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## Automation, taxes and transfers with International rivalry

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### **Abstract**

Continued automation and declines in low-skill shares of GDP have been widespread globally and linked to inequality. We examine the long-term, global consequences of policies that foster automation or address the distributional consequences of it, using a six-region global macro model. Results depend on whether welfare criteria are Rawlsian, emphasizing the performance of low-skill households, Benthamite, which aggregate pecuniary measures, capital-owner friendly, or simply based on real GDP. Even where automation delivers only bias against the low skilled, we find that the fostering it is a dominant strategy under all but the Rawlsian criterion. We then consider a post automation scenario in which worker displacement is significant, examining inequality-constraining but balance-preserving fiscal interventions, such as tax-financed “earned income tax credits”. These generate only small international spillover effects and are for the most part not preferred under all criteria except the Rawlsian one.

## **Keywords**

Automation, income distribution, taxes, transfers, global modelling

## **JEL Classification**

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**AUTOMATION, TAXES AND TRANSFERS**  
**WITH INTERNATIONAL RIVALRY\***

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# AUTOMATION, TAXES AND TRANSFERS

## WITH INTERNATIONAL RIVALRY

### Abstract

Continued automation and declines in low-skill shares of GDP have been widespread globally and linked to inequality. We examine the long-term, global consequences of policies that foster automation or address the distributional consequences of it, using a six-region global macro model. Results depend on whether welfare criteria are Rawlsian, emphasizing the performance of low-skill households, Benthamite, which aggregate pecuniary measures, capital-owner friendly, or simply based on real GDP. Even where automation delivers only bias against the low skilled, we find that the fostering it is a dominant strategy under all but the Rawlsian criterion. We then consider a post automation scenario in which worker displacement is significant, examining inequality-constraining but balance-preserving fiscal interventions, such as tax-financed “earned income tax credits”. These generate only small international spillover effects and are for the most part not preferred under all criteria except the Rawlsian one.

### 1. Introduction

Since the early 2000s there has been a decline in investment as a share of GDP in the advanced economies, one consequence of which has been a slowdown in the growth rate of total factor productivity (TFP).<sup>1</sup> This, combined with the visible spread of new technology applications in this period is the source of the “Solow paradox”, which highlights the apparent lack of evidence of new technologies in recent productivity statistics.<sup>2</sup> At the same time the steady decline in the share of the low-skilled in value added throughout the OECD and transitional economies has been widely noted (OECD 2012, Autor et al. 2017b).<sup>3</sup> Explanations posited for this are numerous. They include 1) East Asian comparative growth and the resulting surge in labour

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<sup>1</sup> For documentation and discussions on this trend, see Foda (2018), Cetto et al. (2016) and Cardarelli and Lusinyan (2015).

<sup>2</sup> Acemoglu et al. (2016) note Robert Solow's comment in his 1987 *New York Times Book Review* article: “... what everyone feels to have been a technological revolution, a drastic change in our productive lives, has been accompanied everywhere, including Japan, by a slowing-down of productivity growth, not by a step up. You can see the computer age everywhere but in the productivity statistics.”

<sup>3</sup> The complementary rise in the capital share of income is the prime focus of Piketty (2014), Piketty and Zucman (2014) and Rognlie (2015), with Koh et al. (2016) suggesting the change in the capital share is fully explained by the rise in the exchange of intellectual property products (IPPs).

intensive imports by the advanced economies,<sup>4</sup> 2) the rise of intellectual property products as components of intangible capital (Koh et al. 2016), 3) the interaction between IT development and the diminution of competition within IT-intensive oligopolies,<sup>5</sup> and 4) the wider displacement of workers by increasingly intelligent machines.<sup>6</sup> Indeed, the latter effect has been the subject of detailed assessment at the institutional level (IFR, 2018; UNIDO, 2017; World Bank, 2017).

Here we focus on the global, macroeconomic implications of the changes in factor shares, abstracting from the detailed interactions within factor markets that may be causing them. For this purpose it is convenient to think of changes in TFP and factor shares as stemming from “choices of technique”, which we might think of as a generalization of “technology”. By adopting such a characterization of technology, we can examine the economic incentives and impacts of automation and the associated macroeconomic policy responses in a global setting.<sup>7</sup>

We employ a global macro model on six regions with each having low-skill, skilled and capital-owning households. The model is special for the purpose of this application in that it embodies a technology specification that allows the separation of changes in factor bias from those to total factor productivity (TFP). This allows us to assume that the “Solow paradox”, whereby visible automation has not been shown to deliver significant TFP, will continue over decades. The analysis therefore centres on pure bias shocks that reduce the low-skill share of value added to the benefit of capital. Under these circumstances automation is, nonetheless, growth enhancing in that it raises saving rates by virtue of income concentration, the marginal product of capital, expected rates of return on investment and hence capital growth. Initial experiments examine whether, and under what criteria, such automation is domestically beneficial when regions are

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<sup>4</sup> There is a long literature on the roles of Asian finance and trade in labour market performance in advanced economies, with recent contributions including Pierce and Schott (2012), Autor et al. (2013), Arora et al. (2015), Acemoglu et al. (2016) and Tyers (2015b, 2016).

<sup>5</sup> See Ezrachi and Stucke (2016), Moazed and Johnson (2016), Autor et al. (2017a) and Barkai (2017).

<sup>6</sup> See, for example, Acemoglu and Autor (2011), Acemoglu and Restrepo (2015), Susskind and Susskind (2015) and Autor (2016).

<sup>7</sup> While alternative perspectives on this change come under the general headings, “automation”, “robotics”, “artificial intelligence (AI)”, “digitalization” and “computerisation”, we refer to the collective of technical changes that save labour by using more composites of skill and capital as “automation” and so treat automation as change that causes the share of low-skill labor in total factor income to decline and the capital share to rise.

economic rivals. These suggest that the fostering of automation is a dominant strategy under all but a Rawlsian criterion that considers only the welfare of low-skill households.<sup>8</sup>

Once worker displacement is significant, however, the case for balance-preserving yet inequality-constraining fiscal interventions will strengthen. Generalised “earned income tax credit” arrangements financed by additional taxation emerge as marginal or negative across all the advanced economies under a Benthamite criterion, which adds pecuniary welfare measures, and a simple real GDP criterion. They are favoured under the Rawlsian criterion and rejected by capital owners. If implemented, these fiscal interventions vary as to which tax instrument performs best, with raised capital income taxes emerging as the lesser of two evils.

We caution at the outset that these experiments with a calibrated model should be thought of as numerical theory rather than fully fledged empirical analysis. Nonetheless, the results are more than illustrative, by virtue of the model’s calibration to representative data. Section 2 reviews the stylized facts and the existing literature related to these issues. Section 3 outlines the model used, referring for details to an available appendix, Section 4 describes our results and Section 5 concludes.

## **2. Background**

This section first reviews the well-trodden links between automation and inequality. We summarise some elements of the literature on egalitarian fiscal interventions and briefly examine prior work on strategic interactions between regions associated with automation and fiscal responses to it. The emphasis throughout is on the factor bias element of automation shocks, which have been dominant thus far, at least in the advanced economies.

### **2.1 Automation and income inequality**

By affecting relative demands, levels of employment and real rewards to factors of production, automation leads to changes in both inequality and factor shares of GDP. Figure 1 presents trends through time in factor shares for key economies. The well-known trends are evident: low-skill labour shares have fallen, while skilled labour and capital shares have risen. Figure 2 shows

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<sup>8</sup> That automation is, in part, a policy choice is suggested by China’s immense public investments in it (State Council 2015, the National Development and Reform Commission 2016, *The Economist* 2017).

levels of income inequality, as measured by Gini coefficients, along with the restorative effects of fiscal policies on income distributions. Labour shares have fallen, Gini coefficients have risen, yet much of this has occurred while measured TFP has stagnated, at least in the OECD, as indicated in Figure 3.

Several studies aim to shed light on the links between biased technical change and income inequality. Acemoglu and Restrepo (2015) find that inequality increases during technological transitions, but self-correcting forces serve to limit the increase in inequality over longer periods. They see automation as squeezing out tasks previously performed by low-skill labour while creating new tasks, usually more highly skilled, thus increasing inequality between the two labour types. Historically, however, the medium-term implications are moderated by the subsequent standardization of these tasks, allowing them to come available to low-skill workers. The peculiar qualities of AI raise questions as to the parallels with such prior innovations as electrification (Goldin and Katz 1998). These depend on the potential adaptability of AI, leading to the prospect of the singularity (Kurzweil 2005) and the possible elimination of all low-skill jobs (Susskind 2017).

Harris et al. (2018) also consider the time paths of automation effects. They see rapid investment in automation *creating* employment in the early stage, reducing by half the negative impacts of labour saving and easing the demand constraint on growth. As the investment wave recedes, however, this risks deeply unbalanced economies in which growth is deeply demand-constrained, exposing the full magnitude of labour market disruption temporarily hidden from view by the investment boom. As with many shocks to the economy, Pareto improvements from “good” technical changes are only “potential”, requiring complementation by difficult redistributive policies (Arther, 2017). Over time, most technical advances enable more production with less sacrifice, yet history suggests that the concentration of wealth in too few hands leads to social pressures that will either be addressed through politics or violence or both (Wolcott, 2018).

Tyers and Zhou (2017) look at automation in the very long run using an elemental three-household general equilibrium model. They quantify the sources of income inequality, finding that changes in factor bias were the primary causes of the observed increase in the US Gini coefficient between 1990 and 2016 and that, over the next two decades, US labour displacement

could be so large as to necessitate significant fiscal intervention. Zhou and Tyers (2018) apply a similar approach to the rise of inequality in China. They find that, between 1995 and 2015, the combination of structural change and biased technical change raised income inequality, with the latter having the dominant effect. Even there, the prospect of labour displacement emerges as significant if the rate of neutral TFP growth continues to slow, raising the prospect of costly intervention in China as well.

## **2.2 Macroeconomic policy responses to constrain income inequality**

Policies to mitigate the labour displacement and inequality effects of automation include higher wages through collective bargaining or mandated minimum wages. Although the decline in collective bargaining in labour markets has renewed its popularity it has tended in the past to raise unemployment and could therefore exacerbate the effects of automation on labour displacement (Bandholz, 2016). Moreover, the rise of the “gig economy” (software assisted separation of tasks) weakens labour organization and the wage-setting system, exerting downward pressure on wages (Hong et al., 2018). There is also the idea that greater equality could arise from a wider spread of capital ownership, though this has also proved problematic in the past, as in the case of Thatcherite Britain (Freeman, 2015).

The greatest potential for efficient intervention would appear to be the redistribution of wealth and income via fiscal policies. Such policies require two layers of government decisions, the first being a choice of financing instrument (such as raising direct or indirect tax rates) and the second the type of intervention (as between keeping people in employment via earned income tax credits or offering income maintenance without requiring employment as in the universal basic income, UBI).<sup>9</sup> Yet the indirect effects of fiscal policy complicate these choices.

Automation can reduce a government’s tax revenue when fewer human workers cause reduced collection rates of labour related taxes. Payroll taxes generate more revenue than capital income taxes in many countries, and these can encourage the displacement of workers even when it is not otherwise efficient (Abbott and Bogenschneider 2018). In the US there is a further incentive to automate because firms can claim accelerated tax deductions for automation equipment, but

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<sup>9</sup> Bill Gates’ proposed to ease the inequality and offset the social costs implied by automation’s displacement effects via a “robot tax” to finance a UBI. He argues that robots should be taxed—at either their point of installation, or from the profits firms enjoy by saving on the costs of the human labour displaced. The tax revenue generated could be used to retrain workers, and perhaps to finance an expansion of health care and education, which provide lots of hard-to-automate jobs in teaching or caring for the old and sick (Varoufakis, 2017; Shiller, 2017).



not for human wages. Less directly, human workers are also consumers who pay consumption taxes, such as retail sales tax (RST) in the US or value added tax (VAT) in the UK. Because robot workers are not consumers, they are not subject to these indirect taxes and so firms can avoid any associated burden. Pre-existing tax policies are therefore not “neutral” as between robot and human workers, but instead favour automation.

#### *The choice of financing instrument*

When labour replacement is increasing, higher tax rates are required to finance transfer payments to the unemployed. The main issue is then which tax is most efficient at the margin. The two notable alternatives are a rise in the capital income tax rate (the Gates option of “taxing the robots”) and increasing the tax rate on consumption expenditure. Both create negative multiplier effects. Raising the rate of consumption tax increases the consumer price level relative to other prices and so it raises the scale of transfers in order to sustain the real purchasing power of displaced worker incomes. A capital income tax reduces the after-tax, expected rate of return and therefore the rate of future capital accumulation.<sup>10</sup>

#### *The choice of transfer conditions*

Following significant worker displacement, and after taxes are collected, the best transfer policy must be chosen. Bregman (2017) is one of many advocates of the UBI, which is very prominent in the wider social science literature, though national experiments with it have not yet succeeded.<sup>11</sup> The earned income tax credit is functional in at least the US and the UK, albeit under limited conditions suggesting the possibility of its generalization to all workers earning very low incomes. In the Tyers-Zhou (2017) single country study of worker displacement from automation in the US, the generalized earned income tax credit system, emerges as superior to direct transfers, with financing from taxes on consumption, rather than capital income. By contrast, the similar analysis for the case of China (Zhou and Tyers 2018), while favouring the earned income tax credit system, suggests reliance principally on consumption tax.

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<sup>10</sup> Neither is simple politically. In 2017, the European Parliament voted down a proposed “robot tax”, effectively an additional tax on capital income, citing concerns over stifling innovation (Reuters, 2017). Around the same time, South Korea announced “the world’s first robot tax”, by limiting tax incentives for businesses investing in automation (Yoon, 2017).

<sup>11</sup> The Finland government conducted Europe’s first national government-backed experiment in giving citizens free cash. Since January 2017, a random sample of 2,000 unemployed people aged 25 to 58 have been paid a monthly €560 (£475), with no requirement to seek or accept employment. However, Finland decided not to extend its widely publicized two-year basic income trial and to explore alternative welfare schemes instead (The Guardian, 2018).

### **2.3 Strategic interaction between nations**

Competition between firms, nations, and major trading blocs has taken the form of fostering technological gains. Early mechanization, using waterpower and steam power, had 18th-century British writers conceding that machinery might “destroy the necessity of labour” but still recommended its introduction, because other nations would otherwise out-compete Britain (Mokyr et al., 2015). In the more modern context, adoption of labour saving technology is also a response to the rising cost faced by firms in adjusting labour forces during business cycles and the requirement to produce with greater flexibility tailored to immediate customer demand.

There are interactions between nations, however. Spillovers from successful nations stem from their greater capital income, increased saving and lower real interest rates. In today’s integrated global financial market this raises investment and the capacity for innovation in other nations as well. The bulk of new investment is concentrated in the leader, however, with the medium run consequence that capital accumulation is faster there and, with reduced low-skill wages, its real exchange rate depreciates. The pattern of trade therefore adjusts to favour the leading nation, which experiences inflationary pressure while central banks in other nations must fight deflation.

Nations also interact via fiscal responses to labour displacement. Foreign technical development can be facilitated by a leading nation’s application of direct disincentives to innovate, due for example to taxes on technology *use*. More generally, increased home taxation of capital income raises relative rates of return on capital growth and associated technology installation abroad. Increased home taxation of consumption expenditure is similar to a flat tax on all income, yielding a disincentive to earn and a decline in effort levels and economic dynamism. In what follows we assess the effects of unilateral and multilateral drives to foster automation and of fiscal interventions to moderate its distributional impacts. The spillovers that emerge are those transmitted by financial and product markets.

### **3. Modelling automation, taxes and transfers in a global context**

To obtain an assessment of international rivalry related to automation and fiscal responses to worker displacement, we construct a model of the global macro-economy and simulate the effects of automation with and without fiscal responses. We describe the model in detail in an

accompanying appendix. In what follows we offer a general summary, detailing some key features of particular relevance to the automation experiments that are the focus of this paper.

It identifies six regions, the US, the EU, Japan, China, Australia and the Rest of the World. The EU is modeled as the full 28 and it is assumed that this collective has a single central bank. In each region there are three households, each with factor-specific income (from low skill labour, skill and physical capital) and each with different reduced form consumption behavior that depends on the regional real interest rate and the current and expected future real disposable income. The disposable income of each depends on different tax rates on the three types of factor income, unemployment benefits that flow to the low-skill households and household-specific transfers. Regional production depends on the three primary factors: low skill labour, skilled labour and physical capital, and the use of tradable intermediate goods, with a technology specification that depends on “relative” factor and input use, enabling the separation of shocks to TFP from those to factor shares.

At its core the model’s economic behavior centres on a characterisation of global financial and product markets as trading regionally differentiated assets and products with investment patterns driven in each region by portfolio managers allocating new saving across regions to maximise expected after-tax portfolio returns. In the short run, expected rates of return depart from regional, long maturity bond yields, the latter reflecting equilibria in regional financial markets as between savers, indebted governments and investors. Governments derive revenue from direct taxes on income to each factor and indirect taxes on trade and consumption. Their expenditure is on goods and services and on household-specific transfers. Changes in the scale of sovereign debt alter regional interest premia and therefore affect financial flows.

In each region the demand for the regional currency is driven by a “cash in advance” constraint and, because long maturity assets dominate portfolios, the opportunity cost of money holding is the regional long maturity yield. Central banks derive region-specific monetary expansions from conventional and unconventional monetary policy (UMP), with reliance on the market segmentation theory of the yield curve (Johnson et al. 2010) ensuring that only UMP has a direct effect on markets for long term bonds. Short rates are therefore not modelled explicitly, rather the monetary base in each region is determined as endogenous to the target of monetary policy and regional parameters determine the share of any change in the monetary base that takes the

form of long asset balance sheet expansion. UMP expansions raise home long maturity asset prices and reduce long yields, causing imperfect spill-overs across regions due to global arbitrage that is only partially constrained by asset differentiation.

### *Global financial markets*

Each region's financial market is represented as the market for domestic long maturity assets. Purchasers of these assets are assumed to respond to changes in an expected rate of return on installed domestic capital, which is net of depreciation and capital tax and adjusted for sovereign risk. This rate of return is inversely proportional to the stock of utilized regional capital and its expected future value is first adjusted by a sovereign risk factor and then embedded in an interest parity condition that provides for incomplete arbitrage. Finally, a sovereign risk factor is added to reflect that deteriorating fiscal balances cause investment to be less attractive. The domestic demand for investment financing then depends on the ratio of the expected real rate of return on installed capital, which is defined as after capital income tax, and the real long bond yield that clears the domestic financial market,  $r$ .<sup>12</sup> Since the numerator indicates the market value of domestic assets and the denominator the cost of financing their replacement, this is in the tradition of Tobin's Q.

This investment demand is then matched in each region by a supply of saving that incorporates contributions from all regional households and governments. Here the modelling incorporates explicit portfolios of assets from all regions. Data on regional saving and investment is first combined with that on international financial flows to construct an initial matrix to allocate total domestic saving in each region to investment across all the regions. From this is derived a corresponding matrix of initial shares of region  $i$ 's net (private and government) saving that are allocated to the local savings supply that finances investment in region  $j$ . When the model is shocked, the new shares are calculated so as to favour investment in regions,  $j$ , whose real after tax yields are boosted by the shock. Since these are portfolio investments, the real rate of return available in each region is assumed to be the domestic market clearing yield,  $r$ .

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<sup>12</sup> Since firms do not incur tax when issuing stock or bonds, no taxation is applied in the denominator.

### *Money markets*

Within each region the demand for money is driven by a “cash in advance” constraint. For any one household, home money is held in a portfolio with long maturity bonds, which are claims over physical capital, combined with home and foreign long maturity government debt, and so the opportunity cost of holding money is the long maturity yield. The cash-in-advance constraint is assumed to generate transactions demand for home money across all components of gross (including intermediate) output. To account for the observed dominance of financial transactions over money demand responsiveness to the real purchasing power of financial wealth is also included.<sup>13</sup> The opportunity cost of holding home money is set at the nominal after-tax yield on home, long-term bonds.<sup>14</sup> Real money balances are measured by purchasing power over home products at the GDP price,  $P^Y$ .

For region  $i$ ,  $y_i$  is real, regional gross output, as distinct from real GDP since intermediates are transacted as well as goods and services entering final demand. The consumer price level,  $P^C$ , is defined as a CES aggregate of home and imported consumer prices (excluding exports and domestic intermediate demand). Real financial wealth or assets,  $w^F$ , is represented as the present value of an infinite stream of real dividends that are equal to after-tax returns on the capital stock, at the expected real rate of return on installed capital,  $r^{ce}$ , discounted at the current real financing rate,  $r$ . A price adjustment is also made for relative inflation or deflation of capital goods prices, which raise or lower the purchasing power of financial wealth over home products.<sup>15</sup>

On the supply side of the money market, the proportion of expansions that occur via the purchase of long maturity assets (UMP) is parameterised. Conventional expansions directly affect the money supply while UMP expansions affect both it and the long end of the yield curve. UMP

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<sup>13</sup> The inclusion of financial wealth in the money demand equation follows Ragot (2014) and Mena and Tirelli (2017), who incorporate Baumol (1952) – Tobin (1956) behaviour.

<sup>14</sup> Thus, it is assumed here that the opportunity cost of holding money is measured by the long bond yield, which is the dominant determinant of non-money portfolio yields. Short rates, at least as they have a role in conventional monetary policy, are here embedded in the determination of the monetary base. While housing investment can be sensitive to short rates in economies where most mortgage contracts have variable rates, the assumption that investment financing depends on the long maturity market is a simplifying abstraction in this global analysis.

<sup>15</sup> The last three decades have exhibited advanced region asset price inflation that has exceeded that in goods, for the US by at least six percentage points per year on average, suggesting a rising path of this ratio. This comparative growth in financial wealth is due to the many determinants of wealth inequality, including the forces discussed in this paper.

expansions raise home long maturity asset prices and lower long yields, causing imperfect spillovers due to global arbitrage that is only partially constrained by asset differentiation.<sup>16</sup>

Regional financial market clearance requires that the home financial market in each region clears separately and this implies global financial market clearance. For each region the nominal value of domestic investment represents the sum total of all domestic long bond issues. This is then equated with demand for those bonds from home and foreign (net private and government) savings, along with demands for home long bonds that arise from the “quantitative easing” components of monetary expansions by both home and foreign central banks. Financial balance then requires that total investment spending in each region, in its local currency, is equated with the total supply of financing directed from all represented regions. These flows are originally in foreign currency and so are converted at the appropriate cross exchange rates. The regional real bond yields emerge from this equality. Their convergence across regions is larger the larger are the elasticities of asset substitution across regions.

Nominal exchange rates emerge from the balance of payments condition, which requires that, for each region, the sum of net inflows of payments on the current account and net inflows on the capital and financial accounts, measured in a single (home) currency is zero. A balance of payments in the US is implied by balance in all the other regions.

### *The supply side*

Each region supplies a single differentiated product that is exported, consumed at home and used as an intermediate input both at home and abroad. Production of both final and intermediate goods depends on the same three primary factors with low-skill labour a partially unemployed variable factor while the stocks of physical capital and skill are exogenous and fully employed. Production of final goods draws on these factors and a combination of intermediate inputs comprising the home product and imports of products supplied abroad. This allows the capture of differences between the international effects of a policy change in one large country that are due to the dependence of smaller countries on the supply of inputs on the one hand or final products on the other.

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<sup>16</sup> By contrast, conventional monetary policy involves trade in short term instruments which has no direct impact on the market for long term bonds. Short rates are therefore not modelled explicitly, rather the monetary base in each region is determined as endogenous to the target of monetary policy and an exogenous parameter determines the share of any change in the monetary base that takes the form of long asset balance sheet expansion.

The central production technology is expressed in Cobb-Douglas form. Output and factor inputs are included as relative to initial levels so that shocks to productivity or factor shares do not imply changes in initial output volumes, thus facilitating the subsequent decomposition of technology shocks as between productivity and factor or input bias. In region  $i$  gross output volume,  $y_i$ , is a Cobb-Douglas composite of real value added,  $v_i$ , and of intermediates,  $q_i$ .

$$(1) \quad \frac{y_i}{y_i^0} = \left( \frac{A_i^Y}{A_i^{Y0}} \right) \left( \frac{v_i}{v_i^0} \right)^{\beta_i^Y} \left( \frac{q_i}{q_i^0} \right)^{(1-\beta_i^Y)}, \forall i, i \in (\text{regions}),$$

where  $A^Y$  is total (factor and input) productivity. Value added, in turn, has Cobb-Douglas dependence on domestic primary factors, raw labour,  $L$ , skill,  $S$  and physical capital,  $K$ .

$$(2) \quad \frac{v_i}{v_i^0} = \left( \frac{A_i^V}{A_i^{V0}} \right) \left( \frac{L_i}{L_i^0} \right)^{\beta_i^L} \left( \frac{S_i}{S_i^0} \right)^{\beta_i^S} \left( \frac{K_i}{K_i^0} \right)^{\beta_i^K}, \sum_f \beta_i^f = 1, \forall i, f \in (\text{factors}).$$

To allow for inter-regional substitution in intermediate demand across regional sources, domestically employed intermediate inputs,  $q$ , are a CES composite of products acquired from all regions:

$$(3) \quad q_i = \left( \sum_j \alpha_{ij}^Q q_{ij}^{-\theta^Q} \right)^{-\frac{1}{\theta^Q}}, \forall i,$$

where  $q_{ij}$  is the quantity of region  $j$ 's product that is absorbed by production in region  $i$ .

The composite prices of value added and intermediate inputs are related via:

$$(4) \quad \frac{P_i^V}{P_i^P} = \beta_i^V \frac{y_i}{v_i}, \quad \frac{P_i^Q}{P_i^P} = (1 - \beta_i^V) \frac{y_i}{q_i}, \forall i.$$

Here  $P_i^P$  is the producer price level – the factory gate price of region  $i$ 's product. The real production wages of unskilled and skilled workers and the capital rental rate depend conventionally on the corresponding marginal products.

The gross volume of output,  $y$ , is distinguished from real GDP, which is that portion of output that meets final demand, excluding intermediate use, and which equates to real value added,  $v$  in

(1). The complete set of demands facing country  $i$ 's industries, which must sum to equate with (1), takes the form:

$$(5) \quad y_i = \frac{I_i + G_i}{P_i^P} + \sum_j c_{ji} + \sum_j q_{ji} ,$$

which is a real version of the standard expenditure identity (on the homogeneous domestic output of region  $i$ ) with intermediate demand included.  $I$  and  $G$  are nominal gross investment and nominal government spending net of transfers,  $c_{ji}$  is the volume of final consumption of region  $i$ 's product in region  $j$ , and  $q_{ji}$  is the volume of region  $i$ 's product that is absorbed as intermediate inputs by production in region  $j$ . Net trade is embodied in the second term and real GDP omits the final term. Equating this with (1) determines producer price levels,  $P^P$ , in each region. Producer cost minimisation at these prices then determines all the unit factor rewards.

### *Household disposable income*

Disposable income, for each household, takes the form:

$$(6) \quad Y_{hi}^D = s_{hi}^L \left[ (1 - t_i^L) W_i L_i + \alpha_i W_i^o (F_i - L_i) \right] + s_{hi}^S (1 - t_i^S) W_i^S S_i^K + s_{hi}^K (1 - t_i^K) K_i (P_i^P MP_i^K - P_i^K \delta_i) + T_{hi}^R, \quad \forall h$$

Where  $s_{hi}^f$  is the ownership share of household  $h$  in region  $i$  of factor  $f$ .  $[s_{hi}^f]$  is a unit diagonal matrix in this analysis.  $K_i$  is the regional capital stock,  $F_i$  is the labour force,  $W_i$  is the nominal low-skill wage rate,  $W_i^S$  is the corresponding skilled wage and  $t_i^f$  is the direct tax rate on income to factor  $f$ .  $P_i^K$  is the price of capital goods in region  $i$  and  $\delta_i$  is the corresponding depreciation rate.  $T_h^R = t_h^R N_h Y$  is a direct transfer to the household from government revenue, with  $t_h^R$  the transfer rate to household  $h$  per unit of group population,  $N_h$ , and per unit of nominal GDP.<sup>17</sup>

For each household,  $h$ , in region  $i$ , consumption expenditure,  $C_{hi}$ , is a nominal sum but real consumption behaviour is motivated by current and expected future real, per capita, disposable incomes and the real interest rate. Real consumption, (lower case)  $c_{hi}$ , depends negatively on the after-tax real return on savings (the home bond yield,  $r$ ) and positively on both current and expected future real disposable income per capita for that household:

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<sup>17</sup> The expression (12) is more complex if the labour force participation rates of low skill workers,  $\lambda_{Lh}$ , are unequal across households and, similarly, if participation rates of skilled workers,  $\lambda_{Sh}$ , are unequal across households. The simpler expression is offered here since this is not the case in this analysis. The participation rates within skill groups and across households are kept equal in the experiments conducted, although the rates differ *between* skill groups and may be differently shocked.



$$(7) \quad c_{hi} = \frac{C_{hi}}{P_i^C} = N_i^h A_{hi}^C \left( \frac{r_i}{\tau_i^h} \right)^{-\varepsilon_{hi}^{CR}} \left( \frac{Y_{hi}^D}{N_i^h P_i^C} \right)^{\varepsilon_{hi}^{CY}} \left( \frac{Y_{hi}^{De}}{N_i^h P_i^C [1 + \pi_{hi}^{Ce}]} \right)^{\varepsilon_{hi}^{CY}},$$

where the tax rate on interest income,  $\tau^h$ , is household specific, set as the tax rate on the households dominant source of direct factor income. The expected inflation rate of the consumer price level is  $\pi^{Ce}$ . The elasticities in this expression vary by household, ensuring different consumption responses.

#### *Consumption driven trade and composite pricing*

To capture the home household's substitution between home and foreign products, real aggregate consumption in region  $i$  is a CES composite of region  $i$ 's consumption of products from all regions:

$$(8) \quad c_i = \left( \sum_j \alpha_{ij}^C c_{ij}^{-\theta_i^C} \right)^{-\frac{1}{\theta_i^C}}$$

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

$$(9) \quad C_i = P_i^C c_i = P_i^P \tau_i^C c_{ii} + \sum_{j \neq i} \tau_i^C \tau_i^M \tau_j^X c_{ij} P_j^P \frac{E_j}{E_i},$$

where  $\tau_i^C$  is the power of region  $i$ 's consumption tax. Optimum consumption is consistent with an elasticity of substitution between home and foreign products of  $1/(1+\theta_i^C)$ . Given these consumption volumes, the composite price of all consumption, or the consumer price level, emerges as:

$$(10) \quad P_i^C = \tau_i^C \left[ \left( \alpha_{ii}^C \right)^{\sigma_i^C} \left( P_i^P \right)^{1-\sigma_i^C} + \tau_i^M \sum_{j \neq i} \left( \alpha_{ij}^C \right)^{\sigma_i^C} \left\{ \frac{P_j^P E_j}{E_i} \right\}^{1-\sigma_i^C} \right]^{\frac{1}{1-\sigma_i^C}}.$$

The above are critical equations in this model of the global macro-economy. The complete model is documented in the appendix, which is available upon request from authors.

## 4. Results

The simulations for which we present results adopt long run closures. This implies clearing markets for low-skill labour, the retention of fiscal balance at 2016 levels and endogenous capital stocks at 2016 levels of the expected net rates of return on capital.<sup>18</sup> Fiscal balance is retained in this case by allowing the consumption tax rate to vary, while holding constant the level of government expenditure on goods and services. The central shocks are to the factor shares of value added ( $\beta^L$  and  $\beta^K$  in equation 2) with the low-skill share falling and a complementary rise occurring in the capital share.

We extrapolate the low-skill labour share based on the experience of the US in previous decades, as indicated in the projection components of Figure 4. In this figure, historically recorded factor shares are shown, between 1970 and 2016, while a long run scenario is constructed for shares beyond this period, by simple extrapolation, extending to 2036. We introduce no growth in the skill share to reflect the recent slowdown in the growth of that share, possibly due to an offset between the encroachment of automation on professional employment on the one hand and the creation of new professional jobs on the other (Autor 2016, Beaudry et al. 2017). When we apply the proportional changes to shares indicated in the projections of Figure 4 to any region, it is our implied assumption that, for the advanced regions and China, the prospective pure bias effects of new technology will be the same as they are for the US.<sup>19</sup>

### *Is there an economic first mover advantage in implementing automation?*

Here we assume that governments can initiate automation drives and thereby influence the rate of uptake of new technology. We apply the factor share twist, representing an automation drive, in the US, the EU and China, one at a time, as well as in all advanced regions simultaneously. The long-run economic effects of these shocks are summarised in Table 1. They have the following key elements. Unilaterally, the expected reduction in the market clearing low-skill wage and the rise in inequality, as measured by the Gini coefficient, are clear. The inequality

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<sup>18</sup> Results from short run analysis are available on request from the authors. These depend more substantially on closures that dictate monetary policy targets. Our assumption in both short and long run analyses is that the advanced economies' central banks target consumer price inflation at zero and that inflation expectations are anchored at that level. In the case of China and the rest of the world the monetary policy target is the nominal bilateral exchange rate with the US and consumer behaviour is assumed to be affected by money illusion.

<sup>19</sup> Of course, factor bias effects have sources other than industrial choice of technique. In China, for example, structural change explains a great deal of its historical trends in factor shares (Zhou and Tyers 2018). We deal here only with the shifts in shares due to automation, as defined earlier in the paper.

effects do not spill over to other nations, in part because the effects on real low-skill wages in non-implementing regions are positive. This is mostly due to exchange rate effects. As discussed in Section 2, implementing nations have substantial real depreciations and these reduce consumer prices in other regions.

There is also a substantial rise in the asset to GDP ratio in implementing regions confirming that the increases in income inequality accompany corresponding increases in inequality of wealth. This does spill over to other regions, mainly because of the declines in long bond yields that occur in response to greater income concentration in the implementing region and therefore greater saving globally, in combination with the partial integration of global capital markets represented in the model. With lower real long bond yields globally, investment levels and long run production capacity rise everywhere, though to a dominant extent in the implementing region.

When all advanced regions implement the technology the real consumption wage reductions are moderated but not the inequality increases. This is because the effects of the widespread introduction of the technology raises global capital income and saving rates by substantially more, pushing real bond yields further down and asset prices further up. This does, however, have the positive consequence of greater capital growth globally.

The welfare effects of implementation and, therefore its strategic advantages, depend on the criterion chosen. Consider a Rawlsian criterion that values only the welfare of the poorest. In this case the dominant strategy is for no region to allow automation. The low skilled are losers in all implementing regions. Were the criterion to be the welfare of the skilled or professional households, the dominant strategy is to implement the automation, though this is more marginal in China, where the economic health of the low skilled has a significant bearing on skill demand. If the criterion were the welfare of capital owners, the dominant strategy is to implement in all regions. The same is true if the criterion is real GDP, which might be thought of the “government interest” criterion, given that real GDP indexes the tax base.

#### *Strategic issues in Gini-sustaining fiscal responses and their financing*

Our analysis focusses on avoiding greater inequality through the earned income tax credit. We achieve this by first imposing a more modest automation shock than before in all the advanced economies, including China. Regions implementing the fiscal response then hold their Gini

coefficients constant by adjusting an endogenous flow of transfers to low skilled working households. This flow is financed by increasing either the consumption tax rate or the rate of capital income tax. The results are summarized in Table 2, which shows the marginal effects of the fiscal intervention alone (excluding the primary effects of the automation shocks) on variables that are central to decision making. The most general conclusion from the table is that international interactions due to fiscal policy changes that preserve fiscal balance are very small. The regional effects of unilateral implementation of earned income tax credits are dominant and very similar to the regional effects of collective implementation.

Consider the consumption tax financing alternative first. Low-skill households would be beneficiaries but total welfare would be slightly impaired and there would be no gain or loss to real GDP. Only under a Rawlsian criterion would the US consider this fiscal intervention. By a small margin, the preferred option of the US would be to press China to implement the policy. This is because it receives small but positive spillovers due to the redistribution of global investment that would take place were China to implement the policy. The perspective of the EU is more positive. Though its capital owners would prefer not to implement, its low-skill and skilled workers would be net beneficiaries and its GDP would expand slightly. As for the US, the EU would also gain from implementation by China. By contrast, while a Rawlsian strategy in China would see the policy implemented, it would be costly to the other groups, to total welfare and to GDP growth, and so it is likely a non-starter there. This is because the consumption tax adjustment required in China to stabilize the Gini would push the rate to 50 per cent, which would cut China's real GDP growth by more than other regions and so be impossible politically. Ironically, by most criteria the Chinese best strategy is to press the US to implement it.

Next consider the financing of the policy by increases in the tax rates on capital income. Under a Rawlsian criterion all regions would implement the policy as before, though by a small margin the low-skilled would prefer collective rather than unilateral implementation. By the other criteria the US would not, the EU might on total welfare grounds and the Chinese would not. Stabilising the Gini by this means would require capital income tax rates to rise by about 15 percentage points for the three regions.<sup>20</sup> This would be politically difficult, though more

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<sup>20</sup> The change for Japan would be larger because of its initially low rates of indirect taxation.

affordable in the case of China than the consumption tax option. If, by some means, the three large economies were forced to implement the policy, a total welfare criterion would have them preferring to finance it by capital income taxation, while a real GDP criterion would see governments preferring the consumption tax.

## 5. Conclusion

With its potential to replace labour with machines in various tasks, automation not only threatens the low skilled but also the skilled. Yet the task-creating elements of automation suggest a greater likelihood that the negative impact on employment and real wages will be greater for low-skill than for skilled workers. The fall in real wages of low-skill workers and the rise in returns to capital and skill will continue to exert upward pressure on income inequality. In this study, we examine the incentives for nations to drive the uptake of automation, the risks to welfare and income inequality under automation, and the effects of fiscal responses to alleviate income inequality. In particular, we simulate these changes and scenarios in a global macro model featuring six regions, and therefore are able to consider strategic interactions between nations.

We look into the coming decades, which are expected to see a continuation in the technical twist away from low-skill labour, though this is more likely in the future than in the past to benefit the owners of physical capital rather than skill. This is widely expected to stem from recent accelerations in the development of increasingly adaptable artificial intelligence in combination with robotics. These changes have occurred in the absence, thus far, of significant recent gains to TFP, which does not imply that they do not foster economic growth, though this occurs via increasing returns to capital, increased saving and more rapid capital accumulation and without significant gains in real wages.

In our modelling we first examine whether there is a national, *economic*, first-mover advantage in implementing automation by individual countries, finding no evidence for this due to positive economic spill-overs that act through capital earnings and financing costs. Indeed, unless Rawlsian policy criteria are ubiquitous, in which case governments would resist implementation, the technology twist is a dominant strategy for all regions. We then turn to balance-preserving fiscal interventions to inhibit changes in income inequality, focussing on the earned income tax

credit system and the stabilisation of the Gini coefficient. With the preservation of fiscal balance we find only weak spill over effects, even where financing is via taxes on income from internationally mobile capital. Again, apart from Rawlsian criteria, the dominant strategy in most cases is for governments to refrain from equalising fiscal interventions.

These results paint a pessimistic story about the feasibility of fiscal interventions to stabilise income distributions in the face of accelerated automation. Apart from the EU, where the case for intervention is marginal on total welfare grounds, in the advanced regions only a lurch to policy criteria of the Rawlsian type would see this happen. Moreover, international spillovers from interventions that retain fiscal balance appear too small for there to be a more egalitarian global equilibrium.

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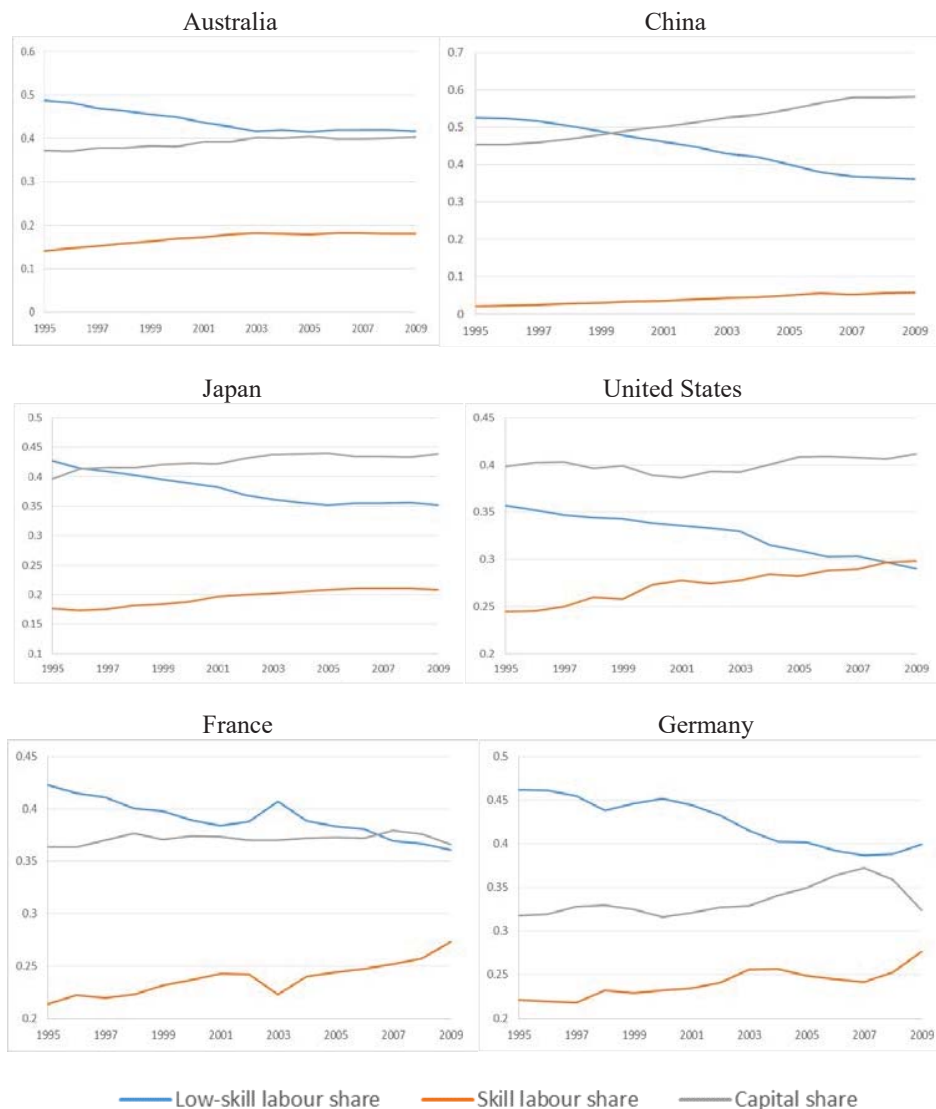
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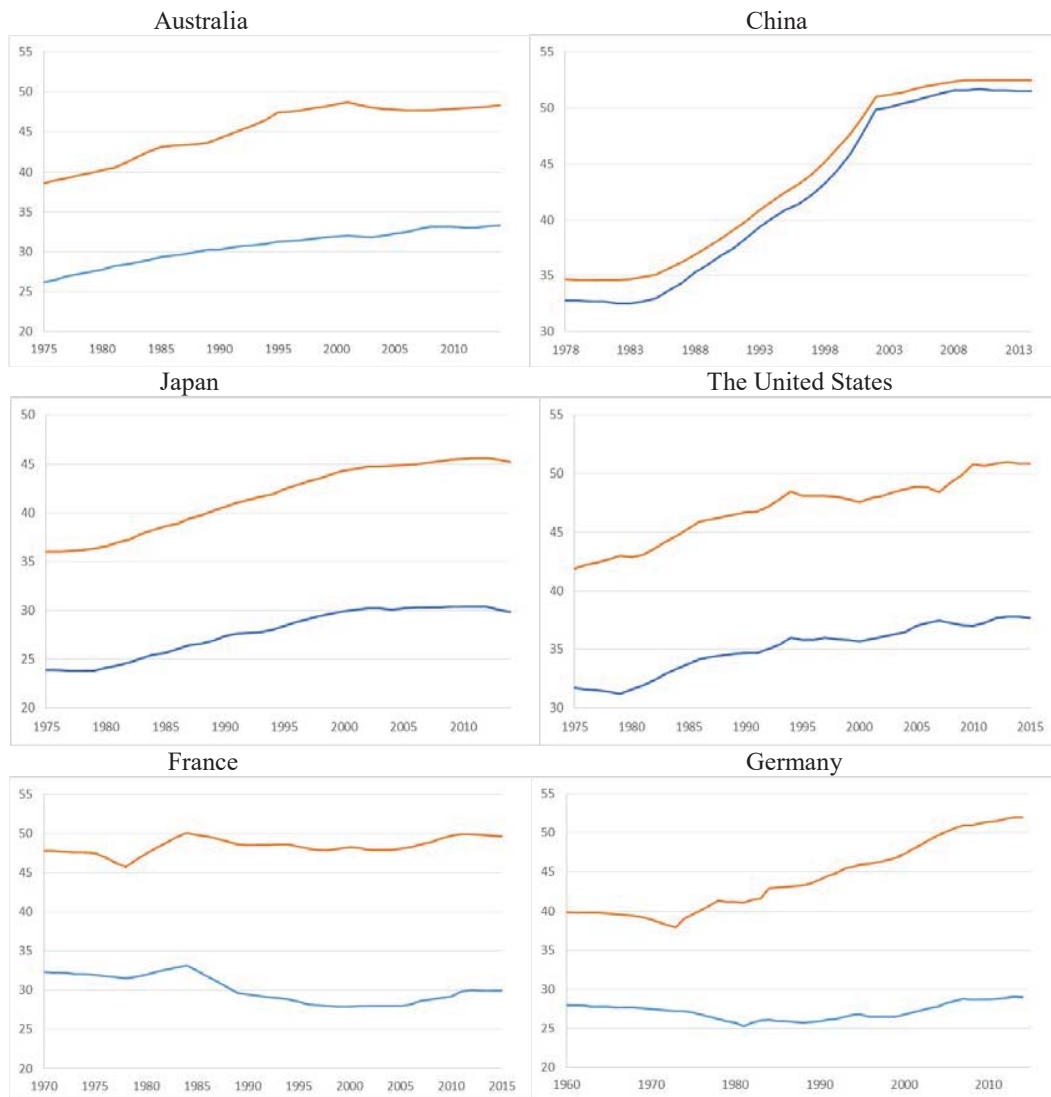
**Figure 1. Factor shares in selected economies, 1995-2009**



Note: The capital share is calculated as the share of payment for capital in value added; labour share is the share of payment to medium- and low-skilled persons in value added; skill share is the share of payment to highskilled persons in value-added. Labour skill types are classified on the basis of educational attainment levels as defined in the International Standard Classification of Education (ISCED): low-skilled (ISCED categories 1 and 2), medium-skilled (ISCED 3 and 4) and high-skilled (ISCED 5 and 6). Capital compensation is derived as a residual and defined as gross value added minus labour income. Hence it is the gross compensation for capital, including profits and depreciation allowances. Because of its derivation as a residual, it reflects the remuneration for capital in the broadest sense. This does not include only traditional reproducible assets such as machinery and buildings, but it also includes non-reproducible assets. Examples are mineral resources and land, intangible assets (such as R&D knowledge stocks, software, databases, brand names and organizational capital) and financial capital.

Source: authors' own calculation based on data from the World Input Output Database (WIOD) (Timmer et al. 2015).

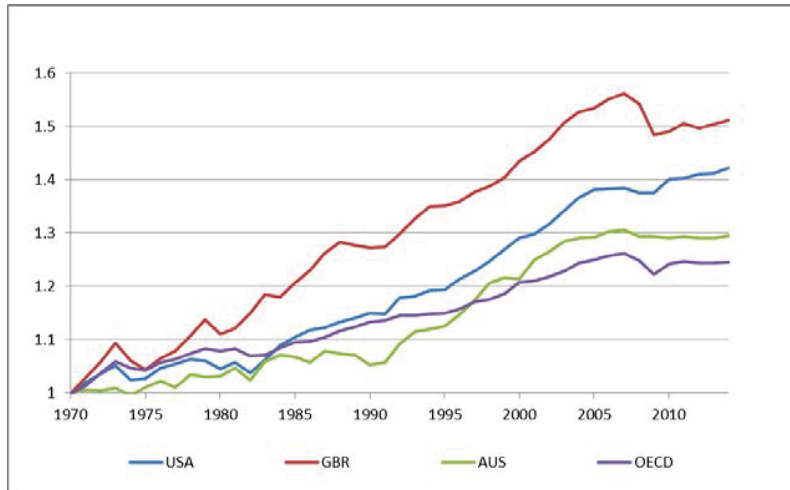
**Figure 2. Gini coefficients before and after taxes and transfers**



Source: SWIID database.

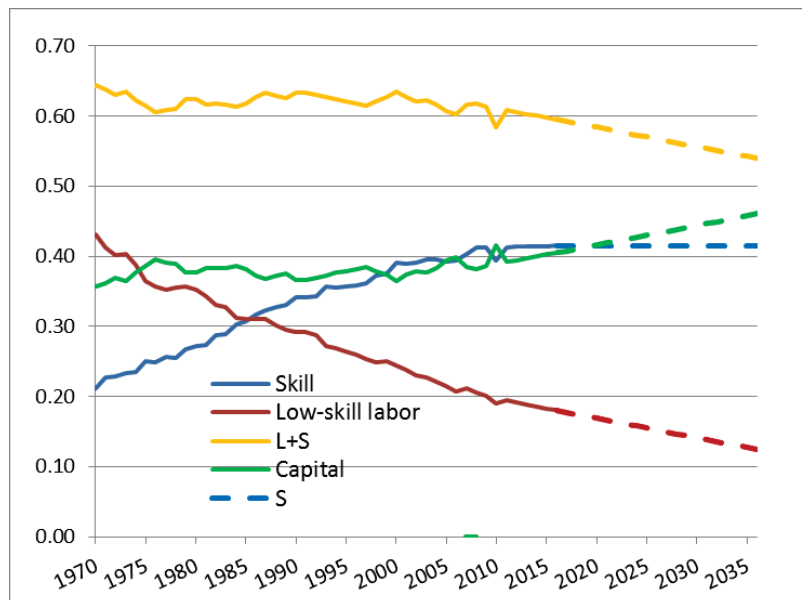
Note: The orange line is Gini index of inequality in equivalized household market (pre-tax and pre-transfer) income. The blue line is Gini index of inequality in equivalized household disposable (post-tax and post-transfer) income.

**Figure 3. Total factor productivity, 1970-2014**  
 (United States, United Kingdom, Australia, OECD overall)



Source: Penn World Tables, international comparisons of production, income and prices, version 9.0. TFP is the portion of output change not explained by the quantities of inputs used in production and is reported at constant national prices (2011=1). We normalize the data to set TFP in 1970 at unity.

**Figure 4. Past and projected factor shares of value added in the US**



Source: Authors' own calculations, based on Tyers and Zhou (2017).



**Table 1. First mover effects of the technical twist against low skill, favouring capital<sup>a</sup>**

Effects on:  of technical change <sup>b</sup> in:	US				EU				China			
	US	EU	China	US, EU, Japan, China, Australia	US	EU	China	US, EU, Japan, China, Australia	US	EU	China	US, EU, Japan, China, Australia
Welfare <sup>c</sup> (low skilled)	-11.1	1.3	2.3	-6.7	4.7	-11.6	1.8	-5.6	4.8	5.5	3.9	3.4
Welfare <sup>c</sup> (skilled)	10.2	1.4	2.5	15.8	5.0	11.5	1.9	19.6	4.8	5.6	4.1	40.3
Welfare <sup>c</sup> (capital owning)	28.5	1.4	2.5	35.1	5.0	33.3	1.9	43.1	5.1	5.6	56.3	73.5
Welfare <sup>c</sup> (total)	9.8	1.4	2.4	15.3	4.9	10.1	1.8	18.0	4.9	5.6	25.2	38.8
Gini coefficient	25.9	0.1	0.1	26.1	0.3	32.0	0.1	32.5	0.2	0.0	28.8	29.0
Real low skill consn wage	-22.8	1.4	2.5	-18.8	5.0	-21.8	1.9	-16.0	5.1	5.6	-11.2	-1.4
Real GDP	11.3	0.2	0.3	12.3	0.8	13.0	0.2	14.7	0.3	0.9	35.0	38.6
Real effective exch rate	-16.3	7.7	11.2	2.9	11.3	-22.6	6.3	-8.0	4.6	7.4	-26.8	-18.0
Financial assets/GDP ratio	50.3	4.0	3.6	68.9	12.8	48.9	3.2	81.2	14.9	3.4	82.2	124.9
Real long bond rate	-12.2	-3.4	-2.9	-20.7	-9.7	-6.5	-2.5	-20.9	-10.6	-2.0	2.6	-21.2
Real investment	13.9	3.6	2.9	26.1	10.8	6.9	2.6	26.5	11.9	2.0	8.0	26.9

a The length of run is sufficient to allow the global distribution of capacity (capital stock) to adjust to sustain the initial levels of the expected net rate of return across regions. The consumption tax rate adjusts to sustain fiscal balance and the initial level of government spending. The real low-skill wage adjusts to maintain full employment.

b The shock is a (two decade) 30% reduction in the value added share of low-skill labour and a corresponding rise in the capital share, corresponding to the projection for the US in Figure 4 but applied in the advanced regions and China.

c The standard welfare measure is the purchasing power at domestic consumer prices of household specific disposable income per capita.

Source: Simulations using the model described in the text.

**Table 2. Marginal effects (%) of generalised earned income tax credits that sustain Gini coefficients following tech twist<sup>a,b</sup>**

	Effects on:	US				EU				China			
	Tax credits implemented <sup>c</sup> by:	US, EU, Japan, China, Australia				US, EU, Japan, China, Australia				US, EU, Japan, China, Australia			
Welfare measure <sup>d</sup>	Financed by tax on:	US	EU	China	Australia	US	EU	China	Australia	US	EU	China	Australia
W (low skill)	Consumption	14.9	-0.2	0.9	15.9	-0.7	16.7	0.2	15.7	0.3	-0.6	0.0	-0.7
	Capital income	13.2	-0.2	-0.2	12.9	-0.2	16.2	-0.1	15.9	-0.1	-0.6	12.9	12.4
W (capital owning)	Consumption	-8.5	-0.2	1.1	-7.5	-0.9	-8.5	0.3	-9.5	0.3	-0.8	-37.4	-38.0
	Capital income	-19.6	-0.2	-0.2	-12.1	-0.2	-11.2	-0.1	-11.4	-0.1	-0.9	-25.5	-26.1
W (total)	Consumption	-0.8	-0.2	1.0	0.2	-0.8	1.2	0.3	0.2	0.3	-0.7	-19.7	-20.3
	Capital income	-0.5	-0.2	-0.2	-0.7	-0.2	2.1	-0.1	1.9	-0.1	-0.7	-6.6	-7.1
Real GDP	Consumption	0.0	0.0	0.2	0.1	-0.3	0.3	0.0	0.1	0.0	-0.2	-2.8	-3.0
	Capital income	-1.7	-0.1	0.0	-1.8	-0.1	-1.5	0.0	-1.6	-0.1	-0.2	-10.2	-10.4

a The length of run is sufficient to allow the global distribution of capacity (capital stock) to adjust to sustain the initial levels of the expected net rate of return across regions. The consumption tax rate adjusts to sustain fiscal balance and the initial level of government spending. The real low-skill wage adjusts to maintain full employment.

b The primary shock is a 20% reduction in the value added share of low-skill labour and a corresponding rise in the capital share, more modest than the projection for the US in Figure 4 but applied in the advanced regions and China. This table shows the per cent changes in welfare measures and real GDP that are achieved by the fiscal response in isolation – that is, the differences between the effects on welfare measures due to automation alone and the effects due to automation with fiscal intervention.

c Additional elements of the closure in this case are that, for the fiscal policy implementing region(s) only, the Gini coefficient is made exogenous along with government expenditure on goods and services. Fiscal balance is then achieved by making endogenous the rate of transfer to the low-skill household, along with either the capital income tax rate or the consumption tax rate.

d The standard welfare measure is the purchasing power at domestic consumer prices of household specific disposable income per capita.

Source: Simulations using the model described in the text.

**Appendix to**  
**AUTOMATION, TAXES AND TRANSFERS**  
**WITH INTERNATIONAL RIVALRY**

**A1 Modelling Global Macro Interdependence**

The financial sector and monetary policy are central to this model of the global economy. The demand for money as a financial asset is driven by a “cash in advance” constraint applying across the whole of GDP and home money is held in a portfolio with regionally differentiated long maturity bonds, which are claims over physical capital and government debt across the regions. Since portfolios are dominated by long maturity assets, the opportunity cost of holding money is the long bond yield, which is modelled as emerging from equilibrium in a thus weakly segmented global market for loanable funds. Central banks derive monetary expansions in regionally specific proportions from conventional monetary policy and from UMP, with reliance on the market segmentation theory of the yield curve (Johnson et al. 2010) to ensure that conventional monetary policy has no direct impact on the market for long term bonds. Short rates are therefore not modelled explicitly, rather the monetary base in each region is determined as endogenous to the target of monetary policy and an exogenous parameter determines the share of any change in the monetary base that takes the form of long asset balance sheet expansion. UMP expansions raise home long maturity asset prices and lower long yields, causing imperfect spill-overs across regions due to global arbitrage that is only partially constrained by asset differentiation.

Amongst the six regions identified, the US, the EU, Japan, China, Australia and the Rest of the World, the EU is modeled as the full 28 and it is assumed that this collective has a single central bank. In each region there are three households, each with factor-specific income (from low skill labour, skill and physical capital) and each with different reduced form consumption behaviour that depends on the real interest rate and current and expected future real disposable income.

## A1.1 Financial Markets and External Balance

A multi-region general equilibrium structure is used that centres on the global financial capital market. It is assumed that the financial products of each region are differentiated and that portfolio managers assign new net saving across regions so as to maximise expected portfolio returns given this differentiation. Although there is a tendency for financial flows to move the global economy toward uncovered interest parity, in the length of run considered asset differentiation leaves this process incomplete. At the same time, expected rates of return depart from regional bond yields, the latter reflecting short run equilibria in regional financial markets, as between savers, indebted governments and investors.

### *Investment*

Each region's financial market is represented as the market for domestic long maturity assets. These behave like equity, in the sense that income from them is assumed to be taxed after depreciation, even though they include government debt issued to a level that depends on fiscal policy as well as both debt and equity issued by domestic investors. Purchasers of these assets are assumed to respond to changes in an expected rate of return on installed domestic capital,  $r^{ce}$ , which is net of depreciation and capital tax and adjusted for sovereign risk. This rate of return has a number of components. First, since only the after-depreciation component of capital income is taxed, nominal capital income after tax for region  $i$  is:

$$(A1) \quad Y_i^{KN} = (1 - t_i^K) K_i (P_i^P MP_i^K - P_i^K \delta_i),$$

where  $P^P$  is the producer price of the regional product<sup>1</sup> and  $P^K$  is the price of capital goods.<sup>2</sup> The ad-valorem tax rate,  $t^K$ , is here defined as the rate applied to income from financial assets, including both debt and equity, and  $\delta$  is the depreciation rate of physical capital. The marginal physical product of capital,  $MP^K$ , is derived from the production technology, specified later. It is

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<sup>1</sup> The producer price level is the factory door price of the regional good, which differs in this model from the GDP price level,  $P^V$ , due to indirect taxation and from the consumer price,  $P^C$ , which includes imported products. This emerges from (A23), below.

<sup>2</sup> In this single product model the product and capital goods prices are separated by a single parameter:  $P^K = \gamma P^P$ . This allows shocks to represent the relative cheapening of capital goods over time as their information technology content rises.

inversely proportional to the stock of utilized regional capital,  $K$ . The regional real rate of return net of both tax and depreciation is then:<sup>3</sup>

$$(A2) \quad r_i^c = \frac{Y_i^{KN}}{P_i^K K_i} - \delta_i = (1 - t_i^K) \left( \frac{P_i^P MP_i^K}{P_i^K} - \delta_i \right) - \delta_i .$$

To obtain the expected future value of this rate, it first adjusted by a sovereign risk factor and then embedded in an uncovered interest parity condition, here operating in real terms:

$$(A3) \quad r_i^{ce} = r_i^c \left( \frac{\varphi_i^o}{\varphi_i} \right) + \hat{e}_i^e ,$$

where  $\hat{e}^e$  is the exogenous, expected proportional change in the *real* exchange rate and the interest premium factor,  $\varphi$ , permits consideration of the effects of changes in the fiscal balance on sovereign risk. A deteriorating fiscal balance causes investment to be less attractive. For this reason, a further adjustment is made using an interest premium factor,  $\varphi_i$ , that is defined relative to the US ( $\varphi_{US} = 1$ ). This permits consideration of the effects of changes in sovereign risk in association with the fiscal balance. Increments to regional sovereign risk, relative to the US, cause investments in regions with increasing fiscal deficits to be less attractive.

$$(A4) \quad \varphi_i = \varphi_i^o \left[ \left( \frac{G_i}{T_i} / \frac{G_{US}}{T_{US}} \right) \right]^{\phi} , \quad \forall i \neq "US" ,$$

where  $\phi$  is a positive elasticity indicating sensitivity to sovereign risk,  $G$  is government expenditure net of transfers,  $T$  is gross government revenue also net of transfers, and the zero superscripts indicate initial values.

The domestic demand for investment financing then depends on the ratio of the expected real rate of return on installed capital,  $r^{ce}$ , which is defined as after capital income tax, and the after tax real long bond yield that clears the domestic financial market,  $r$ . Since the numerator indicates the market value of domestic assets and the denominator the cost of financing their replacement, this is in the tradition of Tobin's Q. Accordingly, since firms do not incur tax when issuing stock or bonds, no taxation is applied in the denominator.

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<sup>3</sup> This is a real rate of return because it depends on the real volumes,  $MP^K$  and  $K$ , adjusted only by the ratio of  $P^P$  and  $P^K$ . It is therefore impervious to common inflation.

$$(A5) \quad \frac{I_i^D / P_i^K}{I_i^0 / P_i^{K0}} = \left[ \left( \frac{r_i^{ce}}{r_i} \right) / \left( \frac{r_i^{ce0}}{r_i^0} \right) \right]^{\varepsilon_i^I},$$

where  $\varepsilon^I$  is a positive elasticity and the zero superscripts indicate initial values. Since investment demand,  $I^D$ , is defined as nominal, it is adjusted by the capital goods price. The yield ratio deviates from unity not only because income from new investments is taxed after depreciation, but also due to the regional differentiation of assets. In part, this differentiation reflects the fact that, at short to medium lengths of run, the economy is not in a financial steady state.

This investment demand is then matched in each region by a supply of saving that incorporates contributions from all regional households. Here the modelling incorporates explicit portfolios of assets from all regions. Data on regional saving and investment is first combined with that on international financial flows to construct an initial matrix to allocate total domestic saving in each region to investment across all the regions. From this is derived a corresponding matrix of initial shares of region  $i$ 's net (private and government) saving that are allocated to the local savings supply that finances investment in region  $j$ ,  $i_{ij}^{S0}$ . When the model is shocked, the new shares are calculated so as to favour investment in regions,  $j$ , whose real yields are boosted by the shock. Since these are portfolio investments, the real rate of return available in each region is assumed to be the domestic market clearing yield,  $r$ .

Region  $i$ 's portfolio manager allocates the proportion  $i_{ij}^S$  of its annual (private plus government) saving to new investments in regions  $j$ , such that  $\sum_j i_{ij}^S = 1$ .<sup>4</sup> Because the newly issued equity is differentiated across regions based on un-modelled and unobserved region-specific properties, their services are combined via a constant elasticity of substitution (CES) function specific to each regional portfolio manager. Thus, region  $i$ 's household portfolio management problem is to choose the shares,  $i_{ij}^S$ , of its private saving net of any government deficit,  $S_i^D = S_i^P + T^D + T^I - G$ , which are to be allocated to the assets of region  $j$  so as to maximise a CES composite representing the value of the services yielded by these assets:

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<sup>4</sup> The manager does not re-optimize over total holdings every year. This is because the model is deterministic and risk is incorporated only via exogenous premia. The motivations for continuous short run rebalancing, other than the arrival of new saving, are therefore not represented.

$$(A6) \quad \max_{i_{ij}^S} U_i^F = S_i^D \left[ \sum_j \alpha_{ij} (i_{ij}^S)^{-\rho_i} \right]^{\frac{1}{\rho_i}} \text{ such that } \sum_j i_{ij}^S = 1.$$

Here  $\alpha_{ij}$  is a parameter that indicates the benefit to flow from region  $i$ 's investment in region  $j$ . The CES parameter,  $\rho_i$ , reflects the preparedness of region  $i$ 's household to substitute between the assets it holds. To induce rebalancing in response to changes in rates of return the  $\alpha_{ij}$  are made dependent on ratios of after-tax yields in destination regions,  $j$ , and the home region,  $i$ , via:<sup>5</sup>

$$(A7) \quad \alpha_{ij} = \beta_{ij} \left[ \frac{r_j (1-t_j^K)}{r_i (1-t_i^K)} \right]^{\lambda_i} \quad \forall i, j, \quad \lambda_i > 0 \quad \forall i.$$

Here,  $t_i^K$  is the rate of capital income tax rate in region  $i$ . This relationship indicates the responsiveness of portfolio preferences to yields, via the (return chasing) elasticity  $\lambda_i$ . The allocation problem, thus augmented, is:

$$(A8) \quad \max_{i_{ij}^S} U_i^F = S_i^D \left[ \sum_j \beta_{ij} \left[ \frac{r_j (1-t_j^K)}{r_i (1-t_i^K)} \right]^{\lambda_i} (i_{ij}^S)^{-\rho_i} \right]^{\frac{1}{\rho_i}} \text{ such that } \sum_j i_{ij}^S = 1.$$

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

$$(A9) \quad \frac{i_{ij}^S}{i_{ik}^S} = \left( \frac{\beta_{ij}}{\beta_{ik}} \right)^{\frac{1}{1+\rho_i}} \left[ \frac{r_j (1-t_j^K)}{r_k (1-t_k^K)} \right]^{\frac{\lambda_i}{1+\rho_i}}.$$

This reveals that region  $i$ 's elasticity of substitution between the bonds of different regions is  $\sigma_i^I = \lambda_i / (1 + \rho_i) > 0$ , which has two elements. The return-chasing behaviour of region  $i$ 's household ( $\lambda_i$ ) and the imperfect substitutability of regional bonds, and therefore the sluggishness of portfolio rebalancing ( $\rho_i$ ). For the purposes of this analysis the values of  $\sigma_i^I$  are seen as indicating the extent of each region's integration with global financial markets.

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<sup>5</sup> Note that region  $i$ 's market bond yield,  $r_i$ , is determined concurrently and indicates the replacement cost of capital in region  $i$  and therefore the opportunity cost for region  $i$ 's household of investment in region  $j$ .

The optimal share of the net domestic saving of region  $i$  that is allocated to assets in region  $j$  then follows from (A9) and the normalisation condition, that  $\sum_k i_{ik}^S = 1$ . Start by setting:

$$(A10) \quad \eta_{ijk} = \frac{i_{ik}^S}{i_{ij}^S} = \left( \frac{\beta_{ik}}{\beta_{ij}} \right)^{\frac{1}{1+\rho_i}} \left[ \frac{r_k (1-t_k^K)}{r_j (1-t_j^K)} \right]^{\frac{\lambda_i}{1+\rho_i}}, \text{ so } i_{ik}^S = i_{ij}^S \delta_{ijk}.$$

Then, substituting in the normalisation condition,  $\sum_k i_{ik}^S = 1 = i_{ij}^S \sum_k \eta_{ijk}$ , which yields

$$(A11) \quad i_{ij}^S = \frac{1}{\sum_k \left( \frac{\beta_{ik}}{\beta_{ij}} \right)^{\frac{\sigma_i^I}{\lambda_i}} \left[ \frac{r_j (1-t_j^K)}{r_i (1-t_i^K)} \right]^{\sigma_i^I}}.$$

The calibration of the key matrix  $[\beta_{ij}]$  is explained in the appendix.

#### *The markets for regional money*

Within each region the demand for money is driven by a “cash in advance” constraint. For any one household, home money is held in a portfolio with mainly long maturity assets, which are claims over physical capital, combined with home and foreign long maturity government debt. The cash-in-advance constraint is assumed to generate transactions demand for home money across all components of gross (including intermediate) output. Transactions demand is then augmented by the real purchasing power of financial wealth, to account for the observed dominance of financial transactions over money demand.<sup>6</sup> The opportunity cost of holding home money is set at the nominal after-tax yield on home long term bonds.<sup>7</sup> Real money balances are measured in terms of purchasing power over home products at the GDP price,  $P^Y$ .

$$(A12) \quad m_i^D = a_i^{MD} (y_i)^{\varepsilon_i^{MY}} (w_i^F)^{\varepsilon_i^{MW}} \left( \frac{r_i (1 + \pi_i^e)}{\tau_i^K} \right)^{-\varepsilon_i^{MR}} = \frac{M_i^S}{P_i^Y} = \frac{\mu_i M_i^B}{P_i^Y}.$$

<sup>6</sup> The inclusion of financial wealth in the money demand equation follows Ragot (2014) and Mena and Tirelli (2017), who incorporate Baumol (1952) – Tobin (1956) behaviour.

<sup>7</sup> Thus, it is assumed here that the opportunity cost of holding money is measured by the long bond yield, which is the dominant determinant of non-money portfolio yields. Short rates, at least as they have a role in conventional monetary policy, are here embedded in the determination of the monetary base. While housing investment can be sensitive to short rates in economies where most mortgage contracts have variable rates, the assumption that investment financing depends on the long maturity market is a simplifying abstraction in this global analysis.



For region  $i$ ,  $y_i$  is real, regional gross output, as distinct from real GDP since intermediates are transacted as well as goods and services entering final demand. Real financial wealth is  $w_i^F$ ,  $\tau_i^K$  is the power of the capital income tax rate in region  $i$  and  $\pi_i^e$  is the expected inflation rate of the consumer price level,  $P^C$ , defined as a CES aggregate of home and imported consumer prices. Real financial wealth or assets,  $w^F$ , is represented as the present value of an infinite stream of real dividends that are equal to after-tax returns on the capital stock, at the expected real rate of return on installed capital,  $r^{ce}$ , discounted at the current real financing rate,  $r$ . A price adjustment is also made for relative inflation or deflation of capital goods prices, which raise or lower the purchasing power of financial wealth over home products.

$$(A13) \quad W_i^F = \frac{r_i^{ce} (1 - t_i^K) (P_i^K / P_i^Y) K}{r_i} .$$

The last three decades have exhibited advanced region asset price inflation that has exceeded that in goods, for the US by at least six percentage points per year on average,<sup>8</sup> suggesting a rising path of this ratio. This comparative growth in financial wealth is due to the many determinants of wealth inequality, including the forces discussed in this paper.

On the supply side of the money market, the proportion of expansions that occur via the purchase of long maturity assets (UMP) is parameterised. Conventional expansions directly affect the money supply while UMP expansions affect both it and the long end of the yield curve. UMP expansions raise home long maturity asset prices and lower long yields, causing imperfect spill-overs due to global arbitrage that is only partially constrained by asset differentiation.<sup>9</sup>

Regional financial market clearance requires that the home financial market in each region clears separately and this implies global financial market clearance. For region  $i$ , the nominal value of domestic investment,  $I_i^D$ , from (5), represents the sum total of all domestic long bond issues.

This is then equated with demand for those bonds from home and foreign (net private and government) savings, along with demands for home long bonds that arise from the “quantitative easing” components of monetary expansions by both home and foreign central banks.

<sup>8</sup> This is readily concluded from a comparison of the path of a broad index of stock prices, such as the Wilshire Capital Price Index, and the US CPI, since 1990.

<sup>9</sup> By contrast, conventional monetary policy involves trade in short term instruments which has no direct impact on the market for long term bonds. Short rates are therefore not modelled explicitly, rather the monetary base in each region is determined as endogenous to the target of monetary policy and an exogenous parameter determines the share of any change in the monetary base that takes the form of long asset balance sheet expansion.

### *Global financial balance*

Financial balance then requires that total investment spending in region  $i$ , in  $i$ 's local currency, is equated with the total supply of financing directed from all represented regions:

$$(A14) \quad I_i^D = \sum_j \left( \left[ i_{ji}^S S_j^D + \theta_{ji}^{QE} s_j^{QE} \Delta M_j^B \right] \frac{E_j}{E_i} \right), \quad \forall i,$$

where  $E_i$  is the nominal exchange rate of region  $i$  relative to the US\$, which is the numeraire in the model ( $E_{US}=1$ ). The “quantitative easing” component of the current period’s expansion of the monetary base by region  $j$ 's central bank,  $s_j^{QE}$ , and the share of this expansion that takes the form of acquisitions of region  $i$ 's long bonds,  $\theta_{ji}^{QE}$ , both determine central bank demand. These flows are originally in foreign currency and are therefore converted at the appropriate cross rates. The regional real bond yields (interest rates,  $r_j$ ) emerge from this equality. Their convergence across regions is larger the larger are the elasticities of asset substitution,  $\sigma_j^I$ .

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

$$(A15) \quad X_i - M_i + \sum_{j \neq i} \left( \left[ i_{ji}^S S_j^D + \theta_{ji}^{QE} s_j^{QE} \Delta M_j^B \right] \frac{E_j}{E_i} \right) - \sum_{j \neq i} \left( i_{ij}^S S_i^D + \theta_{ij}^{QE} s_i^{QE} \Delta M_i^B \right) = 0, \quad \forall i \neq "US"$$

The first terms are values of exports and imports (formulated in the appendix) while the second two terms are financial inflows and outflows. The first parenthesised term represents acquisitions of region  $i$ 's home-issued long bonds by foreign savers and by foreign central banks, the latter associated, as above, with the “quantitative easing” component of the current period’s expansions of the monetary bases across regions. These net saving and central bank flows are originally in foreign currency and so are converted at the appropriate cross rates. The second parenthesised term represents acquisitions of foreign-issued long bonds by region  $i$ 's home savers and its own central bank. A balance of payments in the US is implied by balance in all the other regions. These equations determine the nominal exchange rates. Since these are defined relative to the US\$, that for the US is always unity ( $E_{US} = 1$ ).

### *Calibration of international financial flow determinants*

The key matrix for calibration is  $[\beta_{ij}]$ . These elements are readily available, first, by noting that only relative values are required and hence, for each region of origin,  $i$ , one value can be set to unity, and second, by making the assumption that the initial database has the steady state property that the net rates of return in regions  $j$  are initially the same as the market bond yield,  $r_j$ . Then, since in the base data  $r_{ij}^{e0} = r_j^0$ ,  $r_{ik}^{e0} = r_k^0$ , the  $\beta_{ij}$  s are available from (A9).

### *Shocking or restricting the global pattern of financial flows*

Some applications require that at least some international financial flows to be exogenous. In a Chinese recession, for example, it is very likely that foreign reserves would be repatriated and that this would significantly alter the flows between China and both the US and EU. A means is therefore required by which the parameters determining bilateral flows can be shocked to represent such effects. It turns out that this is readily done by rendering particular shares,  $i_{ij}^S$ , exogenous in the model closure, while the corresponding parameters,  $\beta_{ij}$ , are made endogenous. This removes the necessity to calculate the shocks to the  $\beta_{ij}$  s that would lead to target shifts in the flows.

## **A2: The Non-Financial Model Components**

### *The supply side*

Although each region supplies a unique differentiated product, production is assumed to draw on a combination of intermediate inputs comprising the home product and imports of products supplied abroad. This allows the capture of differences between the international effects of a policy change in one large country that are due to the dependence of smaller countries on the supply of inputs on the one hand or final products on the other.

The central production technology is expressed in Cobb-Douglas form because total factor productivity and factor shares are readily observed and hence parameterised. Output and factor inputs are included as relative to initial levels so that shocks to productivity or factor shares do

not imply changes in initial output volumes, thus facilitating the subsequent decomposition of technology shocks as between productivity and factor or input bias.

In region  $i$  gross output volume,  $y_i$ , is a Cobb-Douglas composite of real value added,  $v_i$ , and of intermediates,  $q_i$ .

$$(A16) \quad \frac{y_i}{y_i^0} = \left( \frac{A_i^Y}{A_i^{Y0}} \right) \left( \frac{v_i}{v_i^0} \right)^{\beta_i^V} \left( \frac{q_i}{q_i^0} \right)^{(1-\beta_i^V)}, \quad \forall i, i \in (\text{regions}),$$

where  $A^Y$  is total (factor and input) productivity. Value added, in turn, has Cobb-Douglas dependence on domestic primary factors, raw labour,  $L$ , skill,  $S$  and physical capital,  $K$ .

$$(A17) \quad \frac{v_i}{v_i^0} = \left( \frac{A_i^V}{A_i^{V0}} \right) \left( \frac{L_i}{L_i^0} \right)^{\beta_i^L} \left( \frac{S_i}{S_i^0} \right)^{\beta_i^S} \left( \frac{K_i}{K_i^0} \right)^{\beta_i^K}, \quad \sum_f \beta_i^f = 1, \quad \forall i, f \in (\text{factors}).$$

To allow for inter-regional substitution in intermediate demand across regional sources, domestically employed intermediate inputs,  $q$ , are a CES composite of products acquired from all regions:

$$(A18) \quad q_i = \left( \sum_j \alpha_{ij}^Q q_{ij}^{-\theta_i^Q} \right)^{-\frac{1}{\theta_i^Q}}, \quad \forall i,$$

where  $q_{ij}$  is the quantity of region  $j$ 's product that is absorbed by production in region  $i$ .

The composite prices of value added and intermediate inputs from (A16) depend on their marginal products:

$$(A19) \quad \frac{P_i^V}{P_i^P} = \beta_i^V \frac{y_i}{v_i}, \quad \frac{P_i^Q}{P_i^P} = (1 - \beta_i^V) \frac{y_i}{q_i}, \quad \forall i.$$

The real production wages of unskilled and skilled workers and the capital rental rate depend conventionally on the corresponding marginal products, from (A16) and (A17).

$$(A20) \quad \begin{aligned} w_i &= \frac{W_i}{P_i^P} = MP_i^L = \beta_i^V \beta_i^L \frac{y_i}{L_i}, & w_i^S &= \frac{W_i^S}{P_i^P} = MP_i^S = \beta_i^V \beta_i^S \frac{y_i}{S_i}, \\ \frac{R_i^R}{P_i^P} &= MP_i^K = \beta_i^V \beta_i^K \frac{y_i}{K_i}, & & \end{aligned}$$

Here the upper case,  $W$ , and the lower case  $w$ , signify nominal and real wage values, and  $R^R$  is the nominal capital rental rate.  $P_i^P$  is the producer price level – the factory gate price of region  $i$ 's product.

The gross volume of output,  $y$ , is distinguished from real GDP, which is that portion of output that meets final demand, excluding intermediate use, and which equates to real value added,  $v$  in (A16). The complete set of demands facing country  $i$ 's industries, which must sum to equate with (A16), takes the form:

$$(A21) \quad y_i = \frac{I_i + G_i}{P_i^P} + \sum_j c_{ji} + \sum_j q_{ji} ,$$

which is a real version of the standard expenditure identity (on the homogeneous domestic output of region  $i$ ) with intermediate demand included.  $I$  and  $G$  are nominal gross investment and nominal government spending net of transfers,  $c_{ji}$  is the volume of final consumption of region  $i$ 's product in region  $j$ , and  $q_{ji}$  is the volume of region  $i$ 's product that is absorbed as intermediate inputs by production in region  $j$ . Real GDP omits the final term. Equating this with (A16) determines producer price levels,  $P^P$ , in each region. Producer cost minimisation at these prices then determines the factor rewards indicated in (A19).

#### *The GDP price, $P^Y$*

The revenues from both direct and indirect taxes,  $T^D$  and  $T^I$ , play key roles in the formulation. Total nominal expenditure on GDP is  $Y$  and GDP at factor cost (or at producer's prices) is  $Y^{FC}$ , which is the total of direct payments to the collective household in return for the use of its factors, equating to  $P^V v$ , where  $P^V$  is the price of value added. Region  $i$ 's nominal GDP is then

$$(A22) \quad Y_i = P_i^Y v_i = Y_i^{FC} + T_i^I = P_i^V v_i + T_i^I .$$

The GDP price would be the same as the producer price,  $P^P$ , were it not for intermediate use and indirect taxes. In their presence we have, from (A20), that:

$$(A23) \quad P_i^Y = P_i^V + \frac{T_i^I}{v_i}$$

Producers in region  $i$  choose  $v_i$  and  $q_i$  to minimise their total cost,  $P_i^P y_i = P_i^V v_i + \hat{P}_i^Q q_i$ , where  $\hat{P}_i^Q$  is region  $i$ 's CES composite price of intermediates drawn from all regions. Because (A16) is Cobb-Douglas, the value added share of total expenditure by firms on factors and inputs is just  $\beta_i^V = (P_i^V v_i) / (P_i^P y_i)$ . Substituting in (A23) for  $P^V$  we have the GDP price in terms of the producer price:<sup>10</sup>

$$(A24) \quad P_i^V = \beta_i^V \frac{y_i}{v_i} P_i^P + \frac{T_i^I}{v_i}.$$

### *Factor and household incomes*

Income from capital is already specified in (1). This is the level of income, after tax, that accrues to the capital-owning household in each region. Households,  $h$ , are factor-specific, so

$h \in (L, S, K)$ , with low-skill worker income  $Y_i^L = W_i L_i$ , skilled income  $Y_i^S = W_i^S S_i$  and capital income net of depreciation  $Y_i^{KN} = (1 - t_i^K) K_i (P_i^P MP_i^K - P_i^K \delta_i)$ .

### *Direct tax*

Constant marginal direct tax rates,  $t^W$ ,  $t^S$  and  $t^K$ , apply to all labour, skill and net capital income, respectively. The corresponding ‘‘powers’’ of these rates are  $\tau^L = (1 + t^L)$ ,  $\tau^S = (1 + t^S)$  and  $\tau^K = (1 + t^K)$  and so, bearing in mind that taxation of capital income is after depreciation (1), total direct tax revenue is:

$$(A25) \quad T_i^D = t_i^L W_i L_i + t_i^S W_i^S S_i + t_i^K K_i (P_i^P MP_i^K - P_i^K \delta_i).$$

Indirect tax revenue,  $T^I$ , depends on consumption and so it will emerge later.

### *Household disposable income*

Disposable income, for each household, takes the form:

$$(A26) \quad Y_{hi}^D = s_{hi}^L \left[ (1 - t_i^L) W_i L_i + \alpha_i W_i^o (F_i - L_i) \right] + s_{hi}^S (1 - t_i^S) W_i^S S_i^K + s_{hi}^K (1 - t_i^K) K_i (P_i^P MP_i^K - P_i^K \delta_i) + T_{hi}^R, \quad \forall h$$

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<sup>10</sup> To calibrate the initial database units are chosen so that the GDP price levels in all regions and nominal exchange rates between them are all initially unity. This implies that  $P^V = P^P$  and that the value added share is  $\beta_i^V = v_i^0 / y_i^0$ .

Where  $s_{hi}^f$  is the ownership share of household  $h$  in region  $i$  of factor  $f$ .  $T_h^R = t_h^R N_h Y$  is a direct transfer to the household from government revenue, with  $t_h^R$  the transfer rate to household  $h$  per unit of group population,  $N_h$ , and per unit of nominal GDP.<sup>11</sup> Total disposable income is the sum of  $Y_h^D$  across households, which is also GDP at factor cost (household primary income) less total direct taxes, plus net transfers from the government to households and the unemployed:

$$Y^D = \sum_h Y_h^D = Y^{FC} - T^D + T^R + \alpha W_0 (F - L). \text{ Since, from (A20), GDP at factor cost is full GDP}$$

less net indirect tax revenue, this can be written as

$$(A27) \quad Y^D = Y - T^I - T^D + T^R + \alpha W_0 (F - L) .$$

where total regional transfers are  $T_i^R = \sum_h T_{hi}^R$ .

For each household,  $h$ , in region  $i$ , consumption expenditure,  $C_{hi}$ , is a nominal sum but real consumption behaviour is motivated by current and expected future real, per capita, disposable incomes and the real interest rate. Real consumption, (lower case)  $c_{hi}$ , depends negatively on the after-tax real return on savings (the home bond yield,  $r$ ) and positively on both current and expected future real disposable income per capita for that household:

$$(A28) \quad c_{hi} = \frac{C_{hi}}{P_i^C} = N_i^h A_{hi}^C \left( \frac{r_i}{\tau_i^h} \right)^{-\varepsilon_{hi}^{CR}} \left( \frac{Y_{hi}^D}{N_i^h P_i^C} \right)^{\varepsilon_{hi}^{CY}} \left( \frac{Y_{hi}^{De}}{N_i^h P_i^C [I + \pi_{hi}^{Ce}]} \right)^{\varepsilon_{hi}^{CY}} ,$$

where the tax rate on interest income,  $\tau^h$ , is household specific, set as the tax rate on the households dominant source of direct factor income. The expected inflation rate of the consumer price level is  $\pi^{Ce}$ . The elasticities in this expression vary by household, ensuring different consumption responses.

### *Consumption driven trade and composite pricing*

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<sup>11</sup> The expression (A24) is more complex if the labour force participation rates, as defined in (6), of low skill workers,  $\lambda_{Lh}$ , are unequal across households and, similarly, if participation rates of skilled workers,  $\lambda_{Sh}$ , are unequal across households. The simpler expression is offered here since this is not the case in this analysis. The participation rates within skill groups and across households are kept equal in the experiments conducted, although the rates differ *between* skill groups and may be differently shocked.

To capture the home household's substitution between home and foreign products, real aggregate consumption in region  $i$  is a CES composite of region  $i$ 's consumption of products from all regions:

$$(A29) \quad c_i = \left( \sum_j \alpha_{ij}^C c_{ij}^{-\theta_i^C} \right)^{\frac{1}{\theta_i^C}}$$

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

$$(A30) \quad C_i = P_i^C c_i = P_i^P \tau_i^C c_{ii} + \sum_{j \neq i} \tau_i^C \tau_i^M \tau_j^X c_{ij} P_j^P \frac{E_j}{E_i},$$

where  $\tau_i^C$  is the power of region  $i$ 's consumption tax.

Optimum consumption is consistent with an elasticity of substitution between home and

Given these consumption volumes, the composite price of all consumption, or the consumer price level, emerges from the combination of (A26) and (A27) in (A28) as:

$$(A31) \quad P_i^C = \tau_i^C \left[ \left( \alpha_{ii}^C \right)^{\sigma_i^C} \left( P_i^P \right)^{1-\sigma_i^C} + \tau_i^M \sum_{j \neq i} \left( \alpha_{ij}^C \right)^{\sigma_i^C} \left\{ \frac{P_j^P E_j}{E_i} \right\}^{1-\sigma_i^C} \right]^{\frac{1}{1-\sigma_i^C}}.$$

### *Private saving*

Households receive factor incomes amounting to GDP at factor cost,  $Y^{FC}$ . Their disposal of nominal income is this sum less direct tax, net of transfers to households and the unemployed (A26). Private saving differs across households. It is what remains after consumption expenditure (gross of indirect taxes) is further deducted from disposable income.

$$(A32) \quad S^P = \sum_h [Y_h^D - C_h].$$

Since total consumption expenditure, inclusive of consumption tax, is

$$(A33) \quad C = \sum_h C_h = P^C \sum_h c_h = P^P \tau_C \sum_h c_h,$$

And total disposable income is from (A26), aggregate private saving can also be written as:



$$(A34) \quad S^P = Y^D - C = [Y - T^I - T^D + T^R + \alpha W_0 (F - L)] - C.$$

### *Indirect tax revenue*

This includes revenue from consumption, import and export taxes:

$$(A35) \quad T_i^C = t_i^C \left( P_i^P c_{ii} + \sum_{j \neq i} \tau_i^M \tau_j^X c_{ij} P_j^P \frac{E_j}{E_i} \right),$$

$$(A36) \quad T_i^M = t_i^M M_i, \quad M_{ij} = P_j^P \tau_j^X (q_{ij} + c_{ij}) \frac{E_j}{E_i}, \quad M_i = \sum_{j \neq i} M_{ij},$$

$$(A37) \quad T_i^X = t_i^X X_i, \quad X_{ij} = P_i^P \tau_i^X (q_{ji} + c_{ji}), \quad X_i = \sum_{j \neq i} X_{ij},$$

$$(A38) \quad T_i^I = T_i^C + T_i^M + T_i^X, \quad T_i = T_i^D + T_i^I.$$

### *Government and total domestic saving*

This is government revenue from direct taxes, indirect taxes and seigniorage, less government expenditure, both measured net of direct transfers. To simplify the demand side, spending by the government on goods and services,  $G^X$ , is assumed to be directed only at home goods. The government pays no taxes and so this expenditure faces the home producer price  $P^P$ . But, as modelled, the government encompasses the central bank and its revenue includes seigniorage. Yet since the market for short maturity assets is not included in the model, that part of seigniorage that is committed to their purchase is excluded as well. Thus, government saving incorporates only the share of expansions in the monetary base that affect the government's trading in the long bond markets that are central to the characterisation of global and national financial markets. That is, the share associated with unconventional monetary policy.

$$(A39) \quad S_i^G = T_i^D + T_i^I + s_i^{QE} \Delta M_i^B - G_i, \quad G_i = T_i^R + G_i^X + \alpha_i W_i^0 (F_i - L_i)$$

Total domestic saving is therefore:

$$(A40) \quad S_i^D = S_i^P + S_i^G = Y_i + \Delta M_i^B - C_i - G_i^X.$$

### *Intermediate input demand*

To capture region  $i$ 's home firms' substitution between intermediate inputs sourced from home and abroad, real aggregate input use,  $q_i$ , is a CES composite of intermediate demands for

products from all regions (A18). Home firms then choose their mix of intermediate products to minimise expenditure in a way that accounts for home indirect tax rates, foreign export taxes and differing foreign product prices and exchange rates:

$$(41) \quad V_i^Q = \hat{P}_i^Q q_i = P_i^P y_i - P_i^V v_i = P_i^P q_{ii} + \sum_{j \neq i} \tau_i^M \tau_j^X q_{ij} P_j^P \frac{E_j}{E_i},$$

where  $\tau_i^M$  and  $\tau_j^X$  are, respectively, the powers of region  $i$ 's import tax and the region of origin,  $j$ 's export tax. Consumption taxes are not levied on intermediate input use.  $E_i$  is region  $i$ 's nominal exchange rate, measured as US\$ per unit of home currency.<sup>12</sup>

Optimum intermediate use is consistent with an elasticity of substitution between home and foreign products of  $\sigma_i^Q = 1 / (1 + \theta_i^Q)$ . The corresponding derived demands are then:

Given these volumes, the composite price of all intermediates in region  $i$ ,  $\hat{P}_i^Q$ , emerges from the combination of (A18) and (A41) as:

$$(A42) \quad \hat{P}_i^Q = \frac{1}{A_i^Q} \left[ (\alpha_{ii}^Q)^{\sigma_i^Q} (P_i^P)^{1-\sigma_i^Q} + \tau_i^M \sum_{j \neq i} (\alpha_{ij}^Q)^{\sigma_i^Q} \left\{ \frac{P_j^P E_j}{E_i} \right\}^{1-\sigma_i^Q} \right]^{\frac{1}{1-\sigma_i^Q}}.$$

### *Real exchange rate*

Each region has a real exchange rate relative to the US that is the rate of exchange between regional product bundles. With the regions specified as single product economies this measure parallels the terms of trade. Both real and nominal exchange rates are expressed according to the financial convention, so that an appreciation is a rise in value.

$$(A43) \quad e_i^{US} = \frac{P_i^Y}{\left( \frac{P_{US}^Y}{E_i} \right)} = E_i^{US} \frac{P_i^Y}{P_{US}^Y}.$$

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<sup>12</sup> The US\$ is the numeraire in the model, so  $E_{US}=1$ .

### *Exports and Imports*

These are evaluated regionally and bilaterally. Regional totals are single subscripted. Region  $i$ 's exports comprise bilateral flows of consumption goods as well as flows of intermediate inputs, priced at the home producer price and marked up by the power of the home export tax:

$$(A44) \quad X_i = \sum_{i \neq j} X_{ij}, \quad X_{ij} = \sum_{i \neq j} (c_{ji} + q_{ji}) P_i^P \tau_i^X .$$

Region  $i$ 's imports also comprise final demand and intermediate flows, priced at the producer price of the region of origin, marked up by the power of that region's export tax and converted to home currency by the appropriate cross rate.

$$(A45) \quad M_j = \sum_{i \neq j} M_{ij}, \quad M_{ij} = \sum_{i \neq j} (c_{ji} + q_{ji}) P_i^P \tau_i^X \frac{E_i}{E_j} .$$

### *Effective exchange rates*

Real and nominal effective exchange rates are trade-weighted averages of bilateral rates. These assist with the interpretation of the results considering that all the bilateral nominal rates are defined relative to the US\$.

$$(A46) \quad e_i^e = \frac{\sum_{j \neq i} \left[ \left( \frac{X_{ij}}{P_i^P \tau_i^X} + \frac{M_{ij}}{\tau_j^X P_j^P E_j / E_i} \right) e_{ij} \right]}{\sum_{j \neq i} \left( \frac{X_{ij}}{P_i^P \tau_i^X} + \frac{M_{ij}}{\tau_j^X P_j^P E_j / E_i} \right)}, \quad E_i^e = \frac{\sum_{j \neq i} (X_{ij} + M_{ij}) E_{ij}}{\sum_{j \neq i} (X_{ij} + M_{ij})} .$$

### *Welfare and inequality*

For distributional analysis, the shares of disposable income and the population shares are then

$$(A47) \quad s_{hi}^{YD} = Y_{hi}^D / Y_i^D, \quad s_{hi}^N = N_i^h / \sum_h N_i^h, \quad \forall h \in (Lh, Sh, Kh) .$$

Our measure of group welfare is real disposable income at consumer prices,  $V_h = Y_h^D / P_C$  and a three-group Gini coefficient is calculated, first by calculating the area under the three-household Lorenz curve:

$$(A48) \quad A_i^L = 0.5 \left[ s_{Lhi}^N s_{Lhi}^{YD} + s_{Shi}^N (2 s_{Lhi}^{YD} + s_{Shi}^{YD}) + s_{Khi}^N (1 + s_{Lhi}^{YD} + s_{Shi}^{YD}) \right],$$

and the corresponding Gini coefficient is then

$$(A49) \quad G_i^C = 2(0.5 - A_i^L) .$$

### A3: The Database and Parameters

The model database is built on national accounts, international trade and financial data for the global economy in 2011. The relative sizes of the four major economic regions, the US, the EU, Japan and China are indicated in Table A1, from which it is clear that China's economy (even measured without PPP adjustment) is not the smallest of them and it matches the largest in investment, exports and saving. The structures of the regional economies are indicated in Table A2. They differ in important ways. The US has a high consumption share of GDP, China a low one. Necessarily, then, the US has a low saving share while China has a high one. Some regions are more dependent on indirect taxes than others, which makes a difference to the proportion of GDP made up of factor cost and hence the size of the household budget and the gap between producer and GDP prices. The EU is relatively dependent on indirect taxes, for example. Since these taxes (at least those accounted for in the model) fall most heavily on consumption, changes in saving behaviour have strong implications for fiscal deficits and, indirectly, for interest premia. Investment is larger in some than in others, being extraordinarily high in China. And then, of course there are the fiscal deficits that are largest in the US and Japan, and the current account surpluses or capital-financial account deficits in Japan and China, at least partly funding the very substantial deficit in the US.

Interactions between these large economies through trade are captured in the consumption expenditure matrix shown in Table A3. It is derived from the combination of national accounts with a matrix of trade flows. The flows are expenditures inclusive of indirect taxes, converted into the shares of total expenditure on goods and services by each country. Implicit, and consistent with the one-good per region model, is the assumption that investment and government spending make demands on the markets for home goods only. As it turns out, this assumption has important implications for the representation of China in the model. Since its consumption is comparatively low and its investment high, home products are mostly absorbed

by investment and government spending and so China's consumption is distributed more evenly across regional goods than for the other economies. This suggests a case for an import-dependent capital goods industry in the model.

A complete list of the behavioural parameters used in the model is provided in Table A1. Policy variables in the model are listed in Table A2 and closure choices that determine which are exogenous and can be shocked are indicated in Table A3. The financial interactions between the regions are indicated by the saving-to-investment flows in Table A4. These show the expected Feldstein-Horioka (1980) behaviour but also that there are substantial financial interactions between the US, the EU, Japan and China, in particular. The share of excess saving directed to the US might be expected to change due to the recent decline in reserve accumulation by China and its substitution with outward FDI that, most recently, has not been directed to the US (Tyers et al. 2013). The flows implied by the model database system of payments for financial assets and goods and services are then summarised in Tables A5-A8.

**Table A1: Parameters**

	US	EU(26)	Japan	China	Australia	RoW
Production shares <sup>a</sup>						
Value added, $\beta^V$	0.67	0.67	0.67	0.67	0.67	0.67
Intermediates, $(1 - \beta^V)$	0.33	0.33	0.33	0.33	0.33	0.33
Value added shares						
Labour, $\beta^L$	0.18	0.18	0.18	0.26	0.18	0.24
Skill, $\beta^S$	0.47	0.47	0.47	0.24	0.47	0.21
Capital, $\beta^K$	0.35	0.35	0.35	0.50	0.35	0.55
Income tax rates <sup>b</sup>						
$t^L = t^S = t^K$	0.02	0.02	0.13	0.04	0.10	0.07
Indirect tax rates <sup>c</sup>						
$t^C$	0.20	0.40	0.05	0.20	0.10	0.15
$t^M$	0.15	0.43	0.11	0.19	0.11	0.31
$t^X$	0.00	0.00	0.00	0.00	0.00	0.00
Money parameters <sup>d</sup>						
Reserve ratio, $\rho$	0.05	0.05	0.05	0.15	0.05	0.10
Cash ratio, $\mu$	0.08	0.10	0.17	0.21	0.10	0.20
Elasticities						
$c$ to $r$ , $\varepsilon^{CR}$	0.10	0.10	0.10	0.10	0.10	0.10
$c$ to $Y^D$ , $\varepsilon^{CY}$ Low income	1.25	1.34	1.03	1.09	1.28	1.10
$c$ to $Y^D$ , $\varepsilon^{CY}$ Skilled	0.90	0.99	0.79	0.89	1.00	0.84
$c$ to $Y^D$ , $\varepsilon^{CY}$ Capital owning	0.80	0.88	0.70	0.79	0.90	0.75
Investment, $I_i$ to $r^C/r_i$ , $\varepsilon^I$	1.00	1.00	1.00	1.00	1.00	1.00
Premium to $G/T$ , $\phi_i$	0.20	0.20	0.20	0.20	0.20	0.20
$m^D$ to $y$ , $\varepsilon^{MY}$	0.60	0.60	0.60	0.60	0.60	0.60
$m^D$ to $w^F$ , $\varepsilon^{MF}$	0.40	0.40	0.40	0.40	0.40	0.40
$m^D$ to $(r + \pi^e)$ , $-\varepsilon^{MR}$	0.60	0.60	0.60	0.60	0.60	0.60
Elasticities of substitution						
Factors-inputs, $VA_i/Q_i$ , $\sigma_i^V$	1.00	1.00	1.00	1.00	1.00	1.00
Factors, $L_i, S_i, K_i$ , $\sigma_i^f$	1.00	1.00	1.00	1.00	1.00	1.00
Consn, $c_{ij}/c_{ik}$ to $P_{ij}^C / P_{ik}^C$ , $\sigma_i^C$	2.00	2.00	2.00	2.00	2.00	2.00
Inputs, $q_{ij}/q_{ik}$ to $P_{ij}^O / P_{ik}^O$ , $\sigma_i^O$	0.90	0.90	0.90	0.90	0.90	0.90
Saving $i^S_{ij}/i^S_{ik}$ to $r/r_j$ , $\sigma_i^I$	15.0	15.0	15.0	5.0	15.0	5.0

a Production shares are based on demographic and occupational data from Tyers et al. (2017), as well as estimates of factor incomes and capital stocks from the GTAP Database.

b These income tax rates are lower than observed because direct transfers and sovereign debt service are deducted from income tax revenue so that observed fiscal balances are consistent with T-G, where G includes only expenditure on goods and services.

c Although export taxes appear in the modelling, no values are applied since such taxes are usually very indirect. To infer the rates for other indirect taxes, approximate rates are initially chosen for the consumption tax rate and the import tax rate is then determined for consistency with the data on indirect tax revenue. In regions where other indirect taxes are major contributors to revenue, this tends to inflate the values of  $t^C$  and  $t^M$ .

d The money parameters are crude characterisations, made on the assumption that the EU behaves as if it had a single central bank to cover all 26 members. Money demand parameters stem from a survey of estimates used in other models (including McKibbin and Wilcoxon 1995, Knell and Stix, 2006 and Teles and Zhou 2005).

e Consumption elasticities and elasticities of substitution are central among a variety of estimates in use in other models (including McKibbin and Wilcoxon 1995 and Jin 2011).

**Table A2: Exogenous Variables for Experimentation**

Policy	Instrument	
Tax rates	Labour income tax	$t_L$
	Capital income tax	$t_K$
	Consumption tax (GST)	$t_C$
	Import tariff	$t_M$
	Export tax	$t_X$
Fiscal policy	Government spending, US\$ trillion	$G$
	fiscal surplus, US\$ trillion	$S_G$
Monetary policy	Monetary base, US\$ trillion	$M_B$
	Reserve to deposit ratio	$\rho$
Expectations over future values	Consumer price inflation rate	$\pi^{Ce}$
	GDP price inflation rate	$\pi^{Ye}$
	Real exchange rate appreciation	$\hat{e}^e$
	Nominal disposable income	$Y_D^e$
	Rate of return on installed capital	$r_C^e$
Saving	Consumption preference shifters	$A^C$
Technical change <sup>a</sup>	Productivity of all factors and inputs	$A^Y$
	Total factor productivity	$A^V$
	Bias toward value added from inputs	$\beta^V$
	toward labour	$\beta^L$
	toward skill	$\beta^S$
toward capital	$\beta^K$	

<sup>a</sup> Bias shocks are readily implemented since they do not alter the original levels of output and the database structure, due to the relative formulation of production functions (A15) and (A16).

**Table A3: Closure Choices and Policy Regimes**

	In each case, holding fixed or exogenous one of:	
Labour market	Nominal wage	$W$
	Labour use	$L$
Government	Nominal expenditure	$G$
	Fiscal surplus	$S_G = T - G$
Monetary target	Monetary base	$M_B$
	Consumer price level	$P^C$
	GDP price level	$P^Y$
	Producer price level	$P^P$
	Exchange rate	$E$



**Table A4: Relative Economic Sizes of China and the Other Large Regions, ca 2011**

% of world	China	US	EU(26)	Japan
GDP	11	22	26	9
Consumption, $C$	8	27	26	9
Investment, $I$	20	15	22	8
Government spending, $G$	7	20	30	10
Exports, $X$	17	17	25	7
Imports, $M$	15	21	23	8
Total domestic saving, $S^D$	19	13	20	9

Sources: National accounts data supply most of the elements though adjustments have been required to ensure that current accounts sum to zero globally, as do capital/financial accounts. The IMF-IFS database is the major source but there is frequent resort to national statistical databases.

**Table A5: Regional Economic Structure, 2011**

% of GDP	US	EU(28)	Japan	China	Australia	RoW
$C$	0.712	0.580	0.605	0.450	0.536	0.550
$I$	0.155	0.191	0.200	0.410	0.275	0.240
$G$	0.171	0.217	0.204	0.114	0.177	0.199
$X$	0.139	0.175	0.151	0.285	0.217	0.200
$M$	0.177	0.163	0.161	0.259	0.204	0.189
Indirect tax rev, $T^I$	0.144	0.235	0.047	0.125	0.070	0.130
Direct tax rev, $T^D$	0.017	0.015	0.124	0.035	0.093	0.061
Total tax rev, $T$	0.161	0.250	0.171	0.160	0.163	0.191
Private saving, $S^P$	0.127	0.169	0.224	0.390	0.301	0.259
Govt saving, $S^G$	-0.010	0.034	-0.034	0.046	-0.013	-0.008
Total saving, $S^D$	0.155	0.191	0.200	0.410	0.275	0.240
Monetary base, $M^B$	0.133	0.114	0.220	0.411	0.134	0.250
Capital stock, $K$	3.317	3.414	4.239	2.740	4.027	2.000

Sources: National accounts data supply most of the elements though adjustments have been required to ensure that current accounts sum to zero globally, as do capital/financial accounts. The IMF-IFS database is the major source but there is frequent resort to national statistical databases.

**Table A6: Shares of Total Domestic Saving Directed to Investment in each Region, 2011<sup>a</sup>**

% of row total saving	US	EU(28)	Japan	China	Australia	RoW
US <sup>b</sup>	68.0	13.3	6.4	6.4	1.5	4.4
EU(26) <sup>c</sup>	12.9	80.1	2.3	2.3	0.9	1.5
Japan <sup>d</sup>	14.0	3.3	72.2	6.2	0.7	3.6
China <sup>e</sup>	9.2	0.6	0.9	81.1	0.1	8.0
Australia <sup>e</sup>	13.0	4.8	2.3	2.1	77.3	0.4
Rest of world	3.4	3.9	2.6	2.8	0.1	87.2

a These shares sum to 100 horizontally. They are based on 2011 investment flows. The original flow matrix is inconsistent with data on saving and investment from national accounts and so a RAS algorithm is used to ensure that row and column sums are consistent with other data. The row sums of the flow matrix are total saving by region and the column sums are total investment by region. These sums are sourced from the IMF-IFS database and the World Bank database.

b USA: values are based on official statistics, BEA.

c EU and China: indirect information from USA, Australian and Japanese statistics.

d Japan: estimated based on FDI data, assuming investment outflow=FDI\*1.6. The ratio 1.6 is that of USA reported inward investment from Japan divided by Japanese reported outward FDI to the USA.

e Australia: Australian Bureau of Statistics "International Investment Position, Australia: Supplementary Statistics, 2011".

f ROW is a residual. Its saving is inferred from national accounts estimates and its investment abroad is determined to balance the matrix of financial flows.

**Table A7: Shares of Consumption of final Goods by Region of Origin, 2011<sup>a</sup>**

% of row consn expenditure	US	EU(28)	Japan	China	Australia	RoW
US	82.5	6.0	1.6	2.4	0.4	7.2
EU(26)	6.3	74.5	1.8	4.0	0.4	13.0
Japan	2.8	3.5	84.6	2.6	0.5	6.1
China	10.9	19.1	11.7	42.7	0.6	15.0
Australia	7.1	11.3	3.3	8.1	60.4	9.8
Rest of world	12.5	19.2	3.4	9.2	0.3	55.4

a These shares sum to 100 horizontally. They are based on the 2011 matrix of trade flows combined with consumption expenditure data in each region. The resulting matrix is inconsistent as between data sources and so a RAS algorithm is used to force consistency of bilateral elements with national accounts data.

Sources: Implied trade flows are for 2011, drawn from the World Trade Organisation database.

**Table A8: Use Shares of Intermediate Goods by Region of Origin, 2011<sup>a</sup>**

% of row intermediate expenditure	US	EU(28)	Japan	China	Australia	RoW
US	79.0	5.4	0.9	4.8	0.2	9.7
EU(26)	4.3	75.4	0.8	6.1	0.2	13.3
Japan	2.2	1.8	81.9	4.6	2.2	7.3
China	1.7	3.0	1.9	67.8	3.4	22.2
Australia	0.8	1.3	0.4	0.9	94.1	2.5
Rest of world	1.5	2.3	0.4	1.1	0.8	93.9

a These shares sum to 100 horizontally. They are based on the 2011 matrix of trade flows combined with intermediate use expenditure data in each region. The raw matrix of consumption plus intermediate use flows is inconsistent as between data sources and so a RAS algorithm is used to force consistency of bilateral elements with national accounts data.

Sources: Implied trade flows are for 2011, drawn from the World Trade Organisation database.

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