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Trade Liberalisation and Technology Choice

by

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Abstract

This paper considers the links between trade liberalisation and technology choice in the non-liberalising country. Trade-liberalisation-induced changes in relative product prices have direct effects on equilibrium relative factor returns. The consequent changes in relative input costs may also lead producers to switch to alternative technologies, which will in turn induce a further indirect change in relative factor returns. Will this indirect affect exacerbate or ameliorate the direct effect on relative factor returns? We find that this depends on the relative cost savings across sectors and factor cost shares.

Outline

Non-Technical Summary

The search for explanations of the decline in the return to unskilled labour relative to skilled labour in developed countries has occupied the attention of both trade and labour economists over the last few years. We have also observed in recent years increased exports of unskilled labour intensive products from developing to developed countries (following trade liberalisation by the former). Standard trade theory predicts that falling prices and increased imports of goods that are intensive in a particular factor will depress the relative return to that factor in the importing countries, and the observed changes in labour markets in the developed countries are consistent with this prediction. Trade economists have therefore been interested in the extent to which increased exports of goods by developing countries might have been responsible for the fall in the relative wage of unskilled workers in the developed countries. However the general conclusion that has emerged from the empirical literature is that while these 'trade effects' might be directly responsible to some extent, skill-biased technology change has been a more significant factor.

Much of the literature has treated the trade and the technology change explanations as though they were independent and exogenous. However, the development and/or adoption of different technologies might itself be a consequence of changes in the relative prices of factors of production (and thus endogenous). Given that increased trade has affected product prices and hence factor prices, the obvious question is whether it may also have induced the utilisation of different technologies in the developed countries.

This paper investigates the links between the choice of technology in a non-liberalising (developed) country and trade liberalisation elsewhere. It does not consider the development of the alternative technologies themselves, but takes these as already in existence. The choice between these technologies is governed by the prevailing factor costs - a technology will only be used if it is profitable.

When trade liberalisation in the developing countries generate world price changes that directly induce changes in equilibrium relative wages in the developed country, the corresponding changes in relative input costs may lead producers to switch to an alternative technology, and this will in turn induce a further, indirect change in equilibrium relative wages. The consequent question is then whether these indirect relative wage changes will exacerbate or ameliorate the direct changes in relative wages.

The paper uses a model that includes skilled labour, unskilled labour and capital as factor inputs adding value to intermediate inputs. Capital is assumed to be internationally mobile at a fixed return. It demonstrates that for product price changes to generate a fall in the relative wage of unskilled labour requires that the unskilled-labour intensive product have one or more of (a) a decline in its relative value-added price; (b) a larger share of intermediates in unit costs; or (c) a larger total share of labour (skilled

and unskilled) in its unit costs. For exogenous technology changes in the sector intensive in unskilled labour to have the same effect requires it have (a) a lower rate of improvement in total input productivity or (b) a larger total share of labour in unit costs.

By restricting attention to alternative technologies that differ only in their primary input usage and assuming complementarity between skilled labour and capital inputs, the paper also concludes that alternative extant technologies would only be adopted if they were more unskilled-labour intensive than current technologies. The effects of these induced technology changes on relative wages depend on the relative (potential) cost savings induced in the two sectors, and on relative total labour cost shares. Substantial cost savings due to the adoption of alternative technology in the unskilled-labour intensive sector would tend to ameliorate the original decline in the relative wage of unskilled labour. It is cost savings in the skilled-labour intensive sector that tend to exacerbate the original change. A decline in the relative return to unskilled labour will follow either exogenous or induced technology changes if the latter result in relatively larger cost reductions in the skilled-labour intensive sector. Whether trade liberalisation by developing countries has induced such changes in their developed trading partners is an empirical question worthy of further investigation.

I Introduction

The search for explanations of the decline in the return to unskilled labour relative to skilled labour in developed countries has occupied the attention of both trade and labour economists over the last few years[1]. For trade economists the focus has been on the extent to which trade liberalisation by relatively unskilled labour-abundant countries might have been responsible for the fall in the relative wage of unskilled workers in their trading partners, since this outcome is consistent with the predictions of the Heckscher-Ohlin and Stolper-Samuelson Theorems[2]. The general conclusion that has emerged from this literature is that, while this trade liberalisation might perhaps be directly responsible to some extent, skill-biased technology change has been a more significant factor[3]. But even accepting this conclusion, there remains the issue of what forces have given rise to changes in the utilised technology. In particular, might trade liberalisation in the developing countries also be indirectly responsible for the shift in relative wages through its effects in inducing the adoption of new technologies in the developed countries[4].

In this paper we investigate the links between trade liberalisation and technology choice in the non-liberalising country. By changing relative product prices, trade liberalisation directly induces changes in equilibrium relative wages. The corresponding changes in relative input costs may then lead producers to switch to alternative technologies, which will in turn induce a further, indirect change in equilibrium relative wages. We do not examine the actual development of the alternative technologies themselves, but take these as already in existence prior to the liberalisation, and not in use because they would be unprofitable at the prevailing factor costs. One can then ask whether the indirect relative wage changes that are caused by the liberalisation-induced changes in technology will exacerbate or ameliorate the direct liberalisation-induced changes in relative wages. These are the two central questions investigated in this paper: what characterises the input composition of any technology change in developed countries induced by trade liberalisation n their developing trading partners? And, what effects might these induced

[1] See the symposia in the Summer 1995 and Spring 1997 issues of the *Journal of Economic Perspectives*, the September 1998 issue of the *Economic Journal* and the discussion and references in Slaughter (1999).
[2] These predictions carry over "on average" in more general models, depending on the source of comparative advantage – see Falvey (1999)
[3] Discussion of the evidence on technology change can be found in Autor, Katz and Kreuger (1998), Berman, Bound and Griliches (1994), Berman, Bound and Machin (1998), Bound and Johnson (1992) Katz and Murphy (1992), Machin (1996), Machin and van Reenen (1998) and Lucke (1999). Some studies find a major role for price changes, at least in the UK. See, for example, Haskel and Slaughter (1999).
[4] This link has been emphasised by Wood (1994).

technology changes be expected to have on relative factor returns assuming no further change in product prices?

Most analyses in this area begin with a simple illustrative model that assumes two primary factors of production – skilled and unskilled labour. The conditions under which trade liberalisation or technology change will increase the relative wage of skilled workers are then easily derived. In the next section we use this framework to illustrate how price changes can lead to the adoption of alternative extant technologies. If trade liberalisation leads to a decline in the relative cost of unskilled labour, then it will encourage a switch to more unskilled-labour-intensive technologies. Whether this switch will exacerbate or ameliorate the direct effects of the trade liberalisation on relative wages is ambiguous in general.

In applied analysis it is recognised that other primary factors (particularly capital) and also intermediate goods must be considered along with labour inputs. In section III we investigate the effects of including both of these in the illustrative model, under the simplifying, yet not unrealistic assumption that capital is internationally mobile. In particular, we investigate the characteristics that product price changes and technology changes must exhibit in order to generate a further decline in the relative return to unskilled labour in this (slightly) more general framework.

Section IV then looks at the characteristics of technology changes induced by a fall in the relative cost of unskilled labour, and its implications for relative wages. While our assumption of internationally mobile capital rules out changes in its return as a source of technology change, changes in the relative prices of intermediates may alter the optimal intermediate and primary factor input mixes. Section V presents a summary and some conclusions.

II Trade-induced Technological Change

The argument that changes in relative prices, possibly induced by trade liberalisation, can lead to a switch in technology may be illustrated using Figure 1. For simplicity we assume that there are only two primary factors (skilled labour, S, and unskilled labour, U), that all technologies are Leontief[5], that there is only one available technology for the unskilled-

[5] This avoids ambiguities concerning changes in factor proportions under a given technology (induced by a change in input costs for example) and changes in technology.

labour intensive good 1, but two possible technologies for the skilled-labour intensive good 2, and that these technologies differ in their skill-intensities.

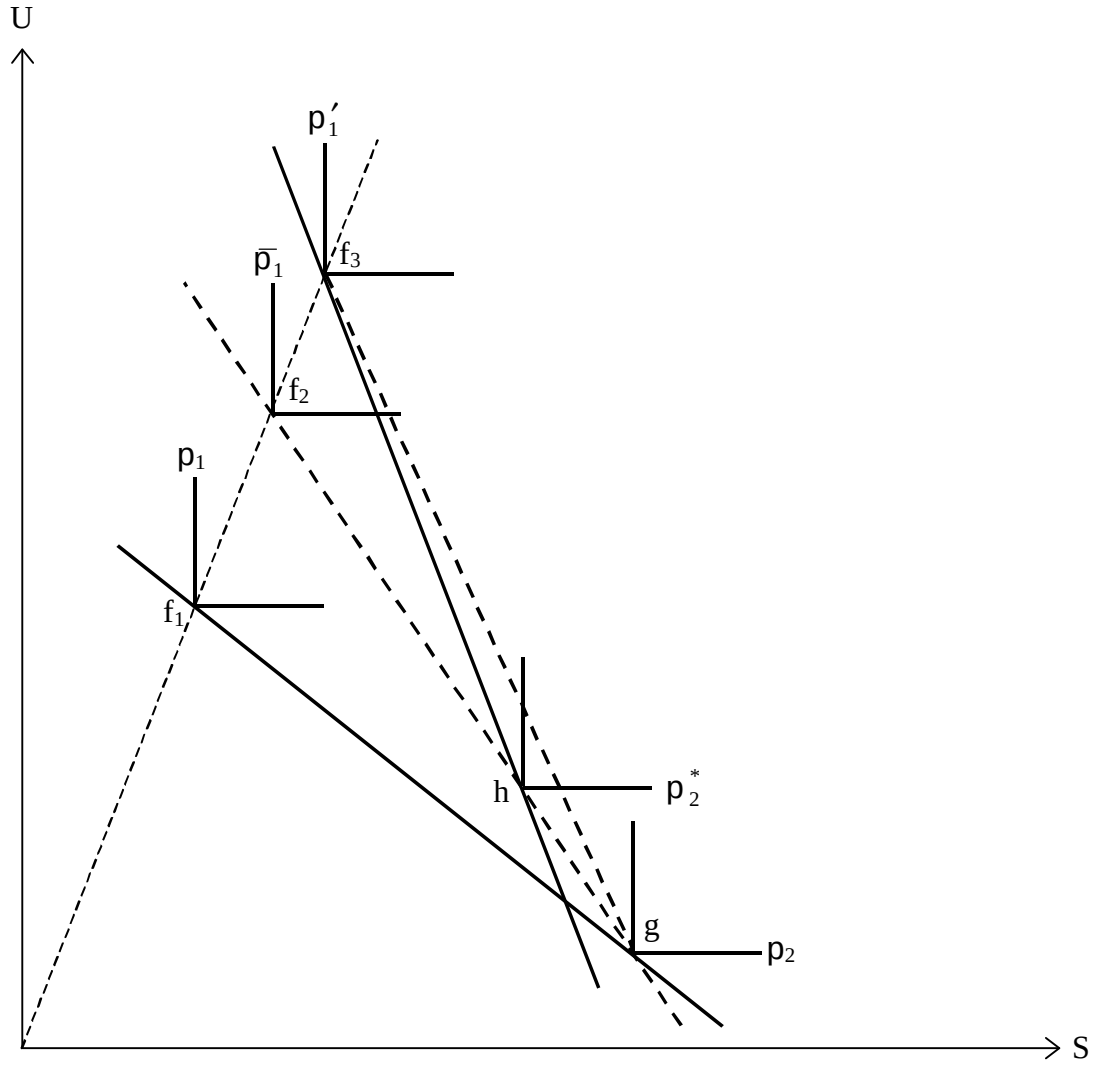

Figure 1 An induced switch in technology

At given product prices both goods are produced in the initial equilibrium. Good 2 using the technology shown by the unit value-added isoquant p_2, with both p_2 and the unit value-added isoquant for good 1, p_1, tangential to the unit value isocost line f_1g (so that zero profits are made in both sectors). The alternative production technology for good 2, shown by the unit value-added isoquant p_2^*, will not be used, since the current price would not cover the unit production cost with that technology.

Now let the price of good 1 fall, so that its unit value-added isoquant is one further from the origin. In order to maintain equilibrium in factor markets, the relative price of unskilled labour must fall, so that the unit isocost line rotates clockwise around point g. For 'small' decreases in the price of good 1 the original technology will continue to be used in production of good 2. But if the price of good 1 falls to the extent that its unit value-added isoquant becomes $\bar{p}_1$, producers of good 2 will be indifferent between using the two technologies available to them ($\bar{p}_1$, p_2 and p_2^* are all tangential to the unit isocost f_2hg). Further falls in the price of good 1, and consequent reductions in the relative cost of unskilled labour, will then result in the adoption of the alternative technology for good 2, as for example when the unit value-added isoquant for good 1 is p_1', so that the unit isocost line in the new equilibrium is f_2h, and the original good 2 technology is no longer least-cost. The change in the (relative) price of good 1 has thus induced a switch in technologies in the production of good 2. Note that the switch in the technology used to produce good 2 does not cause a 'jump' in the relative wage rate for unskilled labour, but does cause a jump in the derivative of the relative wage rate with respect to the relative product prices (f_3h is steeper than f_2g).

The adoption of alternative technologies in the production of good 1 can be demonstrated in a similar fashion. Again we begin from an initial equilibrium where these alternative technologies are not profitable. A reduction in the price of good 1 shifts all such unit isoquants equi-proportionately away from the origin. The relative cost of unskilled labour falls and the isocost line becomes steeper. Given a sufficient change in relative input prices, it may become profitable to switch to an alternative technology in the production of good 1, and again, this alternative technology would be one more unskilled-labour intensive than the original technology.

Figure 1 may also be used to illustrate another possible source of technology switching - changes in the prices of intermediate inputs. Suppose that production of good 1 requires the use of one intermediate (not good 2), which is also used in fixed proportions. A rise in the price of the intermediate would then reduce value-added in good 1, so leading to the same direction of movement of the good 1 unit value-added isoquants as would a fall in the price of good 1 itself, and with similar consequences.

In summary, if trade-liberalisation-induced product price changes would lead to a fall in the relative cost of unskilled labour, then both sectors could be induced to switch to more unskilled-labour intensive technologies. The implications that this has for relative factor returns are investigated in Section IV below in a more general context.

III Trade Liberalisation or Technology Change?

We now extend the model to include internationally mobile capital and intermediate inputs[6], and investigate the conditions that relative product price and technology changes must satisfy to generate a fall in the equilibrium relative return to unskilled labour. Consider a country currently producing two (composite) goods (1 and 2), using three factors of production (skilled labour S, unskilled labour U and capital K) under the usual competitive assumptions. All inputs are used in fixed proportions in production under any given technology, but these proportions differ across technologies and sectors. Then if p_j is the domestic price of value-added in sector j (j=1,2), the competitive profit conditions imply that, in equilibrium

$$p_j = a_{Uj}.w + a_{Sj}.v + a_{Kj}.r$$

where r, w and v are the returns to capital, unskilled and skilled labour respectively, and a_{ij} is the number of units of input i required to produce one unit of product j. The price of value-added in sector j depends on the output price (p_j) and the prices of the intermediate inputs ($p_k; k = 1,..,n.$) with

$$p_j = p_j - \sum_{k=1}^{n} a_{kj}.p_k$$

For convenience we assume that capital is freely tradable on an international market at given return r[7], that sector 2 is the relatively more skill-intensive sector under all alternative technologies[8], and that this country imports the relatively unskilled-labour intensive good (1).

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[6] Haskel and Slaughter (1999) investigate the combined effects of product price changes and sectoral TFP changes on factor returns in a model with many goods and factors and including intermediate inputs. Francois and Nelson (1998) also consider the implications of generalisations of the two-sector model for relative factor returns.

[7] Wood (1991) provides arguments and evidence justifying such an assumption.

[8] That is $s_2 > s_1$, where $s_j = a_{Sj} \big/ a_{Uj}$. Empirically, relative factor usage across sectors does tend to be reasonably stable over time.

[A] Now suppose that, as a result of *trade liberalisation* by this country's unskilled-labour-abundant trading partners, the value-added prices of these two goods change. With unchanged technologies, the changes in equilibrium factor returns (Δw and Δv, given $\Delta r = 0$) can be solved using the competitive profit conditions – i.e.

$$\begin{aligned} \Delta p_1 - \sum_{k=1}^{n} a_{k1}.\Delta p_k &= a_{U1}.\Delta w + a_{S1}.\Delta v + a_{K1}.0 \\ \Delta p_2 - \sum_{k=1}^{n} a_{k2}.\Delta p_k &= a_{U2}.\Delta w + a_{S2}.\Delta v + a_{K2}.0 \end{aligned} \qquad (1)$$

If $\hat{x}$ denotes the proportional change in any variable *x*, and θ_{ij} is the cost share of input i in sector j (e.g. $\theta_{Uj} = w.a_{Uj} / p_j$) in the initial equilibrium, then these two equations can be solved for:

$$\hat{w} = \frac{\theta_{S2}.[1-\theta_{I1}].\hat{p}_1 - \theta_{S1}.[1-\theta_{I2}].\hat{p}_2}{|\theta|}; \hat{v} = \frac{\theta_{U1}.[1-\theta_{I2}].\hat{p}_2 - \theta_{U2}.[1-\theta_{I1}].\hat{p}_1}{|\theta|} \quad (2A)$$

so that

$$\hat{w} - \hat{v} = \frac{\theta_{L2}.[1-\theta_{I1}].\hat{p}_1 - \theta_{L1}.[1-\theta_{I2}].\hat{p}_2}{|\theta|}; \qquad (2B)$$

where $|\theta| = \theta_{U1}\theta_{S2} - \theta_{U2}\theta_{S1}$ (and sign $|\theta| = \text{sign}\ [s_2 - s_1] > 0$, since $s_2 > s_1$ by assumption), $\theta_{Ij} = \sum_{k=1}^{n} \theta_{kj}$ is the share of intermediates in unit costs in sector j, and $\theta_{Lj} = \theta_{Uj} + \theta_{Sj}$ is the total share of labour (skilled and unskilled) in the unit costs of sector j.

If relative product price changes are to induce a decline in the relative return to unskilled labour, we require that $\theta_{L2}.[1-\theta_{I1}].\hat{p}_1 < \theta_{L1}.[1-\theta_{I2}].\hat{p}_2$, which implies that

$$\hat{v} > \frac{[1-\theta_{I2}].\hat{p}_2}{\theta_{L2}} > \frac{[1-\theta_{I1}].\hat{p}_1}{\theta_{L1}} > \hat{w}$$

There are three sources of bias that can generate this outcome. (a) If trade liberalisation by unskilled-labour-abundant countries tends to reduce the relative value-added price of the unskilled labour intensive product in their trading partners (i.e. $\hat{p}_1 < \hat{p}_2$). With unchanged technology there are two channels through which trade liberalisation can change value-added prices – through changes in the prices of the final output or through changes in the prices of intermediates. A fall in the relative value-added price of the unskilled labour intensive product could be due to a fall in its output price or an increase in the price of its intermediate inputs. (b) If the share of intermediates in unit costs is lower in the more skill-

intensive sector (i.e. $\theta_{I1} > \theta_{I2}$). (c) If the total labour share in unit costs is lower in the skill-intensive sector (i.e. $\theta_{L1} > \theta_{L2}$). Together the last two conditions imply that the share of the remaining input (capital) is higher in the skill-intensive sector.

[B] Alternatively suppose there is (exogenous) *technical progress* in the two sectors, with no change in product prices. Such progress will also cause a shift in equilibrium relative factor returns. Technical progress can affect the input coefficients of both intermediate and primary inputs[9]. Changes in the former affect value-added prices. Let a'_{ij} denote the unit input requirements under the new technologies. Then, without loss of generality, we can decompose the change in input coefficients into

$$a'_{ij} = \delta_j . a_{ij} + \Delta a_{ij} , \tag{3}$$

where δ_j and Δa_{ij} are defined such that[10]

$$w.\Delta a_{Uj} + v.\Delta a_{Sj} + r.\Delta a_{Kj} + \sum_{k=1}^{n} p_k .\Delta a_{kj} = 0 \tag{4}$$

Thus δ_j captures the change in total input productivity, and the Δa_{ij} measure the "input bias" (i.e. the change in the optimal input mix at the initial input prices) inherent in this change in technology. Then

$$\begin{aligned} w.a'_{Uj} + v.a'_{Sj} + r.a'_{Kj} + \sum_{k=1}^{n} p_k .a'_{kj} &= \delta_j .[w.a_{Uj} + v.a_{Sj} + r.a_{Kj} + \sum_{k=1}^{n} p_k .a_{kj}] + 0 \\ &= \delta_j . p_j \end{aligned} \tag{5}$$

Note that technical progress implies that $0 < \delta_j < 1$, and the smaller is δ_j the larger the total input productivity improvement in sector j.

The changes in relative labour returns can then be solved from the competitive profit conditions at the new factor prices

$$a'_{Uj} .[w + \Delta w] + a'_{Sj} .[v + \Delta v] + a'_{Kj} [r + \Delta r] + \sum_{k=1}^{n} a'_{kj} . p_k = p_j \tag{6}$$

which, using (5) and noting $\Delta r = 0,$ implies

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[9] More generally, it has been argued that the globalisation of markets has affected input usage in developed countries by inducing their industries to "narrow their product mix" or "outsource certain production operations" – see Wood (1998). For a general discussion of this "fragmentation" phenomenon see Arndt and Kierzkowski (1999).

[10] Equation (4) plus the system of n+3 equations corresponding to (3), yields a system of n+4 equations in n+4 unknowns (δ_j, and Δa_{ij} $i = L, S, K$ and $i = 1,..n.$).

$$a'_{Uj}.\Delta w + a'_{Sj}.\Delta v = [1-\delta_j].p_j \qquad (7)$$

In this case it is convenient to use the new equilibrium as a base from which to calculate the relative changes in labour returns. Equation (7) then translates into a system of equations:

$$\begin{aligned} \theta'_{U1}.\hat{w} + \theta'_{S1}.\hat{v} &= 1-\delta_1 \\ \theta'_{U2}.\hat{w} + \theta'_{S2}.\hat{v} &= 1-\delta_2 \end{aligned} \qquad (8)$$

where $\theta'_{Uj} = \dfrac{a'_{Uj}.w'}{p_j}$ etc. denote the labour-cost shares in the new equilibrium, $\hat{w} = \dfrac{\Delta w}{w'}$ etc.,

and $|\theta'| = \theta'_{U1}.\theta'_{S2} - \theta'_{U2}.\theta'_{S1}$ (so $\text{sign}|\theta'| = \text{sign}\,[s'_2 - s'_1] > 0$). These equations yield solution

$$\hat{w} - \hat{v} = \frac{\theta'_{L2}.[1-\delta_1] - \theta'_{L1}.[1-\delta_2]}{|\theta'|} \qquad (9)$$

Note that $\dfrac{\Delta w}{w'} = \dfrac{\Delta w}{w + \Delta w}$, so that $\dfrac{\Delta w}{w} > \text{or} < \dfrac{\Delta v}{v}$ as $\dfrac{\Delta w}{w'} > \text{or} < \dfrac{\Delta v}{v'}$, implying that the sign of the term on the right side of (9) also determines the relative change in factor returns from the initial equilibrium. Since (9) has the same form as (2B), its interpretation follows accordingly.

The change in equilibrium relative factor returns depends on the relative rates of total input productivity change in the two sectors, and on the shares of labour in unit costs. There are two potential sources of change in relative labour returns. If labour shares are equal in the two sectors in the new equilibrium (i.e. $\theta'_{L1} = \theta'_{L2} = \theta'_L$) then

$$\hat{w} - \hat{v} = \frac{\theta'_L.[\delta_2 - \delta_1]}{|\theta'|} \qquad (9A)$$

and the change in relative labour returns depends only on the relative total input productivity bias[11]. This outcome corresponds to that in the two input case[12]. A higher rate of total input productivity improvement in the skill-intensive sector – *skill-biased technical change* - will (tend to) induce a decline in the relative return to unskilled labour. If rates of total input productivity change are the same in the two sectors (i. e. $\delta_1 = \delta_2 = \delta$) then

$$\hat{w} - \hat{v} = \frac{[\theta'_{L2} - \theta'_{L1}].[1-\delta]}{|\theta'|} \qquad (9B)$$

[11] Haskel and Slaughter (1998) discuss the roles of sector-biased and factor-biased technical change in this context. They note that, for a large country, technical change will also have an indirect effect on relative factor returns through its effects on relative output supplies and, hence, relative product prices.

[12] See Findlay and Grubert (1959) and Jones and Engerman (1996).

In the absence of any sectoral bias in total input productivity changes, a fall in the relative return to unskilled labour will result if total labour has a larger cost share in the unskilled-labour intensive sector in the new equilibrium[13].

In summary, the conditions under which product price and technology changes will generate a decline in the relative return to unskilled labour in this extended model are consistent with those in the two input case. A fall in the relative (value added) price of the unskilled-labour intensive output, or a higher rate of total input productivity improvement in the skilled-labour intensive sector, will generate such a decline. When more than two inputs are considered, we note that decline in the relative return to unskilled labour is more likely, ceteris paribus, if the total labour and intermediate shares are lower in the more skill intensive sector (i.e. the capital share is higher in this sector).

IV Technical Change Induced by Trade Liberalisation

As noted in the introduction, the general consensus appears to be that skill-biased technical change has been the more important source of induced changes in relative labour returns. But it has also been argued here that the changes in relative product prices, and their accompanying changes in labour returns, may themselves have induced firms to change technologies. This possibility was illustrated for the case of two inputs in Section II. In this section we examine this process in the extended model and consider the implications of such trade-liberalisation-induced technology change for relative labour returns.

To do this we suppose that there exist alternative ("new") technologies in each sector, whose unit input requirements are denoted by b_{ij}, and that these new technologies preserve the relative factor intensities of the two sectors. Since we are interested in the characteristics of technology choices *induced* by trade liberalisation, we assume that these new technologies involve higher costs per unit of output at the initial factor prices – i.e. for each sector

$$a_{Uj}.w + a_{Sj}.v + a_{Kj}.r + \sum_{k=1}^{n} a_{kj}.p_k = p_j \leq b_{Uj}.w + b_{Sj}.v + b_{Kj}.r + \sum_{k=1}^{n} b_{kj}.p_k \qquad (10)$$

If we let $Da_{ij} = b_{ij} - a_{ij}$, then (10) implies that

[13] Note that the input-bias in the technology change will affect relative total labour cost shares in the new equilibrium relative to the old.

$$w.Da_{Uj} + v.Da_{Sj} + r.Da_{Kj} + \sum_{k=1}^{n} p_k .Da_{kj} \geq 0 . \qquad (11)$$

Now suppose that product prices change (to p'_j and p'_k), as described in section IIIA above. If firms continue to use the old technologies, the new production equilibrium will involve different labour returns that are the solution to

$$a_{Uj}.w' + a_{Sj}.v' + a_{Kj}.r + \sum_{k=1}^{n} a_{kj}.p'_k = p'_j \qquad (12)$$

In particular suppose that the new equilibrium involves a relatively higher real return for skilled labour, in line with what we have observed in practice. Such a change in relative labour costs may make the adoption of more unskilled labour intensive technologies profitable in both sectors[14]. That is, trade liberalisation can induce the adoption of new technologies, and they are likely to be skilled-labour saving in nature[15], though we must also take into account interactions with changes in the cost of intermediates.

Suppose that the new technology would be preferred in sector j at the new factor and product prices, i.e.

$$p'_j \geq b_{Uj}.w' + b_{Sj}.v' + b_{Kj}.r + \sum_{k=1}^{n} b_{kj}.p'_k \qquad (13)$$

Equations (12) and (13) can be combined to give

$$w'.Da_{Uj} + v'.Da_{Sj} + r.Da_{Kj} + \sum_{k=1}^{n} p'_k.Da_{kj} \leq 0 \qquad (14)$$

Combining (11) and (14) we have

$$[w' - w].Da_{Uj} + [v' - v].Da_{Sj} + \sum_{k=1}^{n} [p'_k - p_k].Da_{kj} \leq 0 \qquad (15)$$

Condition (15) implies a negative "correlation" between changes in input prices and changes in input usage. This is the (unsurprising) outcome that any shift in technology will be towards one which uses relatively more (less) of those inputs whose relative costs have fallen (risen) on average. One can infer no more than this in general.

[14] Were factor substitution possible under existing technologies, we would observe shifts towards more unskilled labour techniques.

[15] Note that this is opposite to the assumption by Wood (1998) that import-competing firms will switch to unskilled-labour saving techniques in response to import competition from the South. Such a switch could be related to the "fragmentation" of production (with unskilled labour-intensive operations being moved offshore) or to a change in the output mix towards more skill-intensive products. The former could arise as a consequence of improvements in international communications – a change in a different technology to that considered in the text. The latter could arise as a result of relative product price changes.

Consider, however, the special case where the new technologies differ from the old only in their primary factor usage[16] (i.e. $Da_{kj} = 0$ for $k = 1...n.$), and where $w' - w < 0$ and $v' - v > 0$[17]. Then (15) reduces to

$$[w' - w].Da_{Uj} + [v' - v].Da_{Sj} \leq 0 \qquad (15A)$$

and this condition will *not* be satisfied if

$$Da_{Uj} < 0 \ \textit{and} \ Da_{Sj} > 0$$

That is, the alternative technology cannot use less unskilled labour *and* more skilled labour per unit of output. This leaves three possibilities $Da_{Uj} < 0$ *and* $Da_{Sj} < 0$ (if $Da_{Kj} > 0$); $Da_{Uj} > 0$ *and* $Da_{Sj} > 0$ (if $Da_{Kj} < 0$); and $Da_{Uj} > 0$ *and* $Da_{Sj} < 0$. These possibilities can be narrowed further if one exploits the "complementarity" between capital and skilled labour inputs (i.e. that Da_{Kj} and Da_{Sj} have the same sign)[18], to

$$Da_{Uj} > 0 \ \textit{and} \ Da_{Sj} < 0$$

The fall in the relative value-added price of the unskilled-labour intensive product is likely to induce a shift in both sectors to technologies that use more unskilled labour and less skilled labour and capital per unit of output.

This shift to new technologies will induce a further change in equilibrium factor returns. Let us denote these returns by ($\tilde{w}, \tilde{v}$). Then

$$p'_j = b_{Uj}.\tilde{w} + b_{Sj}.\tilde{v} + b_{Kj}.r + \sum_{k=1}^{n} b_{kj}.p'_k \qquad (16)$$

What are the implications of this shift in technologies for equilibrium relative labour returns? Let $\tilde{c}_j$ denote the reduction in unit cost in sector j from using the new technology (rather than the old) at the new equilibrium factor prices – i.e.

$$\tilde{c}_j = a_{Uj}.\tilde{w} + a_{Sj}.\tilde{v} + a_{Kj}.r + \sum_{k=1}^{n} a_{kj}\,p'_k - p'_j \geq 0 \qquad (17)$$

Maintaining our assumption that there is no change in intermediate input usage, we can combine (17) with the equality in (12) to give

$$\tilde{c}_j = a_{Uj}.[\tilde{w} - w'] + a_{Sj}.[\tilde{v} - v'] \geq 0$$

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[16] Where alternative technologies differ only in their intermediate input usage, a change in intermediate product prices can induce a change in technology, but the impact of this change on relative wages will occur as result of the consequent change in value-added prices, as analysed in section IIIA above.

[17] For example if $\hat{p}_1 < 0$ and $\hat{p}_2 = 0$.

[18] For evidence on this complementarity see Bergstrom and Panas (1992).

which can be converted into proportional changes and cost shares as

$$\hat{c}_j = \tilde{\theta}_{Uj}.\hat{w} + \tilde{\theta}_{Sj}.\hat{v} \qquad (18)$$

where $\hat{c}_j = \frac{\tilde{c}_j}{p'_j}, \tilde{\theta}_{Uj} = \frac{a_{Uj}.w'}{p'_j}$, and $\hat{w} = \frac{\tilde{w} - w'}{w'}$ etc. Taking equation (18) for each of the two sectors gives a system that yields a solution for the proportional changes in labour returns of the same form as (2) above – i.e.

$$\hat{w} - \hat{v} = \frac{\tilde{\theta}_{L2}.\hat{c}_1 - \tilde{\theta}_{L1}.\hat{c}_2}{\left|\tilde{\theta}\right|} \qquad (19)$$

where sign $\left|\tilde{\theta}\right| = \text{sign}\ [s_2 - s_1] > 0$. The effects of the trade-liberalisation-induced changes in technology on relative labour returns depend on relative labour cost shares and relative cost reductions in the two sectors. Induced technology changes will further reduce the relative return to unskilled labour where the cost savings tend to be larger in the skill-intensive product, or where the total labour cost share is smaller in the skill intensive product.

In summary, while a bias towards more unskilled labour intensive techniques might have been necessary for the alternative technologies to be adopted[19], the effects of this choice on relative labour returns depends only on the relative cost savings so generated in the two sectors and their total labour cost shares. It is interesting that it is substantial cost savings in the skilled-labour intensive sector, rather than the import-competing unskilled-labour intensive sector, that are more likely to exacerbate the decline in the relative wage of the unskilled. To the extent that trade liberalisation prompts the adoption of alternative technologies in the import-competing sector this is likely to ameliorate the direct effects of the liberalisation on relative wages.

V Conclusions

We had two primary objectives in this paper. The first was to investigate the characteristics of any technology change in developed countries that might have been induced by the effects of trade liberalisation in developing countries. The second was to determine whether these indirect effects of trade liberalisation on relative wages, operating through switches to

[19] One should note that the empirical evidence does not find widespread shifts to more unskilled-labour intensive techniques. See, for example, Berman, Bound and Griliches (1994), Berman, Bound and Machin (1997) and Lucke (1999).

alternative technologies, are likely to ameliorate or exacerbate the direct effects of trade liberalisation on relative wages, operating through value-added price changes.

To this end we set up a model that included skilled labour, unskilled labour and capital as factor inputs and also allowed for intermediate inputs. Capital was assumed to be internationally mobile at a fixed return. We then examined the "biases" required for product price changes (as a result of liberalisation by trading partners) and exogenous technology changes, respectively, to generate a fall in the relative wage of unskilled labour. For price changes the biases required were that the unskilled-labour intensive product have one or more of (a) a decline in its relative value-added price; (b) a larger share of intermediates in unit costs; or (c) a larger total share of labour (skilled and unskilled) in its unit costs. For technology changes the biases required were that this sector have (a) a lower rate of improvement in total input productivity or (b) a larger total share of labour in unit costs.

Changes in the cost of inputs provided an incentive to switch to alternative technologies in both sectors, if such switches would be cost reducing. Restricting attention to alternative technologies that differed only in their primary input usage and assuming complementarity between skilled labour and capital inputs, we concluded that such technologies would only be adopted if they were more unskilled-labour intensive than current technologies. The effects of these induced technology changes on relative wages depended on the relative (potential) cost savings that they induced in the two sectors, and relative total labour cost shares. Substantial cost savings due to the adoption of alternative technology in the unskilled-labour intensive sector would tend to ameliorate the original decline in the relative wage of unskilled labour. It is cost savings in the skilled-labour intensive sector that tend to exacerbate the original change. A decline in the relative return to unskilled labour will follow either exogenous or induced technology changes if the latter result in relatively larger cost reductions in the skilled-labour intensive sector. Whether trade liberalisation by developing countries has induced such changes in their developed trading partners is an empirical question worthy of further investigation[20].

[20] Though one should note that the empirical evidence to date does not indicate that there have been widespread shifts to more unskilled-labour intensive techniques in developed countries. See, for example, Berman, Bound and Griliches (1994), Berman, Bound and Machin (1997) and Lucke (1999).

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