int_t^s r(v)dv \qquad (6)$$

As all real variables are normalized by the economy's endowment of workers, profits are discounted adjusting for the rate of growth of population plus productivity growth, n. Solving the top-tier optimization problem gives the firm's factor demands for labour, energy and materials:

$$X_{ij} = \delta_{ij}^{O} \left(A_i^{O}\right)^{\sigma_i^{O}-1} Q_i \left(\frac{P_i^*}{P_j}\right)^{\sigma_i^{O}} \quad j \in \{L, E, M\} \tag{7}$$

and the optimal evolution of the capital stock, where λ_i is the shadow value of an additional unit of investment in industry i.

$$\lambda_i = \left(1 + \phi_i \frac{J_i}{K_i}\right)\left(1 - \tau_4\right) P^I \tag{8}$$

$$\frac{d\lambda_i}{ds} = (r + \mu_{ei} + \delta_i)\lambda_i - (1 - \tau_2) P_i^* \frac{dQ_i}{dK_i} - (1 - \tau_4) P^I \frac{\phi_i}{2} \left(\frac{J_i}{K_i}\right)^2 \tag{9}$$

By integrating (9) along the optimum path of capital accumulation, it is straightforward to show that λ_i is the increment to the value of the firm from a unit increase in its investment at time t. It is related to q, the after-tax marginal version of Tobin's Q (Abel, 1979), as follows:

$$q_i = \frac{\lambda_i}{(1 - \tau_4) P^I} \tag{10}$$

Thus we can re-write (8) as:

$$\frac{J_i}{K_i} = \frac{1}{\phi_i}(q_i - 1) \tag{11}$$

Inserting this into (3) gives total purchases of new capital goods:

$$I_i = \frac{1}{2\phi_i}(q_i^2 - 1) K_i \tag{12}$$

Importantly, the model assumes that only fraction (α_2) of firms make investment decisions using the fully forward-looking Tobin's q described above. This allows the model to capture the inertia or lagged effect which is often observed in empirical investment studies. This improves the model's ability to mimic historical data and is consistent with the existence of firms that are unable to borrow. The remaining (1 - α_2) of firms use a slowly-adjusting version, Q, which is driven by a partial adjustment model. In each period, the gap between Q and q closes by fraction α_3 so the investment decisions of forward- and backward-looking firms converge over time.

$$Q_{it+1} = Q_{it} + \alpha_3(q_{it} - Q_{it}) \tag{13}$$

Given this, (12) can be rewritten so I_i is a function of both q (for forward-looking firms) and the slowly adjusting Q (for backward-looking firms):

$$I_i = \alpha_2 \frac{1}{2\phi_i}(q_i^2 - 1)K_i + (1 - \alpha_2)\frac{1}{2\phi_i}(Q_i^2 - 1)K_i \tag{14}$$

The weight on unconstrained behaviour, α_2, is taken to be 0.3. This is based on a range of empirical estimates reported by McKibbin and Sachs (1991).

So far, this section has described the demand for investment goods by each sector without describing where these investment goods come from. Investment goods in the model are supplied, in turn, by a 7th industry that combines capital, labour and the outputs of other industries to produce raw capital goods. We assume that this representative investment good-producing firm faces an optimization problem which is identical to those of the other 6 industries. That is, it has a nested CES production function, uses inputs of capital, labour, energy and materials in the top tier, incurs adjustment costs when changing its capital stock, and earns zero profits.

2. Households

Households supply labour, save, consume goods and services and consume public goods supplied by the Government. Their objective is to maximise intertemporal utility subject to a lifetime budget constraint. The constraint is that the present value of consumption must equal the sum of the expected present value of the future stream of after-tax labour income (plus transfers from the government) and their initial financial assets.

Within each country/region, household behaviour is modelled by a representative agent with an intertemporal utility function of the following form:

$$U_t = \int_t^\infty (\ln C(s) + \ln G(s)) e^{-\theta(s-t)} ds \tag{15}$$

where C(s) is the household's aggregate consumption of goods and services at time s, G(s) is government consumption at time s (which is taken to be a measure of public goods provided) and q is the rate of time preference. The household maximises this intertemporal utility function subject to the constraint that the present value of consumption (which can be adjusted by risk premium μ_h) be equal to the sum of human wealth, H, and initial financial assets, F:

$$\int_t^\infty P^c(s) C(s) e^{-(R(s)+\mu_h-n)(s-t)} = H_t + F_t \tag{16}$$

Human wealth, H, is defined as the expected present value of the future stream of after tax labour income plus transfers:

$$H_t = \int_t^{\infty} (1-\tau_1)(W(L^G + L^C + L^I + \sum_{i=1}^{12} L^i) + TR)e^{-(R(s)+\mu_h-n)(s-t)}ds \tag{17}$$

Where τ_1 is the tax rate on labour income, TR is the level of government transfers, L^C is the quantity of labour used directly in final consumption, L^I is labour used in producing the investment good, L^G is government employment, and L^i is employment in sector i. Financial wealth is the sum of real money balances, MON/P, real government bonds in the hand of the public, B, the net holding of claims against foreign residents, A, and the value of capital in each sector and holdings of emissions permits, Qi^P:

$$F = \frac{MON}{P} + B + A + q^I K^I + q^C K^C + \sum_{i=1}^{12} q^i K^i + \sum_{i=1}^{12} P_i^P Q_i^P \tag{18}$$

Solving this maximisation problem gives the result that aggregate consumption spending is equal to a constant proportion of private wealth, where private wealth is defined as financial wealth plus human wealth:

$$P^C C = (\theta + \mu_h)(F + H) \tag{19}$$

However, as with firms, the model assumes that some consumers are liquidity-constrained and consume a fixed fraction, g, of their after-tax income (INC). This allows the model to mimic the empirical findings of authors such as Campbell and Mankiw (1990) and Hayashi (1982). The share of consumers who are not liquidity-constrained and choose consumption in accordance with (19) is denoted by α_8. Consequently, total consumption expenditure is given by:

$$P^C C = \alpha_8(\theta + \mu_h)(F_t + H_t) + (1 - \alpha_8)\gamma INC \tag{20}$$

Once the level of overall consumption has been determined, spending is allocated among goods and services according to a two-tier CES utility function. At the top tier, the demand equations for capital, labour, energy and materials can be shown to be:

$$P_i X_{Ci} = \delta_{Ci} P^C C \left(\frac{P^C}{P_i}\right)^{\sigma_C^O - 1}, \quad i \in \{K, L, E, M\} \tag{21}$$

where X_{Ci} is household demand for good i, $\sigma^O{}_C$ is the top-tier elasticity of substitution and the δ_{Ci} are the input-specific parameters of the utility function. The price index for consumption, P^C, is given by the following (with similar demand and price equations for the materials tier):

$$P^{C} = \left(\sum_{j=K,L,E,M} \delta_{Cj} P_j^{\sigma_C^O - 1} \right)^{\frac{1}{\sigma_C^O - 1}} \tag{22}$$

Household capital services consist of the service flows of consumer durables plus residential housing. The supply of household capital services is determined by consumers themselves who invest in household capital, K^C, to generate a desired flow of capital services, C^K, according to the following production function:

$$C^{K} = \alpha K^{C} \tag{23}$$

where α is a constant. Accumulation of household capital is subject to the condition:

$$\dot{K}^{C} = J^{C} - \delta^{C} K^{C} \tag{24}$$

We assume that changing the household capital stock is subject to adjustment costs so household spending on investment, I^C, is related to J^C by:

$$I^{C} = \left(1 + \frac{\phi^{C}}{2} \frac{J^{C}}{K^{C}} \right) J^{C} \tag{25}$$

Thus, the household's investment decision is to choose I^C to maximise:

$$\int_t^{\infty} (P^{CK} \alpha K^{C} - P^{I} I^{C}) e^{-(R(s)+\mu_z-n)(s-t)} ds \tag{26}$$

where P^{CK} is the imputed rental price of household capital and μ_z is a risk premium on household capital (possibly zero). This problem is nearly identical to the investment problem faced by firms, including the partial adjustment mechanism outlined in equations 12 and 13, and the results are very similar. The only important difference is that no variable factors are used in producing household capital services.

3. The labour market

Labour is assumed to be perfectly mobile among sectors within each country or country/region but is immobile between countries/regions. As a result, wages will be equal across sectors within each country/region, but are generally not be equal between countries/regions.

In the long run, labour supply is completely inelastic and is determined by the exogenous rate of population growth. Long run wages adjust to move each country/region to full employment. In the short run, however, nominal wages are assumed to adjust slowly according to an overlapping contracts model where wages are set based on current and expected inflation and on labour demand relative to labour supply. This can lead to short-run unemployment if unexpected shocks cause the real wage to be too high to clear the labour market. Similarly, employment can temporarily exceed its long-run level if unexpected events cause the real wage to be below its long run equilibrium.

4. Government

Each country/region's real government spending on goods and services is taken to be exogenous. It is assumed to be allocated among inputs in fixed proportions, which are based on 2006 values. The government spends money on goods and services, interest payments on government debt, investment tax credits and transfers to households. It receives revenue from sales taxes, capital and labour taxes and from the sales of new government bonds. The government budget constraint may be written in terms of the accumulation of public debt as follows:

$$\dot{B}_t = D_t = r_t B_t + G_t + TR_t - T_t \quad (27)$$

where B is the stock of debt, D is the budget deficit, G is total government spending on goods and services, TR is transfer payments to households and T is total tax revenue net of any investment tax credit.

$$\lim_{s \to \infty} B(s) e^{-(R(s)-n)s} = 0 \quad (28)$$

This prevents per capita government debt from growing faster than the interest rate forever. If the government is fully leveraged at all times, (28) allows:

$$B_t = \int_t^{\infty} (T - G - TR) e^{-(R(s)-n)(s-t)} \mathrm{d}s \quad (29)$$

As a result, the current level of debt will always be exactly equal to the present value of future budget surpluses. The implication of (29) is that a government running a budget deficit today must run an appropriate budget surplus as some point in the future. Otherwise, the government would be unable to pay interest on the debt and agents would not be willing to hold it. To ensure that (29) holds at all points in time we assume that the government levies a lump sum tax in each period equal to the value of interest payments on the outstanding debt.

In effect, therefore, any increase in government debt is financed by consols and future taxes are raised enough to accommodate the increased interest costs. Other fiscal closure rules are possible, such as requiring the ratio of government debt to GDP to be unchanged in the long run or that the fiscal deficit be exogenous with a lump sum tax ensuring this holds. These closures have interesting implications but are beyond the scope of this paper.

5. Financial markets and the balance of payments

The 24 country/regions in the model are linked by flows of goods and assets. Flows of goods are determined by the import demands described above. These demands can be summarised in a set of bilateral trade matrices which give the flows of each good between exporting and importing countries. There is one 24 by 24 trade matrix for each of the 6 goods. Trade imbalances are financed by flows of assets between countries. Each country/region with a current account deficit will have a matching capital account surplus, and vice versa. Asset markets are assumed to be perfectly integrated across country/regions. With free mobility of capital, expected returns on loans denominated in the currencies of the various country/regions must be equalised period to period according to a set of interest arbitrage relations of the following form:

$$i_k + \mu_k = i_j + \mu_j + \frac{\dot{E}_k^j}{E_k^j} \tag{30}$$

where i_k and i_j are the interest rates in countries k and j, μ_k and μ_j are exogenous risk premiums demanded by investors (which could be zero), and E^j_k is the exchange rate between the currencies of the two countries. However, in cases where there are institutional rigidities to capital flows, the arbitrage condition does not hold and we replace it with an explicit model of the relevant restrictions (such as capital controls).

Capital flows may take the form of portfolio investment or direct investment but we assume these are perfectly substitutable *ex ante*, adjusting to the expected rates of return across economies and across sectors. Within each economy, the expected returns to each type of asset are equated by arbitrage, taking into account the costs of adjusting physical capital stock and allowing for exogenous risk premiums. However, because physical capital is costly to adjust, any inflow of financial capital that is invested in physical capital will also be costly to shift once it is in place. This means that unexpected events can cause windfall gains and losses to owners of physical capital, and ex post returns can vary substantially across countries and sectors. For example, if a shock lowers profits in a particular industry, the physical capital stock in the sector will initially be unchanged but its financial value will drop immediately.

6. Money demand and monetary rules

Money enters the model via a constraint on transactions.[14] The model uses a money demand function in which the demand for real money balances is a function of the value of aggregate output and short-term nominal interest rates:

$$MON = PYi^{\varepsilon} \tag{31}$$

where Y is aggregate output, P is a price index for Y, i is the interest rate, and ε is the interest elasticity of money demand. Following McKibbin and Sachs (1991), ε is taken to be -0.6.

On the supply side, the model includes an endogenous monetary response function for each country/region. Each country/region's central bank is assumed to adjust short-term nominal interest rates following a Henderson-McKibbin-Taylor rule as shown in the equation below. The interest rate evolves as a function of actual inflation (π) relative to target inflation (π^T), output growth (Δ_y) relative to growth of potential output (Δ_y^T) and the change in the exchange rate (Δ_e) relative to the bank's target change (Δ_e^T):

$$i_t = i_{t-1} + \beta_1(\pi_t - \pi_t^T) + \beta_2(\Delta y_t - \Delta y_t^T) + \beta_3(\Delta e_t - \Delta e_t^T) \tag{32}$$

The parameters in (32) vary across countries. For example, countries that peg their exchange rate to the US dollar have a very large value of β_3.

7. Parametrisation

Estimating G-Cubed's parameters began by constructing a consistent time series of input-output tables for the US, described in detail in McKibbin and Wilcoxen (1999). First, it started with the detailed benchmark US input-output transactions tables produced by the

[14] Unlike other components of the model this is simply assumed rather than being derived from optimizing behaviour. Money demand can be derived from optimization under various assumptions: money gives direct utility; it is a factor of production; or it must be used to conduct transactions. The distinctions are unimportant for the purposes of this model.

Bureau of Economic Analysis (BEA) which were then converted to a standard set of industrial classifications and aggregated into 6 sectors. Second, the treatment of consumer durables was then corrected because they are included in consumption rather than investment in the US National Income and Product Accounts (NIPAs) and the benchmark input-output tables. Third, the value-added rows of the tables were supplemented using a detailed dataset on capital and labour input by industry constructed by Dale Jorgenson and his colleagues. Finally, prices were obtained for each good in each benchmark year from the output and employment data set constructed by the Office of Employment Projections at the Bureau of Labor Statistics (BLS).

This dataset allowed the estimation of the model’s parameters for the US. To estimate the production side of the model, we began with the materials tier because it has constant returns to scale and all inputs are variable. In this case it is convenient to replace the production function with its dual unit cost function. For industry i, the unit cost function for materials is:

$$c_i^{\mathrm{E}} = \frac{1}{A_i^{\mathrm{E}}}\left(\sum_{k=1}^{5} \delta_{ik}^{\mathrm{E}}\, p_{ik}^{1-\sigma_i^{\mathrm{E}}}\right)^{\frac{1}{1-\sigma_i^{\mathrm{E}}}} \tag{33}$$

Assuming the materials node earns zero profits, c will be equal to the price of the node’s output. Using Shephard’s lemma to derive demand equations for individual commodities and then converting these demands to cost shares gives expressions of the form:

$$s_{ij}^{\mathrm{E}} = \delta_{ij}^{\mathrm{E}}\left(\frac{P_j}{A_i^{\mathrm{E}} P_i}\right)^{1-\sigma_i^{\mathrm{E}}}, \; j = 1, \ldots, 5 \tag{34}$$

where s^{E}_{ij} is the share of industry is spending on energy that is devoted to purchasing input j. The parameters A_i^E, σ_i^E and δ_{ij}^E were found by estimating (33) and (34) as a system of equations. Estimates of the parameters in the materials tier were found through a similar approach.

The output node must be treated differently because it includes capital, which is not variable in the short run. We assume that the firm chooses output, Q_i, and its top-tier variable inputs (L, E and M) to maximize its restricted profit function, p:

$$\pi_i = p_i Q_i - \sum_{j=\mathrm{L,E,M}} p_j X_{ij} \tag{35}$$

where the summation is taken over all inputs other than capital. Inserting the production function into (35) and rewriting gives:

$$\pi_i = P_i A_i^O \left(\delta_{ik}^{\frac{1}{\sigma_i^O}} K_i^{\frac{\sigma_i^O - 1}{\sigma_i^O}} + \sum_{j=L,E,M} \delta_{ij}^{\frac{1}{\sigma_i^O}} X_{ij}^{\frac{\sigma_i^O - 1}{\sigma_i^O}} \right)^{\frac{\sigma_i^O}{\sigma_i^O - 1}} - \sum_{j=L,E,M} P_j X_{ij} \qquad (36)$$

where K_i is the quantity of capital owned by the firm, δ_{ik} is the distributional parameter associated with capital, and j ranges over inputs other than capital. Maximising (36) with respect to variable inputs produces the following factor demand equations for industry i:

$$X_{ij} = \delta_{ij} P_j^{-\sigma_i^O} \delta_{ik}^{\frac{1}{\sigma_i^O - 1}} K_i \left((P_i A_i^O)^{1-\sigma_i^O} - \sum_k \delta_{ik} P_k^{1-\sigma_i^O} \right)^{\frac{\sigma_i^O}{1-\sigma_i^O}}, \quad \forall j \in \{L, E, M\} \qquad (37)$$

This system of equations can be used to estimate the top-tier production parameters. The results are listed in McKibbin and Wilcoxen (1999).

Much of the empirical literature on cost and production functions fails to account for the fact that capital is fixed in the short run. Rather than using (37), a common approach is to use factor demands of the form:

$$X_{ij} = \delta_{ij} P_i^{-\sigma_i^O} \frac{Q_i}{A_i^O} \left(\sum_{k=K,L,E,M} \delta_{ik} P_k^{1-\sigma_i^O} \right)^{\frac{\sigma_i^O}{1-\sigma_i^O}} \qquad (38)$$

This expression is correct only if all inputs are variable in the short run. McKibbin and Wilcoxen (1999) shows that using equation (38) biases the estimated elasticity of substitution toward unity for many sectors in the model. The treatment of capital thus has a very significant effect on the estimated elasticities of substitution.

Estimating parameters for country/regions other than the US is more difficult because timeseries input-output data is often unavailable. In part, this is because some countries do not collect the data regularly and in part it is because some of the model's geographic entities are regions rather than individual countries. As a result, restrictions are imposed so that substitution elasticities within individual industries are equal across country/regions. By doing so, the US elasticity estimates can be used everywhere. The share parameters (the δ's in the equations above), however, are derived from regional input-output data taken from the GTAP version 9 database and differ from one country/region to another. In effect, we are assuming that all country/regions share a similar but not identical production technology.

This is intermediate between one extreme of assuming that the country/regions share common technologies and the other extreme of allowing the technologies to differ in arbitrary ways. The country/regions also differ in their endowments of primary factors, their government policies, and patterns of final demands.

Final demand parameters, such as those in the utility function or in the production function of new investment goods were estimated by a similar procedure: elasticities were estimated from US data and share parameters were obtained from regional input-output tables. Trade shares were obtained from 2009 UN Standard Industry Trade Classification (SITC) data aggregated up from the four-digit level. The trade elasticities are based on a survey of the literature and vary between 1 and 3.

8. Numerical implementation

G-Cubed is implemented via three software components. The first consists of a sequence of programs written in the Ox language that construct G-Cubed's dataset from raw data. The second component consists of a set of files specifying the model's economic structure in a portable, general-purpose language we developed called 'Sym'. Sym is a set-driven matrix language that descends from GAMS and GEMPACK. It imposes rigorous conformability rules on all expressions to eliminate a broad range of potential errors in the design and coding of the model. A useful consequence of these rules is that subscripts are generally unnecessary and the model can be expressed very concisely and clearly. The third component is a suite of Ox programs that are used for setting up simulations and solving the model according to the two-point boundary value algorithm described in McKibbin (1986). It allows models with large numbers of forward-looking costate variables (the model has almost 200) to be solved quickly on computers with limited resources.

9. Generating a baseline

Because G-Cubed is an intertemporal model, it is necessary to calculate a baseline, or 'business-as-usual', solution before the model can be used for policy simulations. This requires assumptions about the future course of key exogenous variables. The model takes the underlying long-run rate of world population growth plus productivity growth to be 2.5% per annum and take the long-run real interest rate to be 5%. It also assumes that tax rates and the shares of government spending devoted to each commodity remain unchanged.

As these assumptions do not necessarily match the expectations held by agents in the real world, the model's solution in any given year, say 2006, will generally not reproduce that year's historical data exactly. In particular, it is unlikely that the costate variables based on current and expected future paths of the exogenous variables in the model will equal the actual values of those variables in 2006. This problem arises in all intertemporal models and is not unique to G-Cubed, but it is inconvenient when interpreting the model's results.

To address the problem, the model adds a set of constants, one for each costate variable, to the model's costate equations. For example, the constants for Tobin's q for each sector in each country are added to the arbitrage equation for each sector's q. Similarly, constants for each real exchange rate are added to the interest arbitrage equation for each country, and a constant for human wealth is added to the equation for human wealth. To calculate the constants, the model uses Newton's method to find a set of values that will make the model's costate variables in 2006 exactly equal their 2006 historical values. After the constants have been determined, the model will reproduce the base year exactly given the state variables inherited from 2005 and the assumed future paths of all exogenous variables.

One additional problem is to solve for both real and nominal interest rates consistently since the real interest rate is the nominal interest rate from the money market equilibrium less the ex ante expected inflation rate. To produce the expected inflation rate implicit in historical data for 2006 the model adds a constant to the equation for nominal wages in each country.

Finally, the model is then able to construct the baseline trajectory by solving the model for each period after 2006 given any shocks to variables, shocks to information sets (announcements about future policies) or changes in initial conditions.