

ECONOMICS

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

by

Rod TYERS

Business School

University of Western Australia,

Research School of Economics

Centre for Applied Macroeconomic Analysis (CAMA)

Australian National University

and

Yixiao ZHOU

School of Economics and Finance

Curtin Business School

Curtin University

DISCUSSION PAPER 18.07

AUTOMATION, TAXES AND TRANSFERS
WITH INTERNATIONAL RIVALRY*

Rod TYERS

Business School
University of Western Australia,
Research School of Economics
Centre for Applied Macroeconomic Analysis (CAMA)
Australian National University
rod.tyers@uwa.edu.au

Yixiao ZHOU

School of Economics and Finance
Curtin Business School
Curtin University
yixiao.zhou@curtin.edu.au

September 2018

Prepared originally for the 9th RMUTP International Conference, Bangkok, 2018

Key words:

Automation, income distribution, taxes, transfers, global modelling

JEL Codes:

C68, D33, F21, F42, O33

* We are grateful to Markus Brueckner, Peter Dixon, Jane Golley, Bob Gregory, Warwick McKibbin and Jenny Wilkinson, with whom we have had constructive discussions on the topic of this paper. We thank the discussant and participants at the 9th RMUTP International Conference for helpful comments on the paper.

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).¹ 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.² 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).³ Explanations posited for this are numerous. They include 1) East Asian comparative growth and the resulting surge in labour

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

² 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.”

³ 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,⁴ 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,⁵ and 4) the wider displacement of workers by increasingly intelligent machines.⁶ 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.⁷

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

⁴ 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).

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

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

⁷ 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.⁸

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

⁸ 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).⁹ 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

⁹ 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.¹⁰

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.¹¹ 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.

¹⁰ 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).

¹¹ 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 €60 (£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 .¹² 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 .

¹² 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.¹³ The opportunity cost of holding home money is set at the nominal after-tax yield on home, long-term bonds.¹⁴ 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.¹⁵

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

¹³ 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.

¹⁴ 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.

¹⁵ 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.¹⁶

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.

¹⁶ 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 .

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

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 δ_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.¹⁷

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:

¹⁷ The expression (12) is more complex if the labour force participation rates of low skill workers, λ_{Lh} , are unequal across households and, similarly, if participation rates of skilled workers, λ_{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.

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

where the tax rate on interest income, τ^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 π^{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 τ_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.¹⁸ 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 (β^L and β^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.¹⁹

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

¹⁸ 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.

¹⁹ 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.²⁰ This would be politically difficult, though more

²⁰ 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.

References

- Abbott, R. and Bogenschneider, B. (2018), “Should robots pay taxes? Tax policy in the age of automation”, *Harvard Law and Policy Review*, Vol. 12. Online available at SSRN: <https://ssrn.com/abstract=2932483> or <http://dx.doi.org/10.2139/ssrn.2932483>
- Acemoglu, D., D. Autor, D. Dorn, G. Hanson and B. Price (2016), “Import competition and the great US employment sag of the 2000s”, *Journal of Labour Economics*, Vol. 34, No. S1, pp.141-198, Part 2, January.
- Acemoglu, D. and P. Restrepo (2015), “The race between man and machine: implications of technology for growth, factor shares and employment”, *NBER Working Paper*, No. 22252.
- Acemoglu, D. and D. Autor (2011), “Skills, Tasks and Technologies: Implications for Employment and Earnings”, *Handbook of Labour Economics*, Vol. 4b, pp. 1043-1171.
- Arora, V., R. Tyers and Y. Zhang (2015), “Reconstructing the savings glut: the global implications of Asian excess saving”, *International Journal of Economics and Finance*, Vol. 7, No. 7, pp.19-42, July.

- Arther, W.B. (2017), “Where is technology taking the economy?” *McKinsey Analytics*. Online available at <https://www.mckinsey.com/business-functions/mckinsey-analytics/our-insights/where-is-technology-taking-the-economy>
- Autor, D. (2016), “Why Are There Still So Many Jobs? The History and Future of Workplace Automation”, *Journal of Economic Perspectives*, Summer, Vol. 29, No. 3, pp. 3–30.
- Autor D.H., D. Dorn and G. Hanson (2013), “The China syndrome: local labour market effects of import competition in the US”, *American Economic Review*, Vol. 103, No. 6, pp.2121-68, October.
- Autor, D.H., D. Dorn, L.F. Katz, C. Patterson and J. Van Reenen (2017a), “The fall of the labour share and the rise of superstar firms”, *Working Paper, Massachusetts Institute of Technology*. Online available at <https://economics.mit.edu/files/12979>
- _____ (2017b), “Concentrating on the fall of the labour share”, *CEsifo Working Paper*, No. 6336. Available at SSRN: <https://ssrn.com/abstract=2932777>.
- Avent, R. (2016), *The Wealth of Humans: Work Power and Status in the 21st Century*, New York: St Martin’s Press.
- Bandholz, H. (2016), The economic and social consequences of robotization, *The World Bank Jobs and Development Blog*, online available at <http://blogs.worldbank.org/jobs/economic-and-social-consequences-robotization>
- Barkai, S. (2017), Declining labour and capital shares, job market paper, online available at <http://home.uchicago.edu/~barkai/doc/BarkaiDecliningLaborCapital.pdf>
- Barrat, J. (2013), *Our Final Invention: Artificial Intelligence and the End of the Human Era*, New York: St Martin’s Press.
- Beaudry, P., D.A. Green and B.M. Sand (2017), “The great reversal in the demand for skill and cognitive tasks”, *Journal of Labor Economics, Journal of Labor Economics*, 34, No.S1 (Part 2, January 2016): S199-S247.
- Bregman, R. (2017), *Utopia for Realists and How We Can Get There*, Bloomsbury.

- Bretchger, L. and F. Hettich (2002), “Globalization, capital mobility and tax competition: theory and evidence for OECD countries”, *European Journal of Political Economy*, Vol. 18, Issue 4, pp. 695-716.
- Brynjolfsson, E., D. Rock and C. Syverson (2017), “Artificial intelligence and the modern productivity paradox: A clash of expectations and statistics”, *NBER Working Paper*, No. 24001.
- Cardarelli, R. and L. Lusinyan (2015), “U.S. Total Factor Productivity Slowdown: Evidence from the United States”, *IMF Working Paper*, WP/15/116.
- Cette, G., J. Fernald and B. Mojon (2016), “The Pre-Great Recession Slowdown in Productivity”, *Federal Reserve Bank of San Francisco Working Paper Series*, 2016-08.
- The Economist (2017), “The Future Lies in Automation,” online available at <https://www.economist.com/news/special-report/21720073-factories-are-upgrading-still-lag-far-behind-rich-world-future-lies>.
- Ezrachi, A. and M.E. Stucke (2016), *Virtual Competition: The Promise and Perils of the Algorithm-Driven Economy*, Cambridge MA: Harvard University Press.
- Fleisher, B., H. Li and M.Q. Zhao (2010), “Human capital, economic growth, and regional inequality in China”, *Journal of Development Economics*, Vol. 92, Issue 2, pp. 215-231.
- Foda, K. (2016), “The Productivity Slump: A Summary of the Evidence”, Brookings Institute. Online available at <https://www.brookings.edu/research/the-productivity-slump-a-summary-of-the-evidence/> (accessed 29 July 2018).
- Freeman, R.B. (2015), “Who owns robots rules the world”, *IZA World of Labour*. Online available at <https://wol.iza.org/uploads/articles/5/pdfs/who-owns-the-robots-rules-the-world.pdf?v=1>
- Fuest, C., B. Huber and J. Mintz (2003), “Capital mobility and tax competition: A survey”, *Foundations and trends in Microeconomics*, Vol. 1, No. 1, pp.1-62.
- Goos, M., A.S. Manning and A. Salomons (2014), “Explaining job polarization: routine-biased technological change and offshoring”, *American Economic Review*, Vol. 104, No. 8, pp. 2509-26.

- Gordon, R.J. (2014), “The turtle’s progress: secular stagnation meets the headwinds”, Chapter 3 in Baldwin, R. and Teulings, C. (Eds.) (2014), *Secular Stagnation: Facts, Causes, and Curses*, Centre for Economic Policy Research.
- Guardian (2018), “Finland to end basic income trial after two years”. Online available at <https://www.theguardian.com/world/2018/apr/23/finland-to-end-basic-income-trial-after-two-years>
- _____ (2015), *The Rise and Fall of American Growth: The U.S. Standard of Living Since the Civil War*, Princeton University Press.
- Harris, K., A. Kimson, A. and A. Schwedel (2018), “Why the automation boom could be followed by a bust”, *Harvard Business Review*. Online available at <https://hbr.org/2018/03/why-the-automation-boom-could-be-followed-by-a-bust>
- Hemous, D. and M. Olsen (2014), “The rise of the machines: Automation, horizontal innovation and income inequality”. Online available at https://www.brown.edu/academics/economics/sites/brown.edu.academics/economics/files/uploads/rise_machines_paper_feb16.pdf
- Henley, J. (2018), “Finland to end basic income trial after two years”, *The Guardian*. Online available at <https://www.theguardian.com/world/2018/apr/23/finland-to-end-basic-income-trial-after-two-years>
- Hong, G.H., Kóczán, Z., Lian, W. and Nabar, M. (2018), “More slack than the eye? Recent wage dynamics in advanced economies”, *IMF Working Paper*, WP/18/50.
- IFR is abbreviation for International Federation of Robotics (2018), press release, “Industrial robot sales increase worldwide by 31 percent”. Online available at <https://ifr.org/ifr-press-releases/news/industrial-robot-sales-increase-worldwide-by-29-percent>
- Johnson, R.S., R.A. Zuber and J.M. Gandar (2010), “A re-examination of the market segmentation theory as a pedagogical model”, *Journal of Financial Education*, Vol. 36, No. ½, pp. 1-37, Spring/Summer.
- Kanbur, R., Y. Wang and X. Zhang (2017), “The great Chinese inequality turnaround”, *BOFIT Discussion Paper*, 6-2017, Bank of Finland Institute for Economics in Transition,

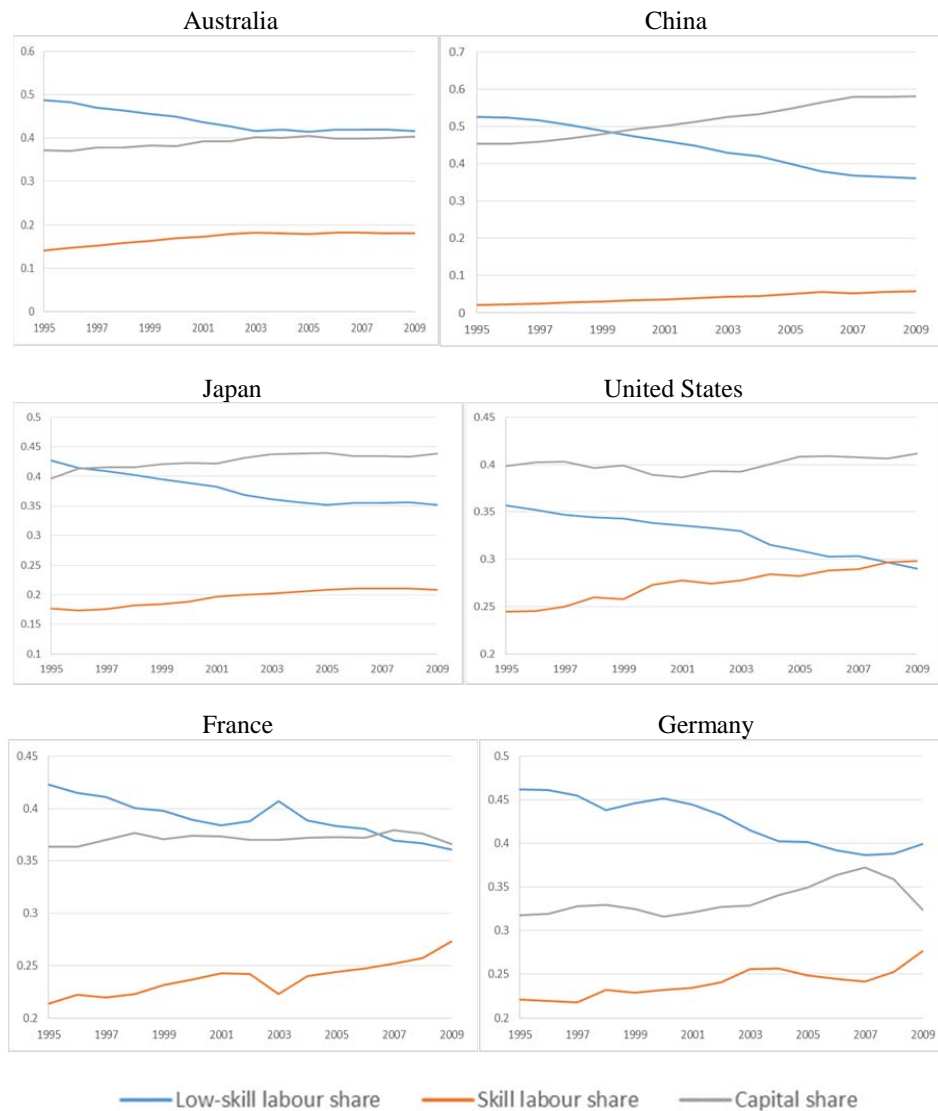
- Helsinki. Online available at
<https://helda.helsinki.fi/bof/bitstream/handle/123456789/14667/dp0617.pdf?sequence=1>
- Koh, D., R. Santaaulalia and Y. Zheng (2016), “Labour share decline and intellectual property products capital”, *Barcelona Graduate School of Economics Working Paper*, No. 927, February.
- Kurzweil, R. (2005), *The Singularity is Near*, New York: Viking Books.
- Korinek, A. and J.E. Stiglitz (2017), “Artificial intelligence, worker-replacing technological progress and income distribution”, *NBER Working Paper*, No. 24174.
- Marx, K. (1887), *Capital: A critique of political economy*. Online available at
<https://www.marxists.org/archive/marx/works/download/pdf/Capital-Volume-I.pdf>
- Moazed, A. and N.L. Johnson (2016), *Modern Monopolies: What it Takes to Dominate the 21st Century Economy*, New York: St Martin’s Press.
- Mokyr, J. (2013), “Is technological progress a thing of the past?” *VOX*, 8 September.
- Mokyr, J., C. Vickers and N.L. Ziebarth (2015), “The history of tech anxiety and the future of economic growth: is this time different?” *Journal of Economic Perspectives*, Vol. 29, No. 3, pp. 31-50.
- National Development and Reform Commission (2016). *The Development Plan for Robotics Industry (2016-2020)*, or in Chinese 机器人产业发展规划（2016-2020年）, in Chinese at http://www.ndrc.gov.cn/zcfb/zcfbghwb/201604/t20160427_799898.html.
- Nordhaus, W.D. (2015), “Are we approaching an economic singularity? Information technology and the future of economic growth”, *NBER Working Paper*, No. 21547, issued September 2015, rev January 2016.
- OECD (2012), “Labour Losing to Capital: What Explains the Declining Labour Share?” in *OECD Employment Outlook 2012*, OECD Publishing, Paris.
- Pierce, J.R. and P.K. Schott (2012), “The surprisingly swift decline of U.S. manufacturing employment”, *American Economic Review*, Vol. 106, No. 7, pp.1632-62.
- Piketty, T. (2014), *Capital in the Twenty-First Century*, Cambridge, MA: The Belknap Press of Harvard University Press.

- Piketty, T. and G. Zucman (2014), “Capital is back: wealth-income ratios in rich countries 1700-2010,” *The Quarterly Journal of Economics*, pp. 1255-1310.
- Reuters (2017), “European parliament calls for robot law, rejects robot tax”. Online available at <https://www.reuters.com/article/us-europe-robots-lawmaking/european-parliament-calls-for-robot-law-rejects-robot-tax-idUSKBN15V2KM>
- Rognlie, M. (2015), “Deciphering the fall and rise in the net capital share: accumulation, or scarcity?” *Brookings Papers on Economic Activity*, Spring, pp. 1-69.
- Shiller, R.J. (2017), “Robotization without taxation?” *Project Syndicate*. Online available at <https://www.project-syndicate.org/commentary/temporary-robot-tax-finances-adjustment-by-robert-j--shiller-2017-03?barrier=accesspaylog>
- State Council of the People’s Republic of China (2015), *Made in China 2025*, in Chinese at: <http://www.miit.gov.cn/n11293472/n11293877/n16553775/n16553792/16594486.html>.
- Susskind, D. (2017), “A model of technological unemployment”, *Balliol College Oxford Discussion Paper*. Online available at <https://www.economics.ox.ac.uk/materials/papers/15126/819-susskind-a-model-of-technological-unemployment-july-2017.pdf>.
- Susskind, R. and D. Susskind (2015), *The Future of the Professions: How Technology will Transform the work of Human Experts*, UK: Oxford University Press.
- Timmer, M.P., E. Dietzenbacher, B. Los, R.R. Stehrerand, G.J. de Vries (2015), “An Illustrated User Guide to the World Input–Output Database: The Case of Global Automotive Production”, *Review of International Economics*, Vol. 23, Issue 3, pp. 575–605.
- Tyers, R. (2015a), “Pessimism shocks in a model of global macroeconomic interdependence”, *International Journal of Economics and Finance*, Vol. 7, No. 1, pp. 37-59, January.
- _____ (2015b), “International effects of China’s rise and transition: neoclassical and Keynesian perspectives”, *Journal of Asian Economics*, Vol. 37, pp. 1-19, April.
- Tyers, R. (2016), ‘China and Global Macroeconomic Interdependence’, *The World Economy*, Vol. 39, No. 11, pp.1674-1702.

- Tyers, R., Y. Zhang and T.S. Cheong (2013), “China’s saving and global economic performance”, Chapter 6 in R. Garnaut, F. Cai and L. Song (eds,) *China: A New Model for Growth and Development*, Canberra: ANU E Press and Beijing: Social Sciences Academic Press, Pp 97-124.
- Tyers, R. and Y. Zhou (2017), “Automation and inequality with taxes and transfers”, CAMA Working Paper 70/2017, Australian National University, November.
- _____ (2018), “Deflation forces and inequality”, CAMA Working Paper 15/2018, Australian National University, April.
- UNIDO (2017), “Industry 4.0: Opportunities behind the challenge”, Background Paper, United Nations Industrial Development Organization, online available at https://www.unido.org/sites/default/files/files/2017-11/UNIDO%20Background%20Paper%20on%20Industry%204.0_27112017.pdf
- Varoufakis, Y. (2017), “A tax on robots?” *Project Syndicate*. Online available at <https://www.project-syndicate.org/podcasts/a-tax-on-robots-1>
- Wolcott, R.C. (2018), “How automation will change work, purpose, and meaning?” *Harvard Business Review*. Online available at <https://hbr.org/2018/01/how-automation-will-change-work-purpose-and-meaning>
- World Bank (2017), “Trouble in the making? The future of manufacturing-led development”. Online available at <https://openknowledge.worldbank.org/handle/10986/27946>
- Yoon, S. (2017), “Korea takes first step to introduce ‘robot tax’”, *The Korean Times*. Online available at http://www.koreatimes.co.kr/www/news/tech/2017/08/133_234312.html
- Zhou, Y. (2016), “Human capital, institutional quality and industrial upgrading: global insights from industrial data”, *Economic Change and Restructuring*, first online, doi:10.1007/s10644-016-9194-x.
- Zhou, Y. and L. Song (2016), “Income inequality in China: causes and policy responses”, *China Economic Journal*, Vol. 9, Issue 2, pp.186-208.
- Zhou, Y. and R. Tyers (2018), “Automation and income inequality in China”, *China Economic Review*, <https://doi.org/10.1016/j.chieco.2018.07.008>.

Zodrow, George R. (2010), "Capital Mobility and Capital Tax Competition", *National Tax Journal*, 63(4): 865-901.

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).

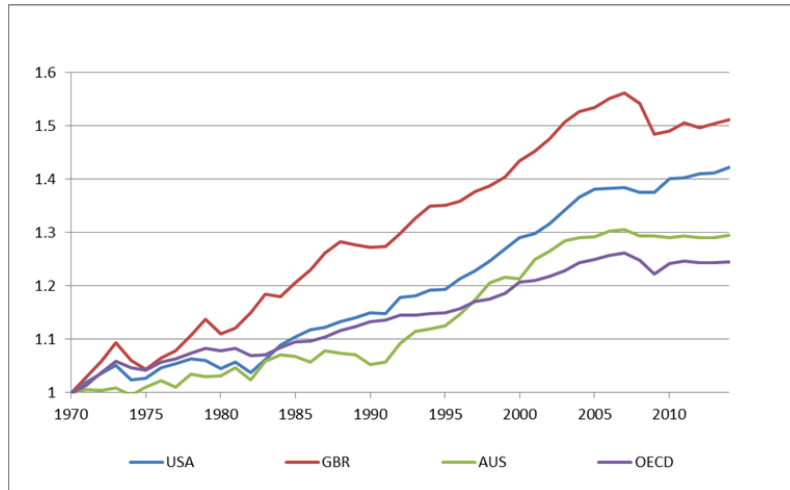
Figure 2. Gini coefficients before and after taxes and transfers



Source: SWIID database.

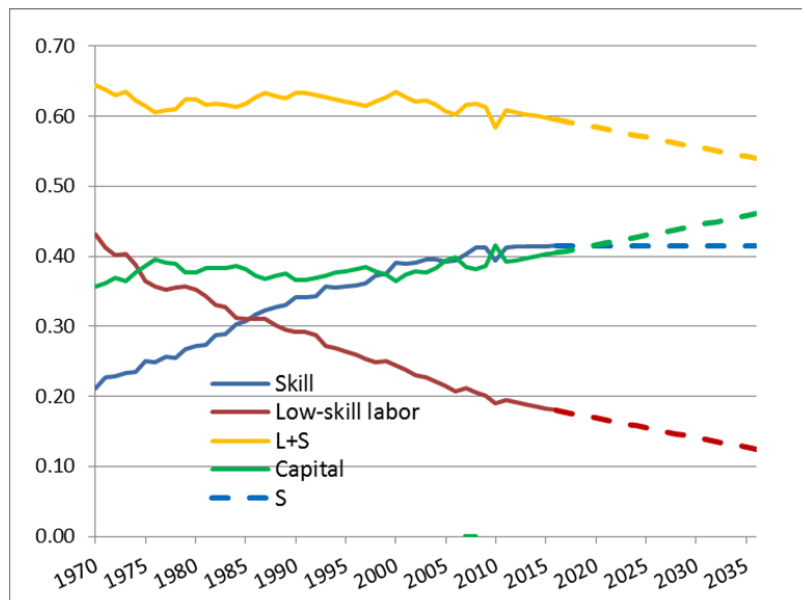
Note: The orange line is Gini index of inequality in equivalized household market (pre-tax and pre-transfer) income. The blue line is Gini index of inequality in equivalized household disposable (post-tax and post-transfer) income.

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^a

Effects on: of technical change^b 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 ^c (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 ^c (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 ^c (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 ^c (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^{a,b}

	Effects on:	US				EU				China			
	Tax credits implemented ^c by:	US, EU, Japan, China, Australia				US, EU, Japan, China, Australia				US, EU, Japan, China, Australia			
Welfare measure ^d	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.

Editor, UWA Economics Discussion Papers:
Sam Hak Kan Tang
University of Western Australia
35 Sterling Hwy
Crawley WA 6009
Australia

Email: ecoadmin@biz.uwa.edu.au

The Economics Discussion Papers are available at:

Since 1980: <https://ideas.repec.org/s/uwa/wpaper.html>

Since 2004: <http://www.business.uwa.edu.au/school/disciplines/economics>

ECONOMICS DISCUSSION PAPERS - 2016		
DP NUMBER	AUTHORS	TITLE
16.01	Xu, R., Wu, Y. and Luan, J.	ANALYSIS OF FARMERS' WILLINGNESS TO ADOPT GENETICALLY MODIFIED INSECT-RESISTANT RICE IN CHINA
16.02	Lia, Y., Fan, J., Zhao, D., Wu, Y. and Li, J.	TIERED GASOLINE PRICING: A PERSONAL CARBON TRADING PERSPECTIVE
16.03	Clements, K.W., Lan, Y. and Si, J.	UNCERTAINTY IN CURRENCY MISPRICING
16.04	Parsons, C. and Vézina, P.L.	MIGRANT NETWORKS AND TRADE:THE VIETNAMESE BOAT PEOPLE AS A NATURAL EXPERIMENT
16.05	Chang, S., Connelly, R. and Ma, P.	WHAT WILL YOU DO IF I SAY 'I DO'? : THE EFFECT OF THE SEX RATIO ON TIME USE WITHIN TAIWANESE MARRIED COUPLES
16.06	Yu, F. and Wu, Y.	BIASES IN PATENT EXAMINATION AND FIRMS' RESPONSES: EVIDENCE FROM THE PHARMACEUTICAL INDUSTRY
16.07	Fan, J., Li, J., Wu, Y., Wang, S. and Zhao, D.	THE EFFECTS OF ALLOWANCE PRICE ON ENERGY DEMAND UNDER A PERSONAL CARBON TRADING SCHEME
16.08	Golley, J., Tyers, R. and Zhou, Y.	CONTRACTIONS IN CHINESE FERTILITY AND SAVINGS: LONG RUN DOMESTIC AND GLOBAL IMPLICATIONS
16.09	McGrath, G. and Neill, K.	FOREIGN AND DOMESTIC OWNERSHIP IN WESTERN AUSTRALIA'S GAS MARKET
16.10	Clements, K.W. and Si, J.	SIMPLIFYING THE BIG MAC INDEX
16.11	Priyati, R.Y. and Tyers, R.	PRICE RELATIONSHIPS IN VEGETABLE OIL AND ENERGY MARKETS
16.12	Wu, J., Wu, Y. and Wang, B.	THE GREENNESS OF CHINESE CITIES: CARBON DIOXIDE EMISSION AND ITS DETERMINANTS
16.13	Arslan, C., Dumont, J.C., Kone, Z., Özden, Ç., Parsons, C. and Xenogiani, T.	INTERNATIONAL MIGRATION TO THE OECD IN THE TWENTY-FIRST CENTURY
16.14	Tomioka, K. and Tyers, R.	HAS FOREIGN GROWTH CONTRIBUTED TO STAGNATION AND INEQUALITY IN JAPAN?

16.15	Donovan, J. and Hartley, P.	RIDING THE IRON ORE CYCLE: ACTIONS OF AUSTRALIA'S MAJOR PRODUCERS
16.16	Czaika, M. and Parsons, C.	HIGH-SKILLED MIGRATION IN TIMES OF GLOBAL ECONOMIC CRISIS
16.17	Lefroy, T., Key, J. and Kingwell, R.	A LONGITUDINAL EXAMINATION OF BROADACRE FARM SIZE AND PERFORMANCE IN WESTERN AUSTRALIA
16.18	Arthmar, R. and McLure, M.	SRAFFA, MYRDAL AND THE 1961 SÖDERSTRÖM GOLD MEDAL
16.19	Azwar, P. and Tyers, R.	POST-GFC EXTERNAL SHOCKS AND INDONESIAN ECONOMIC PERFORMANCE
16.20	Chen, A. and Groenewold, N.	OUTPUT SHOCKS IN CHINA: DO THE DISTRIBUTIONAL EFFECTS DEPEND ON THE REGIONAL SOURCE?
16.21	Wu, Y., Zhu, X. and Groenewold, N.	THE DETERMINANTS AND EFFECTIVENESS OF INDUSTRIAL POLICY IN CHINA: A STUDY BASED ON FIVE-YEAR PLANS
16.22	Liu, H.	THE INCOME AND PRICE SENSITIVITY OF DIETS GLOBALLY
16.23	Asano, A., Neill, K. and Yamazaki, S.	DECOMPOSING FISHING EFFORT: MODELLING THE SOURCES OF INEFFICIENCY IN A LIMITED-ENTRY FISHERY
16.24	Golley, J., Tyers, R. and Zhou, Y.	FERTILITY AND SAVINGS CONTRACTIONS IN CHINA: LONG-RUN GLOBAL IMPLICATIONS
16.25	Taylor, G., Tyers, R.	SECULAR STAGNATION: DETERMINANTS AND CONSEQUENCES FOR AUSTRALIA

ECONOMICS DISCUSSION PAPERS – 2017		
DP NUMBER	AUTHORS	TITLE
17.01	Tyers, R. and Zhou, Y.	AUTOMATION AND INEQUALITY WITH TAXES AND TRANSFERS
17.02	Ye, L. and Robertson, P.	HITTING THE GREAT WALL: RURAL-URBAN MIGRATION AND CHINA'S GROWTH SLOWDOWN
17.03	Ye, L. and Robertson, P.	MIGRATION AND GROWTH IN CHINA: A SCEPTICAL ASSESSMENT OF THE EVIDENCE
17.04	Clements, K. Si, J. and Vo, L.	FOOD AND AGRICULTURAL PRICES ACROSS COUNTRIES AND THE LAW OF ONE PRICE
17.05	Chen, M., Clements, K., Gao, G. and Si, J.	THREE FACTS ABOUT WORLD METAL PRICES
17.06	Cornes, R., Fiorini, L. and Maldonado, W.	EXPECTATIONAL STABILITY IN AGGREGATIVE GAMES
17.07	Hartley, P.	THE COST OF DISPLACING FOSSIL FUELS: SOME EVIDENCE FROM TEXAS
17.08	Shehabi, M. R.	ASSESSING KUWAITI ENERGY PRICING REFORMS
17.09	Perdana, S. and Tyers, R.	GLOBAL CLIMATE CHANGE MITIGATION: STRATEGIC INTERACTION OR UNILATERAL GAINS?
17.10	McLure, M.	RICARDIAN EQUIVALENCE, THE ITALIAN FISCAL TRADITION AND WA GOVERNMENT NET DEBT
17.11	Trinh, J.	THE PARETO DISTRIBUTION AND ITS RELATIONSHIP TO PIKETTY'S THIRD FUNDAMENTAL LAW OF CAPITALISM

17.12	McLure, M.	THINKING OUTSIDE THE BOX: A NEW HISTORY OF EDGEWORTH'S AND PARENTO'S DEVELOPMENT OF THE BOX DIAGRAM
17.13	Zhou, Y. and Tyers, R.	AUTOMATION AND INEQUALITY IN CHINA
17.14	Arthmar, R. and McLure, M.	THE ECONOMIC AND SOCIAL CONSEQUENCES OF THE WAR: PIGOU, THE PRESS AND THE STRUGGLE FOR AN HONOURABLE PEACE
17.15	Shehabi, M. R.	CONTEMPORARY KUWAITISATION DYNAMICS AND THEIR HISTORICAL PERSPECTIVES
17.16	Clements, K. and Si, J.	WHAT DO AUSTRALIAN ECONOMICS PhDs DO? THE UWA EXPERIENCE
17.17	Arthmar, R. and McLure, M.	KEYNES AND THE ROYAL SWEDISH ACADEMY
17.18	Chen, A. and Groenewold, N.	CHINA'S 'NEW NORMAL': IS THE GROWTH SLOWDOWN DEMAND- OR SUPPLY- DRIVEN?
17.19	Groenewold, N.	CHINA'S 'NEW NORMAL': HOW WILL CHINA'S GROWTH SLOWDOWN AFFECT AUSTRALIA'S GROWTH?

ECONOMICS DISCUSSION PAPERS – 2018

DP NUMBER	AUTHORS	TITLE
18.01	Tyers, R. and Zhou, Y.	LOST INFLATION?
18.02	McLure, M.	PARETIAN FISCAL SOCIOLOGY
18.03	McLure, M. and Montesano, A.	THINKING OUTSIDE THE BOX: EDGEWORTH, PARETO AND THE EARLY HISTORY OF THE BOX DIAGRAM
18.04	Tyers, R. and Zhou, Y.	DEFLATION FORCES AND INEQUALITY
18.05	Clements, K. and Si, J.	DIVISIA AND FRISCH ARE FRIENDS
18.06	Trinh, J. and McLure, M.	PILETTY'S $(r - g)$ LAW IS PARETO'S LAW: CONSISTENT ANALYSES OF INCOME DISTRIBUTION PREDICATED ON INCONSISTENT DEFINITIONS OF INEQUALITY
18.07	Tyers, R. and Zhou, Y.	AUTOMATION, TAXES AND TRANSFERS WITH INTERNATIONAL RIVALRY
18.08	Li, Q., Vo, L. H. and Wu, Y.	INTANGIBLE CAPITAL DISTRIBUTION IN CHINA
18.09	Vo, L. H.	WHY DON'T AGRICULTURAL PRICES ALWAYS ADJUST TOWARDS PARITY?