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Capital-Skill Complementarity and Rising Wage Inequality in the UK

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Abstract

The consensus in the literature investigating the causes of increased wage inequality in developed nations since 1980 is that skill-biased technical change is responsible for the widening of the wage distribution. A shortcoming in this literature is that technical change is commonly determined residually; that is, those changes in relative wages unexplained by other factors are attributed to changes in technology. We move this on by specifying a CGE model that identifies four labour types and four capital assets. When capital assets are measured in efficiency units and there is capital-skill complementarity, we can explain a large component of the increase in UK wage inequality in terms of changes in factor endowments. This is the first CGE analysis of relative wages to link changes in technology with movements in observable variables and also the first investigation of the connection between capital-skill complementarity and rising wage inequality and in the UK.

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1. INTRODUCTION

Rising wage inequality in developed nations since 1980 has been well documented and its causes extensively examined. Most studies focus on the contributions of increased trade between the skilled labour-abundant North and unskilled labour-abundant South, and/or skill-biased technical change. The consensus is that the impact of trade has been minimal to insignificant and rising skill premiums can be attributed to skill-biased technical change. Bound and Johnson (1992), Lawrence and Slaughter (1993), Mincer (1993), Berman, Bound and Griliches (1994), Tyers and Yang (1997, 2000), Berman, Bound and Machin (1998) and Haskel and Slaughter (2002) all reach this conclusion; whilst a notable exception is Wood (1994, 1995, 1998), who champions the role of increased trade.[1]

However, one can challenge the manner by which many studies reach this conclusion. Several authors go to great lengths to quantify changes relating to trade and the mechanisms by which it influences relative wages, but pay little attention to changes in technology. The impact of skill-biased technical change is commonly determined residually, as the proportion of the increase in relative wages unexplained by trade. As Johnson (1997, p. 47) summarises this approach, "… *it must have been* X_1*,* X_2*, or* X_3*, (b) it was not* X_2*, or* X_3*, (c) ergo, it was* X_1*.*" In CGE settings, residually determined skill-biased technical change is modelled by adjusting production function parameters so as to simulate observed changes in relative wages (McDougall and Tyers, 1994; Cline, 1997; Tyers and Yang, 2000; Abrego and Whalley, 2000 and 2003; De Santis, 2002 and 2003).

[1] For literature reviews see Greenaway and Nelson (2000 and 2003).

An alternative view of skill-biased technical change is an increase in the stock of capital equipment when there is capital-skill complementarity. The notion of capital-skill complementarity is due to Griliches (1969) and means that capital equipment is less substitutable for skilled labour than unskilled labour in production. In such a situation, technical improvements that reduce the price of equipment will, in turn, lead to equipment deepening, an increase in the relative demand for skilled labour, and a rise in the skill premium. As demonstrated by Krusell *et al.* (2000), such a treatment of skill-biased technical change allows changes in relative wages to be tracked in terms of (observable) factor supply changes.[2]

Formally, suppose output (Y) is a constant elasticity of substitution (CES) aggregation of capital (K), skilled labour (S) and unskilled labour (L)[3]

$$Y = \left[\alpha L^{\mu} + (1-\alpha)(\beta S^{\rho} + (1-\beta)K^{\rho})^{\mu/\rho}\right]^{1/\mu} \quad (1)$$

$$\sigma_{LS} = \sigma_{LK} = \frac{1}{1-\mu}, \; \sigma_{SK} = \frac{1}{1-\rho}$$

where α and β are share parameters bound between zero and one; σ_{LS}, σ_{LK}, and σ_{SK} elasticities of substitution between unskilled labour and skilled labour, unskilled labour and capital, and skilled labour and capital respectively. The derivative of the ratio of the marginal product of skilled labour (MPS) to the marginal product of unskilled labour (MPL) with respect to capital is then:

[2] Tyers and Yang (2000) also model skill-biased technical change in such a fashion but only identify one capital asset and technical change is residually determined.

[3] Although complementarity is between capital equipment and skilled labour, and not aggregate capital and skilled labour, we only specify one capital asset for ease of illustration.

$$\frac{\partial(MPS/MPL)}{\partial K} = (\mu-\rho)\left[\frac{\varphi(SK)^{\rho-1}\left[\beta S^{\rho}+(1-\beta)K^{\rho}\right]^{(\mu-2\rho)/\rho}}{\alpha L^{\mu-1}}\right]$$

where $\varphi = \beta(1-\alpha)(1-\beta)$.

This is positive if $\mu > \rho$, which necessitates $\sigma_{LK} > \sigma_{SK}$. Consequently, growth of the capital stock will *ceteris paribus* increase the skill premium if complementarity between skilled labour and capital is greater than that between unskilled labour and capital.

In this paper, we undertake the first CGE analysis of relative wages that links changes in technology with movements in observable variables, which is also the first investigation of the connection between capital-skill complementarity and rising wage inequality and in the UK.[4] An essential component of our analysis is the estimation of the stocks of four capital assets in the UK. We deflate investment data by quality-adjusted prices so that we can measure technical change as variations in efficiency units of capital assets. Our CGE model is based on the GTAP5inGAMS core static model and the Global Trade Analysis Project (GTAP) database, both of which are modified to suit our needs. Significant alterations to the base model include: (a) the augmentation of the UK component of the GTAP database to incorporate our capital estimates and data for four labour types, and (b) modifications to the production specification in the GTAP5inGAMS model to induce complementarities between certain factors of production. Our results indicate that an increase in the effective supply of capital equipment is the principal cause of rising wage inequality in the UK.

[4] The UK is an interesting case since relative wages have risen faster here than in any other OECD country outside of the US (Slaughter, 1998).

The paper has four further sections. Section 2 outlines our capital stock estimates. The construction of our CGE model and the salient features of the model's database are described in Section 3. Section 4 documents our simulation results and the outcomes of several sensitivity analyses. Section 5 concludes.

2. CAPITAL STOCK ESTIMATION

At least two capital assets need to be identified to successfully model capital-skill complementarity. We divide the UK economy into 22 industry groups and estimate the stocks of four capital assets – buildings, vehicles, and high-tech and low-tech equipment – in each industry group. The estimation of the stock of capital asset j in industry i at time t $[K_{ji}(t)]$ requires aggregating investment in asset j by industry i across time periods. This creates several difficulties: first, additions to the capital stock that are still in service must be distinguished from those that are not; second, the productive capacity of older assets may have diminished due to physical deterioration; third, newer capital that embodies improved technology will be more efficient than older capital. Put simply, we must decide how to depreciate investment in different time periods.

We use the Perpetual Inventory Method (PIM). This estimates $K_{ji}(t)$ as a weighted sum of additions to the capital stock across time periods. Specifically,

$$K_{ji}(t) = \sum_{v=t_j^0}^{v=t} \theta_j(t,v) I_{ji}(v), \qquad t \geq t_j^0 \tag{2}$$

where $\theta_j(t,v)$ is the efficiency at time *t* of an asset installed at time *v* as a proportion of the efficiency of an asset of vintage *t*; $I_{ji}(v)$ represents investment in asset *j* by industry *i* at time *v*; and t_j^0 is the starting point for the PIM calculation for asset *j*.

Guided by Hulten and Wykoff (1981a and 1981b), we operationalise equation (2) assuming that depreciation follows a geometric series.[5] When depreciation is geometric, a constant proportion of the asset is depreciated each time period and equation (2) takes the form

$$K_{ji}(t) = \sum_{v=0}^{v=t-t_j^0} (1 - \delta_j)^v I_{ji}(t - v) \tag{3}$$

where δ is the geometric rate of depreciation.

We parameterise equation (3) using Hulten and Wykoff's (1981a) study of market asset prices. They estimate geometric depreciation rates for 15 equipment assets (including office, computing and accounting machinery) seven vehicle categories and ten types of structures. We take averages of Hulten and Wykoff's (1981a, Table 1, p. 95) estimates in each category to produce estimates of the rates of depreciation for low-tech equipment, vehicles and structures, and use the author's estimate for office, computing, and accounting machinery as the rate of depreciation for high-tech equipment. Rates of geometric depreciation employed by our capital stock estimates are reported in Table 1.[6]

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[5] Other patterns of depreciation include: "one-hose shay" or light bulb depreciation, where efficiency is unchanged over the service life of the asset, and straight-line depreciation, where depreciation is constant over an asset's service life.

[6] We do not specify a survival function in equation (3) because Hulten and Wykoff's (1981a) estimates are based on asset prices multiplied by the expected probability of survival; that is, the authors' depreciation estimates account for the fact that some assets of a particular vintage will survive longer than others.

Table 1: Geometric rates of depreciation (per annum)

Asset	Rate
Buildings	0.03
Vehicles	0.17
High-tech equipment	0.27
Low-tech equipment	0.13

Source: Average depreciation rates from Hulten and Wykoff (1981a, Table 1, p. 95).

No existing data source presents investment data disaggregated by industry and asset type for the complete set of industries in the UK. We generate such a series by (a) estimating investment shares by industry and asset type in two years of interest to our analysis (1980 and 1997), (b) estimating investment shares in intermediate years using a linear interpolation procedure, and (c) attributing aggregate investment to each asset in each industry using our estimates of investment shares.

The *Input-Output Tables for the United Kingdom* (1979 and 1984) and the *United Kingdom Input-Output Supply and Use balances* (1995 and 1997) record gross fixed capital formation by industry group and product type. Industry groups differ across data sources.[7] We generate "consistent" industry groups by appropriately aggregating industry groups. Our concordance across data sources is guided by the SIC composition of each industry in each year.[8] For example, our 1979, 1995 and 1997 data sources contain the industry group "Agriculture, forestry and fishing", while "Agriculture", "Forestry", and "Fishing" industry groups are listed in 1984. Consistency across data sources is obtained by generating an "Agriculture, forestry and fishing" consistent industry group. Our concordance procedure produces 22 consistent industry groups.

[7] In our 1979 data source they are built on the 1968 Standard Industrial Classification (SIC), 1984 industry groups are compiled according to the 1980 SIC, and 1995 and 1997 industry groups are consistent with the 1992 SIC.

[8] As there is not an exact mapping between industries defined by different classifications, we sacrifice a degree of precision in order to represent the UK economy in greater detail.

We gather product types into four groups: buildings, vehicles, and low-tech and high-tech equipment. The division of equipment into high-tech and low-tech components follows Morrison Paul and Siegel (2001). High-tech equipment is comprised of the manufacture of office machinery and manufacture of computers and other information processing equipment. Our remaining assignments are as follows: expenditure on motor vehicles and parts, shipbuilding aerospace equipment, and other transport equipment is classified as investment in vehicles; there is a one-to-one mapping between construction expenditure and investment in buildings; and gross fixed capital formation of all other product types is taken to represent investment in low-tech equipment.

Appropriately aggregating industry groups and product types facilitates the calculation of investment shares by industry and asset type for 22 consistent industries and four capital assets in four different years. As we deduce investment shares for 18 years from estimates in two time periods (see below), we reduce distortions created by outliers by taking averages of 1979 and 1984 investment shares as our estimate of 1980 investment shares, and 1995 and 1997 means as approximations of 1997 investment shares. Shares for intermediate years are calculated using a simple interpolation procedure; specifically, 1980 investment shares progress towards 1997 in a linear fashion.[9]

The final building block is real annual aggregate investment. We source these data from the 2001 *Economics Trends Annual Supplement*, which lists real aggregate gross fixed capital formation from 1948 onwards. Multiplying aggregate annual investment by industry investment shares creates industry investment series. Multiplying these by

[9] To assess the validity of our calculations, we exam the degree of consistency between our investment shares and those available from the record for a subset of industry groups in the appendix.

appropriate asset shares completes the estimation of investment series by industry and asset type. More concisely, $I_{ji}(t)$ has the form

$$I_{ji}(t) = I(t)\phi_i(t)\omega_{ji}(t) \quad (4)$$

where $I(t)$ is aggregate investment; $\phi_i(t)$ is investment by industry *i* as a proportion of aggregate investment, $\sum_{i=1}^{i=22}\phi_i(t) = 1 \;\; \forall \;\; t$; and $\omega_{ji}(t)$ is investment in asset *j* as a proportion of total investment by industry *i*, $\sum_{j=1}^{j=4}\omega_{ji}(t) = 1 \; \forall \;\; i$, and *t*.

So far our investment series have ignored quality improvements. We capture changes in the quality of high-tech equipment by specifying the average annual change in the quality-adjusted price of this asset.[10] Triplett (1989) synthesises estimates of various computer-related indices from several studies to create a price index for computer systems for the years 1957-84. The average annual decrease in the quality-adjusted price of computer systems in Triplett's preferred index, a time-series generalised Fisher ideal index, during this period is 18.6%.

Several authors have estimated quality-adjusted computer price indexes post 1984. Nelson, Tanguay and Patterson (1994) find that, on average, the price of personal computers declined by 25 percent per year between 1984 and 1991 and Berndt, Griliches and Rappaport (1995) by 30 percent each year between 1989-92. Baker (1997) concentrates on portable computers between 1990 and 1995. He concludes that prices declined by 29 percent each year. Finally, Berndt and Rappaport (2001) find

[10] Deflating annual investment in computers by a price index that adequately captures quality improvements would represent an ideal situation. Unfortunately, however, no such index exists for the UK (the Office for National Statistics first used hedonic regression techniques to capture quality adjustments in computer equipment in February 2003).

that between 1983 and 1989 the quality-adjusted price of desktop computers fell by 31 percent annually and that of mobile computers declined by 21 percent.

Unfortunately no study brings together the various computer price indexes estimated post 1984 and therefore facilitates a direct extension of Triplett's (1989) price index. We estimate the average annual decrease in the price of computer systems by noting that Triplett's (1989) results indicate that the rate of decline in the price of peripherals has been less rapid than that for computers.[11] Consequently, we set the average annual rate of decline at 25%, an estimate in the lower range of those above, from 1980 onwards.

A further complication is that we do not have enough information to quantify quality changes in other assets. As our analysis focuses on changes in capital shares, we account for this by discounting our estimate of the average annual decreases in the price of computer systems by five percentage points; that is, we assume that the price of computers systems declined 20% per year between 1980 and 1997. Consequently, the stock of asset *j* in industry *i* measured in efficiency units, $K^{e}_{ji}(t)$, is calculated from

$$K^{e}_{ji}(t) = \sum_{v=0}^{v=t-t^{0}_{j}} (1 - \delta_{j})^{v} I^{e}_{ji}(t - v) \tag{5}$$

where

$$I^{e}_{ji}(t - v) = \frac{I_{ji}(t - v)}{(1 - x_{j})^{t-v-t^{0}_{j}}}$$

[11] For example, Triplett's figures indicate that the price of computer systems declined at an average annual rate of 15.1% between 1972 and 1984, whereas the corresponding figures for disk drives and printers were 12.6% and 13.7% respectively.

and x_j is the average annual decline in the quality-adjusted price of asset j ($x_j = 0.2$ if j = high-tech equipment, zero otherwise).

Assigning starting periods for PIM calculations completes our capital stock estimates. Following Oulton and O'Mahony (1994), capital stock calculations for buildings, vehicles, and low-tech equipment begin in 1852, 1936, and 1888 respectively. Our starting period for computers is 1953, which coincides with the release of the first commercial computers.[12]

3. MODEL STRUCTURE AND AGGREGATION

We isolate the impact of skill-biased technical change by specifying a global model. Our reference dataset is Version 5 of the GTAP database. This provides a detailed representation of trade, protection and production for the global economy in 1997. Five primary factors, 57 sectors and 66 regions are identified.[13] We augment the UK component of GTAP to include four labour types – highly-skilled, skilled, semi-skilled and unskilled – outlined in a related paper (Winchester, Greenaway and Reed, 2003) and three capital assets - buildings, vehicles, and a high-tech-low-tech aggregate. We display capital cost shares by industry and asset type in Table A.1.[14]

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[12] We assume that investment shares before 1980 are constant at 1980 values and develop a pre 1948 real aggregate investment series by estimating an exponential trend.

[13] Dimaranan and McDougall (2002) provide further description.

[14] Our conversion of capital stock units into capital cost shares assumes that risk premiums are equal across assets and that there is equal tax treatment of assets. Equating asset price to the present value of future earnings, the cost share of capital asset j relative to that of asset q in industry i, $\frac{kshare_{ji}}{kshare_{qi}}$, is given by

$$\frac{kshare_{ji}}{kshare_{qi}} = \frac{(r+\delta_j)K_{ji}}{(r+\delta_q)K_{qi}}$$

where r is the real interest rate, which we set equal to 0.04.

Our CGE model is an adaptation of the GTAP5inGAMS core static, which is summarised in Box 1.[15]

Box 1: The GTAP5inGAMS core static model

Imports
Using the Armington assumption (Armington, 1969), imports are differentiated by source and composite imports are differentiated from domestic production. The regional composition of imports is the same in public, private and intermediate demand, but the aggregate share of imports may differ across demands.

Production
Goods and services are produced by perfectly competitive firms under constant returns to scale technologies. Leontief nests of value added and a composite of intermediate inputs produce outputs. At a lower level of the production nest, a Cobb-Douglas aggregation of primary factors produces value added in each sector, and a further Leontief nest of intermediate inputs by product type produces an intermediate composite for each sector.

Expenditure on final goods
A utility maximising representative agent determines private, public and investment demand in each region. Public and investment expenditures are fixed in absolute value, so only the value of private expenditure changes with income. Private and public expenditures are Cobb-Douglas functions of domestic-import composites by product category.

Primary Factors
Factors are perfectly mobile intersectorally but immobile internationally. Land and natural resources are specific to agriculture and mining respectively.

Source: Winchester and Richardson (2003).

We conduct simulations using two different aggregations, which differ with respect to UK factors of production and are outlined in Box 2. Fourteen sectors are recognised, which is the most detailed sectoral classification permitted by our data. Skilled labour-abundant (UK, Western Europe, and Other Developed) and unskilled labour-abundant (Rapidly Developing and Rest of World) country groups are present. Aggregation (A) merges highly-skilled and skilled labour, and semi-skilled and

[15] Rutherford and Paltsev (2000) describe the model in detail.

unskilled labour.[16] These composite factors are labelled more-skilled and less-skilled labour respectively. Four labour types are distinguished in aggregation (B). Both aggregations identify three capital assets: buildings, vehicles, and an amalgamation of high-tech and low-tech equipment. Due to data limitations, only two types of labour (professional and production) and one capital asset are identified in regions outside the UK in both aggregations. Natural resources and land are identified in all regions in both aggregations.

Box 2: Model aggregations

Regions	**Factors**[d]
United Kingdom (UK)	*United Kingdom*
Western Europe (WE)[a]	(A)
Other Developed (OD)[b]	More-skilled labour (M)
Rapidly Developing (RD)[c]	Less-skilled labour (L)
Rest of World (RoW)	Buildings (B)
	Equipment (E)
	Vehicles
Sectors	Natural Resources
Agriculture & mining	Land
Food and beverages	
Textiles, wearing apparel & leather	(B)
Paper products & publishing	Highly-skilled labour (H)
Fuels and chemicals	Skilled labour (Sk)
Other minerals	Semi-skilled labour (Se)
Metal products	Unskilled labour (U)
Transport equipment	Buildings (B)
Electronic equipment	Equipment (E)
Other manufacturing	Vehicles
Water	Natural Resources
Construction	Land
Trade	
Transport	*Other regions*
Communication	Professional Labour
Financial & public services	Production labour
Dwellings	Capital
	Natural Resources
	Land

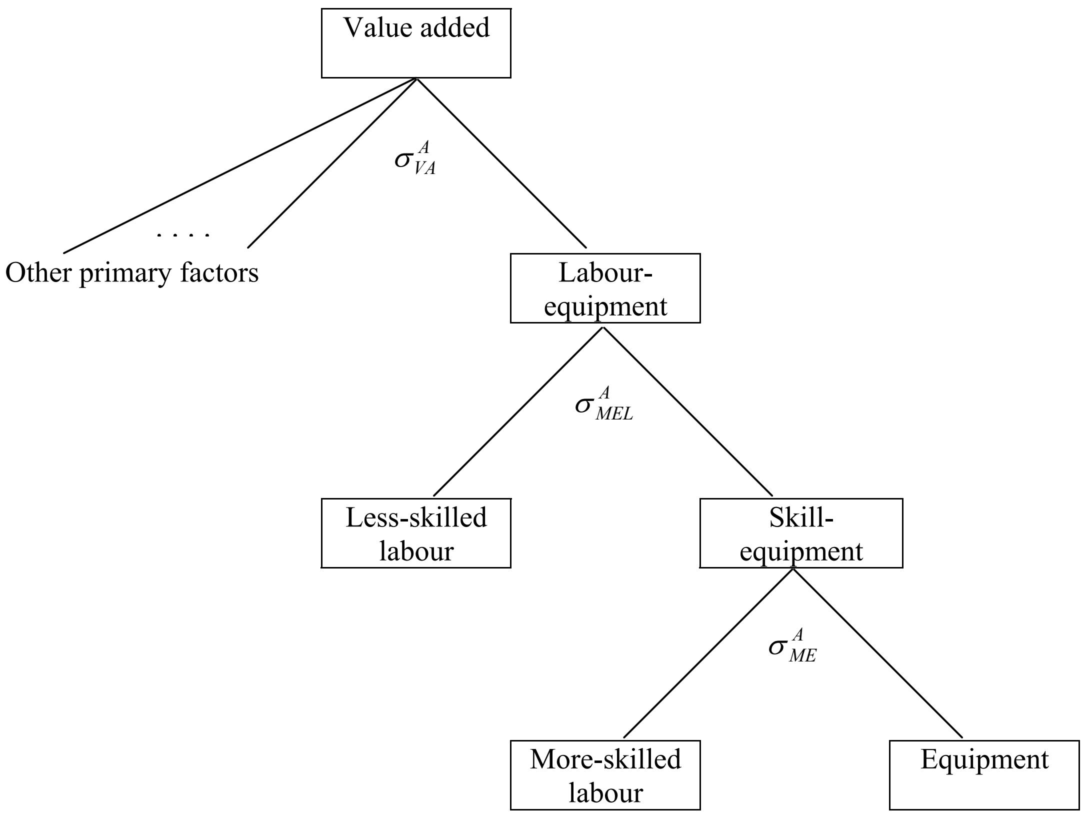
Notes: [a] The EU-15 and the European Free Trade Area. [b] Japan, United States, Canada, Australia, and New Zealand. [c] China, Hong Kong, Taiwan, Korea (Rep.), Indonesia, Malaysia, Philippines, Thailand, Vietnam. [d] More-skilled labour is the aggregate of highly-skilled and skilled labour; less-skilled labour is the aggregate of semi-skilled and unskilled labour; equipment is the aggregate of high-tech and low-tech equipment; and professional and production labour classifications are taken from the GTAP database.

[16] Such an aggregation allows us to model capital-skill complementarity using conventional techniques, such as those employed by Krusell *et al.* (2000) and Tyers and Yang (2000).

We specify two alternative production structures, one for each aggregation. Both specifications differ from that set out in GTAP5inGAMS and are necessary to model factor complementarities.[17] The form of value added production for simulations built on aggregation A is outlined in Figure 1. A CES aggregator brings together more-skilled labour (M) and equipment (E) in the bottom level of the nest. The M-E composite enters with less-skilled labour (L) in a further CES function; a third CES aggregator combines the M-E-L composite with other primary factors. Substitution possibilities at the third, second and first level of the nest are governed by parameters σ_{ME}^{A}, σ_{MEL}^{A}, and σ_{VA}^{A} respectively. Tyers and Yang (2000), who in turn draw on Hamermesh (1993) and Krusell *et al.* (2000), influence our selections of these parameter values. Tyers and Yang's parameters range from 0.3 to 0.7 for branch elasticities of substitution between capital and professional labour and 0.7 – 2.8 for branch elasticities of substitution between capital-professional labour and production labour. Accordingly, we choose σ_{ME}^{A} = 0.5 and σ_{MEL}^{A} = 1.5. We employ a Cobb-Douglas aggregator in the top level of the nest, σ_{VA} = 1.

[17] We also make two modifications to consumption in the model. Specifically, we double all Armington elasticities in GTAP database and assume that the representative consumer in each region allocates expenditure across private, public and investment spending according to Cobb-Douglas function.

Figure 1: UK value added nest in aggregation (A)

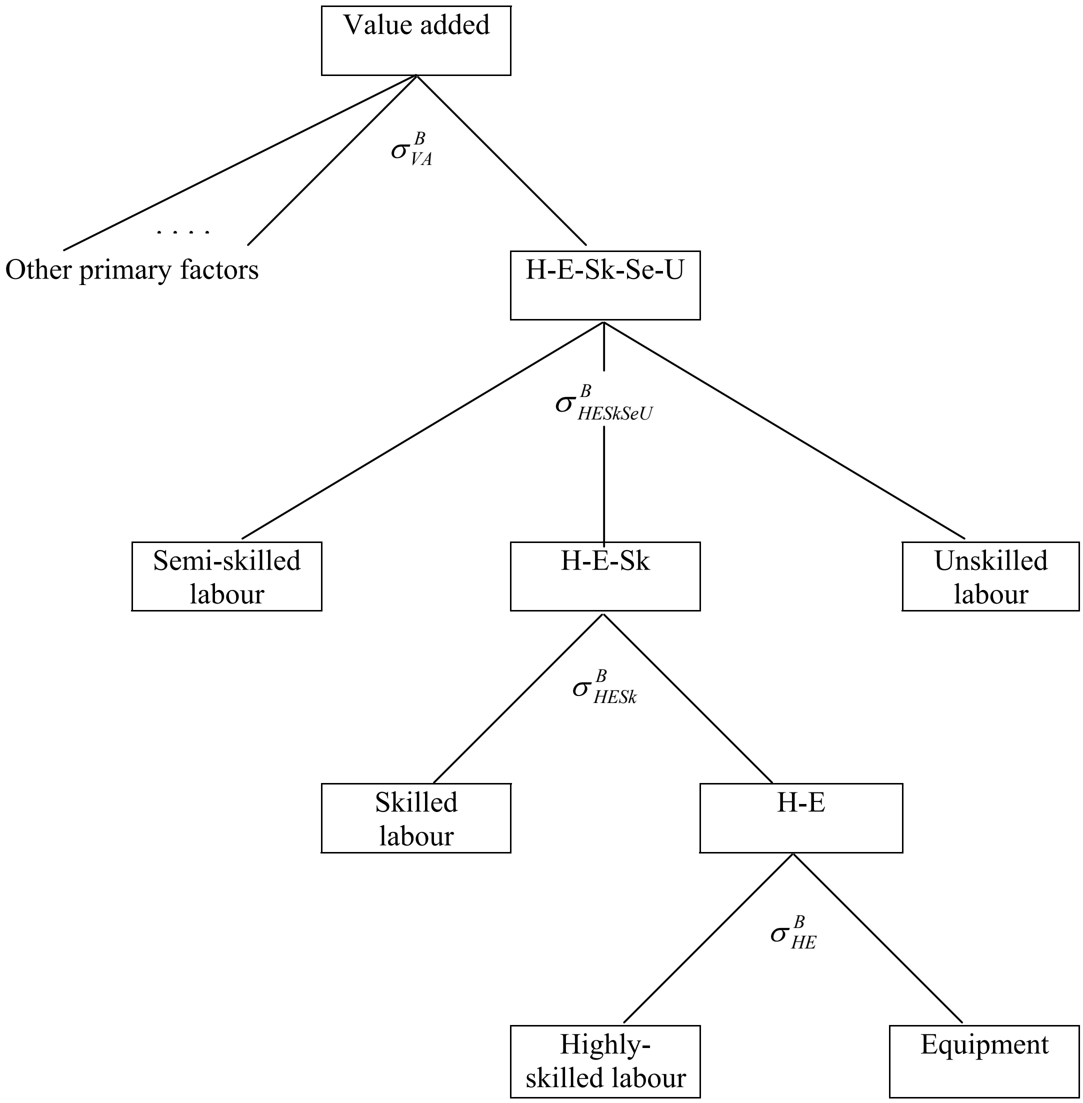


The structure of valued added used to operationalise Aggregation (B) is depicted in Figure 2. Value added is comprised of four CES aggregators, which allow substitution possibilities between equipment and assorted labour types to differ. The ease of substitution between: equipment (E) and highly-skilled labour (H); E-H and skilled labour (Sk); E-H-Sk and semi-skilled (Se) and unskilled labour (U); and E-H-Sk-Se-U and other primary factors are determined by σ^B_{HE}, σ^B_{HESk}, $\sigma^B_{HESkSeU}$, and σ^B_{VA} respectively. There is little information to guide the assignment of these parameter values. Nevertheless, we tie our assignment of elasticity parameters to empirical estimates by noting that Grant (1979), as reported by Hamermesh (1993, Table 3.8, p. 115), finds that the elasticity of substitution between capital and different types of labour is a decreasing function of skill level.[18] Consequently, we assume that the labour cost-weighted average of σ^B_{HE} and σ^B_{HESk} is equal to σ^A_{ME} and stipulate that the ratio of σ^B_{HE} to σ^B_{HESk}, λ, is equal to 0.3. That is,

$$\sigma^A_{ME} = \pi_H \sigma^B_{HE} + (1-\pi_H)\sigma^B_{HESk} \text{ and } \sigma^B_{HE} = \lambda \sigma^B_{HESk}$$

where π_H is the cost share of highly-skilled labour in the combined cost of highly-skilled and skilled labour.

Figure 2: UK value added nest in aggregation (B)



[18] Grant's (1979) analysis identifies three different groups of labour by years of education (13 or more, 9-12, or eight or less).

Furthermore, we suppose that the branch elasticity of substitution between H-E-Sk and semi-skilled and unskilled labour is equal to that between equipment-more-skilled labour and less-skilled labour in aggregation (A), $\sigma^{B}_{HESkSeU}$ = 1.5, and that the top level of the value added nest is Cobb-Douglas, σ^{B}_{VA} = 1.

4. SIMULTION RESULTS

We subject each model to three shocks, each representative of a significant change occurring between 1980 and 1997. The first, shock (1), captures changes in globalisation. We remove changes in UK imports relative to GDP, in source and in total, by specifying an endogenous import tariff in each sector.[19] Shock (2) simulates the combined effect of shock (1) and changes in labour employment shares as set out by Winchester, Greenaway and Reed (2003). Shock (3), in addition to changes specified by Shock (2), simulates the impact of changes in capital stock shares measured in efficiency units.[20] Backcast shocks to import volumes and capital and labour shares are outlined in the appendix (Tables A.2 and A.3).

Simulated results together with actual changes in relative wages are displayed in Table 2. The output for shock (1) indicates that reduced trade barriers increased the ratio of more-skilled to less-skilled labour by about half of one percentage point in aggregation (A). Movements in relative wages, with the exception of the skilled to semi-skilled wage ratio, are also consistent with Heckscher-Ohlin/Stolper-Samuelson predictions in Aggregation (B). In general, although these results replicate the pattern

[19] As we focus on changes in the composition of UK factor endowments in subsequent shocks (see below) our globalisation shock differs from that in an associate paper, Winchester, Greenaway and Reed (2003), where we fix UK imports at 1980 values and remove the change in the regional composition of global GDP. Both forms of the globalisation simulation, however, yield similar results.

[20] When calculating changes in capital stock shares, we hold aggregate capital in raw units constant rather than capital measured in efficiency units so that improvements in the efficiency of equipment do not influence capital to labour ratios for other assets.

of growing wage inequality evident in the data, simulated changes are only a small fraction of actual movements.

Table 2: Simulated and actual changes in relative wages, 1980-97 (%)

Relative wage	(1) Trade	(2) (1) + Labour	(3) (2) + Capital	Actual
		Aggregation A		
$\frac{w_{More-skilled}}{w_{Less-skilled}}$	0.60	-36.59	0.81	18.82
		Aggregation B		
$\frac{w_{Highly-skilled}}{w_{Skilled}}$	1.25	-56.71	-3.79	14.11
$\frac{w_{Highly-skilled}}{w_{Semi-skilled}}$	1.03	-65.30	-1.81	16.84
$\frac{w_{Highly-skilled}}{w_{Unskilled}}$	1.94	-61.59	12.61	26.56
$\frac{w_{Skilled}}{w_{Semi-skilled}}$	-0.21	-19.84	2.05	2.39
$\frac{w_{Skilled}}{w_{Unskilled}}$	0.69	-11.27	17.04	10.91
$\frac{w_{Semi-skilled}}{w_{Unskilled}}$	0.90	10.69	14.68	8.31

Note: Trade refers to a globalisation shock as described in the text and summarised in Table A.2, and labour and capital refer to changes in labour and capital employment shares respectively, as detailed in Table A.3.
Source: Backcast simulations described in text. Actual changes are from Winchester, Greenaway and Reed (2003).

Most measures signify a sharp decline in wage inequality when shock (2) is simulated. The simplest gauge of wage inequality, the ratio of more-skilled to less-skilled wages, decreases by about 37% and all expressions for the relative wage of highly-skilled labour fall by around 60%. In other measures of wage inequality, the ratios of skilled to semi-skilled and skilled to unskilled wages experience moderate decreases and wage inequality between the semi-skilled and unskilled increases. The comparatively small decline in the relative wage of skilled labour is a by-product of the large increase in the supply of highly-skilled labour and production complementarities between the two labour types at the high end the skill distribution. The increase in the semi-skilled to unskilled wage ratio can be attributed to the fall in the endowment of semi-skilled labour relative to that of unskilled labour (see Table A.3). Overall, shock (2) indicates that a substantial decrease in wage inequality would have been observed had increased globalisation and movements in labour employment shares been the only changes occurring between 1980 and 1997.

Turning to the output of shock (3), although the results underestimate changes in the more-skilled to less-skilled wage ratio and the increase in the highly-skilled wage relative to those for other labour types, simulated changes are much closer to observed movements. The results suggest that changes in capital endowments account for 67% of the difference between the simulated change in the more-skilled to less-skilled wage ratio in shock (2) and the actual change in this ratio.[21] The model overestimates changes in the skilled to unskilled and semi-skilled to unskilled wage ratios, but only marginally so. The Aggregation (B) simulation does, however, replicate the observed pattern of changes in wage inequality, and indicates that growth in equipment's share of the capital stock when there is capital-skill complementarity is the dominant explanation for the observed increase in wage inequality.[22]

Our findings are consistent with Krusell *et al.* (2000) and Tyers and Yang (2000). The former conduct simulations using a neoclassical aggregate production function that incorporates capital-skill complementarity. They conclude that, during the period 1963-92 in the US, changes in the relative quantities of different types of labour

[21] The corresponding figures for the ratios of highly-skilled to skilled, highly-skilled to semi-skilled, and highly-skilled to unskilled wages are 75%, 77% and 84% respectively.

[22] The more-skilled to less-skilled wage ratio, calculated as an employment weighted average, changes by –33% and +7% following shocks (2) and (3) respectively in Aggregation (B).

decreased the skill premium by about 40% while the increase in the effective supply of equipment facilitated a 60% rise in this premium. While technical change is determined residually in Tyers and Yang's (2000) examination of growing wage inequality, the authors' preferred results are derived from a model that dictates a large increase in the effective supply of capital when there is capital-skill complementarity.

We ask two rhetorical questions before proceeding. First, is it possible that improvements in the efficiency of computers, which account for less than seven percent of aggregate investment, are responsible for dramatic changes in the wage distribution? We think the answer is yes - rapid advancements in the computer industry are unparalleled in recent history. This is summarised by Forester (1985, p. i), as quoted in Berndt (1996, p. 102), "… *if the automobile and airplane business had developed like the computer business, a Rolls Royce would cost $2.75 and run for 3 million miles on one gallon of gas. And a Boeing 767 would cost just $500 and circle the globe in 20 minutes on five gallons of gas*."[23] The timing of the increase in the skill premium is a second consideration. Why, when spectacular advancements in computer technology have occurred since the computer's inception, did the skill premium only begin to rise in recent decades?[24] A possible answer, as noted by Autor, Katz and Krueger (1998), is the change in the nature of computer technology. Prior to the advent of personal computers, computers were cumbersome machines managed by highly specialised operators. During the 1970s producers undertook projects to put computers in the hands of a single user. The Apple II, released in 1977, and IBM's

[23] The significance of computerisation is also highlighted in more formal settings: Krueger (1993), Berman, Bound and Griliches (1994), and Autor, Katz and Krueger (1998), link computerisation and recent growth in wage inequality in empirical studies, while Bresnahan (1999) adopts a theoretical approach. Bresnahan's concludes that computers have not influenced the output of skilled labour through direct use, but because they have altered the organisation of the workplace, a situation Bresnahan refers to as organisational complementarity.

[24] The skill premium was reasonably constant during the 1970s even though the relative supply of skilled labour was increasing. This indicates that improvements in the efficiency of computers could have placed upward pressure on the skill premium. Nevertheless, this pressure has grown in intensity since 1980.

first personal computer, created in August 1981, were the products of such endeavours and signalled the dawn of a new computing era. These machines where relatively simple to operate and could be used to perform a wide range of tasks.[25] Therefore, we conjecture that output was produced under different sets of elasticity parameters pre and post 1980.

Sensitivity Analysis

Due to the uniqueness of our production specification, we subject our simulations to an extensive sensitivity analysis. We report changes in the relative wage of more-skilled to less-skilled labour under alternative parameter values following shock (3) in Table 3. The relationships between simulated changes in relative wages and key parameter values have intuitive appeal: simulated movements in wage inequality increase as substitution possibilities between equipment and more skilled labour decrease and/or the increase in the stock of equipment is made larger. The analysis reveals that the change in the relative wage is mildly sensitive to changes in the elasticity of substitution between more skilled labour and equipment and the average annual decrease in the quality-adjusted price of high-tech equipment. However, in light of the sharp decrease in wage inequality simulated in shock (2), our conclusions are robust to alternative (plausible) values of these parameters.

[25] The change in the character of computers is evident in documentation concerning the IBM 5110 Computing System, configured in 1978, "*Unlike the 5100 — which met the needs of professional and scientific problem-solvers — the 5110 was offered as a full-function computer to virtually all business and industry…*" and "*could be used to automate such applications as general ledger and accounts payable*" and "*be programmed to provide a variety of reports to help management analyse sales, schedule resources, reduce inventory costs and plan future growth.*" (Before the Beginning: Ancestors of the IBM Personal Computer).

Table 3: Simulated changes in the more skilled-to less-skilled relative wage in aggregation (A) under alternative parameter values following shock (3), 1980-97 (%)

σ^{A}_{VME}	Quality-adjusted price of high-tech equipment, average annual decrease				
	0.18	0.19	0.20	0.21	0.22
0.30	-2.53	4.98	14.09	25.36	39.61
0.40	-6.64	-0.60	6.57	15.22	25.83
0.50	-9.93	-4.98	0.81	7.63	15.81
0.60	-12.61	-8.49	-3.76	1.75	8.22
0.70	-14.83	-11.38	-7.45	-2.94	2.28

Source: Backcast simulation described in text.

Our sensitivity analysis for Aggregation (B) is reported in Table 4. Highly-skilled labour, which has an employment share of less than 15%, is closely tied to equipment in our production specification, so movements in relative wages involving the highly-skilled wage are especially sensitive to the average annual decrease in the quality-adjusted price of high-tech equipment. Simulated changes in relative wages for other labour types, which are more substitutable with equipment, are less sensitive to variations in this parameter. The sensitivity of changes in relative wages relating to highly-skilled and/or skilled labour to changes in λ (the ratio of the elasticity of substitution between highly-skilled labour and equipment to that of highly-skilled-equipment and skilled labour) increases as the average annual decrease in the quality-adjusted price of high-tech equipment gets larger. The change in the highly-skilled wage is particularly sensitive to movements in this parameter; so much so that the model produces implausibly large estimates of the increase in the highly-skilled wage when we increase both λ and the average annual decrease in the quality-adjusted price of high-tech equipment. Simulated changes in semi-skilled and unskilled wages are insensitive to different values of λ. In summary, our conclusions regarding changes in wage inequality not related to highly-skilled labour are robust to alternative conceivable parameter values, but those concerning highly-skilled labour are not. This highlights the need for accurate estimation of efficiency improvements relating to high-tech equipment and additional empirical work to determine the form of production when diverse arrays of labour types and capital assets are specified. What are the elasticities of substitution between these factors? Is the production function weakly separable? The answers to these questions are beyond the scope of our study.

Table 4: Simulated changes in relative wages in aggregation (B) under alternative parameter values following shock (3), 1980-97 (%)

λ	Quality-adjusted price of high-tech equipment, average annual decrease				
	0.18	0.19	0.20	0.21	0.22
			$\frac{w_{Highly-skilled}}{w_{Unskilled}}$		
0.20	-8.72	11.64	44.36	102.31	217.48
0.25	-14.07	1.73	25.22	62.65	127.35
0.30	-18.22	-5.42	12.61	39.36	81.63
0.35	-21.42	-10.67	3.90	24.51	55.13
0.40	-24.12	-14.93	-2.84	13.62	36.97
			$\frac{w_{Skilled}}{w_{Unskilled}}$		
0.20	4.78	8.25	12.32	17.16	22.95
0.25	6.58	10.25	14.57	19.68	25.80
0.30	8.53	12.44	17.04	22.47	28.97
0.35	10.47	14.64	19.52	25.28	32.17
0.40	12.44	16.88	22.05	28.16	35.46
			$\frac{w_{Semi-skilled}}{w_{Unskilled}}$		
0.20	14.15	14.51	14.83	15.11	15.32
0.25	14.09	14.43	14.75	15.03	15.26
0.30	14.04	14.37	14.68	14.96	15.21
0.35	14.00	14.32	14.63	14.91	15.16
0.40	13.97	14.28	14.58	14.86	15.12

Source: Backcast simulation described in text.

5. CONCLUSIONS

This paper has examined the causes of increased wage inequality in the UK using a CGE analysis that specifies a larger number of factors than is the norm. Stocks of four capital assets in different industries were estimated. These data, together with data describing four types of labour, were mapped onto the UK component of the GTAP database. This enabled us to specify production complementarities between capital equipment and labour groups at the high end of the skill distribution. When such complementarities are accounted for and capital assets measured in efficiency units, we find that a significant component of the increase in wage inequality over the last two decades of the twentieth century can be explained by changes in factor endowments. This represents and improvement on studies that determine skill-biased technical change residually and adds value to wage inequality literature.

Sensitivity analysis revealed that our results are moderately sensitive to the elasticity of substitution between more-skilled labour and equipment and the average annual decrease in the quality-adjusted price of high-tech equipment when only two types of labour are identified. When four types of labour are identified our model has difficulty replicating the exact pattern of changes in relative wages and movements in the highly-skilled wage are sensitive to changes in key parameters. Although we tied our estimates of parameters to econometric estimates as closely as possible, this indicates that determining the form of production and values of relevant elasticity parameters when multiple capital assets and several labour types are present is a worthwhile avenue for future research. Nevertheless, our simulations are able to explain much of the observed increase in wage inequality *vis-à-vis* what would have happened if labour supply changes had occurred *ceteris paribus*.

APPENDIX

We examine the validity of our investment shares by using the 1992 *Report on the Census of Production* (RCP) to conduct a consistency check. The data source lists gross fixed capital formation by production and construction industries for three assets – buildings, vehicles, and plant and machinery – in the period 1988-92. We define equipment as the aggregate of high-tech and low-tech equipment, which creates a close match between investment categories identified by the RCP and those in our analysis. This facilitates the comparison of investment shares for seven major industry groups: chemicals and man-made fibres, machinery and equipment, electrical and optical equipment, transport equipment, food and beverages, textiles and leather products, and construction. We report five-year averages of investment shares by industry and asset type calculated from the input-output tables (IO) and the RCP in Table A.4. Investment shares calculated using the two data sources are similar in all industries except for construction. Our average investment share for buildings in this industry is only 50% of the equivalent investment share calculated from the RCP. Conversely, our investment share for equipment in the construction industry is nearly 25% larger than the corresponding RCP investment share. We investigate the issue further using the *1974 Input-Output Tables*. The 1974 Tables report investment data by investment categories outlined by the Central Statistical Office (as used in the RCP) and commodity groups (as used in our breakdown).[26] We find that around 20% of total gross fixed capital formation categorised as equipment investment in our analysis is classified as investment in buildings by the Central Statistical Office. Our procedure, therefore, produces a higher ratio of equipment to buildings investment than that used by the Central Statistical Office, which is confirmed in Table A.4. Thus, the disparity in the IO and RCP investment shares in the construction industry

[26] The 1974 Input-Output Tables is the earliest available data source that facilitates such a comparison.

is largely due to differences in asset classification. In summary, we take the results from the consistency check as evidence supporting the procedure we adopt to generate investment series by industry and asset type.

Table A.1: UK capital cost shares, 1997

	Buildings	Vehicles	High-tech equipment	Low-tech equipment
Agriculture & mining	0.504	0.035	0.002	0.459
Food and beverages	0.301	0.031	0.042	0.626
Textiles & wearing apparel	0.736	0.016	0.023	0.224
Paper & publishing	0.176	0.085	0.040	0.698
Fuels and chemicals	0.137	0.080	0.045	0.738
Other minerals	0.183	0.058	0.128	0.631
Metal products	0.154	0.034	0.050	0.762
Transport equipment	0.215	0.069	0.042	0.673
Electronic equipment	0.144	0.088	0.094	0.673
Other manufacturing	0.124	0.069	0.104	0.703
Water	0.153	0.097	0.056	0.694
Construction	0.108	0.336	0.010	0.546
Trade	0.374	0.152	0.072	0.402
Transport	0.273	0.566	0.050	0.111
Communication	0.079	0.054	0.141	0.726
Financial & public services	0.480	0.148	0.092	0.281
Dwellings	0.950	0.000	0.000	0.050

Source: Capital stock estimates described in text.

Table A.2: Backcast shocks to import volumes relative to GDP 1997-80 (%)

	Western Europe	Other Developed	Rapidly Developing	Rest of World
Agriculture & mining	61	156	184	317
Food and beverages	-29	39	-6	9
Textiles & wearing apparel	-47	-3	-60	-80
Paper & publishing	-46	-21	-78	-76
Fuels and chemicals	-43	-53	-88	-38
Other minerals	-65	-71	-82	-86
Metal products	-5	-1	-59	-36
Transport equipment	-63	-74	-79	-82
Electronic equipment	-62	-59	-92	-73
Other manufacturing	-63	0	-70	-92

Note: Our globalisation shock only considers trade in manufacturing goods due to data limitations.
Source: Trade changes are from the GTAP Version V database (Dimaranan and McDougall, 2002) and the change in UK GDP is taken from the World Bank World Tables database.

Table A.3: Backcast shocks to labour employment shares and effective capital stock shares 1997-80 (%)

Labour employment shares		Effective capital stock shares	
Highly-skilled	-46	Buildings	0
Skilled	-19	Vehicles	26
Semi-skilled	26	Equipment	-72
Unskilled	7		

Source: Changes in labour employments shares are from Winchester, Greenaway and Reed (2003) and changes in capital stock shares are described in the text.

Table A.4
Investment shares from different data sources, 1988-98 averages

Consistent industry group	Buildings		Vehicles		Equipment	
	IO	RCP	IO	RCP	IO	RCP
Chemicals and fibres	0.148	0.149	0.051	0.038	0.802	0.813
Office Equipment	0.160	0.122	0.101	0.089	0.739	0.789
Electrical equipment	0.163	0.168	0.056	0.061	0.780	0.771
Transport equipment	0.129	0.165	0.050	0.017	0.821	0.818
Food and beverages	0.173	0.202	0.085	0.068	0.743	0.730
Textiles and leather	0.106	0.102	0.110	0.075	0.784	0.823
Paper and publishing	0.113	0.135	0.082	0.061	0.805	0.804
Construction	0.101	0.218	0.357	0.344	0.542	0.438
Industry average	0.137	0.158	0.111	0.094	0.752	0.748

Source: IO investment shares are calculated from input-output tables, as described in text, and RCP investment shares are calculated from the *Report on the Census of Production*.

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