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Relative wages and trade-induced changes in technology[☆]

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Abstract

We develop a model where trade liberalization leads to skill-biased technological change, which in turn raises the relative return to skilled labor. When firms get access to a larger market, the relative profitability of different technologies changes in favor of the more skill-intensive technology. As the composition of firms changes to one with predominantly skill-intensive firms, the relative demand for skilled labor increases. This way, we establish a link between trade, technology and relative returns to skilled and unskilled labor.

JEL classification: F12; F15; J31; O33

Keywords: Technology; Trade; Economic integration; Relative wages

1. Introduction

Although the debate about the causes of increased wage inequality in industrialized countries has been going on for many years, no clear consensus has as yet emerged. The empirical literature has established a number of empirical facts, but theorists have not agreed on which theory, or theories, is consistent with these facts. In particular, there is still no consensus about the extent to which increased foreign competition through trade has played a role in what seems to be a shift in labor demand towards highly skilled

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workers and away from low-skilled workers. A number of studies have concluded that skilled-biased technological change seems to be the main driving force behind this development, whereas increased import competition from low-wage countries appears to have played only a minor role (e.g. Berman et al., 1994; Desjonqueres et al., 1999). However, it has also been pointed out that technological change may be driven by factors related to the increased integration of product markets (see e.g. Burda and Dluhosch, 2002; Haskel and Slaughter, 2001; Falvey and Reed, 2000; Neary, 2002a, b). Yet, the nature of a possible link between technological change and increased competition through trade remains largely unexplored.

In this paper, we explore such a link by developing a model of imperfect competition and intra-industry trade with heterogenous firms utilizing technologies that differ in their relative use of skilled and unskilled labor. Two technologies are available: a "modern" one and a "traditional" one. The modern technology is associated with relatively high fixed costs and relatively low variable costs. Market integration (in the form of reduced trade costs) leads to an expansion of the market for the individual firm, and enhances the profitability of modern relative to traditional firms. As a consequence, the relative return to skilled labor increases, at the same time as the skill-intensity in the industry increases; a phenomenon that has been observed in the empirical literature but is hard to reconcile with traditional trade theory and the Heckscher-Ohlin-Samuelson model.

In our analysis, the exogenous change that triggers an expansion of trade and a change in technology is product market integration between similar economies. The resulting trade expansion is purely intra-industry in nature. Thus, unlike most of the literature on trade and income inequality, we focus on North–North trade rather than North–South trade. By focusing on market integration between industrialized countries, our model links trade liberalization to changes in technology in a way which we believe captures an important driving force behind the recent increase in the relative demand for skilled labor in these countries.

We show that product market integration may give rise to technological change—attained through a change in the composition of firms—which increases the relative demand for skilled labor. However, we also show that when trade costs fall below a certain threshold, at which all firms are using the more skill-intensive technology, and there can thus be no further change in the composition of firms, further trade liberalization leads to a fall in the relative return to skilled labor. The reason is that firms expand output by increasing their variable costs, which are relatively intensive in unskilled labor.

The rest of the paper is organized as follows: Section 2 gives a brief review of the related literature. Section 3 presents the basic features of the model. In Section 4, we analyze the relationship between market integration and technological change, and derive the impact on relative factor returns and factor intensities of increased economic integration. Finally, in Section 5 we offer some concluding remarks.

2. Related literature

The empirical literature on the sources of an increased skill-premium in the industrialized countries is vast. A number of studies have been carried out using data from different countries. This literature has produced a number of empirical facts on which most researchers in the area seem to agree. These facts include the following: (i) the wage premium to skilled workers has increased in several industrialized countries; and (ii) the skill-intensity has increased within practically all industries (see e.g. the survey by Wood, 1998).

Several trade theorists have pointed out that within a Heckscher-Ohlin framework, the simultaneous increase in the relative price of skilled workers and skill-intensity is difficult to explain. For a given technology, there should be a negative instead of a positive relation between relative factor price and factor intensity. This means that even if the relative wage to skilled labor increases as a consequence of an increased specialization in skill-intensive production, firms should substitute the relatively cheaper factor for the relatively dearer one, thus decreasing their skill-intensity.

Technological change, on the other hand, needs to have a sectorial bias to affect relative factor prices in an *unambiguous* way: Technological progress in the skill-intensive sector leads to an increase in the relative return to skilled labor, whereas skilled-biased technological change in the whole economy does not necessarily affect relative factor prices. In order for the skill-intensity to increase, the bias moreover needs to be of such a magnitude that it offsets the effect of an increased skill premium, which in itself tends to lower the ratio between skilled and unskilled labor. Hence, as pointed out by Neary (2002a), the only way skill-biased technological progress in a small open economy could explain the empirical facts is if it were disproportionately concentrated in the skill-intensive sector at the same time as it were sufficiently diffused throughout the economy to ensure that the skill-ratio would increase in all sectors.

There are a few theoretical papers that explore a possible link between trade, technological change and relative returns to skilled and unskilled labor. Dinopoulos and Segerstrom (1999) develop a dynamic general equilibrium model in which trade liberalization increases R&D investment. Assuming that R&D is skill-intensive relative to the production of final goods, trade liberalization also leads to an increase in the relative wage to skilled labor at the same time as there is skill upgrading within each industry. Other models of endogenous innovation that generate a similar link between trade liberalization and skilled-biased technological change are Acemoglu (2003) and Thoenig and Verdier (2003).

Markusen and Venables (1997) focus on the role of foreign direct investment and multinational firms in explaining the increase in the skill premium. They develop a model with two types of firms; national exporting firms (with high variable costs and low fixed costs) and multinational firms (with low variable costs and high fixed costs); and identify the circumstances under which investment liberalization is likely to raise the skill premium in both the skilled-labor abundant and the unskilled-labor abundant country. Investment liberalization and convergence between countries tend to raise skill premia because the relative profitability of multinational versus national exporting firms is increased. Trade liberalization, however, tends to lower skill premia because it affects the relative profitability in the opposite direction.

Falvey and Reed (2000) investigate the link between the choice of production techniques and relative factor prices in a non-liberalizing developed country when trade liberalization occurs elsewhere. In their model, the increased skill premium that follows from an increased specialization in skill-intensive production induces firms to switch to more unskilled labor intensive techniques. They make the point that if the cost savings associated with this switch are larger in the skill-intensive sector than in the unskilled labor intensive sector, this induced change in technology will tend to exacerbate the increase in the relative return to skilled labor. However, they acknowledge that the empirical literature does not seem to support a shift towards more unskilled labor intensive techniques in the developed countries.

Neary (2002a) addresses the link between product market competition, trade and relative wages by developing an oligopoly model in which firms invest more aggressively in R&D (which are sunk costs) as a consequence of trade liberalization (in the form of removing import quotas). Assuming again that R&D is skill-intensive relative to production activities, this implies that the firms adopt more skill-intensive production techniques as a consequence of trade liberalization. Neary (2002b) adopts a similar framework and shows how the threat of competition from foreign firms encourages domestic firms to increase investments, which in turn impacts on the skill intensity and skill premium. The mechanism focused on by Neary is one where trade liberalization changes the degree of competition in the market, which leads firms to alter their strategic behavior.

Our model shares some features with the model developed by Neary (2002b). As in Neary's analysis, we focus on market integration between developed countries and we assume that markets are characterized by Cournot competition. With respect to the former similarity, a crucial difference is that in Neary's analysis it is the *threat of import competition* that leads to technical change, while in ours it is the *rise in intra-industry trade* that causes such a change.[1] With respect to the latter similarity, a crucial difference is that we assume free entry and exit and a large number of firms, implying that we abstract from the strategic aspects of firm behavior, which is the main focus of Neary's analysis.

From a methodological point of view, our model is similar to Markusen and Venables (1997). As in their model, firms are heterogenous with respect to technology. Furthermore, we adopt a similar equilibrium concept where, in equilibrium, there are no profitable opportunities for firms to enter with either technology. Thus, as in Markusen and Venables (1997), we allow for the simultaneous existence of firms producing with different technologies. However, unlike in their analysis, here trade liberalization generates increased skill premia.

3. The model

We assume that there are two economies, Home (H) and Foreign (F), producing two homogenous goods, X and Y. There are two factors of production, skilled and unskilled labor. Labor is mobile between sectors, but internationally immobile. The

[1] Dinopoulos et al. (2002) also develop a model where a rise in intra-industry trade generates an increased skill premium. They assume non-homotheticity in consumption as well as production, the latter taking the form of skill-biased output expansion. Because trade liberalization leads to an output expansion at the level of the firm, it tends to increase the relative demand for skilled labor.

good Y is produced with constant returns to scale, using unskilled labor only, and is sold under perfect competition. We choose this good as the numeraire. The good X is produced with increasing returns to scale, using both unskilled and skilled labor.

In the X-sector, there are two types of potential entrants: firms producing with traditional technology and firms producing with modern technology. The traditional technology is characterized by relatively low fixed costs and relatively high variable costs, whereas the modern technology is characterized by relatively high fixed costs and relatively low variable costs. Fixed costs consist of costs of skilled labor (S) only, whereas variable costs consist of costs of unskilled labor (L) only. There is free exit and entry.[2] When firms have entered, they compete as Cournot oligopolists in nationally segmented markets. The number of firms in each market, which is endogenously determined by free entry and exit, is treated as a continuous variable. Note that although firms may be large in the economy, they are assumed to ignore the effects of their entry and output decisions on national expenditure.

We assume that countries are completely symmetric, and shall therefore only present the equations defining Home's tastes and technology, simply noting that the same equations apply to Foreign. The utility of a representative consumer is given by a Cobb–Douglas function, yielding the following demand functions:

$$D_Y = (1-\beta)E, \tag{1}$$

$$D_X = \beta E/p, \tag{2}$$

where E is total income, p is the price of X in terms of Y and β is the budget share spent on good X. Total income is given by

$$E = w_L L + w_S S, \tag{3}$$

where L and S are Home's endowments of unskilled and skilled labor, respectively, while w_L and w_S are the returns to unskilled and skilled labor, respectively.

We choose units so that one unit of unskilled labor produces one unit of output of Y. Furthermore, we assume that the numeraire good Y is freely traded, which implies that the return to unskilled labor is equal to one in both countries (since they are symmetric, they will always produce both goods):

$$w_L = 1. \tag{4}$$

This means that the relative return to skilled labor is captured by w_S.

The different technologies available for firms in the X-sector are defined by the following cost function:

$$C^k = F^k w_S + c^k w_L (X_{\mathrm{d}}^k + X_{\mathrm{e}}^k) + t w_L X_{\mathrm{e}}^k, \quad k = \mathrm{M}, \mathrm{T}. \tag{5}$$

The superscript denotes type of technology so that T stands for the traditional technology and M stands for the modern technology. F^k is the fixed requirement of skilled labor, c^k the requirement of unskilled labor to produce one unit of output, t the amount

[2] Note that our specification of the model does not allow firms to choose technology strategically. The only strategic decision the firm faces is whether or not to enter the market (cf. Markusen and Venables, 1997).

of unskilled labor required in order to ship one unit of output across the border, X_{d}^{k} the amount of output supplied to the domestic market, and X_{e}^{k} the amount of output exported to the foreign market. With respect to the two different technologies, we assume that

$$F^{\mathrm{M}} > F^{\mathrm{T}}, \tag{6}$$

$$c^{\mathrm{M}} < c^{\mathrm{T}}, \tag{7}$$

which implies that technology M requires higher fixed costs but lower marginal costs than technology T.

Note that, according to (5), trade costs are incurred in unskilled labor only. This is a simplifying assumption that does not affect the main results of the analysis. However, some of the results discussed in subsequent sections are sensitive to the assumption about factor intensity of trade costs. Therefore, before concluding, we shall discuss how alternative assumptions would affect the analysis.

Firms compete in segmented markets, and first-order conditions for profit maximization in each market imply that marginal revenue equals marginal cost. Written in complementary slackness form, we have that

$$p(1-\theta_{\mathrm{d}}^{k}) \leqslant w_L c^k, \quad X_{\mathrm{d}}^{k} \geqslant 0, \quad k = \mathrm{M}, \mathrm{T}, \tag{8}$$

$$p(1-\theta_{\mathrm{e}}^{k}) \leqslant w_L (c^k + t), \quad X_{\mathrm{e}}^{k} \geqslant 0, \quad k = \mathrm{M}, \mathrm{T}, \tag{9}$$

where θ, the optimal markup, is given by the firm's market share divided by the Marshallian price elasticity of demand in that market. As the price elasticity is one, given our assumption about demand, the firm's markup is simply its market share. Using that countries are symmetric, this may be written as

$$\theta_{\mathrm{d}}^{k} = \frac{X_{\mathrm{d}}^{k}}{\sum_h n^h (X_{\mathrm{d}}^{h} + X_{\mathrm{e}}^{h})}, \quad k = \mathrm{M}, \mathrm{T}, \quad h = \mathrm{M}, \mathrm{T}, \tag{10}$$

$$\theta_{\mathrm{e}}^{k} = \frac{X_{\mathrm{e}}^{k}}{\sum_h n^h (X_{\mathrm{d}}^{h} + X_{\mathrm{e}}^{h})}, \quad k = \mathrm{M}, \mathrm{T}, \quad h = \mathrm{M}, \mathrm{T}, \tag{11}$$

where n^k is the number of firms in Home that produce with technology k.

Free entry and exit in the X-sector implies that profits are either zero (for firms that operate in the market), or negative (for potential entrants that do not operate in the market):

$$p(X_{\mathrm{d}}^{k} + X_{\mathrm{e}}^{k}) \leqslant F^k w_S + c^k w_L (X_{\mathrm{d}}^{k} + X_{\mathrm{e}}^{k}) + t w_L X_{\mathrm{e}}^{k}, \quad n^k \geqslant 0, \quad k = \mathrm{M}, \mathrm{T}. \tag{12}$$

The zero-profit condition in (12) is satisfied with equality if there are firms in Home producing with technology k; otherwise it is satisfied as an inequality (i.e., n^k is the associated complementary slackness variable).

Goods-market clearing in the Y-sector is given by

$$D_Y = Y, \tag{13}$$

while factor-market clearing is given by the following conditions:

$$L = \sum_k n^k (c^k (X_d^k + X_e^k) + t X_e^k) + Y, \tag{14}$$

$$S = \sum_k n^k F^k. \tag{15}$$

4. Market integration and relative wages

We now turn to the impact of market integration on technical change, skill intensity and relative wages. The equilibrium is given by Eqs. (2)–(4), (8)–(15) and the unknown variables Y, w_L, w_S, p, θ_d^T, θ_e^T, θ_d^M, θ_e^M, D_Y, n^T, n^M, X_d^T, X_e^T, X_d^M, X_e^M, and E. This leaves us with a system of 16 equations and inequalities that solve simultaneously for 16 unknowns.

We shall first explore the effect of market integration on the relative return to skilled labor when there is no technical change. We show that, in this case, there will be a negative effect on the relative return to skilled labor from reductions in trade costs. Then we investigate how the possibility of technical change affects the relationship between trade costs and relative wages. In order to explore the more complicated general equilibrium effects, we have to rely on numerical simulations.

4.1. Market integration with one type of firm

We start by analyzing the relationship between w_S and t in a situation where there is only one type of firm, say, traditional type.[3] Using (13) and (15) in (14) we get

$$w_S = \frac{\beta}{1-\beta} \frac{L}{S} - \frac{(c^T X^T + t X_e^T)}{F^T (1-\beta)}. \tag{16}$$

where $X^T \equiv X_d^T + X_e^T$. Differentiation of this expression with respect to trade costs yields

$$\frac{\partial w_S}{\partial t} = -\frac{1}{F^T (1-\beta)} \left[c^T \frac{\partial X^T}{\partial t} + t \frac{\partial X_e^T}{\partial t} + X_e^T \right]. \tag{17}$$

The derivative $\partial X_e^T / \partial t$ is negative since an increase in trade costs will lead to decreased trade volumes. The derivative $\partial X^T / \partial t$ is also negative because the increase in domestic sales will be less than the decrease in exports. The two first terms in (17)

[3] The model then becomes similar to a reciprocal dumping model with free entry and exit (cf. Brander and Krugman, 1983).

are thus positive (taking the minus sign outside the brackets into account) while the last term is negative. Thus, expression (17) reveals that a change in trade costs has two counteracting effects on the return to skilled labor: On the one hand, the tendency of firms to produce smaller quantities when home markets become more protected will have a positive impact on the relative return to skilled labor.[4] On the other hand, increased costs in terms of unskilled labor for exporting a given quantity will have a negative impact on the relative return to skilled labor. The first term in (17) shows the effect of changes in the demand for unskilled labor as firms' variable costs are altered in response to output changes. The second term shows the effect of changes in the demand for unskilled labor used in exporting the good as firms respond to changes in trade costs by reducing exports. Both these effects will contribute to increasing w_S as trade costs increase. The last term shows the effect of changes in the demand for unskilled labor as the amount of labor required to export a given quantity changes. This effect pulls in the other direction and contributes to a decrease in w_S as trade costs increase.

Fig. 1 shows the relationship between w_S and t when we use the equilibrium conditions of the model.[5] We see that w_S is increasing in trade costs, implying that the two first terms in (17) dominate the last term. We also see that this increase is larger for high levels of t than for low levels of t. The reason for this is that there is a non-monotonic relationship between t and the total amount of unskilled labor used to trade goods. While an increase in trade costs from a low level tends to increase the

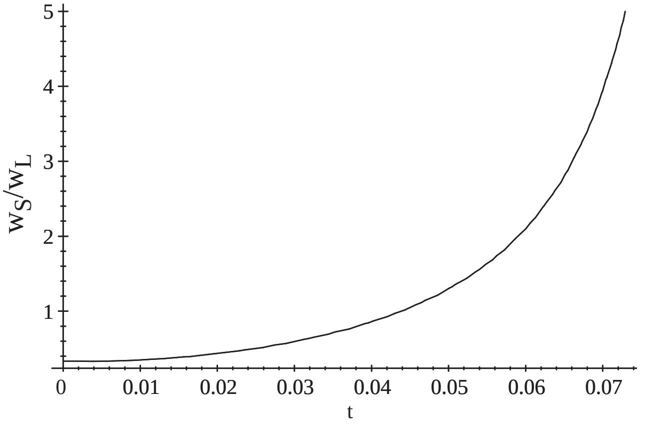

Fig. 1. The return to skilled labor with one type of firm only.

[4] Note that, although entry is free in general, the number of firms is fixed by resource constraints in this case. Entry of new firms is not possible because skilled labor required to cover the fixed costs cannot be drawn from elsewhere in the economy. The return to skilled labor is determined by the ratio between total operating profits and the number of skilled workers.

[5] The equations that are used to find the relationship between w_S and t are given in appendix. The graph in Fig. 1 is based on the following parametrization: $S = L = 10$, $F = 1$, $c = 0.1$ and $\beta = 0.5$.

demand for unskilled labor stemming from trade costs, an increase from a high level tends to decrease this demand. [6]

4.2. Market integration with co-existence of modern and traditional firms

The main point made in this paper is that when we allow for entry of firms producing with another technology, the positive relationship between w_S and t may turn negative. In other words, with the possibility of entry of firms with another technology, reduced trade costs may lead to increased relative returns to skilled labor. In this section, we first show that market integration may make it more attractive for firms producing with the modern technology to enter. We then analyze the effect of a change in the composition of firms—more specifically an increase in the share of modern firms—on the relative demand for skilled labor. Finally, we turn to the relationship between market integration and the relative demand for skilled labor. While the two first issues may be explored analytically, we need to rely on numerical simulations to explore the latter.

Market integration and composition of firms: Suppose that we are in an equilibrium where only traditional firms are operating. Whether this equilibrium is stable with respect to potential entry of modern firms depends on whether a modern firm entering would be able to make non-negative profits. We shall show that, for a certain range of parameter values, an equilibrium with only traditional firms is stable under autarky, but not under free trade. Similarly, for a certain range of parameters, an equilibrium with only modern firms is stable under free trade, but not in autarky. The implication of this is that for certain parameter values, market integration creates an incentive for firms producing with the modern technology to enter. Their entry triggers technical change and affects relative wages.

Let us first consider an equilibrium with only traditional firms in autarky. The relevant condition for when this equilibrium is stable with respect to entry is when the profit of an entering modern firm in the resulting Cournot–Nash-equilibrium is negative, i.e.,

$$\Pi^{\mathrm{M}} = (p - c^{\mathrm{M}})X^{\mathrm{M}} - w_S F^{\mathrm{M}} < 0 \tag{18}$$

in an equilibrium where $n^{\mathrm{M}} = 1$ and $n^{\mathrm{T}} = (S - F^{\mathrm{M}})/F^{\mathrm{T}}$. Solving the model for a given n^{T} and $n^{\mathrm{M}} = 1$ gives us the following expression for profits of the modern firm (see Appendix A):

$$\Pi^{\mathrm{M}} = \frac{\beta L[S\varphi^2 - F^{\mathrm{M}}[\phi^2 - n^{\mathrm{T}}c^{\mathrm{M}}((\varphi + n^{\mathrm{T}}c^{\mathrm{T}}))]]}{S[(1-\beta)\phi^2 + \beta n^{\mathrm{T}}c^{\mathrm{M}}(\varphi + n^{\mathrm{T}}c^{\mathrm{T}})]}, \tag{19}$$

where $\phi = n^{\mathrm{T}}c^{\mathrm{T}} + c^{\mathrm{M}}$ and $\varphi = n^{\mathrm{T}}(c^{\mathrm{T}} - c^{\mathrm{M}}) + c^{\mathrm{M}}$.

[6] Total trade costs exhibit an inverted u-shaped relationship with trade costs so that the demand for unskilled labor stemming from trade costs is highest for intermediate levels. This implies that for a high level of t, further increases in t will unambiguously lead to increases in w_S. It is obvious from (17) that for high t the second term dominates. For low levels of t, however, we cannot *a priori* exclude the possibility that the increased demand for unskilled labor used to export the good dominates so that w_S decreases with increases in t. Of course, were trade costs to be intensive in skilled labor instead, the second and third effects in (17) would go in the opposite direction.

From this follows that $\Pi^{\mathrm{M}} < 0$ in autarky if and only if

$$S\varphi^2 < F^{\mathrm{M}}[\phi^2 - n^{\mathrm{T}}c^{\mathrm{M}}(\varphi + n^{\mathrm{T}}c^{\mathrm{T}})]. \tag{20}$$

By substituting $(S - F^{\mathrm{M}})/F^{\mathrm{T}}$ for n^{T} and dividing through with F^{T} and $(c^{\mathrm{T}})^2$, we can express this condition in the following way:

$$\frac{S}{F^{\mathrm{T}}}(\varphi^a)^2 < \frac{F^{\mathrm{M}}}{F^{\mathrm{T}}}\left[(\phi^a)^2 - \left(\frac{S}{F^{\mathrm{T}}} - \frac{F^{\mathrm{M}}}{F^{\mathrm{T}}}\right)\frac{c^{\mathrm{M}}}{c^{\mathrm{T}}}\left(\varphi^a + \left(\frac{S}{F^{\mathrm{T}}} - \frac{F^{\mathrm{M}}}{F^{\mathrm{T}}}\right)\right)\right], \tag{21}$$

where $\phi^a = (S - F^{\mathrm{M}})/F^{\mathrm{T}} + c^{\mathrm{M}}/c^{\mathrm{T}}$ and $\varphi^a = ((S - F^{\mathrm{M}})/F^{\mathrm{T}}) \times (1 - c^{\mathrm{M}}/c^{\mathrm{T}}) + c^{\mathrm{M}}/c^{\mathrm{T}}$. In Fig. 2, the curve *aa* shows combinations of $F^{\mathrm{M}}/F^{\mathrm{T}}$ and $c^{\mathrm{M}}/c^{\mathrm{T}}$ for which profits of an entering modern firm are zero. To the right of this curve, profits are negative and an equilibrium with only traditional firms stable, whereas to the left, profits are positive and an equilibrium with only traditional firms unstable.

Let us now consider the same kind of equilibrium in free trade. The relevant condition for stability is again that the profit of an entering modern firm in the resulting Cournot–Nash-equilibrium be negative, but now in an equilibrium where $n^{\mathrm{M}} = 1$ and $n^{\mathrm{T}} = (2S - F^{\mathrm{M}})/F^{\mathrm{T}}$. Because the two countries are assumed to be identical, moving from autarky to free trade is equivalent to doubling the size of the economy. $\Pi^{\mathrm{M}} < 0$

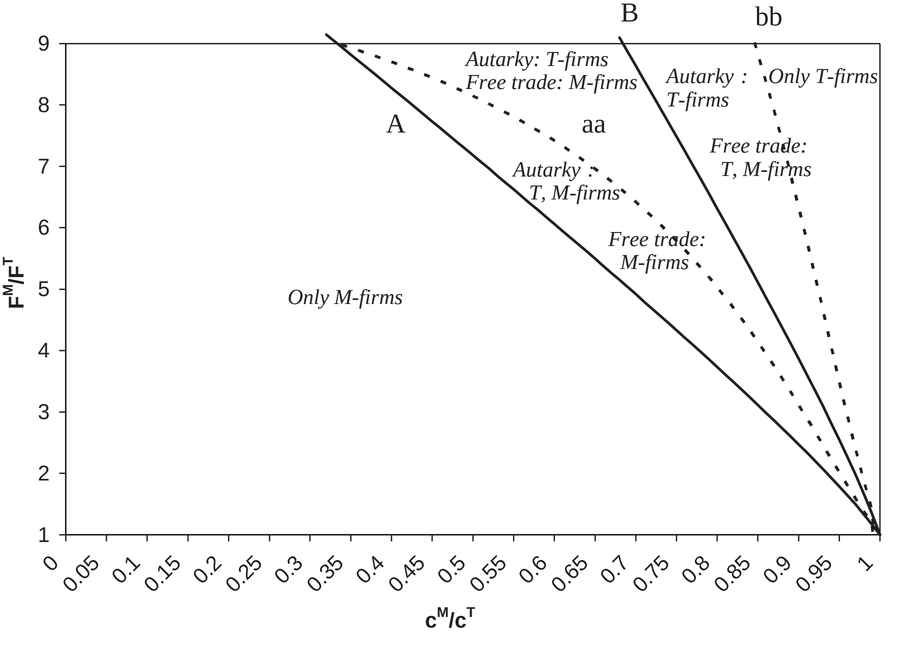

Fig. 2. Conditions for stability with respect to entry ($S/F^{\mathrm{T}} = 10$).

under free trade if and only if

$$\frac{2S}{F^{\mathrm{T}}}(\varphi^{\mathrm{f}})^2 < \frac{F^{\mathrm{M}}}{F^{\mathrm{T}}}\left[(\phi^{\mathrm{f}})^2 - \left(\frac{2S}{F^{\mathrm{T}}} - \frac{F^{\mathrm{M}}}{F^{\mathrm{T}}}\right)\frac{c^{\mathrm{M}}}{c^{\mathrm{T}}}\left(\varphi^{\mathrm{f}} + \left(\frac{2S}{F^{\mathrm{T}}} - \frac{F^{\mathrm{M}}}{F^{\mathrm{T}}}\right)\right)\right], \tag{22}$$

where $\phi^{\mathrm{f}} = (2S - F^{\mathrm{M}})/F^{\mathrm{T}} + c^{\mathrm{M}}/c^{\mathrm{T}}$ and $\varphi^{\mathrm{f}} = ((2S - F^{\mathrm{M}})/F^{\mathrm{T}}) \times (1 - c^{\mathrm{M}}/c^{\mathrm{T}}) + c^{\mathrm{M}}/c^{\mathrm{T}}$.

Combinations of $F^{\mathrm{M}}/F^{\mathrm{T}}$ and $c^{\mathrm{M}}/c^{\mathrm{T}}$ for which profits of an entering modern firm are zero are shown by the curve *bb* in Fig. 2. This curve is located to the right of curve *aa*, which means that there is a set of combinations of $F^{\mathrm{M}}/F^{\mathrm{T}}$ and $c^{\mathrm{M}}/c^{\mathrm{T}}$ for which an equilibrium with only traditional firms is stable in autarky, but not in free trade (this set is represented by the area between the two curves *aa* and *bb*). Within this set the advantage of having lower marginal costs is sufficiently large in relation to the disadvantage of having higher fixed costs for the modern firm to make non-negative profits when trade allows for a market expansion.

Next we turn to the issue of stability of equilibria with only modern firms. Let us start with autarky. The relevant condition for stability is now when the profit of an entering traditional firm in the resulting Nash-equilibrium is negative, i.e.,

$$\Pi^{\mathrm{T}} = (p - c^{\mathrm{T}})X^{\mathrm{T}} - w_S F^{\mathrm{T}} < 0 \tag{23}$$

in an equilibrium where $n^{\mathrm{T}} = 1$ and $n^{\mathrm{M}} = (S - F^{\mathrm{T}})/F^{\mathrm{M}}$. Solving the model for a given n^{M} and $n^{\mathrm{T}} = 1$ gives us the following expression for profits of the traditional firm (see Appendix A):

$$\Pi^{\mathrm{T}} = \frac{\beta L[S\omega^2 - F^{\mathrm{T}}[\psi^2 - n^{\mathrm{M}}c^{\mathrm{T}}(\omega + n^{\mathrm{M}}c^{\mathrm{M}})]]}{[(1-\beta)\psi^2 + \beta n^{\mathrm{M}}c^{\mathrm{T}}(\omega + n^{\mathrm{M}}c^{\mathrm{M}})]}, \tag{24}$$

where $\psi = n^{\mathrm{M}}c^{\mathrm{M}} + c^{\mathrm{T}}$ and $\omega = c^{\mathrm{T}} - n^{\mathrm{M}}(c^{\mathrm{T}} - c^{\mathrm{M}})$.

From this follows that $\Pi^{\mathrm{T}} < 0$ in autarky if and only if

$$S\omega^2 < F^{\mathrm{T}}[\psi^2 - n^{\mathrm{M}}c^{\mathrm{T}}(\omega + n^{\mathrm{M}}c^{\mathrm{M}})]. \tag{25}$$

By substituting $(S - F^{\mathrm{T}})/F^{\mathrm{M}}$ for n^{M} and dividing through with $(F^{\mathrm{T}})^2$ and $(c^{\mathrm{T}})^2$, this condition can be expressed as

$$\frac{S}{F^{\mathrm{T}}}(\omega^{\mathrm{a}})^2 < (\psi^{\mathrm{a}})^2 - \left(\frac{S}{F^{\mathrm{T}}} - 1\right)\left(\omega^{\mathrm{a}} + \frac{c^{\mathrm{M}}}{c^{\mathrm{T}}}\left(\frac{S}{F^{\mathrm{T}}} - 1\right)\right), \tag{26}$$

where $\psi^{\mathrm{a}} = ((S - F^{\mathrm{T}})/F^{\mathrm{T}}) \times (c^{\mathrm{M}}/c^{\mathrm{T}}) + F^{\mathrm{M}}/F^{\mathrm{T}}$ and $\omega^{\mathrm{a}} = F^{\mathrm{M}}/F^{\mathrm{T}} - ((S - F^{\mathrm{T}})/F^{\mathrm{T}}) \times (1 - c^{\mathrm{M}}/c^{\mathrm{T}})$. Note that ω^{a} has to be non-negative in order for a traditional firm to make non-negative operating profits.

In Fig. 2, the curve A shows combinations of $F^{\mathrm{M}}/F^{\mathrm{T}}$ and $c^{\mathrm{M}}/c^{\mathrm{T}}$ for which profits of an entering traditional firm are zero. To the left of this curve, profits are negative and an equilibrium with only modern firms is stable, whereas to the right, profits are positive and an equilibrium with only modern firms is unstable. Curve A is located to the left of curve *aa*, which implies that for a certain set of values of $F^{\mathrm{M}}/F^{\mathrm{T}}$ and $c^{\mathrm{M}}/c^{\mathrm{T}}$, neither equilibria with only traditional firms nor with only modern firms are stable. This indicates that mixed equilibria would arise in this region.[7]

Under free trade, the relevant condition for stability of an equilibrium with only modern firms is when the profit of a traditional firm in the Cournot–Nash-equilibrium with $n^{\mathrm{T}} = 1$ and $n^{\mathrm{M}} = (2S - F^{\mathrm{T}})/F^{\mathrm{M}}$ is negative. The relevant condition is

$$\frac{2S}{F^{\mathrm{T}}}(\omega^{\mathrm{f}})^2 < (\psi^{\mathrm{f}})^2 - \left(\frac{2S}{F^{\mathrm{T}}} - 1\right)\left(\omega^{\mathrm{f}} + \frac{c^{\mathrm{M}}}{c^{\mathrm{T}}}\left(\frac{2S}{F^{\mathrm{T}}} - 1\right)\right), \tag{27}$$

where $\psi^{\mathrm{f}} = ((2S - F^{\mathrm{T}})/F^{\mathrm{T}}) \times (c^{\mathrm{M}}/c^{\mathrm{T}}) + F^{\mathrm{M}}/F^{\mathrm{T}}$ and $\omega^{\mathrm{f}} = F^{\mathrm{M}}/F^{\mathrm{T}} - ((2S - F^{\mathrm{T}})/F^{\mathrm{T}}) \times (1 - c^{\mathrm{M}}/c^{\mathrm{T}})$. Note again that ω^{f} has to be non-negative in order for a traditional firm to make non-negative operating profits.

The combinations of $F^{\mathrm{M}}/F^{\mathrm{T}}$ and $c^{\mathrm{M}}/c^{\mathrm{T}}$ for which profits of an entering traditional firm are zero are shown as curve B in Fig. 2, which is located to the right of the corresponding curve in autarky. This implies that there is a set of values of $F^{\mathrm{M}}/F^{\mathrm{T}}$ and $c^{\mathrm{M}}/c^{\mathrm{T}}$ for which an equilibrium with only modern firms is unstable in autarky, but stable in free trade (this set is defined as the area between curves A and B). Within this set the advantage of having lower fixed costs is sufficiently large in relation to the disadvantage of having higher marginal costs for the traditional firm to make non-negative profits in autarky, but not when trade generates a market expansion.

Curve B is located to the left of curve *bb*, which indicates that there is a certain set of values of $F^{\mathrm{M}}/F^{\mathrm{T}}$ and $c^{\mathrm{M}}/c^{\mathrm{T}}$ for which neither an equilibrium with only modern firms nor with only traditional firms is stable under free trade. Again we would expect to find mixed equilibria within this range of parameter values. In the following, we shall concentrate on situations where $F^{\mathrm{M}}/F^{\mathrm{T}}$ and $c^{\mathrm{M}}/c^{\mathrm{T}}$ are such that we are somewhere in the region defined by the area between curves A and *bb* in Fig. 2, i.e. situations where market integration changes the composition of firms.

Composition of firms, *demand for skilled labor, and wages*: The change in the composition of firms impacts on the relative demand for skilled and unskilled labor and the relative return to skilled labor. If a change in the composition of firms leads to a decrease in the X-sector's demand for unskilled labor (and thereby to an increase in the X-sector's skill-intensity), the relative return to skilled labor will increase. This can be shown by using (1), (4), (14), and (15) to derive the relative return to skilled labor:[8]

$$w_S = \frac{L\beta - L_X}{S(1-\beta)},$$

[7] Note that it is assumed that $S/F^{\mathrm{T}} = 10$ in Fig. 2, which implies that the maximum level of F^{M} consistent with having one traditional firm operating in the economy in autarky is $9S/10$. This in turn implies that the maximum level of $F^{\mathrm{M}}/F^{\mathrm{T}}$ is 9.

[8] Note that this expression is derived assuming an equilibrium where both modern and traditional firms are operating.

where L_X is total demand for unskilled labor in the X-sector, which is given by the following expression:

$$L_X = n^{\mathrm{M}}(c^{\mathrm{M}}X^{\mathrm{M}} + tX_{\mathrm{e}}^{\mathrm{M}}) + n^{\mathrm{T}}(c^{\mathrm{T}}X^{\mathrm{T}} + tX_{\mathrm{e}}^{\mathrm{T}}) \tag{28}$$

where $X^{\mathrm{T}} \equiv X_{\mathrm{d}}^{\mathrm{T}} + X_{\mathrm{e}}^{\mathrm{T}}$ and $X^{\mathrm{M}} \equiv X_{\mathrm{d}}^{\mathrm{M}} + X_{\mathrm{e}}^{\mathrm{M}}$.

By differentiating w_S with respect to n^{M} we get

$$\frac{\partial w_S}{\partial n^{\mathrm{M}}} = -\frac{1}{S(1-\beta)}\frac{\partial L_X}{\partial n^{\mathrm{M}}}. \tag{29}$$

which implies that the effect of an increased proportion of modern firms on the relative return to skilled labor goes in the opposite direction compared to its effect on total demand for unskilled labor in the X-sector. Differentiating (28) with respect to n^{M}, using $\mathrm{d}n^{\mathrm{T}} = -(F^{\mathrm{M}}/F^{\mathrm{T}})\,\mathrm{d}n^{\mathrm{M}}$, yields

$$\frac{\partial L_X}{\partial n^{\mathrm{M}}} = \frac{1}{F^{\mathrm{T}}}[F^{\mathrm{T}}(c^{\mathrm{M}}X^{\mathrm{M}} + tX_{\mathrm{e}}^{\mathrm{M}}) - F^{\mathrm{M}}(c^{\mathrm{T}}X^{\mathrm{T}} + tX_{\mathrm{e}}^{\mathrm{T}})].$$

It can be shown (see Appendix A) that the term in brackets is negative and $\partial L_X/\partial n^{\mathrm{M}} < 0$ if the following condition holds:

$$c^{\mathrm{T}} - c^{\mathrm{M}} > t\left[\frac{X_{\mathrm{e}}^{\mathrm{M}}}{X^{\mathrm{M}}} - \frac{X_{\mathrm{e}}^{\mathrm{T}}}{X^{\mathrm{T}}}\right]. \tag{30}$$

In order for this condition to be satisfied, the product of trade costs and the difference in export shares between modern and traditional firms has to be sufficiently small. It is evident that this will be true as t approaches zero and as it approaches the prohibitive level of trade costs (since $X_{\mathrm{e}}^{\mathrm{M}} = X_{\mathrm{e}}^{\mathrm{T}} = 0$ at that level). It is thus only for intermediate levels of t that condition (30) may not hold so that an increased proportion of modern firms may result in a fall in the relative return to skilled labor. The reason for this is that the higher export propensity of modern firms may entail a larger total demand for unskilled labor as unskilled labor is used to export goods.[9]

Market integration, demand for skilled labor, and wages: In order to relate changes in relative wages to market integration, however, we need to analyze the effect of a reduction in trade costs—and the subsequent technological change taking place through a change in the composition of firms—on the relative return to skilled labor. Because of the complexity of the analysis, we now have to rely on numerical simulations. The simulations are carried out using a solver supplied in the GAMS package which is able to handle complementary slackness problems directly (see Rutherford, 1995).[10]

Our model experiment consists of a successive lowering of trade costs, starting from a prohibitive level. When trade costs are at the prohibitive level or higher, the output

[9] Note that if the condition in (30) is satisfied, the proportion of skilled to unskilled workers is higher in a modern firm than in a traditional firm.

[10] The program performs the necessary checks of whether an equilibrium is consistent with the zero profit conditions.

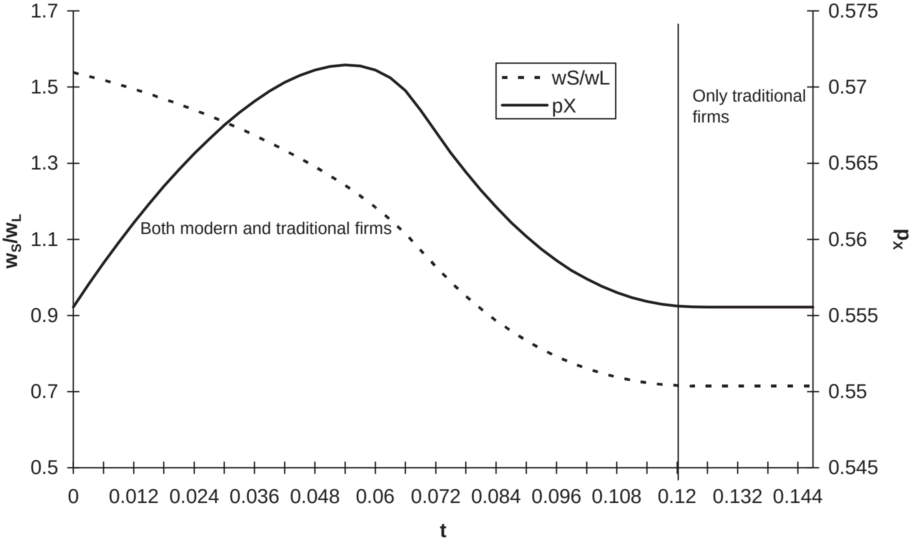

Fig. 3. The return to skilled labor and price of X with co-existence of traditional and modern firms.

of each firm is limited by the size of the domestic market. For a sufficiently small domestic market, producing with the modern technology will not be profitable, and only firms with the traditional technology will be active. As trade costs fall, exports eventually become profitable, and the firms' market expands. This market expansion goes hand in hand with increased competition from foreign producers, which generates downward pressure on the price of good X. In the absence of entry of modern firms, the reduction in trade costs will lead to an output expansion by traditional firms, a fall in the price of X, and a fall in operating profits. Because of the fall in operating profits there will also be a fall in the return to skilled labor.

However, allowing for entry of modern firms, lowering trade costs will at a certain point induce entry of such firms and simultaneously exit of traditional firms. In the simulation shown in Fig. 3, the point at which modern firms enter is the point where it is profitable for this type of firm to export, while the level of trade cost is still too high for exports to be profitable for traditional firms.[11] Only if per unit revenue after having subtracted trade costs is greater than marginal costs, would profit-maximizing firms choose to supply a foreign market. This implies that at the level of t for which

[11] In the simulation shown, the following parametrization has been used: $S=20$, $L=200$, $\beta=2/3$, $F^{\mathrm{T}}=2$, $F^{\mathrm{M}}=10$, $c^{\mathrm{T}}=0.5$, $c^{\mathrm{M}}=0.432$. In order to address the issue of possible multiplicity of equilibria, we have performed the simulations changing trade costs in both directions; that is, decreasing as well as increasing trade costs. No multiple equilibria were found.

entry of modern firms occurs, the price in an autarkic equilibrium with only traditional firms has to satisfy the condition $c^{\mathrm{M}} < p - t < c^{\mathrm{T}}$.[12]

With further reductions in trade costs there is a successive change in the composition of firms so that the share of modern firms increases. This has two opposing effects on the price. First, holding the number of each type of firm constant, a reduction in trade costs leads to increased competition from foreign firms, and has a negative effect on the price of good X. This can easily be seen from (31), which gives the equilibrium price holding the number of each type of firms fixed:

$$p = \frac{2n^{\mathrm{T}}c^{\mathrm{T}} + 2n^{\mathrm{M}}c^{\mathrm{M}} + (n^{\mathrm{T}} + n^{\mathrm{M}})t}{2n^{\mathrm{T}} + 2n^{\mathrm{M}} - 1}. \tag{31}$$

At the same time, however, there will be an effect working in the opposite direction stemming from the change in the composition of firms and its implications for the degree of competition: Since modern firms require more inputs of skilled labor in order to cover fixed costs, an increased share of modern firms implies more concentrated markets in the sense that the total number of firms decreases. The increase in market concentration weakens competition and raises the price. As is evident from Fig. 3, this latter effect dominates to begin with so that the price increases with a reduction in trade costs. Eventually, however, as trade costs are reduced even further, the former effect starts to dominate and the price falls.

As is also shown in Fig. 3, reduced trade costs lead to an increase in the return to skilled labor. This increase continues even after the price starts to fall. Underlying the continuous rise in skilled wages is an increased relative demand for skilled labor stemming from a decrease in total demand for unskilled labor in the X-sector. The overall impact of reduced trade costs on the demand for unskilled workers depends on the net effect of three different forces: Holding the number of each type of firm constant, reduced trade costs lead firms to expand output by employing more unskilled labor, thus decreasing the relative demand for skilled labor. Working in the other direction, an increase in the share of modern firms leads to an increase in the relative demand for skilled labor as entering firms are more skill-intensive than existing firms (provided that the condition in (30) is satisfied). The solid curve in Fig. 4 illustrates the inverted u-shaped relationship between trade costs and skill intensity in production caused by these two opposing forces.

However, the relative demand for skilled labor also depends on the amount of unskilled workers used in trading activities. There is a non-monotonic relationship between trade costs and total resources spent on trading goods implying that the demand for unskilled workers stemming from trading activities is especially large for intermediate

[12] Using the expression for equilibrium price in autarky with only traditional firms (see Appendix A),

$$p = \frac{Sc^{\mathrm{T}}}{S - F^{\mathrm{T}}},$$

this condition can be expressed in terms of the exogenous parameter:

$$\frac{c^{\mathrm{T}}F^{\mathrm{T}}}{S - F^{\mathrm{T}}} < t < \frac{c^{\mathrm{T}}S}{S - F^{\mathrm{T}}} - c^{\mathrm{M}}.$$

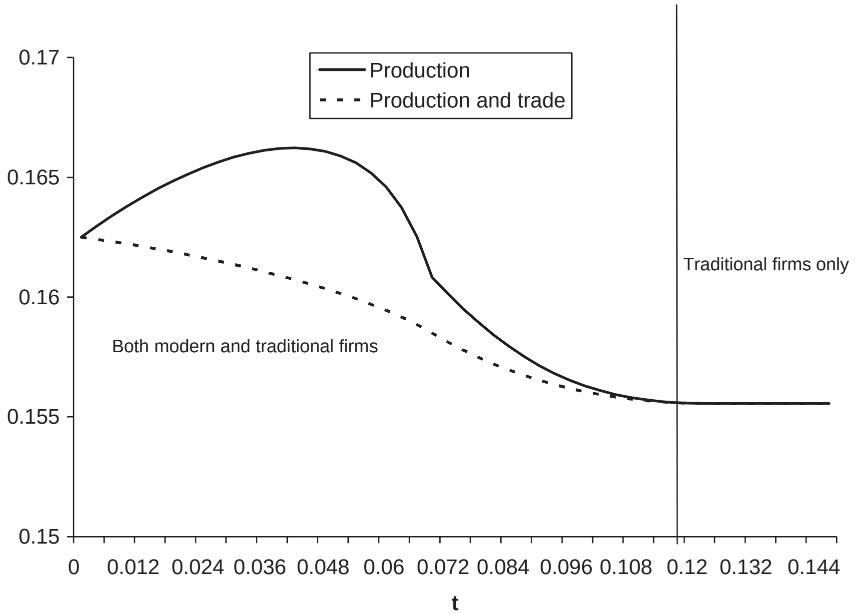

Fig. 4. Skill-intensity in X-sector.

levels of trade costs. The broken curve in Fig. 4 shows the overall skill-intensity in sector X when trading activities have been included. As is evident from this curve, the overall skill-intensity increases monotonically with reductions in trade costs. This means that the increase in the amount of unskilled workers in production of X caused by reductions in t is more than compensated for by a decrease in the amount of unskilled workers used to trade the good.

Taken together, the simulations displayed in Figs. 3 and 4 show that falling trade costs and increased trade may entail an increase in returns to skilled labor at the same time as it leads to an increase in skill intensity.

4.3. Extensions of the analysis

The main result of our analysis; the relationship between trade-induced changes in technology on the one hand, and changes in skill-intensity and relative wages on the other; is robust to alterations in the assumptions about the factor intensity of trade costs. This relationship exists for an interval of trade costs in which a reduction in trade costs leads to a change in the composition of firms producing with different technologies. The results pertaining to trade costs outside this interval, however, are sensitive to such alterations.

As implied by Fig. 1, reduced trade costs entail a decline in the return to skilled labor whenever there is only one type of firm active and trade costs are sufficiently low to induce trade. However, were trade costs to be incurred in skilled labor only, the relationship between w_S and t would be less clear-cut even in the case where there is only one type of firm. As skilled labor is used to trade goods, any reduction in t that leads to increased *total* trade costs will in itself put upward pressure on w_S. Because of the non-monotonic relationship between t and total trade costs, this may happen for relatively high levels of t. Counteracting this effect is the increased demand for unskilled labor induced by increased output levels by firms. However, when the total amount of skilled labor used to trade goods increases, the number of firms will decrease since there is less skilled labor to cover fixed costs. This will dampen the output expansion, not only because there are fewer firms producing at the same level of output, but also because a market with fewer firms will let firms hold back output levels more. Thus, a reduction in trade costs may lead to increases in w_S even if there are only traditional firms; a necessary condition for this to occur being that trade costs are sufficiently low for trade to take place.

A plausible alternative assumption about the factor intensity of trade costs is that both skilled and unskilled labor are used to trade goods. We have simulated reductions in trade costs assuming that t is incurred in both skilled and unskilled labor, using fixed coefficients. The results are similar to the ones shown in Figs. 3 and 4.

A perhaps more important issue to address is whether the main results of our analysis is robust to the inclusion of more sectors in the economy. The analysis so far has effectively only taken one sector into account. The outside sector only serves as a device for attracting unskilled labor when income increases, thereby making a change in the overall proportion of skilled to unskilled labor possible in the X-sector. Because the outside sector only employs unskilled labor, nothing can happen with factor intensities in that sector as trade costs change. However, it is obvious that had this sector employed skilled labor as well, the skill-intensity in this sector would decrease whenever changes in trade costs in the X-sector would give rise to an increase in the relative wage of skilled labor (because of substitution). This would be inconsistent with the empirical observation that an increase in the relative wage of skilled labor has been associated with increased skill-intensities in all sectors, but an inevitable consequence of an increase in the relative price of skilled labor in sectors unaffected by trade liberalization and/or technical change.

The standard way to approach this problem is to assume that the outside sector represents leisure, that both types of labor are in variable supply, and that the relative supplies of skilled and unskilled labor are increasing in the skill premium. The skill-intensity in the economy then rises with the skill premium as relatively more skilled labor is supplied by the households (see Dinopoulos and Segerstrom, 1999; Neary, 2002b). An alternative approach would be to keep the assumption of fixed supplies of skilled and unskilled labor and add sectors in which firms may enter with modern or traditional technologies. In the following we shall adopt the latter approach and analyze a modified version of the model presented in Section 3; the modification consisting of adding one more sector with Cournot competition, free entry and exit, trade costs, and two types of firms; a traditional type with relatively low fixed costs and relatively high marginal costs and a modern one with relatively high fixed costs and relatively low marginal costs. We will denote this additional sector Z. The trade cost incurred by firms in the Z-sector is assumed the same as the one faced by firms

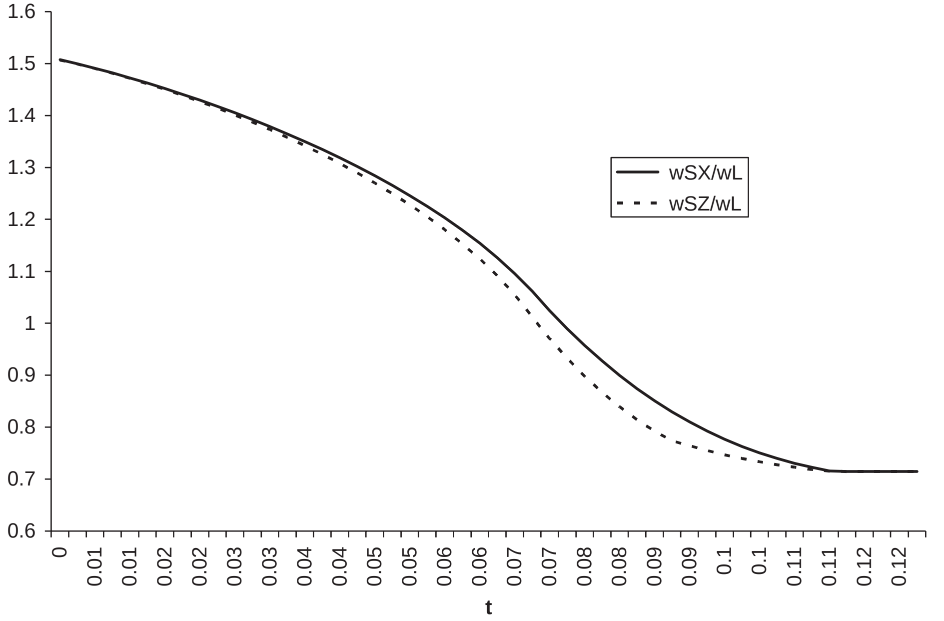

Fig. 5. The return to skilled labor in model with X and Z sector.

in the X-sector. Fixed costs and marginal costs may differ or be the same in the two industries.

In principle, as soon as we add a sector that competes with the X-sector for skilled labor, there is a tendency for the skill-intensity of sectors to move in opposite directions since an increase in the relative price of skilled labor driven by an increased relative demand for skilled labor in one sector is going to give firms incentive to substitute unskilled labor for skilled labor in the other sector. However, Figs. 5 and 6 illustrate a situation where a reduction in trade costs leads to an increase in the relative wage of skilled labor at the same time as there—*within a certain interval* of t—is an increase in the skill-intensity of both sectors.[13] The key assumption underlying this result is a limitation of the degree to which skilled labor can move freely between sectors. Skilled labor is able to move in response to differences in the wages offered by firms in the two different sectors, but not to the extent that the return to skilled labor is completely equalized between sectors.[14] More specifically, we assume the following relationship between the supply of skilled labor in the X-sector (S_X) and the relative return to

[13] The following parameter values have been used: $S = 20$, $L = 200$, $\beta_X = \frac{1}{3}$, $\beta_Z = \frac{1}{3}$, $F_X^{\mathrm{T}} = 1$, $F_X^{\mathrm{M}} = 5$, $c_X^{\mathrm{T}} = 0.5$, $c_X^{\mathrm{M}} = 0.432$, $F_Z^{\mathrm{T}} = 1$, $F_Z^{\mathrm{M}} = 4$, $c_Z^{\mathrm{T}} = 0.5$, $c_Z^{\mathrm{M}} = 0.442$.

[14] This assumption may be justified if skilled workers differ in the extent to which they are specialized in their respective activities. Some workers are likely to be more readily adaptable to production in other sectors than others. For a general equilibrium analysis utilizing this assumption, see Grossman (1983).

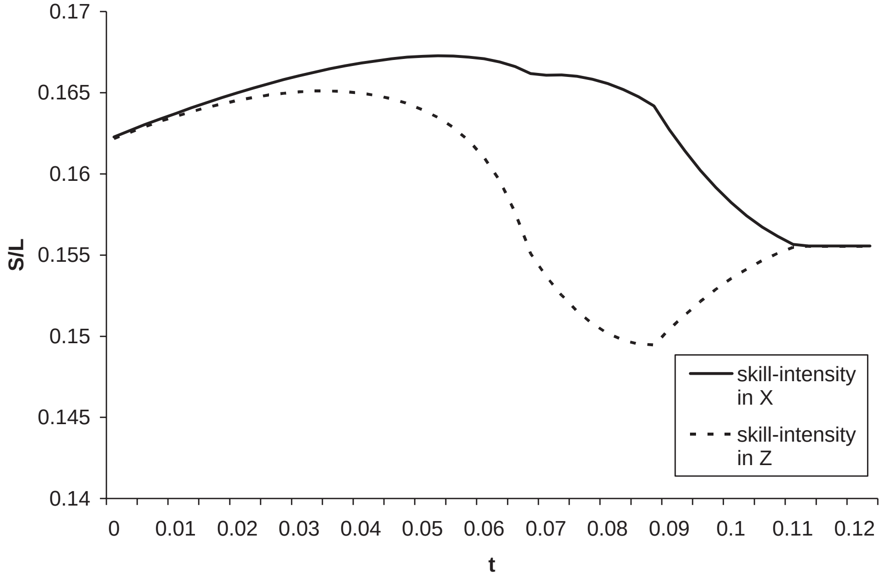

Fig. 6. Skill-intensity in model with X and Z sector.

skilled labor in the two sectors, where w_{XS} and w_{ZS} are the returns to skilled labor in the X and Z sectors, respectively: [15]

$$S_X = \delta S \left(\frac{w_{XS}}{w_{ZS}} \right)^{\gamma}. \tag{32}$$

We interpret our results as showing that the empirically observed changes in relative wages and factor intensities are consistent with what would arise from the kind of trade-induced technical change analyzed here if skilled labor is partly specific to the sector where it is employed or, put differently, possesses human capital that cannot be used to its full extent in another sector.

4.4. Discussion of the results

We have shown that when we have firms producing with technologies that differ in their relation between fixed and variable costs, market integration between identical countries may lead to entry of firms with relatively large fixed costs and exit of firms with relatively large variable costs. On the assumption that fixed costs are more skill-intensive than variable costs, this will increase the relative demand for skilled labor and put upward pressure of the relative return to skilled labor.

There are a number of empirical results that fit well with such a story. For instance, Greenaway et al. (1999) examine the effect of both exports and imports on employment

[15] We have used the following parameter values in Figs. 5 and 6: $\delta = \gamma = 0.5$.

in a large number of manufacturing industries in the UK. They find that increases in both export and import volumes lead to reductions in derived labor demand, indicating that the effect may not primarily work through an increased substitution of foreign for domestic workers in import competing industries. Instead, it appears as if openness to trade in itself affects the production techniques chosen by firms, an interpretation that is consistent with the analysis in this paper. Moreover, Greenaway et al. (1999) find that the employment effects are larger for trade with other EU countries than for trade with low-wage countries in Asia. This suggests that the labor market effects of North–North trade may be more important than the effects of North–South trade. They note that the stronger impact of EU trade may well reflect the fact that most trade between the UK and other EU countries is intra-industry in nature.

Another empirical study that reports results consistent with our analysis is Morrison and Siegel (2000), who examine the relationship between trade, technology, and labor demand using data disaggregated by industry for the US. They report that technological change has had a greater effect on labor demand than trade, but emphasize that there is a significant *indirect* impact from trade. According to their result, trade stimulates computerization, which in turn enhances the relative demand for skilled labor. They stress that trade-induced changes in technology are crucial to the full understanding of the impact of trade on the labor market.

5. Concluding remarks

This paper has explored a possible link between increased international competition through trade, technological change and the relative wage of skilled and unskilled labor. The link focused on is one where improved market access provides incentive to switch to a more skill-intensive technology. This way, we establish a link between trade, technology and relative returns to skilled and unskilled labor. Moreover, we show that as market integration continues and trade costs fall below a certain threshold, the effect on the relative return to skilled labor is reversed and further integration leads to a lower skill premium.

We believe that the present approach adds to the ongoing debate on the development of skill premia and skill ratios in the OECD countries. Most OECD trade consists of trade between industrialized countries with very similar relative factor endowments, and a major share of this trade is intra-industry in nature. Unlike the Heckscher-Ohlin-Samuelson model, the model presented here allows us to address the link between trade, technology and wages within a framework that captures exactly these features of the real world.

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Appendix A.

A.1. Market integration with one type of firm

The relationship between w_S and t for situations where there are only firms using technology k is found in the following way: The first-order conditions for profit maximization imply

$$p\left(1-\frac{d^k}{n^k}\right)=c^k, \tag{A.1}$$

$$p\left(1-\frac{(1-d^k)}{n^k}\right)=c^k+t, \tag{A.2}$$

where $d^k \equiv X_{\mathrm{d}}^k/(X_{\mathrm{d}}^k+X_{\mathrm{e}}^k)$. Dividing (A.1) by (A.2) and simplifying yield

$$d^k=\frac{c^k+tn^k}{2c^k+t}. \tag{A.3}$$

The zero profit condition implies

$$(p-c^k-t(1-d^k))(X_{\mathrm{d}}^k+X_{\mathrm{e}}^k)=F^k w_S; \tag{A.4}$$

factor-market clearing implies

$$n^k=\frac{S}{F^k}, \tag{A.5}$$

$$L=n^k(X_{\mathrm{d}}^k+X_{\mathrm{e}}^k)(c^k+t(1-d^k))+Y, \tag{A.6}$$

and clearing of the market for Y implies

$$(1-\beta)(L+w_S S)=Y. \tag{A.7}$$

Using (A.5) in (A.3) gives

$$d^k = \frac{St + F^k c^k}{F^k(2c^k + t)}. \tag{A.8}$$

Substitution of (A.7), (A.5), and (A.8) into (A.6) and solving for w_S give

$$w_S = \frac{\beta L}{(1-\beta)S} - \frac{(2F^k c^k(c^k + t) + t^2(F^k - S))}{(1-\beta)(F^k)^2(2c^k + t)}(X_{\mathrm{d}}^k + X_{\mathrm{e}}^k). \tag{A.9}$$

Substituting (A.3) and (A.5) into (A.1) yields the equilibrium price:

$$p = \frac{S(2c^k + t)}{2S - F^k}. \tag{A.10}$$

Using (A.10) we find that per unit operating profits are

$$p - c^k = \frac{St + F^k c^k}{2S - F^k}. \tag{A.11}$$

Using this in (A.4), substituting for d^k and solving for w_S, give

$$w_S = \frac{1}{F^k}\left[\frac{St + F^k}{(2S - F^k)} + \frac{(t^2(S - F^k) - F^k c^k t)}{F^k(2c^k + t)}\right](X_{\mathrm{d}}^k + X_{\mathrm{e}}^k). \tag{A.12}$$

By solving (A.9) for $(X_{\mathrm{d}}^k + X_{\mathrm{e}}^k)$ and substituting into (A.12) we get an expression that implicitly defines the relationship between w_S and t.

A.2. Market integration with co-existence of modern and traditional firms

Proposition 1. *In a Nash equilibrium with only one modern firm, the profit of that firm is given by the following expression for any given number of traditional firms,* n^{T}:

$$\Pi^{\mathrm{M}} = \frac{\beta L[S\varphi^2 - F^{\mathrm{M}}[\phi^2 - n^{\mathrm{T}}c^{\mathrm{M}}(\varphi + n^{\mathrm{T}}c^{\mathrm{T}})]]}{S[(1-\beta)\phi^2 + \beta n^{\mathrm{T}}c^{\mathrm{M}}((\varphi + n^{\mathrm{T}}c^{\mathrm{T}}))]},$$

where $\phi = n^{\mathrm{T}}c^{\mathrm{T}} + c^{\mathrm{M}}$ *and* $\varphi = n^{\mathrm{T}}(c^{\mathrm{T}} - c^{\mathrm{M}}) + c^{\mathrm{M}}$.

Proof. Profits are the difference between operating profits and fixed costs:

$$\Pi^{\mathrm{M}} = (p - c^{\mathrm{M}})X^{\mathrm{M}} - w_S F^{\mathrm{M}}.$$

Utilizing the first-order conditions for profit maximizing we find the following expression for operating profits:

$$(p - c^{\mathrm{M}})X^{\mathrm{M}} = \frac{c^{\mathrm{M}}(X^{\mathrm{M}})^2}{n^{\mathrm{T}}X^{\mathrm{T}}}. \tag{A.13}$$

Combining the first-order conditions for both types of firms yields

$$c^{\mathrm{M}}(n^{\mathrm{T}}X^{\mathrm{T}} + X^{\mathrm{M}} - X^{\mathrm{T}}) = c^{\mathrm{T}}n^{\mathrm{T}}X^{\mathrm{T}}. \tag{A.14}$$

From this follows:

$$\frac{X^{\mathrm{M}}}{X^{\mathrm{T}}} = \frac{\varphi}{c^{\mathrm{M}}}. \tag{A.15}$$

Using this expression we find that

$$n^{\mathrm{T}}X^{\mathrm{T}} + X^{\mathrm{M}} = \frac{X^{\mathrm{T}}}{c^{\mathrm{M}}}\,\phi. \tag{A.16}$$

According to the market-clearing condition for X,

$$p(n^{\mathrm{T}}X^{\mathrm{T}} + X^{\mathrm{M}}) = \beta E, \tag{A.17}$$

where $E = L + w_S S$. Solving for p and combining with the first-order condition for profit maximization by the modern firm gives us

$$c^{\mathrm{M}}(n^{\mathrm{T}}X^{\mathrm{T}} + X^{\mathrm{M}})^2 = n^{\mathrm{T}}X^{\mathrm{T}}\beta E. \tag{A.18}$$

Substituting for $n^{\mathrm{T}}X^{\mathrm{T}} + X^{\mathrm{M}}$ from (A.16) yields

$$c^{\mathrm{M}}\,\frac{(X^{\mathrm{T}})^2}{(c^{\mathrm{M}})^2}\,\phi^2 = n^{\mathrm{T}}X^{\mathrm{T}}\beta E,$$

which can be simplified as

$$\frac{X^{\mathrm{T}}}{c^{\mathrm{M}}}\,\phi^2 = n^{\mathrm{T}}\beta E. \tag{A.19}$$

Solving for X^{T} gives us

$$X^{\mathrm{T}} = \frac{c^{\mathrm{M}}}{\phi^2}\,n^{\mathrm{T}}\beta E. \tag{A.20}$$

Substituting this expression for X^{T} in (A.15) gives us the following expression for X^{M}:

$$X^{\mathrm{M}} = \frac{\varphi}{\phi^2}\,n^{\mathrm{T}}\beta E. \tag{A.21}$$

Combining (A.13) with (A.15) gives us

$$(p - c^{\mathrm{M}})X^{\mathrm{M}} = \frac{\varphi}{n^{\mathrm{T}}}\,X^{\mathrm{M}}. \tag{A.22}$$

Substituting the expression in (A.21) for X^{M} in (A.22) yields

$$(p - c^{\mathrm{M}})X^{\mathrm{M}} = \frac{\varphi^2}{\phi^2}\,\beta E. \tag{A.23}$$

Utilizing the factor-market clearing condition for the labor market with the equilibrium values of output levels yields

$$w_S = \frac{\beta L}{S}\,\frac{[\phi^2 - n^{\mathrm{T}}c^{\mathrm{M}}((\varphi + n^{\mathrm{T}}c^{\mathrm{T}}))]}{[(1-\beta)\phi^2 + \beta n^{\mathrm{T}}c^{\mathrm{M}}(\varphi + n^{\mathrm{T}}c^{\mathrm{T}})]}. \tag{A.24}$$

Using this to solve E gives us

$$E = \frac{L\phi^2}{[(1-\beta)\phi^2 + \beta n^{\mathrm{T}}c^{\mathrm{M}}(\varphi + n^{\mathrm{T}}c^{\mathrm{T}})]}. \tag{A.25}$$

Substituting this expression for E in (A.23) gives us

$$(p - c^{\mathrm{M}})X^{\mathrm{M}} = \frac{\beta L\varphi^2}{[(1-\beta)\phi^2 + \beta n^{\mathrm{T}}c^{\mathrm{M}}((\varphi + n^{\mathrm{T}}c^{\mathrm{T}}))]}. \tag{A.26}$$

By combining (A.24) and (A.26) we get the following expression for the profit of the modern firm:

$$(p-c^{\mathrm{M}})X^{\mathrm{M}}-w_S F^{\mathrm{M}}=\frac{\beta L[S\varphi^2-F^{\mathrm{M}}[\phi^2-n^{\mathrm{T}}c^{\mathrm{M}}((\varphi+n^{\mathrm{T}}c^{\mathrm{T}}))]]}{S[(1-\beta)\phi^2+\beta n^{\mathrm{T}}c^{\mathrm{M}}((\varphi+n^{\mathrm{T}}c^{\mathrm{T}}))]}. \qquad \square$$

Proposition 2. *In a Nash equilibrium with only one traditional firm, the profit of that firm is given by the following expression for any given number of modern firms,* n^{M}:

$$\Pi^{\mathrm{T}}=\frac{\beta L[S\omega^2-F^{\mathrm{T}}[\psi^2-n^{\mathrm{M}}c^{\mathrm{T}}(\omega+n^{\mathrm{M}}c^{\mathrm{M}})]]}{[(1-\beta)\psi^2+\beta n^{\mathrm{M}}c^{\mathrm{T}}(\omega+n^{\mathrm{M}}c^{\mathrm{M}})]},$$

where $\psi=n^{\mathrm{M}}c^{\mathrm{M}}+c^{\mathrm{T}}$ *and* $\omega=c^{\mathrm{T}}-n^{\mathrm{M}}(c^{\mathrm{T}}-c^{\mathrm{M}})$.

Proof. Profits are the difference between operating profits and fixed costs:

$$\Pi^{\mathrm{T}}=(p-c^{\mathrm{T}})X^{\mathrm{T}}-w_S F^{\mathrm{T}}.$$

Utilizing the first-order conditions for profit maximizing we find the following expression for operating profits:

$$(p-c^{\mathrm{T}})X^{\mathrm{T}}=\frac{c^{\mathrm{T}}(X^{\mathrm{T}})^2}{n^{\mathrm{M}}X^{\mathrm{M}}}. \tag{A.27}$$

Combining the first-order conditions for both types of firms yields

$$c^{\mathrm{T}}(n^{\mathrm{M}}X^{\mathrm{M}}+X^{\mathrm{T}}-X^{\mathrm{M}})=c^{\mathrm{M}}n^{\mathrm{M}}X^{\mathrm{M}}. \tag{A.28}$$

From this follows:

$$\frac{X^{\mathrm{T}}}{X^{\mathrm{M}}}=\frac{\omega}{c^{\mathrm{T}}}. \tag{A.29}$$

Using this expression we find that

$$n^{\mathrm{M}}X^{\mathrm{M}}+X^{\mathrm{T}}=\frac{X^{\mathrm{M}}}{c^{\mathrm{T}}}\,\psi\,. \tag{A.30}$$

According to the market-clearing condition for X,

$$p(n^{\mathrm{M}}X^{\mathrm{M}}+X^{\mathrm{T}})=\beta E,$$

where $E=L+w_S S$. Solving for p and combining with the first-order condition for profit maximization by the traditional firm give us

$$c^{\mathrm{T}}(n^{\mathrm{M}}X^{\mathrm{M}}+X^{\mathrm{T}})^2=n^{\mathrm{M}}X^{\mathrm{M}}\beta E. \tag{A.31}$$

Substituting for $n^{\mathrm{T}}X^{\mathrm{T}}+X^{\mathrm{M}}$ from (A.30) yields

$$c^{\mathrm{T}}\frac{(X^{\mathrm{M}})^2}{(c^{\mathrm{T}})^2}\,\psi^2=n^{\mathrm{M}}X^{\mathrm{M}}\beta E,$$

which can be simplified as

$$\frac{X^{\mathrm{M}}}{c^{\mathrm{T}}}\,\psi^2=n^{\mathrm{M}}\beta E. \tag{A.32}$$

Solving for X^{M} gives us

$$X^{\mathrm{M}} = \frac{c^{\mathrm{T}} n^{\mathrm{M}} \beta E}{\psi^2}. \tag{A.33}$$

Substituting this expression for X^{M} in (A.29) gives us the following expression for X^{T}:

$$X^{\mathrm{T}} = \frac{\omega}{\psi^2} n^{\mathrm{M}} \beta E. \tag{A.34}$$

Combining (A.27) with (A.29) gives us

$$(p - c^{\mathrm{T}}) X^{\mathrm{T}} = \frac{\omega}{n^{\mathrm{M}}} X^{\mathrm{T}}. \tag{A.35}$$

Substituting the expression in (A.34) for X^{T} in (A.35) yields

$$(p - c^{\mathrm{T}}) X^{\mathrm{T}} = \frac{\omega^2}{\psi^2} \beta E. \tag{A.36}$$

Utilizing the factor-market clearing condition for the labor market with the equilibrium values of output levels yields

$$w_S = \frac{\beta L}{S} \frac{[\psi^2 - n^{\mathrm{M}} c^{\mathrm{T}} (\omega + n^{\mathrm{M}} c^{\mathrm{M}})]}{[(1-\beta)\psi^2 + \beta n^{\mathrm{M}} c^{\mathrm{T}} (\omega + n^{\mathrm{M}} c^{\mathrm{M}})]}. \tag{A.37}$$

Using this to solve E gives us

$$E = \frac{L\psi^2}{[(1-\beta)\psi^2 + \beta n^{\mathrm{M}} c^{\mathrm{T}} (\omega + n^{\mathrm{M}} c^{\mathrm{M}})]}. \tag{A.38}$$

Substituting this expression for E in (A.36) gives us

$$(p - c^{\mathrm{T}}) X^{\mathrm{T}} = \frac{\beta L \omega^2}{[(1-\beta)\psi^2 + \beta n^{\mathrm{M}} c^{\mathrm{T}} (\omega + n^{\mathrm{M}} c^{\mathrm{M}})]}. \tag{A.39}$$

By combining (A.37) and (A.39) we get the following expression for the profit of the traditional firm:

$$(p - c^{\mathrm{T}}) X^{\mathrm{T}} - w_S F^{\mathrm{T}} = \frac{\beta L [S\omega^2 - F^{\mathrm{T}} [\psi^2 - n^{\mathrm{M}} c^{\mathrm{T}} (\omega + n^{\mathrm{M}} c^{\mathrm{M}})]]}{[(1-\beta)\psi^2 + \beta n^{\mathrm{M}} c^{\mathrm{T}} (\omega + n^{\mathrm{M}} c^{\mathrm{M}})]}. \qquad \square$$

Proposition 3. *$F^{\mathrm{T}}(c^{\mathrm{M}} X^{\mathrm{M}} + t X_{\mathrm{e}}^{\mathrm{M}}) < F^{\mathrm{M}}(c^{\mathrm{T}} X^{\mathrm{T}} + t X_{\mathrm{e}}^{\mathrm{T}})$ if $c^{\mathrm{T}} - c^{\mathrm{M}} > t(X_{\mathrm{e}}^{\mathrm{M}}/X^{\mathrm{M}} - X_{\mathrm{e}}^{\mathrm{T}}/X^{\mathrm{T}}) > 0$.*

Proof. By rearranging $F^{\mathrm{T}}(c^{\mathrm{M}} X^{\mathrm{M}} + t X_{\mathrm{e}}^{\mathrm{M}}) < F^{\mathrm{M}}(c^{\mathrm{T}} X^{\mathrm{T}} + t X_{\mathrm{e}}^{\mathrm{T}})$ we can express this condition in the following way:

$$\frac{F^{\mathrm{M}}}{F^{\mathrm{T}}} > \frac{(c^{\mathrm{M}} X^{\mathrm{M}} + t X_{\mathrm{e}}^{\mathrm{M}})}{(c^{\mathrm{T}} X^{\mathrm{T}} + t X_{\mathrm{e}}^{\mathrm{T}})}. \tag{A.40}$$

From (A.43) follows that

$$\frac{F^{\mathrm{M}}}{F^{\mathrm{T}}} = \frac{(p - c^{\mathrm{M}}) X^{\mathrm{M}} - t X_{\mathrm{e}}^{\mathrm{M}}}{(p - c^{\mathrm{T}}) X^{\mathrm{T}} - t X_{\mathrm{e}}^{\mathrm{T}}}. \tag{A.41}$$

Substituting for $F^{\mathrm{M}}/F^{\mathrm{T}}$ in (A.40) and rearranging yield

$$((p-c^{\mathrm{M}})X^{\mathrm{M}}-tX_{\mathrm{e}}^{\mathrm{M}})(c^{\mathrm{T}}X^{\mathrm{T}}+tX_{\mathrm{e}}^{\mathrm{T}})>(c^{\mathrm{M}}X^{\mathrm{M}}+tX_{\mathrm{e}}^{\mathrm{M}})((p-c^{\mathrm{T}})X^{\mathrm{T}}-tX_{\mathrm{e}}^{\mathrm{T}}),$$

which can be simplified to

$$X^{\mathrm{M}}(c^{\mathrm{T}}X^{\mathrm{T}}+tX_{\mathrm{e}}^{\mathrm{T}})>X^{\mathrm{T}}(c^{\mathrm{M}}X^{\mathrm{M}}+tX_{\mathrm{e}}^{\mathrm{M}}) \tag{A.42}$$

Dividing both sides of (A.42) by $X^{\mathrm{M}}X^{\mathrm{T}}$ and rearranging yield

$$(c^{\mathrm{T}}-c^{\mathrm{M}})>t\left[\frac{X_{\mathrm{e}}^{\mathrm{M}}}{X^{\mathrm{M}}}-\frac{X_{\mathrm{e}}^{\mathrm{T}}}{X^{\mathrm{T}}}\right]. \qquad \square$$

Proposition 4. *When both modern and traditional firms co-exist in equilibrium, the export share of a firm producing with the modern technology is at least as large as the export share of a firm producing with the traditional technology, i.e.,* $X_{\mathrm{e}}^{\mathrm{M}}/X^{\mathrm{M}} \geqslant X_{\mathrm{e}}^{\mathrm{T}}/X^{\mathrm{T}}$.

Proof. In an equilibrium where both modern and traditional firms co-exist, profits for both types of firms are zero. Using the zero-profit conditions for both types of firms, we get

$$\frac{(p-c^{\mathrm{M}})X_{\mathrm{d}}^{\mathrm{M}}+(p-c^{\mathrm{M}}-t)X_{\mathrm{e}}^{\mathrm{M}}}{(p-c^{\mathrm{T}})X_{\mathrm{d}}^{\mathrm{T}}+(p-c^{\mathrm{T}}-t)X_{\mathrm{e}}^{\mathrm{T}}}=\frac{F^{\mathrm{M}}}{F^{\mathrm{T}}}. \tag{A.43}$$

Solving the first-order condition for profit maximization of traditional firms in the domestic market for p and substituting into the same condition for modern firms yield

$$c^{\mathrm{T}}(X-X_{\mathrm{d}}^{\mathrm{M}})=c^{\mathrm{M}}(X-X_{\mathrm{d}}^{\mathrm{T}}), \tag{A.44}$$

where $X \equiv n^{\mathrm{T}}(X_{\mathrm{d}}^{\mathrm{T}}+X_{\mathrm{e}}^{\mathrm{T}})+n^{\mathrm{M}}(X_{\mathrm{d}}^{\mathrm{M}}+X_{\mathrm{e}}^{\mathrm{M}})$. From this expression follows that $X_{\mathrm{d}}^{\mathrm{M}}>X_{\mathrm{d}}^{\mathrm{T}}$ (since $c^{\mathrm{T}}>c^{\mathrm{M}}$). Performing the same calculation with respect to the first-order conditions for profit maximization in the foreign market yields

$$c^{\mathrm{T}}\left(X-\left(\frac{c^{\mathrm{T}}+t}{c^{\mathrm{T}}}\right)X_{\mathrm{e}}^{\mathrm{M}}\right)=c^{\mathrm{M}}\left(X-\left(\frac{c^{\mathrm{M}}+t}{c^{\mathrm{M}}}\right)X_{\mathrm{e}}^{\mathrm{T}}\right) \tag{A.45}$$

From this expression follows that $X_{\mathrm{e}}^{\mathrm{M}}>X_{\mathrm{e}}^{\mathrm{T}}$. It also follows that $X_{\mathrm{e}}^{\mathrm{M}}-X_{\mathrm{e}}^{\mathrm{T}} \geqslant X_{\mathrm{d}}^{\mathrm{M}}-X_{\mathrm{d}}^{\mathrm{T}}$ since $(c^{\mathrm{T}}+t)/c^{\mathrm{T}} \leqslant (c^{\mathrm{M}}+t)/c^{\mathrm{M}}$. This implies that $X_{\mathrm{e}}^{\mathrm{M}}/X^{\mathrm{M}} \geqslant X_{\mathrm{e}}^{\mathrm{T}}/X^{\mathrm{T}}$. $\square$

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