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Automation and Inequality with Taxes and Transfers

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Abstract

Technical change in key OECD countries since 1990 is examined in terms of its contributions to total factor productivity and to factor bias. The dependence of real income and inequality on changes in factor abundance, total factor productivity, factor bias, the relative cost of capital goods and the progressivity of the tax system are quantified using an elemental general equilibrium model with three households. For the US, changes in factor bias are shown to have been responsible to the great majority of the observed increase in inequality between 1990 and 2008. The widely anticipated further twist away from low-skill labour is then examined, with downward rigidity of low-skill wages and transfers that sustain low-skill welfare, the increments to which are financed either from capital income or consumption taxes. The potential is identified for unemployment, or "subsidised leisure", to rise to extraordinarily high levels, with Pareto improving gains requiring that the technology twist accompanies substantial increases in total factor productivity.

Keywords

Automation, income distribution, tax, transfers, general equilibrium analysis

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Abstract

Technical change in key OECD countries since 1990 is examined in terms of its contributions to total factor productivity and to factor bias. The dependence of real income and inequality on changes in factor abundance, total factor productivity, factor bias, the relative cost of capital goods and the progressivity of the tax system are quantified using an elemental general equilibrium model with three households. For the US, changes in factor bias are shown to have been responsible to the great majority of the observed increase in inequality between 1990 and 2008. The widely anticipated further twist away from low-skill labour is then examined, with downward rigidity of low-skill wages and transfers that sustain low-skill welfare, the increments to which are financed either from capital income or consumption taxes. The potential is identified for unemployment, or "subsidised leisure", to rise to extraordinarily high levels, with Pareto improving gains requiring that the technology twist accompanies substantial increases in total factor productivity.

1 Introduction

Three prominent trends in global economic performance have arisen in the past two decades. First, rates of growth in economic activity in advanced economies have declined and, in middle income economies they have declined, most notably since the GFC (Lo and Rogoff 2015). Second, when this is combined with the declining trend in global bond yields at all maturities, it suggests a revival of "secular stagnation" (Summers 2014, 2016). And third, most prominently in the advanced Anglo economies, there has been a trend toward the capture of what new income and wealth is generated entirely by high level professional and capital-owning households (Piketty 2014). It comes as no surprise that these three issues are related (Pichelmann 2015) and that they depend, at least in part, on alterations in the rate and composition of technical changes in the period (Gordon 2014, 2015).

In the early 2000s levels of real net investment in the advanced economies began to decline. Yet we know that investment embodies new and more productive technology and so slower rates of capital accumulation imply slower total factor productivity (TFP) growth. Indeed, TFP stopped growing quite suddenly across the OECD around this time and there has been little sign of resurgent growth since. Less suddenly, during the past three decades the advanced economies have shown a trend in factor bias, away from low-skill labour toward skill and physical capital, suggesting that technical change has roles in both stagnation and rising inequality. All this is supportive of altered patterns of technical change as explanations for slower growth and rising inequality.

Gordon (2014, 2015) offers the view that the major gains in capital-embodied productivity are in the past and that advances in information and communication technology (ICT) since the 1980s have contributed little thus far. He identifies the massive gains accruing from the great discoveries of the 19th and 20th centuries, including the internal combustion engine, revolutions in materials science, transmitted electricity, sanitation and such health advances as antibiotics. The more recent ICT advances, he claims, have not revolutionized quality of life and business practices in the way these major innovations did. In response to the claim that the gains from the most recent ICT developments are under-measured (the "Solow paradox" [1]), he asserts that this has been typical of all periods of innovation and was also characteristic of the major gains delivered by older technologies. He is not alone in these views, which are shared at least in part by Clark (2016), Crafts (2016) and Friedman (2016).

To the extent that the rate of technical advance affects expectations over rates of capital return, which are eventually reflected in market interest rates, the trend of bond yields over time is indicative of underlying technical change and the expectations that surround it. Real bond yields have indeed declined since the 1980s, with the decline steepening in the post-GFC period. This offers at least superficial support for technology pessimism as an explanation for sluggish performance and for Summers' (2016) concern over the power of monetary policy. Yet, beyond technical change, there are many explanations for the declining rates of investment and low yields on offer in the advanced economies. These include the redirection of saving in advanced economies to investment in emerging ones, underlying demographic change including to labour force participation rates, the financial consequences of rising levels of perceived risk and the increasingly poor performance of governments in the advanced democracies in public infrastructure and R&D.[2]

By contrast with Gordon and others, the techno-optimists see immense potential for productivity and lifestyle improvements from the further expansion of modern ICT, artificial intelligence (AI) and robotics. Mokyr (2013) and Mokyr et al. (2015) argue that, technology anxiety notwithstanding, we are on the cusp of a new era of progress in innovation that will provide an unprecedented boost to productivity. Yet this literature also has a dark side that is

[1] 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."

[2] See, for demographics, Authers (2016) and Gagnon et al. (2016), for financial determinants, Gome et al. (2015) and, for reviews of all determinants, Teulings and Baldwin (2014), Arsov and Ravimohan (2016) and Taylor and Tyers (2017).

emphasised by many of its proponents, namely that this change is likely to induce greater inequality, not only across income classes but also between regions. It is not simply that machines may replace human work, which has been the key mechanism for distributing income to the middle class for two centuries.[3] But also the ownership of new technologies, software and know-how is now highly concentrated across regions. Repairs and local support tend to rely less on associated local industries and more on direct transactions with a few global centres of supply. As Ford (2016) suggests, the issue is not that we may no longer have "broad-based" innovation; it is that modern innovation may no longer procure broad-based prosperity. Households dependent for their incomes on work, once referred to as the "proletariat", are now being referred to as the "precariat", facing higher employment risk and stagnant prospects (Das 2016 a & b).

This distributionally pessimistic scenario has capital returns being raised by the new technology in well-connected places but not in others (Khanna 2016), and the globalisation of the financial market delivering those returns to savers, while allowing physical capital stocks to erode in less well-connected places. Capital returns no longer depend on the availability of labour, to be combined with physical capital, but rather on technology property rights and skills (Acemoglu and Restrepo 2015), the holders of which will be increasingly attracted to connected cities and their hinterlands. Thus, not only is there the prospect of increased income stratification in the advanced economies but also a new geographic polarisation of the global pattern of economic activity that favours regions with critical mass in AI and robotics R&D.[4]

In this paper the focus is on the ways income stratification is affected by a range of determinants that centre on technical change. The evidence on total factor productivity and factor bias in key OECD countries since 1990 is first explored. An elemental general equilibrium model with multiple households is used in a decomposition of observed changes since 1990 for the US and an analysis of prospective technology shocks. This model embodies a technology specification that allows changes in total factor productivity to be separated from factor bias. Three represented households supply raw labour, skill and capital in different proportions. The effects on their real incomes and the inequality between them are examined in response to changes in factor abundance, total factor productivity and factor

[3] Key contributors include Brynjolfsson and Andrew (2011), OECD (2012), Goos et al. (2014), Hemous and Olsen (2014) and Avent (2016).

[4] This implies the concentration of property rights in the US, parts of Europe, Japan and, less predictably, in China, where immense investments in automation are under way (State Council 2015, Zhou 2016, Zhou and Song 2016).

bias, along with changes in the relative cost of capital goods, labour force participation rates and the progressivity of the tax system.

Changes in factor bias that advantages skill and capital relative to low-skill labour emerges as the dominant explanator of the rise in inequality in that period that is suggested corresponding rises in Gini coefficients.[5] The model is then applied to technical changes that are anticipated and to the associated changes in tax and transfer rates that may be needed to avoid extreme inequality. The alarming "dark side" projections of the displacement of low-skill labour, and even of skill, that are prominent in the techno-optimist literature are then shown to offer the possibility of growth in net welfare even if displaced low-skill workers receive compensatory transfers. Yet, under these circumstances, unemployment or "subsidised leisure" can be expected to rise to extraordinarily high levels. Section 2 reviews data on technical change and income distribution in key advanced economies, while Section 3 describes the general equilibrium framework used to conduct the analysis. Section 4 offers the decomposition analysis for the case of the US over 1990-2008 and Section 5 addresses prospective, capital-concentrating technical change. Section 6 then concludes.

2. Technology, Factor Shares and Inequality in Advanced Economies

That inequality has risen in the US since the 1960s is clear from Figure 1. Indeed, the upward trend is sustained throughout the period, continuing even after the substantial recession of the early 1990s. To examine how much this rising trend in income inequality is driven by technical change we first investigate changes in measured TFP and factor payment shares for the US and other advanced economies. Two striking trends emerge: a slowdown in TFP growth and a twist in shares away from low-skill labour. We then examine the dispersion of wage incomes in the US in search of complementary patterns.

2.1 Technology indicators

The slowdown in TFP growth is clear from Figure 2, which shows the turning point following which TFP stagnated to have been during the early 2000s, prior to the GFC. This is true on average for the OECD and, as shown in Figure, for key individual economies, including the US, Great Britain (the UK) and Australia. The UK had taken the lead in TFP growth early on, in part because of its specialization as a delivery centre for services of low

[5] For an analysis of alternative measures of the US Gini coefficient see Schneider and Tavani (2016).

capital intensity to the European Union (EU). The US caught up via the agency of its ICT boom in the 1990s. Australia's shift to efficient service delivery and ICT uptake in that period saw its productivity also surge. These three regions out-performed the OECD as a whole, though all began to stagnate before the GFC.

Changes after 1995 in the shares of expenditure by producers on capital, low-skill labour and skill are examined in Figure 3 for the US, the UK, Australia and the OECD as a whole. The capital share is calculated as the share of payments to capital in value added. The low-skill labour share is that of payments to "medium- and low-skilled" persons in value added, while the skill share is that of payments to high-skilled persons in value-added. For the OECD as a whole and for all the individual regions listed, the low-skill labour share declined significantly, falling from 37% to 31% in the US, 45% to 37% in the UK, 49% to 42% in Australia and 42% to 35% across the OECD. By contrast, there was a surge in the skill share over this period: 23% to 28% in the United States, 22% to 30% in the United Kingdom, 14% to 18% in Australia and 20% to 25% across the OECD. While on average capital shares also rose, from 38% to 40% across OECD, the major beneficiaries of the incremental factor bias were professional workers. Indeed, in the UK, expansion as a services delivery centre saw the largest boost to the skill share while the physical capital share declined.

2.2 Dispersion in real wage incomes

The modern literature exploring the determinants of wage dispersion surged in the late 1980s following deterioration in the labour market performance of low-skill US and European workers. An extensive survey, grounded in the Stolper-Samuelson Theorem, was offered early on by Wood (1994). The subsequent literature broadened and can be thought of as divided amongst labour economics, global general equilibrium analysis and the combination of applied macroeconomics and international finance.

The early empirical studies focussed on the links between trade and US labour market performance (Bound and Johnson 1992, Borjas and Ramey 1994, Berman et al. 1994 and Leamer 1996). These studies were driven by the observed rise in the skill premium from the late 1980s, which can be observed in the early 1990s in Figure 4. Each sought to apportion blame for the dispersion between trade with developing countries (particularly "outsourcing") on the one hand and labour-saving technical change on the other, with all attributing at least part of the effect to trade. Complementary global general equilibrium studies emerged at the time, beginning with Krugman (1995) and proceeding to the decomposition studies by Tyers and Yang (1997) and Francois and Nelson (1998), both of which suggested that strong growth in developing trading partners had been welfare improving in the developed economies and that technical change was more important than trade in determining labour market performance.[6]

As can be seen from the Figure, later in the 1990s the heat came out of this debate temporarily when the US ICT boom stabilised the level of dispersion and lifted all real wage incomes. It was again resurgent after China's accession to the WTO in 2001. Its growth then accelerated and it became the dominant developing trading partner and the dominant global manufacturer. The resurgent literature noted that the performance of all US worker occupation groups (bar the top one per cent) deteriorated after 2000 (Haskell et al. 2012). This is consistent with the final trends shown in Figure 4, which show a further widening in the dispersion of real wage incomes and deteriorating real incomes to low-skill workers.

This new stylised fact then motivated further labour theories that depended on new models with heterogeneous workers and heterogeneous firms (Helpmann et al 2010, Autor et al. 2013). These tended to suggest a greater role for trade and outsourcing relative to home technology than the earlier empirical literature. Yet technology remained important in model specifications. Product differentiation limited the penetration of external terms of trade effects to domestic labour markets (Tokarick 2005) and wage distribution effects were shown to depend on capital-skill complementarity (Tyers and Yang 2000, Winchester and Greenaway 2007).[7]

Finally, it is worth noting from Figure 4 that, while male income in the US has stagnated and even declined in the 2000s for some education cohorts, corresponding mean female incomes performed better over that same period. While the general pattern of change in real incomes to female and male workers is similar, female workers may have been advantaged in this period by the structural shift in the economy toward services and away from manufacturing. At the sectoral level male workers fared better in financial and health services but less well in other service industries, their participation rate dropping with the decline in manufacturing employment.

2.3 The suffering "middle"

[6] Somewhat later a similar conclusion is drawn from dynamic global modeling by McKibbin and Woo (2003).
[7] A useful survey of global modeling assessments to this point is by Winchester (2006).

The comparatively poor labour market performance of workers in the middle skill levels was noted early on by Gregory (1993) for the US and Australia, and more recently by Acemoglu and Autor (2011), amongst others. In our above analysis of factor shares, and in our modelling below, the middle group is combined with the very low-skill group to form the "low-skill" group. Nonetheless, the implications of technical change for this group appear to have been significant and this is worth mention. Table 2 presents the changes in skill earnings gaps in OECD economies from the year 2002 to the year 2014. In the OECD economy overall, the gap between high- and medium-skill earnings widened and that between medium- and low-skill earnings narrowed, which suggests the twist was in the dispersion of earnings between high-skill persons and the combined medium- and low-skill group. This suggests that it is workers of medium skill that have been most vulnerable to automation and outsourcing.

2.4 Sources of changes in factor shares

In our analysis to be presented below we do not seek the determinants of changes in factor shares through time, regarding them as exogenous technical changes. Of course, at least in the past, these changes have been induced not only by spontaneous cost-reducing technical innovation but also by induced reorganization that occurs in response to external competition and relative price changes. To model the shares as endogenous requires complex specifications of the technology that include parameters that are either unobservable or difficult to identify. For this reason our analysis takes changes in the shares as exogenous and so does not attribute causality.

3. The Model

A closed economy, single product, real general equilibrium structure is used that has a complete financial market with government debt and three household groups. The regional rate of return on equity investment departs from the regional bond yield, the former reflecting expected rates of return on installed capital and the latter short run equilibrium in the financial market between savers, the indebted government and investors.

On the supply side, there are three primary factors with "production" labour (L) a partially unemployed variable factor. The stocks of physical capital (K) and skill (S) are fixed and fully employed. Investment in the current period creates demands on the economy but does not raise the useful capital stock. Households have differing shares of the three primary factors and different consumption behaviour, represented by reduced form relationships that depend on current and expected future disposable income and the interest rate.

3.1 The supply side

Since technology is exogenous and subject to shocks in this analysis, a "relative Cobb-Douglas" formulation allows us to capture changes in productivity and factor bias separably, via simple changes in readily observed parameters: a total factor productivity parameter, θ, and a set of factor shares, β.

(1) $$\frac{y}{y_0}=\theta\left(\frac{L}{L_0}\right)^{\beta^L}\left(\frac{S}{S_0}\right)^{\beta^S}\left(\frac{K}{K_0}\right)^{1-\beta^L-\beta^S},$$

where y_0, L_0, S_0 and K_0 are the initial levels of output and labour, skill and capital inputs. This formulation allows technology bias shocks, to β^L and β^S, to be neutral so far as the initial level of aggregate output is concerned. Marginal products are then:

(2) $$MP^L=\beta^L\frac{y}{L},\quad MP^S=\beta^S\frac{y}{S},\quad MP^K=\left(1-\beta^L-\beta^S\right)\frac{y}{K}\ .$$

The real production wages of unskilled and skilled workers depend conventionally on the corresponding marginal products:

(3) $$w=\frac{W}{P^P}=\beta^L\frac{y}{L},\quad w^S=\frac{W^S}{P^P}=\beta^S\frac{y}{S}\ .$$

Here the upper case wages are nominal and the lower case real, and P^P is the *producer* price level. The real volume of output, y, is distinguished from nominal[8] GDP, $Y = P^Y y$, where P^Y is the *GDP price* level (deflator). Direct and indirect tax revenues, T^D and T^I, and transfers to households, T^R, play key roles in the formulation. GDP at factor cost (or producer prices), Y^{FC}, is the total of direct payments to the collective household in return for the use of its factors. Nominal GDP is then

(4) $$Y=Y^{FC}+T^I,\quad Y^{FC}=C+\left[T^D-T^R-\alpha W_0\left(F-L\right)\right]+S^P\ .$$

This is the standard disposal identity for GDP, or the collective household budget, where C is the total value of final consumption expenditure, including indirect taxes paid, S^P is private saving and the term in square parentheses is direct taxation net of transfers to households (the latter including non-specific transfers, T^R, and unemployment benefits at fraction, α, of the

[8] In this real model, "nominal" refers to prices relative to the model numeraire, which is arbitrary but is generally chosen to be either P^Y or the producer price level, P^P.

initial low-skill wage). The GDP price, P^Y, and the producer price, P^P, would be the same were it not for indirect taxes. In their presence we have:

(5) $$Y = P^Y y = P^P y + T^I \text{, so that } P^Y = P^P + \frac{T^I}{y}.$$

3.2 The demand side

Central to the demand side in any economy-wide model is the financial market, which equates saving to investment. Here investment depends on the expected after-tax yield, or the rate of return on installed capital net of depreciation and capital tax, adjusted for sovereign risk, r^{ce}. This has a number of components. First, since only the after-depreciation component of capital income is taxed, after tax capital income is:

(6) $$Y_{KN} = \left(1-t^K\right)K\left(P^P\, MP_K - P^K\,\delta\right),$$

where P^K is the price of capital goods,[9] t^K is the ad valorem capital income tax rate and δ is the depreciation rate. The rate of return net of both tax and depreciation is then:

(7) $$r^c = \frac{Y_{KN}}{P^K K} - \delta\ .$$

The expected form of this rate is then:

(8) $$r^{ce} = r^c\left(\frac{\varphi^0}{\varphi}\right),$$

where the interest premium factor, φ, permits consideration of the effects of changes in the fiscal balance on sovereign risk. A deteriorating fiscal balance causes investment to be less attractive.

(9) $$\varphi = \varphi^0\left[\left(\frac{G}{T}\Big/\frac{G_0}{T_0}\right)\right]^{\phi},$$

where ϕ is a positive elasticity indicating sensitivity to sovereign risk.

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9 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.

The demand for investment financing depends on the "Tobin's Q like" ratio of the expected rate of return on installed capital, r^{ce} and a domestic market clearing bond yield or financing rate, r .

$$(10) \qquad \frac{I^D}{I^0} = \left(\frac{r^{ce}}{r}\right)^{\varepsilon^I} \quad ,$$

where ε^I is a positive elasticity. This investment demand is then matched by a supply of saving that incorporates the government's fiscal position:

$$(11) \qquad I^D = S^D = S^P + \left(T^D + T^I - G\right),$$

where T^D and T^I are, respectively, direct and indirect tax revenues, S^P is private saving and G is government expenditure on goods, services and transfers to households, h, as well as on unemployment benefits, which are paid at a fraction, α, of the initial nominal low-skill wage, W_0:

$$(12) \qquad G = G^X + T^R + \alpha W_0 \left(F - L\right), \quad T^R = \sum_h T_h^R \quad ,$$

where F is the total low-skill labour force.

Calibration of the financial market is facilitated by the assumption that the initial database has the steady state property that the net rate of return is initially the same as the market bond yield: $r_0^{ce} = r$. Thus, the financial market clearing condition equates the value of domestic investment, I^D, which represents the sum total of all domestic long maturity asset issues, with demand for those assets in the form of net (private and government) savings.

Direct tax

Constant marginal direct tax rates, t^W, t^S and t^K, apply to all labour, skill and capital income, respectively. The corresponding "powers" of these rates are $\tau^L = \left(1 + t^L\right)$, $\tau^S = \left(1 + t^S\right)$ and $\tau^K = \left(1 + t^K\right)$ and so, bearing in mind taxation of capital income after depreciation (6), total direct tax revenue is:

$$(13) \qquad T^D = t^L W L + t^S W^S S^K + t^K K\left(P^P \, MP_K - P^K \, \delta\right).$$

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

Household disposable income and consumption

Three separate households are included in the model, defined based on factor ownership. The first has income dominated by production labour, the second by skill and the third by capital. Because few households depend on only one factor of production, the three are defined based on the stylised factor ownership shares, s_{hf}, offered in Table 2.

Disposable income, for each household, then takes the form:

$$Y_h^D = s_{hL}\left[\left(1-t^L\right)WL + \alpha W_0\left(F-L\right)\right] + s_{hS}\left(1-t^S\right)W^S S^K + s_{hK}\left(1-t^K\right)K\left(P^P\,MP_K - P^K\,\delta\right) + T_h^R \quad (14)$$

where $T_h^R = t_h^R N_h Y$ 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. 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: $Y^D = \sum_h Y_h^D = Y^{FC} - T^D + T^R + \alpha W_0\left(F-L\right)$.

Since, from (5), GDP at factor cost is full GDP less net indirect tax revenue, this can be written as

$$Y^D = Y - T^I - T^D + T^R + \alpha W_0\left(F-L\right) \quad (15)$$

For each household, h, aggregate consumption expenditure, C_h, is a nominal sum but real consumption behaviour is motivated by current and expected future real disposable incomes and the real interest rate. Real consumption, (lower case) c_h, 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:

$$c_h = \frac{C_h}{P^C} = A_h^C\left(\frac{r}{\tau^K}\right)^{-\varepsilon_h^{CR}}\left(\frac{Y_h^D}{P^C}\right)^{\varepsilon_h^{CY}}\left(\frac{Y_h^{De}}{P^C\left[1+\pi_h^{Ce}\right]}\right)^{\varepsilon_h^{CY}}, \quad (16)$$

where the expected inflation rate of the consumer price level is π^{Ce}.[10] The different households have parameters reflecting different sensitivities to these determinants. The consumer price level is marked-up over the producer price level by the power of the consumption tax, $P^C = \tau_C P^P$. This yields consumption tax revenue:

$$T^I = \left(\tau_C - 1\right)P^P \sum_h c_h \quad (17)$$

[10] There is no money-driven inflation in this model but expectations can be formed of a future increase in the consumption tax rate that would raise P^C relative to P^P and P^Y.

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 (15). Private saving differs across households. It is what remains after consumption expenditure (gross of indirect taxes) is further deducted from disposable income.

(18) $$S^P = \sum_h \left[Y_h^D - C_h \right]$$

Since total consumption expenditure, inclusive of consumption tax, is

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

And total disposable income is from (15), aggregate private saving can also be written as:

(20) $$S^P = Y^D - C = \left[Y - T^I - T^D + T^R + \alpha W_0 \left(F - L \right) \right] - C$$

Government and total domestic saving

This is government revenue less government expenditure, both measured net of direct transfers to households and the unemployed. Total domestic saving is then the sum of private and government savings in the home economy, in home currency, where government saving is $S^G = T^D + T^I - T^R - G^X - \alpha W_0 \left(F - L \right)$.

(21) $$S^D = S^P + S^G = Y - C - G^X \ .$$

The product balance

Product balance stems from a version of the expenditure identity in real volume terms:

(22) $$y = \frac{I + G^X}{P^P} + \sum_h c_h \ ,$$

where the final term is the sum of real consumption across the households. Neither investors nor the government pay indirect taxes on their expenditure and so the price they face for the home product is the producer price, P^P.

Welfare and inequality

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

(23) $$s_h^{YD} = Y_h^D / Y^D, \quad s_h^N = N_h / \sum_h N_h \ .$$

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 Lorenz curve:

(24) $$A_L = 0.5\left[s_{Lh}^N s_{Lh}^{YD} + s_{Sh}^N \left(2 s_{Lh}^{YD} + s_{Sh}^{YD} \right) + s_{Kh}^N \left(1 + s_{Lh}^{YD} + s_{Sh}^{YD} \right) \right] ,$$

and the corresponding Gini coefficient is then

(25) $$G^C = 2\left(0.5 - A_L\right) .$$

Parameters, database and operation:

A complete list of the behavioural parameters used in the model is provided in the Appendix, Table A1. The model is structured to resemble the US economy in 2011. The database is built on national accounts as well as international trade and financial data for that year. Trade and international financial flows are eliminated from the data, which is then rebalanced. Closures required to undertake the experiments for Sections 4 and 5, below, are detailed in Table A2. The model code and working software are available on request from the author.

4. US Growth and Inequality from 1990

Our first application is to decompose the aggregate and distributional changes in the US economy into components due to factor use, TFP, factor bias, cheaper capital, reduced income tax and labour force participation changes. Shocks to these elements follow from observation, as indicated in Table 3 and the labour market and fiscal closures adopted are listed in Appendix Table A2. The shocks are applied individually and collectively so that component contributions can be determined. Aggregate performance decompositions are summarized in Table 4. The major contributors to the changes in GDP and real disposable income are, not surprisingly, factor use and total factor productivity. While the considerable relative expansion in the use of high-skill labour militates toward greater equality, the shift in factor shares outweighs it, and aided by reduced income tax rates at high income levels, yields a modelled Gini coefficient that is higher by 15%.

The corresponding distributional decomposition is summarized in Table 5. These results show even more clearly that the drag on the real disposable income of the low-income household is dominated by the change in factor bias. Even though this technical change most favours skilled workers, the growth in real disposable income is greatest for the capital-owning household, principally because this household gains most from the comparatively high rate of capital accumulation and disproportionately from the rise in TFP.

5. Implications of Prospective Automation

It is a simple matter to use the model to calculate the distributional consequences of future changes in factor bias when labour markets clear and there are no changes in government policy. In that case the Cobb-Douglas formulation requires that real compensation should change linearly with factor shares. Yet this is unlikely to be the form that future automation shocks take. If robotics and artificial intelligence do indeed displace labour at an accelerated rate it is most likely that displaced workers would be covered by a social safety net, and thus receive compensatory transfers. It is also unlikely that the low-skill wage will fall by very much, given that it is constrained by minimum wage laws. These conditions suggest the experiments reported here.

The shock is a shift in factor shares away from low-skill labour and in favour of capital, with the skill share remaining constant. Workers thus displaced receive the standard unemployment benefit, to which is added a transfer sufficient to retain the real purchasing power of their incomes at consumer prices. This transfer is financed by additional taxation. Two alternatives are considered. First, the additional transfers are assumed to be financed via a rise in the capital income tax rate. Second, the financing is from a rise in the consumption tax rate. While the consumption tax alternative distorts investment incentives less it suffers from circularity since a higher consumption tax rate raises the scale of transfers in order that the real purchasing power of displaced workers is retained.

These experiments are first carried out with the technology twist only and no change in total factor productivity. Recalling that the low-skill share declined by 22% between 1990 and 2008 (Table 3), the further reductions in the low-income share range up to a maximum of 25%. The downward rigidity of low-skill wages then sees worker displacement and therefore reduced resources, so real GDP falls. With reduced output and collective income, and a higher tax burden, the real disposable incomes of the professional and capital-owning households are impaired as indicated in Figure 5. For the reasons indicated above, this impairment is greatest if the transfers are funded via the consumption tax, the power of which would have to rise by 34%. If funded by capital income tax then the power of this tax would need to rise by 22%. Most striking, however, is the scale of worker displacement. This drives the unemployment rate (the proportion of the combined low-skill and high-skill workforce that is unemployed)[11] to near 25% in the case of capital income tax financing and near 40% in the case of consumption tax financing.

Clearly this outlook is pessimistic. If Mokyr et al. (2015) are to be believed there the primary consequence of the automation will be gains to TFP. So our less pessimistic experiment is to allow sufficient TFP to keep the level of real GDP constant. This is fair in a comparative static context. The technical change should raise collective income at least sufficiently to finance the incomes of those displaced by it. The results in this case are illustrated in Figure 6, which shows that the additional TFP required is between 5 and 10%. In this case, with capital income tax funding, the outcome is roughly Pareto neutral. Any additional TFP growth would further advantage professional and capital-owning households, rendering a Pareto improvement. The social problems that would arise from such high rates of publicly financed leisure could, however, be considerable.

Even then, it is possible that these experiments are too pessimistic. New technologies have, in the past, created new forms of employment. Beyond the concerns of Ford (2016) about the concentrated structure of the new ICT industries there is the fact that the wealthy have always demanded personal services (Autor 2016). However unaesthetic income inequality may be, and however serious are the associated issues with shared public good burdens (Stiglitz 2000), as income becomes more concentrated, personal service jobs are likely to expand and contribute to soaking up some of the unemployment.

6. Conclusion

Technical change since 1990 in key OECD countries is examined in terms of its contributions to total factor productivity and to factor bias. A substantial shift in factor shares is identified, away from low-skill labour toward skill, with a smaller shift toward physical capital. An elemental three-household general equilibrium model is used to quantify the links between real income and inequality on the one hand and changes in factor abundance, total factor productivity, factor bias, the relative cost of capital goods and in the progressivity of the tax system on the other. For the US, changes in factor bias are shown to have been responsible to the great majority of the observed increase in inequality between 1990 and 2008.

[11] High-skill workers remain fully employed by assumption.

We then turn to a further twist away from low-skill labour, this time toward capital, which is widely expected to stem from recent accelerations in the development of artificial intelligence and robotics. Assuming minimum wage laws make low-skill wages rigid downward and that the government protects the welfare of low-skill households via tax-funded transfers, the same model framework is used to evaluate aggregate performance and changes in the welfare of professional and capital-owning households. If the new technology delivers only a shift in bias then aggregate performance is impaired, by most if the transfers are funded from consumption tax and least if they are funded from capital income tax. In either case professional households, rather than capital-owners, are the significant losers, suggesting they may also become transfer claimants. This distributional effect is, however, lessened the more the new technology also delivers increments to total factor productivity. Even then the results show that unemployment, or "subsidised leisure", could rise to truly extraordinary levels, with unforeseen consequences for social cohesion.

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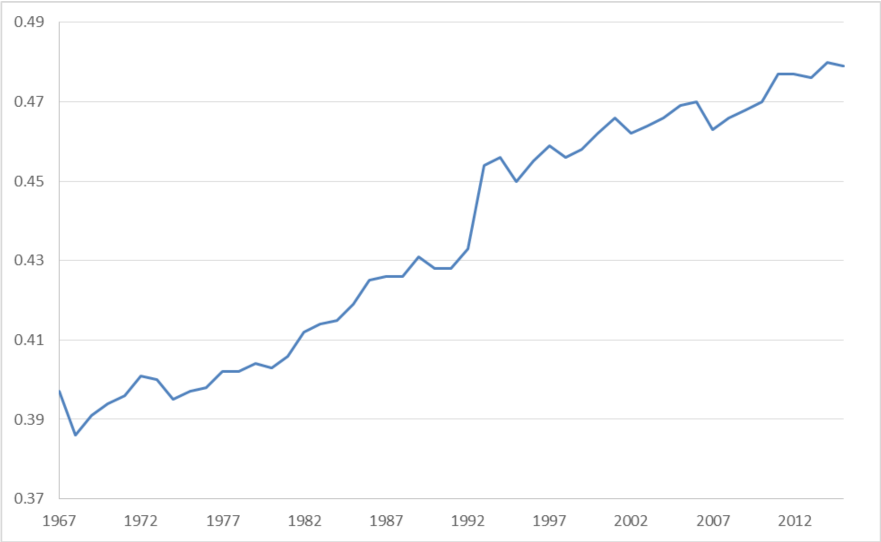
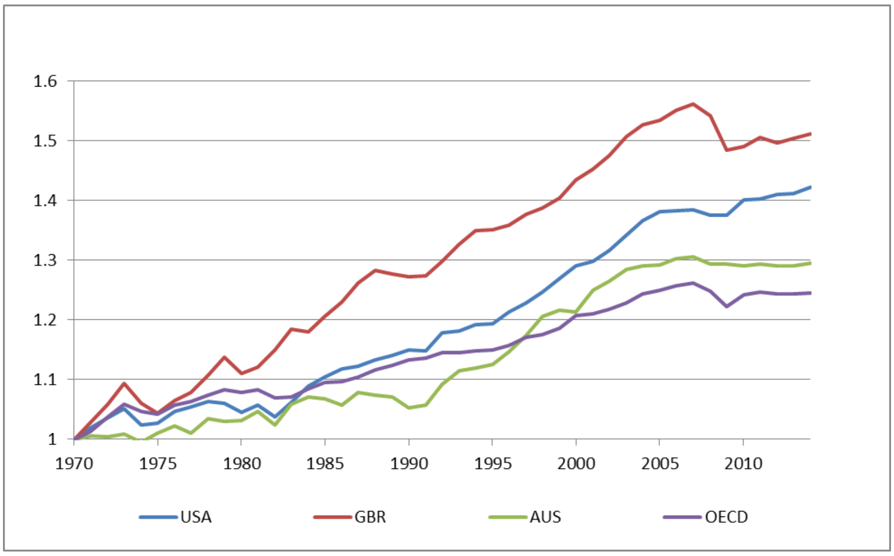
Figure 1. Gini coefficient of the U.S. economy, 1967-2015



Source: U.S. Census Bureau, Current Population Survey, Annual Social and Economic Supplements.

Figure 2. Total factor productivity, 1970-2014

(United States, United Kingdom, Australia, OECD overall)



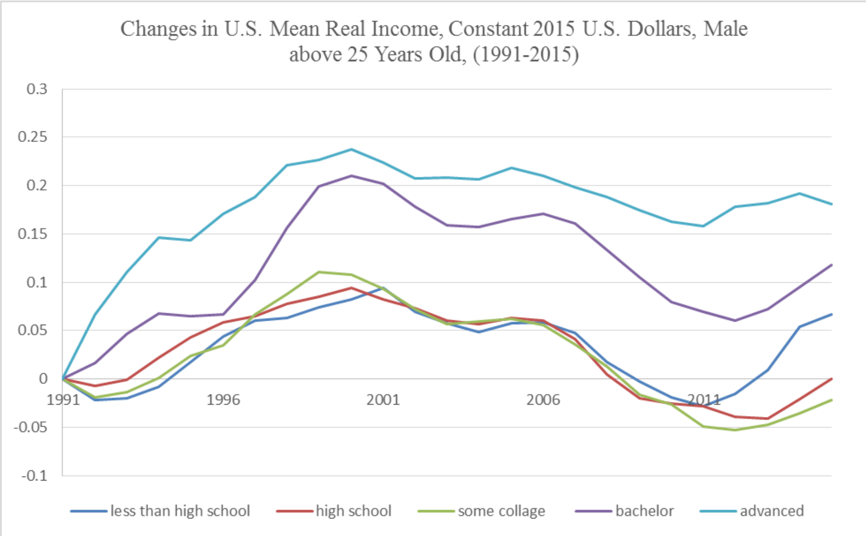
Source: Penn World Tables, international comparisons of production, income and prices, version 9.0. TFP is the portion of output change not explained by the quantities of inputs used in production and is reported at constant national prices (2011=1). We normalize the data to set TFP in 1970 at unity.

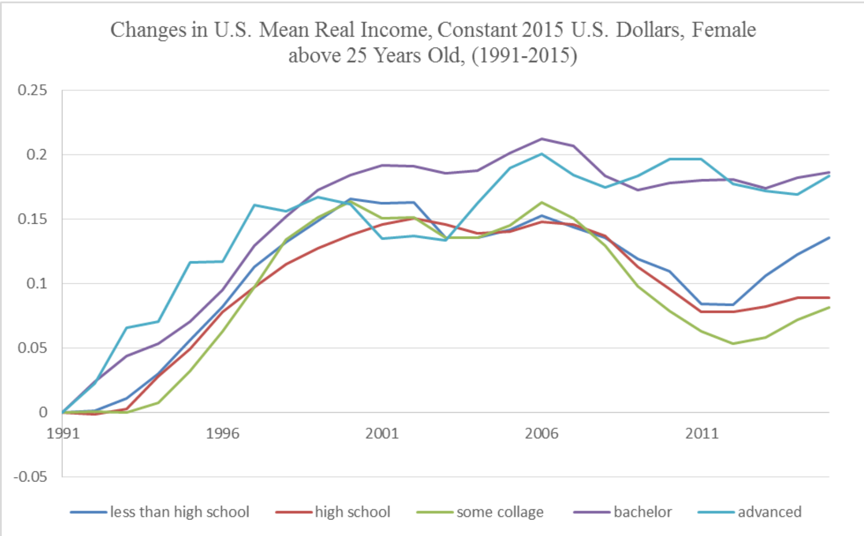
Figure 3. Value Added Shares of Primary Factors (Capital, Labour, and Skill), United States, 1995-2008

Source: WORLD KLEMS (Timmer *et al*. 2015)

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 high-skilled 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.

Figure 4. Trends in Real Worker Incomes in the United States





Source: Mean incomes in constant 2015 U.S. dollars by educational attainment based on Table P-18—Educational Attainment, People 25 Years Old and Over by Mean Income and Sex, 1991 to 2015, the U.S. Bureau of the Census.

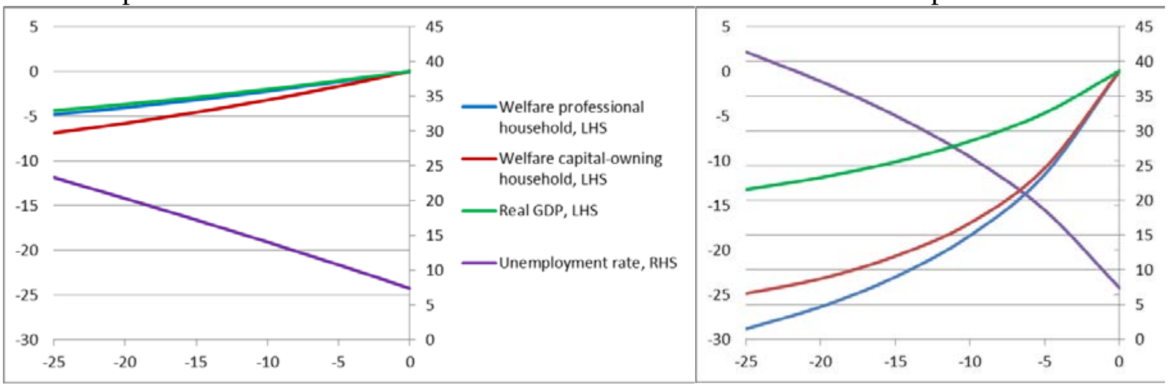
Note: Cumulative percentage changes are shown relative to 1991 means. These are adjusted for price inflation, money earnings for working males and females (aged 25 and above) by educational cohort in terms of the highest level of education attained. Changes along the y-axis are log changes (which approximate percentage changes), smoothed to three-year moving averages to eliminate occasional annual volatility. Less than high school and some high school workers correspond to low-skill workers; high school grad and some college correspond to medium-skill workers; college grad and more than college correspond to high-skill workers.

Figure 5: Effects of Further Twists Against Low-Skill Labour with Compensating Transfers[a]

(% change in listed indicators for given % reductions in the low-skill labour share)

Additional transfers financed by

Capital income tax | Consumption tax



a This summarises the results of a comparative static response to reductions in the low-skill labour share, associated with a complementary rise in the capital share. There is no change in total factor productivity and the low-skill wage is downwardly rigid to reflect minimum wage laws. “Welfare” is an abbreviation for the real purchasing power of disposable income at consumer prices. This measure for the low-skill household is here held constant by tax-financed transfers.

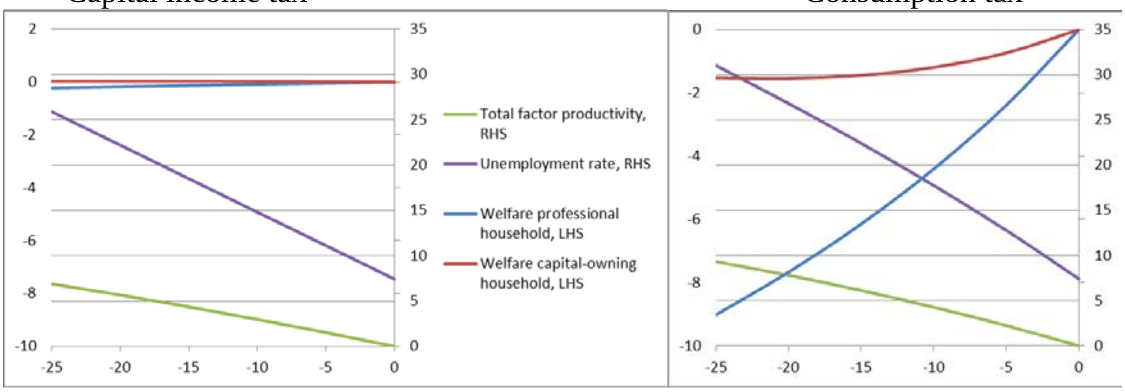
Source: Solutions to the model described in the text.

Figure 6: Effects of Further Twists Against Low-Skill Labour with Compensating Transfers and Total Factor Productivity Sufficient to Sustain Real GDP[a]

(% change in listed indicators for given % reductions in the low-skill labour share)

Additional transfers financed by

Capital income tax | Consumption tax



a This summarises the results of a comparative static response to reductions in the low-skill labour share, associated with a complementary rise in the capital share. In this case there is no change in real GDP but the level of total factor productivity is endogenously determined. The low-skill wage is downwardly rigid to reflect minimum wage laws. “Welfare” is an abbreviation for the real purchasing power of disposable income at consumer prices. This measure for the low-skill household is here held constant by tax-financed transfers.

Source: Solutions to the model described in the text.

Table 1. Earnings Gaps between Skill Groups as % of Low Income

(full-time 25-64 year-old employees)

	Low to medium skill (as % of low skill earnings)		**Medium to high skill (as % of low skill earnings)**	
	2002	**2014**	**2002**	**2014**
Australia	22	14	28	32
Austria	41	28	37	39
Belgium	10	11	29	32
Canada	27	22	28	26
Chile	..	47	..	109
Czech Republic	37	32	60	70
Denmark	14	12	21	23
Finland	5	1	48	35
France	19	9	42	43
Germany	30	..	33	..
Greece	..	25	..	32
Hungary	35	32	78	74
Ireland	32	9	33	60
Israel	27	16	40	52
Italy	28	20	41	33
Korea	41	14	31	33
Luxembourg	28	47	35	37
Mexico	..	72	..	59
Netherlands	19	16	40	42
New Zealand	23	..	19	..
Norway	27	14	24	23
Poland	23	18	58	61
Portugal	49	41	52	49
Slovak Republic	..	37	..	53
Slovenia	37	27	72	59
Spain	27	22	22	34
Sweden	15	8	26	20
Switzerland	33	27	41	37
Turkey	54	37	27	54
United Kingdom	47	32	39	36
United States	52	37	48	50
OECD	28	23	40	47

Source: Authors' calculations based on data from *OECD Employment Outlook*, 2014 and 2016.

Note: Data on mean incomes are not available. Earnings by skill (or education levels) refer to mean annual earnings of full-time for 25-64 year-old employees. Earnings gaps between medium-skilled and low-skilled employees are calculated as the difference between mean earnings of medium-skilled employees and low-skilled employees relative to mean earnings of low-skilled employees; earnings gaps between high-skilled and medium-skilled employees are calculated as the difference between mean earnings of high-skilled employees and medium-skilled employees relative to mean earnings of low-skilled employees. The skill levels are based on the International Standard Classification of Education (ISCED, 2011). Low (skills) corresponds to less than upper secondary ISCED levels 0, 1, 2 (Less than primary, primary and lower secondary education). Medium (skills) corresponds to upper secondary and post-secondary non-tertiary ISCED levels 3 (including partial level completion), and ISCED 4 (Upper secondary and post-secondary non-tertiary education). High (skills) corresponds to tertiary ISCED levels 5, 6, 7 and 8 (short-cycle tertiary education, bachelors or equivalent level, masters or equivalent level, doctoral or equivalent level).

Table 2: Stylised Household Factor Ownership Shares Used in Modelling

	Primary factors		
Households	**Low-skill labour**	**Skill**	**Physical capital**
Low-income	0.95	0.01	0.10
Professional	0.04	0.70	0.20
Capital-owning	0.01	0.29	0.70
All households	100.00	100.00	100.00

Source: These are highly stylized but representative of data on wealth shares from Boshara et al.(2015).

Table 3: Decomposition of Aggregate Performance Changes in the US: Forward Shocks from 1990 to 2008[a]

Variable shocked, 1990 to 2008		**Shock, % change**
Factor use:	Low-skill labour	6.0
	Skill	49.0
	Capital	94.6
Total factor productivity		19.8
Factor shares:	Low-skill labour	-21.2
	Skill	34.4
	Capital	2.6
Cheaper capital relative to goods		-16.7
Reduced power of income tax rates		
	Low-skill labour income	0.0
	Skill income	-4.8
	Capital income	-4.8
Labour force participation rates		
	Low skill labour	-10
	Skill	5

a The decomposition is achieved by shocking these variables individually and collectively. The fiscal deficit as a proportion of GDP varied during this period but changed little, point to point, and so it is not shocked (a closure is adopted that holds government saving constant as a proportion of GDP).

Sources: Factor use, factor share and total factor productivity changes are from WORLD KLEMS (Timmer *et al*. 2015). The relative capital goods price is from FRED and the tax rates are interpretations from IMF, *World Economic Outlook Database* and Pomerleau and Lundeen (2014). The changes in participation rates affect the per capita measures in the modelling. They are inferred from the skilled participation results of Tracey and Fels (2016) and the overall participation rate series from FRED.

Table 4: Decomposition of Aggregate Performance Changes in the US – 1990 to 2008[a]

Per cent change	Factor use	TFP	Factor shares	Cheaper capital	Lower tax rates	Total effects	Av growth rate, %/yr
Real total consumption	58.8	28.1	-9.5	-1.8	4.0	79.5	3.3
Real government spending	48.7	35.2	-8.4	0.4	-21.1	54.8	2.5
Real gross investment	21.5	28.3	8.2	5.8	6.9	70.6	3.0
Real net investment	-85.4	12.7	6.6	6.3	10.2	-49.6	-3.7
Net real rate of return	-34.8	21.2	-0.5	32.2	-0.4	17.8	0.9
Real financing interest rate	-46.0	4.0	-3.5	5.7	-2.8	-42.6	-3.0
Total domestic saving	20.9	28.3	8.5	5.9	6.6	70.2	3.0
Government saving	49.3	29.3	-5.0	-1.2	1.2	73.6	3.1
Real consn low-skill wage[b]	40.9	27.9	-39.9	0.0	0.0	28.9	1.4
Real consn high-skill wage[b]	0.3	19.8	36.4	0.0	0.0	56.5	2.5
Real disposable income	49.7	28.6	-5.0	-0.2	4.1	77.2	3.2
Real GDP	49.5	29.5	-5.5	0.0	0.0	73.5	3.1
Real per capita disposable income	28.0	20.3	-11.1	-6.1	-5.7	25.3	1.3
Gini coefficient	-5.4	0.6	17.2	-0.2	3.2	15.4	0.8

a All but the final column show forward % changes on the 1990 base. Changes in real government spending are constrained so that the fiscal deficit remains the same as a proportion of GDP.
b Real consumption wages are nominal wages divided by the consumer price, P^C.
Source: Back-casting using the model described in the text.

Table 5: Decomposition of Distributional Changes in the US – 1990 to 2008[a]

	Income group	Factor use	TFP	Factor shares	Cheaper capital	Lower tax rates	Total effects	Av growth rates
Real consumption	Low income	53.8	28.9	-32.4	-0.5	0.8	50.5	2.3
	Professional	62.7	29.5	28.0	-2.7	11.5	128.9	4.7
	Capital-owning	63.6	25.4	8.9	-4.6	6.7	100.0	3.9
	Total	58.8	28.1	-9.5	-1.8	4.0	79.5	3.3
Real disposable income	Low income	47.6	26.9	-29.4	0.0	0.2	45.4	2.1
	Professional	53.0	30.1	26.5	-0.1	10.6	120.0	4.5
	Capital-owning	49.4	29.2	7.4	-0.5	6.5	92.1	3.7
	Total	49.7	28.6	-5.0	-0.2	4.1	77.2	3.2
Real disposable income per capita	Low income	32.8	18.3	-35.0	-7.1	-6.6	2.5	0.1
	Professional	-0.9	16.1	13.6	-4.2	3.4	28.0	1.4
	Capital-owning	32.9	25.0	5.3	-1.6	5.1	66.9	2.9
	Total	28.0	20.3	-11.1	-6.1	-5.7	25.3	1.3

a All but the final column show forward % changes on the 1990 base.
Source: Back-casting using the model described in the text.

Appendix: Model Parameters and Operation

Table A1: Key Parameters

	US
Depreciation rate	0.04
Production factor shares[a]	
Labour, β^L	0.18
Skill, β^S	0.47
Capital, β^K	0.35
Initial household consumption volume shares, %[b]	
Low income	30.0
Prof income	40.0
Capital owning	30.0
Initial household saving rates, %[c]	
Low income	3.6
Prof income	17.6
Capital owning	38.5
Income tax rates[d]	
Labour income, t^L	0.18
Professional income, t^S	0.20
Capital income, t^K	0.15
Indirect (consumption) tax rate[e]	
t^C	0.14
Unemployment benefit ratio	
α	0.60
Transfer rates (initial shares of GDP)	
$t_h^R = T_h^R / Y$, %	
Low income	6.0
Prof income	2.0
Capital owning	0.0
Elasticities	
Consumption, c to r, ε^{CR}	
Low income	0.02
Prof income	0.10
Capital owning	0.20
Consumption, c to Y^D, ε^{CY}	
Low income	1.05
Prof income	0.98
Capital owning	0.90
Investment, I_i to r^C_i/r_i, ε^I_i	1.00
Premium to G/T, ϕ_i	0.20

a Production shares are based on estimates of factor incomes and capital stocks from the GTAP Database.
b Initial consumption shares are used to calibrate consumption structure of the model database.
c Initial household saving rates are from disposable income. These emerge from the calibration and are indicative of embodied behaviour but do not remain constant in response to shocks.
d 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.
e Consumption elasticities are consistent with a variety of estimates in use in other models, both of marginal propensities and elasticities (including McKibbin and Wilcoxen 1995 and Jin 2011).

Table A2: Closures: Choices of Exogenous Variables[a]

Long run equilibrium analysis

Labour market
- Back-casting to 1990
  - Endogenous: low-skill wage, *W*
  - Exogenous: employment of low-skill workers, *L*
- Prospective shocks:
  - Exogenous: nominal production wage, *W*
  - Endogenous: Employment of low-skill workers, *L*

Fiscal policy
- Back-casting to 1990
  - Constant net government saving after transfers
    - Endogenous government expenditure, *G*
    - Exogenous: net government saving after transfers, S^G
    - Tax rates exogenous
- Prospective shocks
  - Constant net government saving after transfers
    - Exogenous government expenditure, *G*
    - Exogenous: net government saving after transfers, S^G
    - Endogenous: power of either
      - consumption tax rate, τ_C or
      - capital income tax rate, τ_K.

Note that in the back-casting shocks, S^G is set at a constant proportion of GDP to reflect observation.