Wage inequality between and within groups: trade-induced or skill-bias technical change? Alternative age models for the UK

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Abstract

According to recent econometric studies, technical progress is the main source of the increasing skill premium in the UK and the US. However, it is not yet clear if technical progress is skill-bias or sector-bias and, most importantly, if the use of foreign technology has a role to play. By using alternative AGE models for the UK economy, I show that both trade-induced sector-bias technical change and skill-bias technical change can explain the stylised facts of the UK economy: tertiarisation; deindustrialisation; openness to foreign markets; increased skill premium; rise in wage inequality within the skilled; and unskilled labour groups. However, the model with sector-bias technical change due to trade performs better, because it can also explain two other important stylised facts: the decline of the wage rate of unskilled workers; and the large increase of imported capital goods. © 2002 Elsevier Science B.V. All rights reserved.

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1. Introduction

In the last decade, several studies have been published to explain the causes of the increasing wage inequality between skilled and unskilled workers, in particular...
in the UK and the US. In the UK, the rise in the skill premium is associated with an increase of the wage rate of the skilled workers and with a decline of the wage rate of the unskilled workers (Institute for Employment Research, 1995; Gottschalk, 1997). The econometric evidence suggests that technical change, for example the use of computers in the workplace, is a more convincing cause to explain the increasing skill premium (i.e. Machin, 1996; Autor et al., 1998; Berman et al., 1998; Machin and van Reenen, 1998; Haskel and Heden, 1999). Nevertheless, for two main reasons it is still debatable if wage inequality is due to skill or sector-bias technical change: firstly, the econometric literature does not rule out the possibility that technical change might have occurred mainly in some manufacturing industries; secondly, econometric estimations are generally performed by pooling over manufacturing industries, neglecting the high skill-intensive services, such as financial and business services, which have been growing so rapidly in the last 20 years, in particular in the UK and the US. More precisely, both countries have been recording a fall in manufacturing (deindustrialisation) and a rise in modern services (tertiarisation) in terms of GDP. This implies that the relative demand for different labour categories has changed and that sector-bias technical change might have an important role in explaining the rising skill premium, because modern services are relatively skill-labour intensive compared to manufacturing. In addition, in the literature, trade and technology are treated as two separate causes. However, trade of intermediate goods among developed countries favours technology diffusion (Coe and Helpman, 1995; Xu and Wang, 1999; Keller, 2000). Thus, the links between trade and foreign technical change have not been carefully examined in the trade-wage debate.

The literature on income inequality is now vast. However, few studies have attempted to explain the other important stylised fact that within-group inequality

1 Although Berman et al. (1998) present strong evidence that skill bias technological change occurred in many sectors (i.e. pervasiveness), it must be stressed that three industries, such as electrical machinery, machinery (including computers) and printing–publishing, account for 46% of the within-industry increase in relative demand for skilled labour in their 28-industry 1980s sample. Similar results have been found by Machin and van Reenen (1998). Murphy et al. (1998) show that technological change has increased the demand for a more educated labour force, but that relative wage changes are not due to a factor bias technological change. Finally, Haskel and Slaughter (1999, 2001) find strong correlation between changes in relative factor prices and sector bias technological change.

2 In 1995, the value added share of the financial sector comprised 28.3% in the UK and 30.9% in the US, a share which is well above the share of manufacturing particularly in the US. Also community, social and personal services have grown substantially in relative terms from 5.2% in 1970 to 9.4% in 1995 in the UK and from 8.9% in 1970 to 12.6% in 1995 in the US (OECD, 1999). According to the same source, in the last 20 years, the rapid growth of both these service sectors has favoured the creation of 20 million jobs in the US and 3 million jobs in the UK. In the same period, the loss of manufacturing jobs, especially in the UK, was quite remarkable. At present, almost 45% of the labour force in the UK and the US is employed in financial and personal services.

3 Feenstra and Hanson (1996, 1999) show evidence that outsourcing (i.e. the import of intermediate inputs according to their dataset) is one of the causes of the increase in the relative demand for skilled labour that occurred in the US during the 1980s, though outsourcing is defined as an independent variable and the analysis is restricted only to manufacturing industries.
has also increased in the last two decades in several OECD countries and mainly in the UK and the US (Gottschalk and Joyce, 1998). This fact has not even been taken into account in the trade/wage debate. According to some estimates, half of the total increase in inequality occurred among workers with the same gender, race, education and experience (Gottschalk, 1997). An interesting theoretical result is that obtained by Galor and Moav (2000). They show that an endogenous increase in the rate of technical progress increases wage inequality within groups, because it raises the heterogeneity in ability within a group. Similarly, Bartel and Sicherman (1999) found a positive correlation between the wage rate of workers with the same skill, but with different abilities, and industries with higher rates of technical change. Previous research found also a positive correlation between industry wages and technical change, and between workers' wages and their use of various new technologies. This evidence is modelled in this study, to study the impact of exogenous shocks on wage inequality between as well as within groups.

I use two alternative Applied General Equilibrium (AGE) models calibrated to the UK economy of the late 1970s to better understand how both endogenous and exogenous technical change can affect factor prices, wage inequality within labour groups, sectoral output and welfare in a two-sector general equilibrium setting. Both models are characterised by two primary factors of production (skilled labour and unskilled labour), the skill-intensive modern service sector, the unskill-intensive traditional manufacturing sector, input–output linkages and intra-industry trade in the traditional sector. The first model assumes endogenous sector-bias technical change where trade, by fostering the development of new goods by foreign partners, favours the diffusion of technology in the domestic economy (Romer, 1987, 1994; Rivera-Batiz and Romer, 1991). The second model assumes exogenous technical change (Solow, 1956), which, however, is skill-augmenting and occurs within the country. These models are nested in the sense that they have the same structure and that assumptions on key variables generate the two models as alternatives. Therefore, the results of the simulations are comparable. The statistics for the UK indicate that the wage ratio between skilled and unskilled workers has increased by almost 18% between 1979 and 1992 (Haskel and Heden, 1998). Having this stylised fact as a reference point, transport costs, in the former model, and the skill-augmenting parameter, in the latter model, are changed such that this skill premium is obtained. The results of the numerical simulations are consistent with the stylised facts of the UK economy, though the model with new goods yields better results, because it can also explain the decline in the wage rate of unskilled workers and the relative large increase of imported capital goods.

The remaining sections of the paper have been organised as follows: Section 2 defines the algebraic specification of the models; Section 3 describes the bench-

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mark data set for the UK; Section 4 explores the effects of the policy simulations; and Section 5 provides some conclusions.

2. The models

The main features of the models can be summarised as follows. I consider a small open economy with one traded sector (i.e. manufacturing) and one non-traded sector (i.e. financial and business services). The latter is relatively skill-intensive. The models assume that imports are used in domestic production and that they are imperfect substitutes of domestically produced (by the unskill-intensive exportable sector) capital goods in order to capture both the intra-industry trade phenomenon, and the fact that the unskill-intensive sector can enjoy protection, if transport costs are high. In addition, the models embody the Griliches’s hypothesis of capital-skill complementarity, according to which capital and skilled labour have a lower elasticity of substitution than capital and unskilled labour, so that the skilled labour–capital complementarity holds in relative terms. The intra-industry trade models are based upon the assumptions that preferences are homothetic and that the labour inputs are perfectly mobile between sectors. The numéraire of the model is the price of non-traded good. The models differ about the assumption regarding technical progress. The first model assumes that trade favours the diffusion of foreign technology in the domestic economy (endogenous growth). The second model assumes skill-bias technical change, which is pervasive and occurs within the economy (neoclassical growth). To avoid repetitiveness in the definition of the variables, define $\gamma_s$ and $\rho_s$ ($s = 1, 2, 3$), respectively, as the distribution and the substitution parameters of the three-stage production function of the skill-intensive sector.

2.1. An AGE model with trade-induced technical change

Consider a small open economy where there are two labour factor inputs of production (skilled labour and unskilled labour), which are used to produce both

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6 Business services are disembodied, in the sense that they can be traded across long distances without a substantial loss of the quality of the service provided (see Bhagwati, 1984 for a definition of embodied and disembodied services). However, they represent a small fraction of the trade volume, which indeed is dominated by goods, and embodied services such as retail trade and transport, which are less skill intensive. Hence, the assumption that the skill intensive sector is non-traded is not inappropriate.

7 Hamermesh (1993) (pp. 108–113) presents an extensive survey of the econometric literature in support of the Griliches’s hypothesis for several countries. Evidence in support of this hypothesis for the UK can be found in Nissim (1984), Machin (1996), Machin and van Reenen (1998), Haskel and Heden (1999). In particular, Machin (1996), Haskel and Heden (1999) present evidence suggesting that computers are complements (substitutes) in production to non-manual (manual) workers, as found also recently in another study for the US (Berman et al., 1994).

8 The source of increasing returns is due to specialisation only as in Romer (1987, 1994).
the tradable good $\tilde{Y}$ and, together with an endogenous variety of capital goods, the
non-tradable good $Y$. The non-tradable good $Y$ is skilled labour intensive relative
to the tradable good $\tilde{Y}$. The production function of $\tilde{Y}$ is linear homogenous and
strictly-concave; whereas that of $Y$ exhibits increasing returns to scale if the
number of intermediate goods vary.

The specification of the skill-intensive production function is an extension of the
technology used in Romer (1987, 1994). Output, $Y$, is a function of skilled labour,
$H$, unskilled labour, $L$, the domestic capital good supplied by the unskill-intensive
sector, $Z$, and a set of imported differentiated capital goods $x_i$ indexed by the
variable $i$. The production function is characterised by a multistage CES function
in order to capture two economic facts: firstly, capital inputs and unskilled labour
are imperfect substitutes, which implies that technical change, that reduces the cost
of acquiring capital, can reduce the wage rate of unskilled labour; secondly, the
variety of imported capital inputs, and the domestically produced capital goods, are
also imperfect substitutes. This implies that policy-makers can protect the
unskill-intensive sector with trade policies. Hence, the fundamental assumptions
are that many types of capital goods used in production are imported, that they are
not perfect substitutes, that they compete against the domestically produced capital
good, and that the composite capital good can partly substitute unskilled labour in
the production process of the final good, $Y$.

The first fact, which also implies the Griliches’s hypothesis of ‘skilled
labour–capital complementarity’, is captured by the following CES production
function:

$$Y = \left( \gamma^1 H \rho^1 + (1 - \gamma^1) \left[ \gamma^2 L \rho^2 + (1 - \gamma^2) X \rho^2 \right]^{\rho^1/\rho^2} \right)^{1/\rho^1}, \quad \rho^1 < \rho^2,$$

where $X$ denotes the composite capital good. In order to capture the fact that $L$
and $X$ are relatively substitutes as compared with $H$, I impose the condition that
$\rho^1 < \rho^2$. The solution of the two-stage dual problem yields the following input
demands:

$$H = \left( \frac{\gamma^1}{WH} \right)^{1/(1-\rho^1)} Y,$$

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9 Instead of thinking of just two broad categories, domestic capital and imported capital, let $i$
index many different types of imported capital goods, such as computers, fax machines, printers, electronic
machinery, etc., that are not perfect substitutes for each other.

10 For an econometric evidence for the UK in support of this assumption, see Machin (1996), Haskel
and Heden (1999).

11 This assumption is not unrealistic. Indeed, Keller (2000) has presented evidence according to which
domestic and foreign intermediate inputs embodying technology are not perfect substitutes in their
effect on growth in developed countries. To avoid redundant effort and to increase efficiency (Rivera-
Batiz and Romer, 1991), I assume that only imported goods embody technological change, which implies
that the foreign trade partner is the country investing in research and development (R & D).
\[
L = (1 - \gamma^1)^{1/(1 - \rho^1)} B \left( \frac{\gamma^2}{w^L} \right)^{1/(1 - \rho^2)} Y, \tag{3}
\]

\[
X = (1 - \gamma^1)^{1/(1 - \rho^2)} B \left( \frac{1 - \gamma^2}{P} \right)^{1/(1 - \rho^2)} Y, \tag{4}
\]

where \( B = [\gamma^2/(1 - \rho^1)] w^L \rho^2/(\rho^2 - 1) + (1 - \gamma^2)^{1/(1 - \rho^2)} P \rho^2/(\rho^2 - 1)] \rho^2/(1 - \rho^2); \ w^L \) and \( w^H \) denote the wage rates for unskilled and skilled workers in the tradable sector, respectively;

\[
P = \left[ \gamma^2 + (1 - \gamma^2)^{1/(1 - \rho^3)} \sum_{i=1}^{n} p_i \rho^3/(\rho^3 - 1) \right]^{(\rho^3 - 1)/\rho^3}
\]

the price index of the composite capital good; and \( p_i \) the price of the differentiated imported capital goods.

The second fact, which implies that the domestic capital good and the variety of imported capital goods are imperfect substitutes, is captured by the following specification:

\[
X = \left( \gamma^3 \bar{Z} \rho^3 + (1 - \gamma^3) \sum_{i=1}^{n} x_i \rho^3 \right)^{1/\rho^3}. \tag{5}
\]

This implies that the production of \( Y \) requires many different types of foreign capital goods, which are not perfect substitutes for each other. The cost associated with the purchase of capital inputs is represented by

\[
PX = \bar{Z} + \sum_{i=1}^{n} p_i x_i, \tag{6}
\]

where \( p_i \) is gross of the transport costs. If \( x_i \) enter symmetrically as inputs in final production and are excludable (namely, foreign firms have strong property rights on the invention of the good \( x_i \)),\(^\text{12}\) then the solution of the dual problem at the third stage, which is obtained by minimising Eq. (6) subject to Eq. (5), yields the

\(^{12}\) Rivera-Batiz and Romer (1991), Romer (1994) argue that integration can speed up growth, if research is conducted by one integrated research sector, and countries trade capital goods (i.e. lab equipment model). Here, I assume that the foreign country conducts research, and that trade in capital goods provides the incentive by the domestic country to avoid rediscovering the same design. Basically, as claimed by Rivera-Batiz and Romer (1991), trade in capital goods provides the incentive to avoid redundant effort.
downward sloping import demand function for the variety of imported capital goods:

\[ x_i = \left( \frac{1 - \gamma^3}{\gamma^3} \right)^{1/(1-\rho^3)} p_i^{1/(\rho^3-1)} \bar{Z}. \] (7)

The price \( p_i \) is jointly determined by Eq. (7) and by the profit maximising behaviour of the monopolistic foreign firms, which takes the following form:

\[ p_i(1 - t) \left( 1 - \frac{1}{\mu_i} \right) = c_i, \quad \mu_i > 1, \] (8)

where \( c_i \) denotes the constant marginal cost, \( t \) the constant ad valorem transport cost to ship goods and \( \mu_i \) the absolute value of the price elasticity perceived by the foreign firm \( i \). Given the three-stage production function, it can be shown that under Cournot

\[ \frac{1}{\mu_i} = (1 - \rho^3) + \frac{P_i x_i}{P X} \left( (1 - \rho^2) - (1 - \rho^3) \right) \]

\[ + \frac{P X}{w^L L + P X} \left[ (1 - \rho^2) \left( 1 - \frac{w^L L + P X}{Y} \right) - (1 - \rho^2) \right]. \] (9)

The assertion that new goods can be introduced into an economy implies that the production possibilities sets of foreign firms are non-convex. The non-convexity takes the form of a fixed cost \( f \) (i.e. R & D expenditure), which is set equal to net revenues to determine the equilibrium number of inputs:

\[ [p_i(1 - t) - c_i] x_i = f. \] (10)

For simplicity, the unskill-intensive sector \( \sim \) is characterised by a Cobb–Douglas production function with three factor inputs: the domestic inputs supplied by the skill-intensive sector, \( Z \); unskilled labour, \( \bar{L} \); and skilled labour, \( \bar{H} \):

\[ \bar{Y} = Z^\alpha \bar{L}^\beta \bar{H}^{1-\alpha-\beta}, \] (11)

where \( \alpha \) and \( \beta \) are respectively, the relative share of intermediate inputs and of unskilled labour in the total product. The first-order conditions yield the input demands:

\[ Z = \alpha \bar{Y}, \] (12)

\[ \bar{L} = \beta \bar{Y}/w^L, \] (13)

\[ \bar{H} = (1 - \alpha - \beta) \bar{Y}/w^H, \] (14)
where \( w^L \) and \( w^H \) denote the wage rates for unskilled and skilled workers in the non-tradable sector, respectively.

In order to model both recent evidences that wage inequality has increased within labour groups (Gottschalk and Joyce, 1998) and that a positive correlation exists between the wage rate of workers with the same skill, but with different abilities, and industries with higher rates of technical change (Bartel and Sicherman, 1999), I assume that the following unskilled and the skilled labour possibility curves exist:

\[
\begin{align*}
\overline{L} &= \Omega^L \left[ \theta^L \tilde{L}^e + (1 - \theta^L) \tilde{L}^e \right]^{1/\varepsilon^L}, \quad \varepsilon^L = \eta^L / (\eta^L + 1), \\
\overline{H} &= \Omega^H \left[ \theta^H \tilde{H}^e + (1 - \theta^H) \tilde{H}^e \right]^{1/\varepsilon^H}, \quad \varepsilon^H = \eta^H / (\eta^H + 1),
\end{align*}
\]

where \( \overline{L} \) and \( \overline{H} \), respectively, denote the total unskilled and skilled labour force available in fixed supply, \( \theta^L \) and \( \theta^H \) the share parameters of the transformation functions, and \( \eta^L \) and \( \eta^H \) the constant elasticity values of transformation. For simplicity, I assume that \( \tilde{H} \) (\( \tilde{L} \)) move along the skilled (unskilled) labour possibility frontier without incurring any cost. The basic idea is that \( \tilde{H} \) (\( \tilde{L} \)) can easily acquire the abilities of \( H \) (\( L \)), if market forces demand more labour of the type \( H \) (\( L \)). Assume that two implicit trade unions, one for skilled and one for unskilled workers, maximise the following wage bills, \( W^H \) and \( W^L \):

\[
\begin{align*}
W^H(w^H, w^H) &= w^H H(w^H, w^H) + w^H \tilde{H}(w^H, w^H), \\
W^L(w^L, w^L) &= w^L L(w^L, w^L) + w^L \tilde{L}(w^L, w^L).
\end{align*}
\]

For simplicity, these implicit trade unions do not have market power, so full employment of the category is maintained.\(^{13}\) If the wage bill functions are non-decreasing in the wage rates, homogeneous of degree 1, continuously differentiable and have convex domains, then by using the Hotelling’s lemma, one can obtain the vector of supply functions for each type of labour: \( H = \partial W^H / \partial w^H; \tilde{H} = \partial W^H / \partial w^H; L = \partial W^L / \partial w^L; \) and \( \tilde{L} = \partial W^L / \partial w^L \). In particular, given the labour possibility frontiers (15) and (16), the labour supply schedules for \( L, \tilde{L}, H \) and \( \tilde{H} \) can be re-arranged as follows:

\[
\frac{w^L}{w^L} = \frac{\theta^L}{1 - \theta^L} \left( \frac{L}{\bar{L}} \right)^{1/\eta^L}.
\]

\(^{13}\) If unions have quasi-concave utility functions of the utilitarian form, then the wage bill forms of union preferences imply the assumption of risk-neutrality of individuals and the assumption that membership equals employment (Oswald, 1985).
It is evident that if an economic policy generates a higher demand for \( L \) and \( H \) relative to \( \tilde{L} \) and \( \tilde{H} \), then wage inequality within groups increases. In summary, the within-group inequality of this model is due to inter-industry wage differentials among workers belonging to the same group but with different abilities.

The equilibrium conditions for the goods markets are given by:

\[
\tilde{Y} = \tilde{Z} + \tilde{F} + \tilde{E},
\]

\[
Y = Z + F,
\]

where \( \tilde{F} \) and \( F \) denote the amount of goods purchased by the domestic consumer and \( \tilde{E} \) export sales. In this specification, one unit of any capital good can be produced, if one unit of consumption or exported good is foregone. This specification is very useful because the economic integration (i.e. a decline in \( t \)) would boost the unskill-intensive sector via \( \tilde{E} \), but would limit its expansion due to a contraction in \( \tilde{Z} \), being an imperfect substitute of the imported differentiated capital goods \( x_i \).

The trade balance is always in equilibrium,\(^{15}\) which implies that

\[
(1 - t)\tilde{E} = \sum_{i=1}^{n} p_i x_i
\]

The income of the representative household, \( I \), is given by:

\[
I = w^L L + w^\tilde{L} \tilde{L} + w^H H + w^\tilde{H} \tilde{H} - i\tilde{E}.
\]

The system of Eqs. (1)–(22) is a full description of the general equilibrium model characterised by zero profits and by the clearance of both factor markets and commodity markets. There are 22 unknowns: \( \tilde{Y} \); \( \tilde{L} \); \( \tilde{H} \); \( Y \); \( L \); \( H \); \( X \); \( \tilde{Z} \); \( Z \); \( \tilde{F} \); \( F \); \( \tilde{E} \); \( E \); \( I \); \( x \); \( w^L \); \( w^\tilde{L} \); \( w^H \); \( w^\tilde{H} \); \( P \); \( p \); \( n \); \( \mu \), where \( x \) stands for the symmetric output level of a single representative foreign firm, \( p \) for the price of the foreign capital goods, \( \mu \) for the price elasticity perceived by the foreign firm and \( n \) for the number of imported differentiated capital goods. The variables \( c_i \), \( t \), \( f \), \( \tilde{H} \) and \( \tilde{L} \) are exogenously specified. The welfare function is defined by the GNP Eq. (22), which, by Walras’ law, can be also written as: \( I = F + \tilde{F} \).

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\(^{14}\) The amount of capital goods imported by the non-traded sector (communication, finance, insurance, real estate, business services, community, social and personal services) in the UK is increased exponentially and it comprised 44.2% of the total capital goods imported in 1990. Similarly, the ratio between imported capital goods and the domestically produced capital goods used by the modern non-traded sector is increased from 14.6% in 1979 to 30.3% in 1990 (OECD, 1995). Thus, these statistics are in line with the assumption of the model.

\(^{15}\) Traded goods incur iceberg transport costs at a rate \( t \). This implies that a proportion \((1 - t)\) of goods can be exported and that the price of goods imported is gross of \( t \).
2.2. An AGE model with exogenous skill-augmenting technical change

The neoclassical growth model of Solow (1956) can explain the long-run growth in output per person, if technical change occurs offsetting the dumping effect of diminishing returns. This is obtained by introducing a productivity parameter, which increases the ‘effective’ supply of labour. A variant of the neoclassical growth model, which fits the purposes of this study, is to assume that inventions take the form of a skill-augmenting technical progress and that they are pervasive. Then, the production functions (1) and (11) can be written as follows

\[ Y = \left( \gamma^1 (AH)^{\alpha^1} + (1 - \gamma^1) \left[ \gamma^2 L^{\rho^2} + (1 - \gamma^2) X^{\rho^2} \right]^{\rho^1/\rho^2} \right)^{1/\rho^1}, \]  

(1a)

\[ \tilde{Y} = Z^\alpha \tilde{L}^\beta (AH)^{1 - \alpha - \beta}, \]  

(11a)

where \( \alpha > 0 \) is an index of the ‘effectiveness of skilled labour’. Expression (2) is also modified as follows

\[ H = A^{\rho^1/(1 - \rho^1)} \left( \frac{\gamma^1}{w^H} \right)^{1/(1 - \rho^1)} Y. \]  

(2a)

Since this model postulates that policy interventions do not affect the set of goods available in the economy, then \( x_i \) is homogenous and the production possibilities sets of foreign firms are convex (i.e. \( f = 0 \)). This implies that the market price for \( x_i \) is given and is outside the control of the now competitive foreign firms. In other words, expression (8) is substituted by

\[ p_i(1 - t) = c_i, \]  

(8a)

and both expressions (9) and (10) are eliminated by the system of equations. The remaining 20 equations simultaneously determine the following 20 unknowns: \( \tilde{Y}; \tilde{L}; \tilde{H}; Y; L; H; X; \tilde{Z}; Z; F; \tilde{E}; E; I; x; w^L; w^H; w^H; \tilde{P}; p; \) where \( x \) now stands for total import volume.

3. The benchmark data set

This subsection briefly describes the data used to parameterise the model for the UK (see Table 1). The production and the trade data come from the OECD Input–Output database (OECD, 1995). To parameterise the two-sector model structure, I take the non-traded sector as corresponding to communication, finance, insurance, real estate, business services, community, social and personal services. In particular, the OECD database distinguishes between the capital goods
which are imported and the capital goods which are domestically produced by kinds of activity in a matrix format. All trade and production data I use are for the year 1979, which is the year when it is believed wage inequality among skilled and unskilled workers started to rise in the UK (see Machin, 1996; Haskel and Heden, 1998).

With regard to the sectoral skill–labour intensity, I have used the labour and wage data of the Institute for Employment Research (1995). In 1981, the skill intensity was equal to 0.306 in manufacturing and 1.052 in business and non-marketed services.¹⁶

As for the elasticities of substitution in production, I employ those used by Bhattarai and Whalley (1999). In particular, to be consistent with one of the assumptions of the model that skilled workers are more complementary than

¹⁶ The Institute for Employment Research (1995) reports the number of employees by kind of activities (i.e. primary and utilities, manufacturing, construction, distribution and transport, business and miscellaneous services, non-marketed services and public administration) and by category of workers (i.e. managers and administrators, professional occupations, associate professional and technical occupations, clerical and secretarial occupations, personal and protective service, sales occupations, craft and skilled manual workers, plant and machine operatives, other occupations) for the UK for the 3 years 1981, 1991 and 1994. I define the skilled group as formed by managers and administrators, professional occupations, associate professional and technical occupations.

<table>
<thead>
<tr>
<th>Demand¹</th>
<th>Tradable</th>
<th>Non-tradable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Export demand</td>
<td>975</td>
<td></td>
</tr>
<tr>
<td>Private demand</td>
<td>105 135</td>
<td>9996</td>
</tr>
<tr>
<td>Intermediate demand</td>
<td>6657</td>
<td>15 578</td>
</tr>
</tbody>
</table>

| Inputs¹ | | |
|---------| | |
| Labour | 97 189 | 17 942 |
| Domestic intermediate | 15 578 | 6657 |
| Imported intermediate | | 975 |

| Skill–labour intensity | 0.306 | 1.052 |

| Elasticities of transformation | 5.00 | 5.00 |

| Elasticities of substitution | | |
| First nest | 1.00 | 0.71 |
| Second nest | – | 1.93 |
| Third nest | – | 10.00 |

unskilled workers with respect to capital goods, I assume that the elasticity of substitution between skilled workers and the composite unskilled workers/capital goods is 0.71 and that the elasticity of substitution between unskilled workers and the capital goods is 1.93. The elasticity of substitution between domestic and imported capital goods has been chosen equal to 10, such that the price cost margin is positive and decreases as the number of new goods expands. The constant elasticity values of the skilled and unskilled transformation functions are set equal to five. However, I also perform sensitivity tests in order to assess the robustness of the model results to alternative values of elasticity parameters in production.

The remaining variables, and all the parameters of the model, have been calibrated by using the standard approach widely used in the AGE literature. By the calibration procedure I mean the estimation of unknown parameters, such that the observed values of endogenous variables constitute an equilibrium of the numerical model.

4. The scenarios

Two alternative simulations are presented in Table 2. The scenario labelled ‘Trade-induced technical change’ reports the results of the simulations of the model presented in Section 2.1. The scenario labelled ‘Skill-bias technical change’ reports the results of the simulations of the model presented in Section 2.2. The parameters, which are modified from the benchmark, are the transport costs $t$ for the former scenario, and skill-augmenting parameter $A$ for the latter scenario. Alternatively, $t$ and $A$ are modified such that in equilibrium the gap between the average wage rate of skilled workers and the average wage rate of unskilled workers rises by 18%, as reported by Haskel and Heden (1998) for the UK during the 13-year period from 1979 to 1992. This result is obtained if $t$ falls or if $A$ increases.\footnote{The models have been solved with both MINOS (non-linear programming solver) and MILES (non-linear complementary solver) algorithms employed with GAMS (GAMS, 1998). Needless to say that the results of the simulations are the same regardless of the algorithms used to solve the non-linear programming problems.}

When technical change is endogenous, as a result of cheaper imported intermediate inputs, the demand for domestic tradable intermediate goods declines by 83.6%, whereas the demand of imports raises by a factor of 14. The increased demand for imported intermediate inputs allows foreign firms to make positive profits. A new amount of resources are channelled into R&D activities, which permits the production of new intermediate goods until foreign profits are driven to zero. Since increasing returns arise, if an expansion of intermediates takes the form of a rise in the number of intermediate goods, then the modern sector records an output expansion of 57.9% following endogenous technical improvements (i.e. tertiarisation). In addition, given the Griliches’s hypothesis, technical
Table 2
The impact of trade-induced endogenous technical change and pervasive skill-bias technical change

<table>
<thead>
<tr>
<th></th>
<th>Trade-induced technical change$^a$</th>
<th>Skill-bias technical change$^b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>GNP–welfare</td>
<td>0.041</td>
<td>0.180</td>
</tr>
<tr>
<td>Inequality between groups</td>
<td>0.180</td>
<td>0.180</td>
</tr>
<tr>
<td>Inequality within skilled labour group</td>
<td>0.102</td>
<td>0.128</td>
</tr>
<tr>
<td>Inequality within unskilled labour group</td>
<td>0.061</td>
<td>0.126</td>
</tr>
<tr>
<td>Average skilled labour wage</td>
<td>0.153</td>
<td>0.334</td>
</tr>
<tr>
<td>Average unskilled labour wage</td>
<td>−0.026</td>
<td>0.130</td>
</tr>
<tr>
<td>Output in services</td>
<td>0.579</td>
<td>1.218</td>
</tr>
<tr>
<td>Output in manufacturing</td>
<td>−0.066</td>
<td>0.014</td>
</tr>
<tr>
<td>Skilled labour in services</td>
<td>0.370</td>
<td>0.463</td>
</tr>
<tr>
<td>Unskilled labour in services</td>
<td>0.296</td>
<td>0.663</td>
</tr>
<tr>
<td>Skilled labour in manufacturing</td>
<td>−0.157</td>
<td>−0.199</td>
</tr>
<tr>
<td>Unskilled labour in manufacturing</td>
<td>−0.036</td>
<td>−0.083</td>
</tr>
<tr>
<td>Intermediate demand for services</td>
<td>−0.066</td>
<td>0.014</td>
</tr>
<tr>
<td>Intermediate demand for manufacturing</td>
<td>−0.836</td>
<td>1.542</td>
</tr>
<tr>
<td>Number of new goods</td>
<td>13.970</td>
<td>1544</td>
</tr>
<tr>
<td>Import volume</td>
<td>14.057</td>
<td>1544</td>
</tr>
<tr>
<td>Trade volume–GNP ratio</td>
<td>11.061</td>
<td>1544</td>
</tr>
<tr>
<td>Terms of trade</td>
<td>−0.005</td>
<td>0.000</td>
</tr>
</tbody>
</table>

$^a$ The proportion of goods that can be exported (i.e. $1 - t$) is increased by 19.84%.

$^b$ The skill bias technical change parameter (i.e. $A$) is increased by 75.8%.

change occurs hurting unskilled workers via a decline in their wage rate. Indeed, this is another stylised fact characterising the UK economy. As for the traditional sector, despite the large increase in manufacturing exports (see the results on import volume), the production of tradable goods declines by 6.6%. This result captures the deindustrialisation process, which has also occurred in the UK. Finally, as one would expect from endogenous growth theory, trade volume expands (i.e. openness) and welfare (i.e. GNP) increases. The gains from trade (4.1% of the consumer income) are due to foreign technology diffusion in the domestic economy.

The results of the simulations are similar, if technical change is exogenous and pervasive of the skill-augmenting type. Why is that? If skill-bias technical change occurs, the sector, which is relatively skill intensive, expands. The modern sector, therefore, records a large output growth of 121.8% (i.e. tertiarisation), whereas the unskill-intensive traditional sector expands by only 1.4% (i.e. deindustrialisation), despite the diffusion of technology being pervasive, because the endowment of the economy is given and the resources, which are needed to expand services, are pulled out from the traditional sector.

Finally, the growth of the skill-intensive sector leads to a proportional increase of factor inputs demand, including the demand for foreign intermediate goods, which rises by 154.2% (i.e. openness). As one would expect from the neoclassical growth theory, welfare increases. The large gains (18% of the consumer income)
are determined solely by the rate of technological progress of the domestic economy.\textsuperscript{18}

Regarding the implications for the inequality within groups, as shown in expressions (17) and (18), if the demand of labour by the skill-intensive sector expands, then wage inequality within groups increases due to a different marginal productivity of labour among sectors. In fact, if technological change is trade-induced, the income inequality within the skilled labour group increases by 10.2%, while that within the unskilled labour group increases by 6.1%. In order to understand the labour market equilibria, rearrange Eqs. (15) and (17), and Eqs. (16) and (18), to obtain the labour supply schedules explicitly:

\begin{align*}
L &= \theta^L (w^L / w^L_i)^{\eta^L} \bar{L}, \\
\bar{L} &= (1 - \theta^L) (w^L / w^L_i)^{\eta^L} \bar{L}, \\
H &= \theta^H (w^H / w^H_i)^{\eta^H} \bar{H}, \quad \text{and} \\
\bar{H} &= (1 - \theta^H) (w^H / w^H_i)^{\eta^H} \bar{H},
\end{align*}

where

\begin{align*}
w^L_i &= \left[ \theta^L - \eta^L w^L (1 + \eta^L) + (1 - \theta^L) - \eta^L w^L (1 + \eta^L) \right]^{1/(1 + \eta^L)} \\
w^H_i &= \left[ \theta^H - \eta^H w^H (1 + \eta^H) + (1 - \theta^H) - \eta^H w^H (1 + \eta^H) \right]^{1/(1 + \eta^H)}.
\end{align*}

As shown in Fig. 1, an output expansion due to technology diffusion in the service sector shifts the labour demand schedule in this sector to the right. As the wage rate in services increases, workers in manufacturing have a large incentive to move. As a result, the labour supply schedule in manufacturing shifts upwardly. However, as manufacturing contracts, the labour demand schedules shifts to the left, offsetting the positive effect on the wage rate. The market equilibrium for unskilled workers in manufacturing is, therefore, characterised by lower wages and lower employment. As the wage rate in manufacturing declines, this effect shifts the labour supply schedule in services to the right. The unskilled labour market equilibrium in services is characterised by higher wages and higher employment. The economic implications for skilled workers are different because the wage rate in services rises markedly, as a consequence of the technical progress in the

\textsuperscript{18} One might also change the share parameters of the production functions to simulate a skill-bias technical change hypothesis. In fact, the reduction of and $\beta$ by 4.73% leads to a skill premium equal to 18%. However, I am not satisfied with the implications for the remaining variables. In particular, output in services and manufacturing declines by 0.4 and 3.8%, respectively, because the new combination of production inputs is less efficient. Changing the share parameter of the production function modifies the slope of the isoquant leaving the impact on sectoral output indeterminate in a general equilibrium setting. In addition, the negative impact on sectoral output causes a welfare loss equal to $-3.6\%$. Given these effects, I prefer the extension of the Solow’s model to simulate a pervasive skill-bias technical change hypothesis as it is theoretically founded.
Fig. 1. The effects on the unskilled labour market of trade-induced technical change.
Fig. 2. The effects on the skilled labour market of trade-induced technical change.
skill-intensive sector (see Fig. 2). This results in a large upward shift of the labour supply schedule in manufacturing offsetting the dumping effect of labour demand contraction, such that the wage rate for skilled workers in manufacturing also increases. The market equilibrium for skilled workers is, therefore, characterised by higher wages in both sectors, employment creation in services and job losses in manufacturing.

Also the model, where technical change is exogenous, captures the fact that wage inequality within groups increases. More precisely, wage inequality within the skilled labour group increases by 12.8%, while that within the unskilled labour group increases by 12.6%. However, this model does not capture the other important stylised fact that the average wage rate of unskilled workers has been declining over time. In contrast, the results of the simulations indicate that it raises by 13% because of an adverse effect on labour supply in manufacturing. In order to understand the latter point, consider Fig. 3. An output expansion due to skill-bias technical progress shifts the labour demand schedules to the right. In particular, the labour demand in services rises by a larger percentage. However, as the wage rate in services increase, workers in manufacturing have a large incentive to move. As a result, the labour supply schedule in manufacturing shifts upwardly. By contrast, the labour demand shift in services is so strong that it offsets the upward move of the labour supply schedule due to the higher wage rate in manufacturing. A similar result is obtained for the skilled labour group (see Fig. 4). Hence, further explanation is not needed. In summary, despite workers move from manufacturing to services, the wage rates increase in both sectors because technical progress is pervasive and substantial.

In summary, both types of technical progress lead to results which are consistent with the stylised facts of the UK economy, except for the wage rate of unskilled workers, which rises rather than declining, if skill-bias technical progress occurs. In addition, the model with new goods due to trade captures another important stylised fact of the UK economy, that is the large relative increase of imported capital goods used as inputs in the UK non-traded sector.

To test the robustness of the results, the elasticities of substitution of the multi-stage production function of the non-traded sector have been either increased or decreased. The results are robust for the model with new goods, whereas they might slightly differ if skill-bias technical change is postulated. In particular, the skill premium of 18% cannot be obtained for any value of $A$, if the elasticities of substitution are reduced markedly.19

5. Conclusions

The recent econometric evidence suggests that technical progress is the most important cause of wage inequality, which has been occurring in several developed

19 The results of the sensitivity analysis are available upon request.
Fig. 3. The effects on the unskilled labour market of skill bias technical change.
Fig. 4. The effects on the skilled labour market of skill bias technical change.
countries, in particular in the UK and the US. The main thesis of this paper is that sector bias technical change can be considered as a further or probably as the main cause of the increasing skill premium, if skill-intensive services, such as financial and business services, insurance, communication, are taken into account. Needless to say that the growth of these sectors has been exponential in the last 20 years. In addition, if new designs are imported then the distinction between globalisation and technology, as alternative causes of the increasing skill premium, loses its importance. The worldwide development of information technology, the growth of electronics, the expansion of both foreign direct investment and of the trade volume in intermediate inputs, all suggest that globalisation and technology belong to the same phenomenon, which has opened a new era of development of nations and has to be examined further.

In this study, I present alternative general equilibrium models with endogenous technical change due to trade and exogenous skill-bias technical change applied to the UK economy of the late 1970s, in order to verify if they are able to explain the stylised economic facts of the last 20 years, such as the deindustrialisation process, the development of services, the rise in the skill premium and the increase in wage inequality within the labour groups. It is important to note that most of the assumptions of the models, such as the Griliches’s hypothesis and the substitutability between domestic and imported capital goods, are based upon the econometric evidence; and that the models are nested in the sense that assumptions on key variables yield the models as alternatives. The results of the simulations can explain the stylised facts. However, the model with new goods performs better because it can also explain two other important facts of the UK economy: (i) the wage rate of unskilled workers has declined; (ii) the imports of capital goods used by the modern non-traded sector are increased markedly. The trade/technology-wage debate is, therefore, still an open question. However, from the policy point of view, it does not matter if the increasing skill premium is due to skill-bias technical progress or to the diffusion of foreign technology, because welfare rises under both hypotheses.

One weakness of the models discussed in this paper is that they are not based upon statistical testing procedures. Therefore, they cannot tell us which one is the right model for the UK. Hence, it would be very useful employing the econometric method to estimate a simultaneous equations model for an open economy, which embodies the growing financial and business services, in order to disentangle the causes of the increased skill premium.

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