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Jonathan Haskel

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Jonathan Haskel, Queen Mary and Westfield College, University of London

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Centre for Economic Policy Research
90–98 Goswell Rd, London EC1V 7RR, UK
Tel: (44 20) 7878 2900, Fax: (44 20) 7878 2999
Email: cepr@cepr.org, Website: http://www.cepr.org

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ABSTRACT

The Trade and Labour Approaches to Wage Inequality*

We compare the trade and labour approaches to wage inequality. We first look at the theoretical differences, stressing the different roles ascribed to sector and factor bias, labour supply and the theory of technical change in trade models with endogenous prices. We then briefly review some of the evidence on the sector bias of prices and technology.

JEL Classification: F16, J31, O33
Keywords: wage inequality, technical change, stolper-samuelson effects

Jonathan Haskel
Department of Economics
Queen Mary and Westfield College
Mile End Road
London E1 4NS
UK
Tel: (44 20) 7882 5365
Fax: (44 20) 8983 3580
Email: j.e.haskel@qmw.ac.uk

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NON-TECHNICAL SUMMARY

Wage inequality has risen in many countries in recent years. Two potential causes have been cited for this rise: international trade and technical change. The view that trade is the culprit is based on the fact that developed countries have become increasingly open to trade with developing countries. Since the latter are rich in unskilled labour, they can supply goods where production is 'unskilled-intensive', such as t-shirts from China, at a fraction of developed country costs. Hence, unskilled wages in developed countries must fall. The technology view is that there has been rapid technical change in recent decades, especially with the widespread introduction of computers. This technical change has raised the relative productivity of skilled workers, but reduced demand for unskilled workers and thereby lowering their wage.

The trade explanation has been extensively studied by trade economists, who usually look for the sector bias of price changes, i.e. whether prices have fallen relatively more or less in skill intensive sectors. The technology explanation has been mostly studied by labour economists who usually look for factor bias i.e. whether technical change has favoured skilled or unskilled workers. The purpose of this paper is to try to make precise why different schools look for at different effects.

To see why different approaches are taken, consider the main counter-argument to the trade view, namely that only a comparatively small fraction of goods in developed economies are internationally traded. The service sector makes up an increasingly significant part of production - from restaurants to haircuts to prison services - and although some services are traded, such as financial services, the bulk are not.

Consider too the spread of computers. Many formal studies have documented skill-biased technical change in a number of industries. In addition, such advances seems to be related to computers: industries with faster computer adoption have had faster skill upgrading. Since much of the economy-wide skill upgrading has occurred within particular industries along with increases in the relative wages of skilled workers, it is argued that technical change must have been skill-biased.

For both these reasons then, the view that trade is the main cause of increased wage inequality has been disputed; relative demand has risen for skilled workers due to technology and increase in relative demand must surely raise relative prices. However, the simple demand/supply intuition is a partial equilibrium notion. The key point is that since, in well-functioning markets, wages are determined on the margin, this partial equilibrium intuition breaks down. To see this, consider The Full Monty, a film about a group of unskilled

ex-steelworkers in northern England. At one point, the character Dave takes a low paid job as a security guard in the local supermarket. Security seems a canonical case of a non-traded good. So one might suppose that security guard wages are unaffected by trade.

But the film shows why this reasoning is wrong. Dave is in the security sector because the local steel industry has been forced to close, due perhaps to competition from abroad. Such closures create a flow of unskilled workers potentially available as security guards. These flows drive down security guard wages. So even though supermarket output is non-traded, the wages of people who work there are still affected by trade.

The same reasoning is true for technology. The occupation of security guard is not subject to dramatic technical progress, so are security guard wages unaffected by it? Once again, it depends crucially on what is happening to comparable workers in other sectors. If technical progress is displacing unskilled workers elsewhere, this again creates a flow of 'Daves', reducing security guard wages in the non-traded sector.

This example has an important empirical implication. What drives wages is the potential flow of workers between sectors. This flow is driven by technical change and the pressure of foreign competition moving more in some sectors than in others. Thus whilst the labour-based approach looks for changes in technology and trade within sectors, the trade approach looks for changes across different sectors.

The purpose of the Paper is to make this argument precise. Using a two-factor/two-good model we look at the changes in wage inequality in a one- and two-sector model and how such models might be estimated. We show how flat labour demand curves appear in trade models and how they should be interpreted. We also show how changes in product mix can cause wage changes in trade models when supply changes. Finally, we review the evidence on the sector bias of trade and technology. The UK does seem to show evidence for significant sector-biased price changes in the 1980s. But there does not appear to be evidence for significant sector-biased technology changes.

1. Introduction

Much recent research on changes in wage inequality has been undertaken by two groups who can loosely be identified, by training and/or recent research, as labour economists or trade economists. The empirical research methods adopted by these two groups has been quite different. A good deal of the work by labour economists has documented evidence of skill-biased technical change (SBTC) within many industries (see e.g. Berman, Bound and Griliches, 1994). Much of the work of trade economists has focused on total factor productivity growth and product price changes across industries (see e.g. Leamer, 1998a, Deardorff, 1999).

The purpose of this paper is to try to set out a common framework to understand reasons for the different empirical strategies. We shall argue that most labour economists organise their data analysis, either explicitly or implicitly, from a one-sector model. But most trade economists organise their work, again either explicitly or implicitly, from a multi-sector model[1]. As we set out below, these different models give rise to a very different empirical approach. Labour economists tend to focus on the factor-biased of technical change whereas trade economists look for the sector bias of technical change and/or of price changes.

The next section of this paper sets out two different models as simply as possible. In section three we provide a short review of the evidence on sector bias and section four concludes.

2. Understanding the trade and labour approaches: a simple framework[2]

A standard empirical labour approach is to use industry data to estimate relative labour demand functions and see if there is evidence that technical progress is skill biased. Typically such skill-biased technical change (SBTC) is found in many industries. With the supply/demand intuition the presence of SBTC in many sectors seems strong evidence that technology has caused a rise in the skill premium.

Standard trade theory suggests this reasoning is not conclusive. Consider an industry[3] where there is no skill-biased or any other type of technical progress (or price change). At first pass, this sector would seem to have no change in relative wages since there is no SBTC occurring. But suppose another industry releases workers, perhaps due to falling prices from increased trade competition or technical change. This creates a flow of potential workers willing to work at the first industry and so potentially drives down wages. Relative wages therefore depend on whether technical progress and output prices are changing by more in one sector *relative* to another. It is these

[1] Another way of characterising the contrast is that the labour approach is typically based on a representative firm or firms (all of whom have the same skill intensity), whereas the trade approach is based on technologically heterogenous firms who employ different skill intensities.

[2] See Slaughter (1999a) for a similar perspective and Johnson and Stafford (1998) and Wood (1995).

[3] Defined as a collection of firms with like technology such that they employ workers at the same skill intensity.

differences across sectors, their "sector bias", that potentially cause wage adjustments. Put another way, the finding that there is technical progress *occurring within* many sectors, driven perhaps by computers, may not be informative about changes in wages, for it does not establish whether technical progress is changing more in some sectors than in others. This type of logic is a feature of the Heckscher-Ohlin model and so explains why trade economists typically look for sector bias.[4]

To see this formally, suppose there are two sectors in the economy producing goods *i* and *j*. Following Johnson (1997), suppose that output (Y) is produced by skilled and unskilled labour (N_s and N_u) according to a constant returns CES production function $Y=A[(\alpha(\lambda_s N_s)^{1-1/\sigma}+(1-\alpha)(\lambda_u N_u)^{1-1/\sigma})]^{\sigma/(\sigma-1)}$ where A is a neutral technical parameter, λ_s and λ_u are intensive skilled-labour and intensive unskilled-labour biased technical parameters respectively, α is an extensive skill-biased technical parameter and σ is the elasticity of substitution.[5] Ignoring the λs for the moment, total costs, C, for each sector are

$$C^i = \left((\alpha^i)^\sigma w_s^{1-\sigma} + (1-\alpha^i)^\sigma w_u^{1-\sigma}\right)^{1/(1-\sigma)} (A^i)^{-1} Y^i$$
$$C^j = \left((\alpha^j)^\sigma w_s^{1-\sigma} + (1-\alpha^j)^\sigma w_u^{1-\sigma}\right)^{1/(1-\sigma)} (A^j)^{-1} Y^j \qquad \textbf{(1)}$$

where skilled and unskilled labour receive wages w_s and w_u. Without loss of generality, assume further that sector *i* is skill-intensive, defined by the wage bill share of skilled workers in C being higher in sector *i* than in sector *j*. Using Shephard's lemma, the relative demand for skilled and unskilled labour in sector *i* is

$$\frac{N_s^{\ i}}{N_u^{\ i}} = \left(\frac{\alpha^i}{1-\alpha^i}\right)^\sigma \left(\frac{w_s^{\ i}}{w_u^{\ i}}\right)^{-\sigma} \qquad \textbf{(2)}$$

Equation (2), the relative demand for labour curve, is uncontroversial. Only α, skill-biased TC, appears in these first order conditions. A number of papers have estimated (2) (or more general translog versions of it, see e.g. Berman et al, 1994, for the US, Haskel and Heden, 1999, for the UK and Machin and van Reenen, 1998, for many countries). Typically the $\alpha/(1-\alpha)$ term is specified as a constant or replaced with an assumed correlate such as computers, both of which usually attract a

[4] Leamer (1998a) for example emphasises that an important message of the Heckscher-Ohlin model is that wages are determined on the margin.
[5] Intensive biased technical change (a rise in λ) makes each factor better at the tasks they perform and so raises the productivity of the relevant factor, *ceteris paribus*. Extensive biased technical change (a rise in α) makes skilled workers better at performing the tasks of unskilled workers.

positive coefficient. This is consistent with technology being (extensively) skill-biased. Machin and van Reenen (1998) further add import penetration to (2) and find no relation, thereby arguing that imports have not contributed changes in the relative demand for skilled labour.

What are the implications for wage inequality that follow from this? Assuming one sector, or that workers cannot move between sectors, each sector faces its own upward-sloping supply curve. Equating relative supply denoted $(N^i_s/N^i_u)^S$, and demand, totally differentiating (2) and rearranging gives the change in relative wages as

$$\Delta \ln(w_s / w_u)^i = \Delta \ln(\alpha / 1 - \alpha)^i - \frac{1}{\sigma} \Delta \ln(N_s^i / N_u^i)^S \qquad \textbf{(3)}$$

Hence increases in relative wages occur due to increases in demand from SBTC (net of changes in supply).[6] Since there is evidence for SBTC from the estimation of (2) this suggests that technology has raised the wage premium. Further, since imports are insignificant when added to (2), it is argued that trade has had no effect.

The alternative, favoured by trade economists, is to assume that workers are mobile across sectors. Thus each sector faces a flat relative labour supply curve and so another condition is required to close the model. This then is the production side of the HO model and it is conventionally assumed that each sector is competitive so that revenue equals costs

$$\begin{aligned} p^i Y^i &= C^i \\ p^j Y^j &= C^j \end{aligned} \qquad \textbf{(4)}$$

where p^i and p^j are prices in each sector. Changes in (log) relative wages can be written[7]

$$\Delta \ln\left(w_s / w_u\right) = \frac{1}{V_s^i - V_s^j}\left(\Delta \ln(p^i / p^j) + \Delta \ln(TFP^i / TFP^j)\right) \qquad \textbf{(5)}$$

where V_s^i and V_s^j are the shares of skilled labour in the total wage bill in each sector, w_s and w_u are not indexed by i since free mobility ensures workers can move across sectors, and TFP is total factor productivity. Recall too that by assumption, $V_s^i > V_s^j$.

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[6] Indeed Johnson (1997) and Katz and Autor (1999) use aggregate data on changes in supply and relative wages to infer from (3) the change in aggregate relative demand. As both stress, when applied to aggregate data, changes in α are due to SBTC but also shifts in product demand from domestic or international sources.
[7] This totally differentiates (1), uses Shephard's Lemma and $-\partial \log C/\partial t = \Delta \ln TFP$. See Leamer (1998b).

Equation (5) is standard in the trade literature. First, it shows Stolper-Samuelson type effects of changes in p^i/p^j on w_s/w_u. The effects depends on the sector bias of changes in prices. If prices fall in the skill-intensive sector ($\Delta\ln p^i<0$) then w_s/w_u falls and if prices fall in the unskilled-intensive sector ($\Delta\ln p^j<0$) then w_s/w_u rises. The mechanism works via the zero profit conditions in (4). If prices fall in any sector then that sector is now unprofitable. Relative wages must adjust to restore zero-profit equilibrium. Hence if prices fall in the skill-intensive sector, w_s/w_u must fall (if they rose that would further render the skill-intensive sector unprofitable). If prices fall in the unskilled-intensive sector, w_s/w_u must rise.[8]

Second, equation (5) also shows that the effect of technology depends on sector bias of changes in $\Delta\ln TFP$. The mechanism also works via the zero profit conditions in (4) and has the same intuition as changes in prices. Technical progress reduces a sector's costs and so makes it relatively profitable. Hence, technical progress in a skilled-intensive sector ($\Delta\ln TFP^i>0$) makes the that sector more profitable and hence w_s/w_u must rise; progress in an unskilled-intensive sector ($\Delta\ln TFP^j>0$) means that w_s/w_u must fall. See Findlay and Grubert (1959) for a classic early theoretical analysis of this.

The following points are worth noting.

a. Sector bias and factor bias. Concerning technology, (3) suggests that only factor-biased TC affects wages since it changes the relative productivity of factors *within* a sector. By contrast, (5) suggests that *all* types of technical change, as summarised in $\Delta\ln TFP$, and price changes, are important. The reason is that they change the *relative profitability of sectors*. This is why the typical labour focus is on factor bias and the trade focus on sector bias.

b. SBTC. In (3), SBTC is of course essential. In (5), SBTC does not appear directly. So what is the role of SBTC in the multi-sector model? SBTC is of course part of $\Delta\ln TFP$; since $\Delta\ln TFP$ is increases in output net of measured inputs it includes any form of technical progress, be it biased or neutral (see e.g. Berndt and Wood, 1982 and below). The focus on TFP is appropriate in a multi-sector model since *any* type of technical change, as long as it reduces costs, potentially raises sectoral profitability and so necessitates wage changes.

This argument suggests that SBTC affects relative wages in this model under two conditions: first, that it should have the appropriate sector bias and second, that it should reduce costs. The latter

[8] In terms of flows of workers across sectors, a fall in prices in the skill-intensive sector (*i*) causes firms to move to the unskilled-intensive sector (*j*). Sector *i* contracts and since it is skill-intensive, it releases comparatively more skilled workers. Hence w_s/w_u has to fall to re-employ them. See Deardorff (1994) for a statement of a number of different versions of the Stolper-Samuelson theorem. Note that (5) shows the Jones magnification effect (Jones, 1965) namely that $(\partial\ln(w_s/w_u)/\partial\ln(p^i/p^j))>1$ (since $[1/(V_s^i-V_s^j)]>1$). If V_s^i is not too different to V_s^j

effect depends on the form of SBTC. In (1), SBTC is represented by a rise in α, which raises the productivity of the skilled relative to the unskilled. This type of SBTC is what Johnson (1997) terms extensive SBTC (whereby the skilled become better at performing the tasks previously done by the unskilled - typing this paper for example) which from (2) raises the relative demand for the skilled regardless of σ. From (1), however, a rise in α does not necessarily lower unit cost. Differentiation of (1) shows that it only does so as long as $V_s > \alpha$ (and σ>1). This is not suprising since this type of technical change is a productivity gain by one factor and a loss by another. Intensive SBTC, that makes each factor more productive at the tasks it already performs, by contrast will lower costs.[9]

In the light of this, it is worth noting that it is perfectly possible, in multi-sector models, for SBTC to *lower* relative skilled wages if it occurs in unskilled-intensive sectors and lowers costs there. The intuition is as follows. In one-sector models, SBTC raises relative skilled wages (with certain conditions on technology) to “absorb” the unskilled by pricing them back into work when the skilled become more productive. In multi-sector models, changes in wages have to be consistent with zero profits in all sectors. If SBTC in the unskilled-intensive sector were to raise w_s/w_u the relative profitability of the unskilled-intensive sector would raise further. How then are these unskilled “absorbed”? The answer is that in a multi-sector model output is endogenous. Hence output rises in unskilled-intensive sectors and this absorbs the “extra” unskilled workers.

Consider then the finding that many industries in many countries have had rising relative wages and rising relative skill levels (see e.g. Machin and Van Reenen, 1998). This has led many to argue that this shows evidence of SBTC and that such SBTC has raised relative wages. It is clear from (2) that the evidence is consistent with SBTC[10]. But without knowing the sector bias of SBTC one cannot say whether SBTC has raised relative wages. Indeed it is theoretically possible that SBTC has tended to lower wages, if for example it occurred in the unskilled-intensive sectors, and that skilled sector biased price changes are responsible for the growth in relative wages. So the multi-sector perspective suggests one should treat the finding of widespread SBTC with caution.

To see all this formally, using the cost function in note 9 we can write

$$\Delta \ln TFP^i = \Delta \ln A^i + V_s^i \Delta \ln \lambda_s^{\ i} + V_u^{\ i} \Delta \ln \lambda_u^{\ i} + \left(\frac{\sigma}{\sigma - 1}\right)\left(\frac{V_s^{\ i} - \alpha_i}{1 - \alpha_i}\right) \Delta \ln \alpha^i \qquad \textbf{(6)}$$

then large relative wages changes can result from small relative price or technology changes (Johnson, 1966, finds this may be the case in some of his 2x2 simulations).

[9] The cost function corresponding to the production function above (1) is $C=[(\alpha^{\sigma}(w_s/\lambda_s)^{1-\sigma}+ (1-\alpha)^{\sigma}(w_u/\lambda_u)^{1-\sigma})]^{1/(1-\sigma)} A^{-1} Y$, differentiation of which shows that $\partial C/\partial\lambda<0$. Johnson (1997) argues that the extensive biased TC case is empirically relevant since it is consistent with computers causing SBTC but not raising TFP.

which shows that *TFP* rises if A, λ_s, λ_u and α rise, the latter as long as $\sigma>1$ and $V_s^i>\alpha^j$ (which is the same condition for a rise in α to reduce total costs). Substituting (6) into (5) gives

$$\Delta \ln\left(w_s / w_u\right) = \frac{1}{V_s^{\,i} - V_s^{\,j}} \left(\begin{array}{l} \Delta \ln(p^i / p^j) + \Delta \ln(A^i / A^j) \\ + (V_s^{\,i} \Delta \ln \lambda_s^{\,i} - V_s^{\,j} \Delta \ln \lambda_s^{\,j}) + (V_u^{\,i} \Delta \ln \lambda_u^{\,i} - V_u^{\,j} \Delta \ln \lambda_u^{\,j}) \\ \qquad + \frac{\sigma}{\sigma - 1} \left\{ \left(\frac{V_s^{\,i} - \alpha^i}{1 - \alpha^i} \right) \Delta \ln \alpha^i - \left(\frac{V_s^{\,j} - \alpha^j}{1 - \alpha^j} \right) \Delta \ln \alpha^j \right\} \end{array} \right) \quad \textbf{(7)}$$

So, for example intensive SBTC ($\Delta\ln\lambda_s$) would raise w_s/w_u as long as it was concentrated in the skilled-intensive sector (i.e. $\Delta\ln\lambda_s^i>\Delta\ln\lambda_s^j$), whilst the effect of extensive SBTC ($\Delta\ln\alpha$) depends on upon where it occurs and whether it reduces costs. Note that with this functional form equally intensive SBTC throughout all sectors ($\Delta\ln\lambda_s^i=\Delta\ln\lambda_s^j$) would raise w_s/w_u. The intuition is that although SBTC is equal, the assumption there are more skilled workers the *i* sector means the cost reduction is greater in that sector and hence relative skilled wages rise. Haskel and Slaughter (1998) look at the sector-bias of SBTC and find that over the 1970s (1980s) SBTC was concentrated in unskilled-intensive (skill-intensive) sectors.

c. Labour supply. To see the impact of labour supply, Figure 1 draws (3) and (5) in [w_s/w_u, N_s/N_u] space. Panel (a) shows the downward-sloping relative demand (RD) curve (2) and an assumed upward-sloping relative labour supply curve (RS). Increases in w_s/w_u arising from SBTC i.e. increase in α shift RD to RD^1. Panel (b) shows (5), labelled as an economy-wide relative labour demand curve and relative supply. The curve is horizontal since w_s/w_u is determined by (p^i/p^j and TFP^i/TFP^j). Hence increases w_s/w_u arise from skilled-sector biased rises in prices or tfp ($\Delta\ln p^i>0$, or $\Delta\ln tfp^i>0$) which shift the curve upwards from RD to RD^1.

To see the intuition for the "flat" shape of the curve, consider a rise in relative skilled supply that traces out aggregate relative labour demand. In panel (a) relative wages must fall to absorb the extra skilled workers, and so RD slopes downwards. Panel (b) is the aggregate relative demand curve in a multi-sector model. With many sectors the extra skilled workers can potentially be absorbed by a rise in output in the skilled-intensive sector. The flat shape shows that in the 2x2 model this absorption is done entirely by changes in these output mixes with no change in relative wages; this is the so-called Rybczynski effect (Rybczynski, 1955). Davis (1998) criticises HO theory on the

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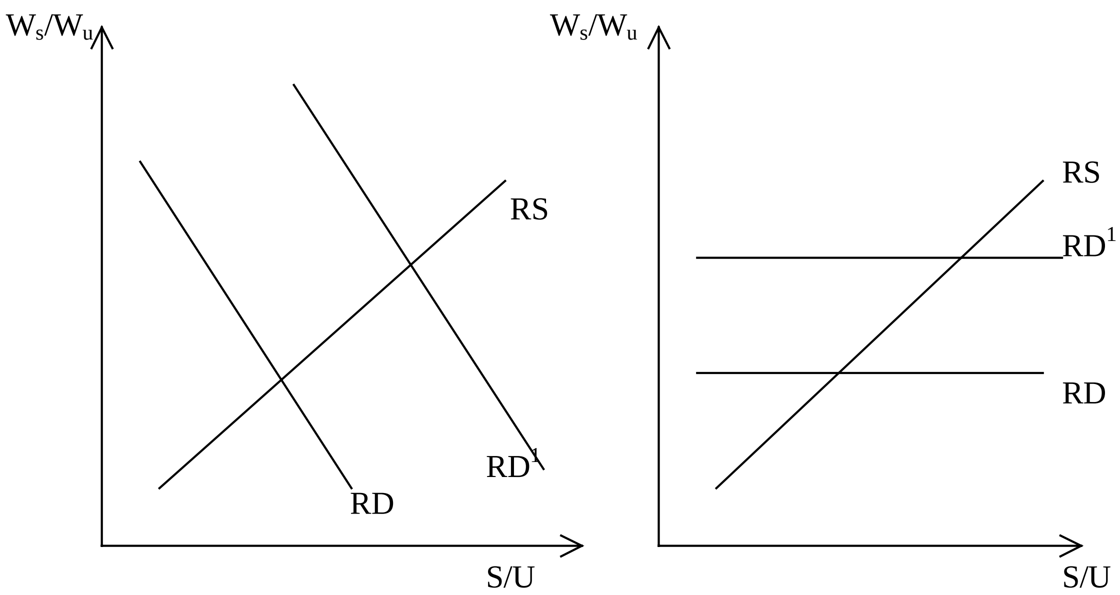
[10] Depending on the extent to which the industry rises in skill-intensity are caused by between-firm averaging effects within-industries. Bernard and Jensen (1997) examine this using plant data for the US.

empirical grounds that estimated labour demand curves are not flat. Note however that a downward-sloping *single sector* relative demand curve such as (2) still holds; it is the *economy-wide* curve that is flat, as is clear algebraically from (5). Note too that although the aggregate RD curve is, in an accounting sense, a weighted average of the individual sectoral demand curves, in a multi-sector model the weights are endogenous. The above exercise of varying RS to trace out RD shows that the employment/output weights adjust rather then relative wages, giving a flat RD curve.

Figure 1
Aggregate relative demand and supply of labour under the one-sector and the two-sector models
a. one sector *b. two sector*

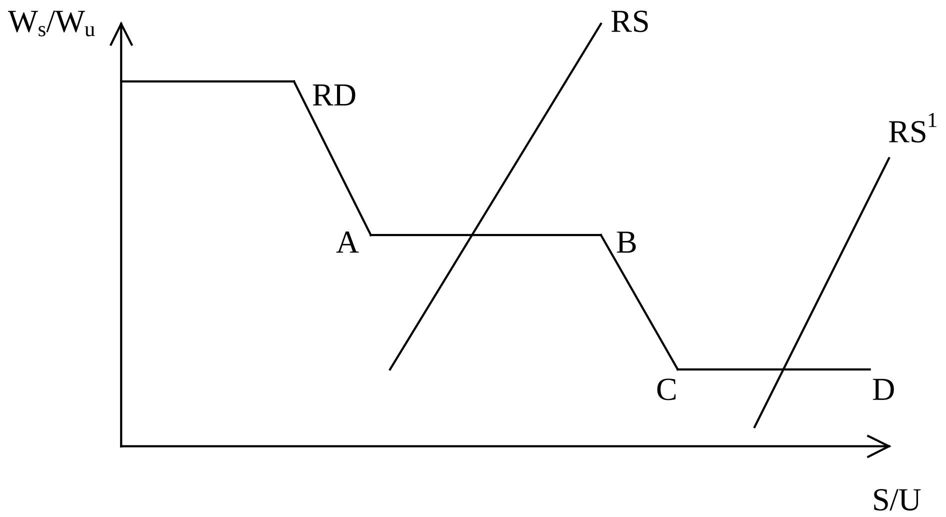


How then might labour supply affect relative wages in this model? First, it depends on the number of factors and products. In the above model with 2 products there are 2 zero profit conditions and with 2 factors of production relative wages are completely determined. In general, if there are N traded goods being produced and M factors, as long as N≥M, there are enough zero-profit conditions to determine factor prices without any effect from labour supply. However, if there is insufficient diversification in the economy such that there are more factors than products then labour supply matters for relative wages since relative wages are not completely determined.[11] Second, as RS increases the economy might shift from producing N goods to N′ goods. This gives a new set of zero-profit conditions in (4) and hence a new flat segment of the national relative demand curve. This is shown in figure 2, where the increases in skilled labour supply mean the economy ceases to produce the most unskilled-intensive products and starts producing new, more skill-intensive products than

[11] Freeman (1995) criticises the knife-edge property of this model.

before. Hence changes in supply affect relative wages as the economy moves from segment AB to CD. Third, if factors are immobile across sectors then each sector is a local labour market, in which case relative supply and demand will determine relative wages.

Figure 2
The aggregate labour demand curve in a multi-sector model with changes in the range of goods



d. *Prices.* To say anything about trade, a convenient additional assumption is that the economy is small and open. Hence price changes can only be due to changes in world trading conditions. A number of recent papers have reconsidered the effects of technical progress when prices are endogenous, either because a country is large or because trading partners share the same technology and technical change is global.

When (p^i/p^j) is endogenous we have to add an equation to (5) whereby p^i/p^j is determined by goods relative supply and relative demand. With homothetic preferences, relative demand does not depend on income, but solely on relative prices (and preference parameters).[12] Relative supply depends on relative wages and, crucially, technology. In this case then, the effect of technology on relative wages depends on what one might call the "direct" effect of sector bias described by (5) at given p^i/p^j and the "indirect" effects working through changes in p^i/p^j due to changes in relative goods supply.

A number of recent papers, summarised in Haskel and Slaughter (1998) have considered the endogenous price case and reached different conclusions. Krugman (1995) and Davis (1997) consider

[12] Krugman (1995) discusses the case where relative demand depends on income effects.

the case of technical change (TC) in a single sector with endogenous prices. Krugman (1995) asserts that in this case the economy is analytically equivalent to being closed and that SBTC in either sector raises w_s/w_u. However, the above algebra suggests that the importance of sector bias arises from the assumption of two sectors, rather than the assumption that the economy is closed or open; (5) still holds regardless of whether prices are endogenous or not. As Haskel and Slaughter (1998) show Krugman's assertion is correct if one assumes Leontief technologies and ignores the direct effect. With general production functions, the direct and indirect effects offset each other and hence the overall impact of TC in one sector on w_s/w_u is ambiguous. If the direct effect exceeds the indirect effect, the results depend unambiguously on sector bias.

Berman, Bound and Machin (1998) consider SBTC in *both* sectors when product prices are endogenous. They claim that relative wages rise in this case. Their model is a special case in two regards however. They assume that SBTC lowers costs in both the skill-intensive and unskilled-intensive sectors and that these reductions in costs are exactly equal. Hence relative profitability does not change and so there is no direct effect on wages. The impact on relative wages comes entirely from the indirect effect of SBTC on relative supply and hence prices. Relative wages rise in this case however only if technology is Leontief. If there is any substitutability in production, relative wages depend on the sector bias of SBTC, see Haskel and Slaughter (1998) for more details.

e. The definition of a sector. The source of heterogeneity in this model derives from sectors (or industries) with different factor intensities ($V_s^i \neq V_s^j$). A number of points follow from this. First, working with a single sector model is equivalent to assuming a representative firm. One would not like to argue that it is "wrong" to work with a representative firm, but representative firm models usually do not have compositional effects which are key in the HO model.[13] Second, empirical applications of the model are usually at the industry level, since an industry (hopefully) groups firms of like technology and hence skill-intensity. If this assumption is incorrect, it is possible that an apparent sector bias is due to within-industry skill-bias and suitable compositional effects. Third, the disappearance of a sector makes a big difference to the determinants of relative wages (in the two sector case this would for example mean N<M as discussed above). Whilst this means the model's results are knife-edged, it is to be expected in a model where wages are determined on the margin since a sector's disappearance is a substantial marginal change. Fourth, factor content analysis is an example of an empirical application that does assume differences in technologies across sectors (for a debate on this approach see Deardorff, 1997, Krugman, 1995 and Leamer, 1996).

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[13] The aggregate relative labour demand curves shown in Figs 1 and 2 shift up as workers flow into the skill-intensive sector. This compositional effect cannot occur in a model with uniform skill-intensity.

f. Other points. The effect of sector bias on relative wages is derived here for a 2x2 model. In even models of higher dimensions the effect of sector bias holds “on average”: factors employed intensively in rising price industries will experience relative price increases. See Ethier (1984).[14] Non-traded sectors can be added to the model but as long as traded prices are exogenous the 2x2 traded sector determines relative wages which are the same throughout the economy due to labour mobility (TC in the non-traded sector changes non-traded prices). Finally, a recent theoretical literature (e.g. Acemoglu, 1999) considers the case that trade might influence technology.

3. Empirical analysis of the HO model

One statistical approach to examining the HO model (Lawrence and Slaughter, 1993, Sachs and Shatz, 1994, Desjonques, Machin and van Reenen, 1997) has been to estimate

$$\Delta \ln p_{kt} = \alpha + \beta \left(\frac{\mathrm{N_s}}{\mathrm{N_u}} \right)_{kt} + \varepsilon_{kt} \qquad \textbf{(8)}$$

where ε_{it} is a random error and (8) is estimated across k industries. However (8) only considers the intensity of two factors. In addition, Stolper-Samuelson price effects arise from the assumption that each sector in the economy makes zero profits, so that when prices change, relative wages have to change to restore zero-profit equilibrium. The zero profit relation links the level of prices and levels of factor inputs. Yet (8) regresses the *change* in prices on the level of factor inputs.

Since the HO model is based on zero-profit conditions, Leamer (1998a) proposes to estimate the N zero-profit conditions in (4) directly. Taking logs, totally differentiating and using the definition of TFP above gives that for each sector k

$$\Delta \ln p^k + \Delta \ln TFP^k = (\Delta \ln w_s) V_s{}^k + (\Delta \ln w_u) V_u{}^k \qquad \textbf{(9)}$$

(where note that (5) can be derived from writing (9) for sector i and j and subtracting the sector j equation from the sector i equation). This equation says that changes in p or TFP can be accompanied by changes in w_s and w_u and still be consistent with zero profits (note the changes in w_s and w_u are weighted by factor cost shares which gives the effect on profitability). In (9), we can use data on prices and outputs and inputs to construct Δp^k, ΔTFP^k, $V_s{}^k$ and $V_u{}^k$. The terms Δw_s and Δw_u are

[14] Deardorff (1994), quoted in Slaughter (1999b) states the correlation version of the Stolper-Samuelson theorem “For any vector of goods price changes, the accompanying vector of factor price changes will be positively correlated with the factor-intensity-weighted averages of the goods price changes”.

unknown since they are the changes in economy-wide factor prices required to maintain zero profits. To find them, Leamer (1998a) suggests running the regressions

$$\begin{aligned} \Delta \ln TFP^k &= \beta_s V_s{}^k + \beta_u V_u{}^k + \varepsilon_1{}^k \\ \Delta \ln p^k &= \gamma_s V_s{}^k + \gamma_u V_u{}^k + \varepsilon_2{}^k \end{aligned} \qquad \textbf{(10)}$$

where ε_1 and ε_1 are errors arising from measurement error, the failure of zero profits to hold exactly and the like (the capital share of total costs can be added into (10)). Comparing (10) and (9), β_s, β_u, γ_s and γ_u are the changes in skilled and unskilled wages consistent with zero profits in response to changes in TFP when prices are constant and changes in prices when TFP is constant. These coefficients can be regarded as summarising the sector bias of $\Delta\ln p_i$ and $\Delta\ln TFP_i$. If $\beta_s>\beta_u$ or $\gamma_s>\gamma_u$ then TFP or price changes are concentrated in skill-intensive sectors, in which case relative skilled wages rise. If $\beta_u>\beta_s$ or $\gamma_u>\gamma_s$ then TFP and price changes are concentrated in unskilled-intensive sectors and relative skilled wages fall. Finally, the estimates of $\Delta\ln w_s = \beta_s + \gamma_s$ and $\Delta\ln w_u = \beta_u + \gamma_u$ can of course be compared with actual changes to gauge the accuracy of the model.[15]

Table 1 reports Leamer's findings using 444 US industries, 1981-91. Consider the top cell in column 1. The figure of –2.11 shows that skilled (non-production) wages would had to have fallen 211% to maintain zero profits in the face of changes in US TFP from 1981-91. The cell beneath that shows the unskilled (production) wage would had to have fallen -337%. So sector bias of $\Delta\ln TFP_{it}$ in the US over this period was in the skill-intensive sector, which would have tended to raise wage inequality. Column 5 shows analogous results for $\Delta\ln p_{it}$ and suggests that price changes were skilled sector biased; again this would have tended to raise wage inequality.

The rest of the table sets out the results for the UK reported in Haskel and Slaughter (1999a) and Gregory and Zissimos (1998). Columns 2 and 6 use 123 three-digit manufacturing industries 1979-86 drawn from the UK Census of Production. Columns 3 and 7 use 67 three-digit industries 1980-89 also drawn from the UK Census.[16] Both these data use non-manuals/manuals as a measure of skill. Columns 4 and 8 use 87 sectors from the UK input/output tables, including the service sector and using fractions of high, medium and low educated workers (measured by matching educational attainment data to their industry categories) as skill measures.

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[15] Leamer also considers the case where ΔlnTFP passes through to prices in which case the sum (ΔlnTFP+Δlnp) is regressed on the cost shares. See also Feenstra and Hanson (1999).
[16] There was a major change in the UK Standard Industrial Classification (SIC) in 1980. The 1979 and 1986 data are matched to the 1968 SIC, necessitating substantial adjustment to the 1986 data. The 1980-89 data is based on the 1980 SIC and so are unadjusted.

Table 1
The sector bias of prices and technology for the US and UK in the 1980s: estimates of (10)
(dependent variables: $\Delta\log p_{it}$ and $\Delta\log TFP_{it}$ for each indicated year interval)

	$\Delta\ln TFP_{it}$				$\Delta\ln p_{it}$			
Column	***(1)***	***(2)***	***(3)***	***(4)***	***(5)***	***(6)***	***(7)***	***(8)***
Study	*L*	*HS*	*HS*	*GZ*	*L*	*HS*	*HS*	*GZ*
Years	*1981-91*	*1979-86,*	*1980-1989*	*1981-91*	*1981-91*	*1979-86*	*1980-1989*	*1981-91*
Data	*4 digit*	*3-digit*	*3-digit*	*IO*	*4 digit*	*3-digit*	*3-digit*	*IO*
Country	*US*	*UK*	*UK*	*UK*	*US*	*UK*	*UK*	*UK*
$\mathbf{V_s^k}$	-2.11	0.06	0.22	-0.47	5.82	0.92	0.77	2.50
	(1.65)	(0.13)	(0.41)	(0.16)	(4.61)	(2.11)	(1.40)	(5.38)
$\mathbf{V_u^k}$	-3.37	0.49	0.29	3.65	4.89	-0.16	0.08	-0.31
	(3.00)	(3.18)	(1.47)	(1.37)	(4.45)	(0.96)	(0.40)	(0.74)
# Obs.	450	123	67	87	450	123	67	87

Notes: Absolute t statistics in parentheses. Capital share of total costs included as a regressor: coefficients not reported. Studies are L (Leamer, 1998a, for the US), HS (Haskel and Slaughter, 1999a, for the UK, heteroscedastic-robust t statistics reported), GZ (Gregory and Zissimos, 1998, for the UK) using, respectively, 4 digit, 3 digit industry and input/output data . V_s and V_u are shares in total costs of: non-production and production workers (L), non-manual and manuals (HS) and high and medium educated workers (GZ). GZ also include the share of low educated workers (not reported).
Sources: Leamer (1998a, table 24), Gregory and Zissimos (1998, table 3), Haskel and Slaughter (1999a, table 5).

Comparing the co-efficients on V_s and V_u reveals a consistent picture for the UK. Growth in *TFP* is *not* concentrated in the skill-intensive sector. By this method then, technology cannot have caused the rise in wage inequality. By contrast, relative price rises are concentrated in the skill-intensive sector, consistent with the idea that price changes have contributed to rising wage inequality.

The question this work raises is what causes $\Delta\log TFP_{it}$ and $\Delta\log p_{it}$. This is taken up in three studies. For the US, Feenstra and Hanson (1999) investigate the causes of ($\Delta\ln TFP$+$\Delta\ln p$) by regressing $(\Delta\ln TFP+\Delta\ln p)_{it}$ on computers and outsourcing. They find significant effects of computers and outsourcing in this regression and significant effects on wage inequality based on regressing the estimated contributions of computers and outsourcing to $(\Delta\ln TFP+\Delta\ln p)_{it}$ on the factor shares (as in 10). For the UK, Haskel and Slaughter (1999a) look at $\Delta\ln p_{it}$ and $\Delta\ln TFP_{it}$ separately and the sector bias of the changes that foreign prices and competition induced. They find changes in foreign prices and trade barriers significantly raised 1980s wage inequality. Also, although foreign competition raised UK TFP, it did not do so in the skilled-intensive sectors and hence did not contribute (statistically significantly) to wage inequality. Finally, Haskel and Slaughter (1999b) find insignificant effects of changes in US trade barriers on 1980s wage inequality via sector biased changes in prices.

4. Conclusion

This paper has tried to compare the "trade" and "labour" approaches to estimating the contributions of trade and technology to wage inequality. The labour approach looks for factor-biased technical change whilst the trade approach looks for sector-biased technical change and price change. We have presented a model to highlight why and argued that the trade approach derives from an explicit model of heterogeneous firms across sectors. In the 1980s data, the US saw a skilled-sector bias to both prices and technology. The UK saw quite well defined skilled-sector biased changes in prices with no strong sector bias for technology.

These issues raise two particular questions for future work. On the theory side, developing the HO model to incorporate further the effects of labour supply would seem desirable. On the empirical side, we need a better understanding of what drives prices and technology and what explains the different sector bias of prices across countries.

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