CSAE WPS/2010-27

Trade liberalisation, skill-biased technical change and wages in developing countries: a model with heterogeneous firms*

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August 26, 2010

Abstract

This paper analyses the effects of trade liberalisation and technical change on real and relative wages. It builds a model with monopolistic competition, heterogeneous firms and two countries, North and South, and solves it numerically. Skill-biased technical change, caused by decreases in the price of imported equipment as a result of reduced trade costs or falls in its world price, tends to increase the relative wages of skilled workers. This increase in the skill premium can occur even in skill-scarce developing countries, as has often been observed in reality, even though Stolper-Samuelson effects pull the other way. What drives the rise in skilled wages when imported equipment becomes cheaper is the rise in demand for skilled workers in the most productive firms in each sector. Whether or not real unskilled wages increase absolutely after trade liberalisation appears to depend on whether trade costs are ad valorem or per-unit.
Keywords: trade liberalisation, skill-biased technical change, wage inequality, real wages, equipment-skill complementarity.
JEL Classification: F12, O33.

*I thank Adrian Wood for many helpful comments and discussions. I am also grateful to seminar participants at the Merton International Trade Seminar at the University of Oxford for useful comments. All errors are mine.

1 Introduction

During the last three decades, the wages of skilled workers relative to unskilled workers have increased in both developed and developing countries (Anderson, 2005; Goldberg and Pavcnik, 2007). According to the Heckscher-Ohlin-Samuelson (HOS) model of trade and the associated Stolper-Samuelson theorem, this is to be expected in countries where skilled labour is an abundant factor relative to the world average, both developed and, as it has been argued in the case of Latin America (Wood, 1997), some developing countries. However, this finding is not restricted to Latin American and other developing countries abundant in skilled labour, but has been documented also for low-income Asian countries where unskilled labour is surely abundant.

This rise in relative skilled wages has not always hurt unskilled workers as there is some evidence that real unskilled wages have risen (Wood, 2002), which may have contributed to falling poverty rates especially in Asian countries (Chen and Ravallion, 2008). However, in some developing countries unskilled wages fell in real as well as relative terms, as in Mexico during the period 1984-1990 (Caselli, 2010).

In order to explain this rising wage differential, observed in both skill-abundant and skill-scarce countries, different strands of the economic literature have focused on different forces, particularly greater openness to trade and skill-biased technical change. Openness to trade may have affected wages not only through the Stolper-Samuelson mechanism, but also through other channels, as argued by Feenstra and Hanson (1997), Wood (2002), Epifani and Gancia (2008), Vannoorenberghe (2008), Bustos (2009) and Riaño (2009).

Skill-biased technical change in this context usually refers to the idea that firms in developing countries, particularly middle-income countries, import new technologies from developed countries, often in the form of machinery and equipment, that increase the relative demand for skilled labour since they are complementary with skills (Acemoglu, 2002a;b). Skill-biased technical change of this sort has been referred to as pervasive (Berman and Machin, 2004).

The large body of theoretical studies on the subject, however, has not fully explained the generally observed facts: rising wage differentials in most developing countries, whether they are skill-abundant or skill-scarce, accompanied by rising real unskilled wages in most, but not all, cases. Some gaps remain to be filled. First, relative wages need to be analysed together with changes in real wages of both skilled and unskilled workers since the forces that determine them are likely to be related (for instance, see Bernard *et al.*, 2007). Second, all the determinants of wages need to be included in the same model because interactions between them could make these variables endogenous. For instance, Acemoglu (2002b; 2007) makes skill-biased technical change endogenous and determined by trade liberalisation. Third, it remains to explore this topic in relation to the extensive research on heterogeneous firms, following Melitz (2003), which has drawn attention to the importance of within-sector structural effects of trade, technical progress and other shocks.

Motivated by these gaps, this paper seeks to construct a model that can explain the generally observed facts mentioned above. The model refers to a small economy with two traded sectors over the short run, with an extension for the long run. It refers formally to a skill-scarce country, which is regarded as the standard case in the South, but the results would be even stronger for a skill-abundant country. The paper extends the model and production function of Vannoorenberghe (2008) to two sectors and two countries, a relatively skill-abundant North and relatively skill-scarce South, as in Bernard *et al.* (2007), and includes equipment, which is complementary to skilled workers and substitutable for unskilled workers, as a third factor of production. Equipment is modelled as an intermediate good bought from abroad and, therefore, its price is taken as exogenous. Firms are heterogeneous and face a sunk cost upon entry, as well as fixed costs for supplying the domestic and export markets.

The form of the production function in the model assumes that firms are heterogeneous in the productivity of skilled labour, which matches some empirical features emphasised in the literature. Not only does the model predict that exporting firms are bigger and more productive, but also that they pay higher average wages as a result of employing relatively more skilled workers, which conforms to the results of Bernard and Jensen (1995; 1997) and Haltiwanger *et al.* (1999).

The model is mainly concerned with the effects on the wages in each sector of skilled and unskilled workers, following trade liberalisation and a decrease in the price of imported equipment. Following other contributions to the literature, the reduction in the price of equipment is referred to as 'skill-biased technical change', although it does not imply a shift of the production function ('technical progress'), but rather a movement along it ('a change in technique'). The fall in the price of equipment may be due to lower variable trade costs or technical progress in the developed country that produces and exports equipment, but technical progress in the North is not modelled in this paper. Skilled and unskilled workers are modelled alternatively as mobile and immobile across sectors, which are reasonable assumptions respectively for the long run and the short run.

This paper contributes to the literature on the effects of trade liberalisation on wages and the role of heterogeneous firms in trade. As in Bernard *et al.* (2007), its framework can accommodate several different effects on wages. One of these, as in the HOS model, is that falling trade costs cause a rise in the real reward of the abundant factor and a decline in the real reward of the scarce factor. A second influence on real wages relates to consumers' taste for variety. Trade liberalisation makes foreign varieties available to consumers, as in Helpman and Krugman (1985). This increase in product variety reduces consumer price indices and raises real income. Another influence on real wages is endogenous changes in industry-level productivity, as analysed by Bernard *et al.* (2007). Higher average firm productivity increases average firm size and reduces the mass of domestically produced varieties, leading to a reduction in the price of the average variety and, possibly, overall real wage increases for both the abundant and the scarce factor of production, although the abundant factor still gains in relative terms. In Bernard *et al.* (2007), this effect is stronger in the sector that uses the abundant factor of production more intensively and, therefore, leads to a magnification of comparative advantage.

Vannoorenberghe (2008) highlights another channel through which a decrease in variable trade costs can affect the skill premium, also present in this model. In a model with two identical countries and firm heterogeneity in the productivity of skilled labour, trade liberalisation leads the most productive and skill-intensive firms to expand their export sales while the least productive firms are driven out of the domestic market. The expansion of the most productive firms and the contraction of the least productive firms have a positive effect on the relative demand for skilled labour. The impact of new entry into the export market may be positive or negative depending on the productivity of newly exporting firms relative to that of the average firm. Vannoorenberghe (2008) shows that this last effect cannot compensate for the other two and, therefore, that a decrease in variable trade costs increases the skill premium.

Two recent papers study the links between trade and technology adoption and are, therefore, more closely related to the present paper. Riaño (2009) develops and estimates a structural model of trade and technology adoption with heterogeneous firms. Firms produce using skilled and unskilled labour and can choose between two technologies: a 'traditional' technology characterised by high marginal costs but low fixed costs, and a 'modern' technology that has low marginal costs but requires a high fixed cost of operation. By identifying plants that purchase imported machinery and equipment as users of modern technology, Riaño predicts a response of technology adoption and the skill premium to a unilateral trade liberalisation of a similar magnitude to the one that actually occurred in Mexico after 1985. In the baseline model, he finds that trade liberalisation leads to an increase in the relative demand for skills and an increase in the skill premium of around 2.4 percent. When he allows for the cheaper sunk cost of technology adoption due to falling import tariffs, the skill premium rises by 4.2 percent following trade liberalisation. Riaño's model is similar to that of Bustos (2009), except that Bustos' model is static, assumes that skilled and unskilled labour are perfect complements in production and does not allow for the possibility of cheaper technology due to falling import tariffs. However, while in these two papers there are only two technologies characterised by the trade-off between fixed and marginal cost, the model in the present paper uses a continuous measure of technology adoption that allows for the fact that larger and more productive firms expand more in absolute terms while all firms may upgrade skills and technology. This is an important characteristic of the new channel presented in this paper through which trade liberalisation can affect wages.

This paper also contributes to the literature on capital-skill complementarity, more specifically equipment-skill complementarity, and, related to this, it identifies a further effect of trade liberalisation on wages. Decreases in the price of imported equipment due to reductions in trade costs lead to higher demand for skilled workers, the complementary factor in production, and, thus, to increases in their earnings. This implies that, even where unskilled labour is the abundant factor of production in developing countries, there can be overall increases in the real wage of skilled workers and in wage inequality following trade liberalisation.

The rest of the paper is structured as follows. Section 2 sets out a standard HOS model with skilled and unskilled labour, adding imported equipment as a third factor of production. While this simple model has some interesting features, in particular that trade liberalisation can lead to cheaper equipment and higher real wages for skilled workers in developing countries, it is not able to show how skilled labour, the scarce factor in most developing countries, can gain relatively. Section 3 develops a model with heterogeneous firms, monopolistic competition and either immobile or mobile labour across sectors, and derives the main equations that characterise its general equilibrium. Section 4 solves the model with numerical simulations, since it is too complicated to be solved analytically. This section shows how real and relative wages in each sector are affected by both trade liberalisation in final goods and skill-biased technical change, caused by a decrease in the price of imported equipment, due to lower trade costs on equipment and/or a decrease in its world price. Section 5 concludes.

2 Heckscher-Ohlin-Samuelson extended

This section introduces imported equipment as a third factor of production into a standard HOS model with skilled and unskilled labour and two sectors (see, for instance, Wood, 1994). There are two countries, North and South, and North is relatively more endowed with skilled labour,

$$\frac{L_s^N}{L_u^N} > \frac{L_s^S}{L_u^S},$$

where subscripts s and u refer to skilled and unskilled labour and superscripts N and S to North and South. In what follows, superscripts are omitted where unnecessary since the focus of the model is on the South.

Consumers all have the same Cobb-Douglas utility function

$$U = Y_1^{\alpha} Y_2^{1-\alpha},$$

which implies that every consumer spends a share α of their income on good 1 and $1-\alpha$ on good 2. Perfectly competitive firms in sector i produce output Y according to the following production function,

$$Y_i = S_i^{\gamma_i} U_i^{1-\gamma_i},$$

where $\gamma_1 > \gamma_2$, which implies that sector 1 is skilled-labour intensive. While skilled (S) and unskilled (U) labour are modelled as substitutes, skilled labour and imported equipment (K) are modelled as perfect complements by assuming that

$$S_i = aK_i, \tag{1}$$

where a is the same in both sectors. If $a = 1$, then each skilled worker would need one 'machine', eg. a computer. The way equipment is introduced in this model is related to that of Krusell *et al.* (2000), with the difference that in their framework equipment-skill complementarity is modelled by making equipment and skilled labour less substitutable than skilled and unskilled labour in their CES production function. Firms maximise profits, given by

$$\pi_i = P_i Y_i - C_i = P_i \left(aK_i\right)^{\gamma_i} U_i^{1-\gamma_i} - w_s a K_i - w_u U_i - r_k K_i,$$

where P_i is the price of each good i, C_i denotes the total cost function and w_s, w_u and r_k are the factor prices for skilled labour, unskilled labour and equipment respectively. The price of equipment is $r_k \equiv r_k^S = r_k^N \cdot \tau$, where r_k^N is the price of equipment in the North and τ represents iceberg trade costs and is greater than 1. Equilibrium in factor markets requires the sum of the demands for each factor in the two sectors to equal the fixed supply of that factor in the economy,

$$\bar{L} = L_1 + L_2 \qquad \text{for } L = \{S, U\}.$$

This implies that workers can move freely across sectors and that wages are equalised across sectors.

Assuming perfect competition, profit maximisation yields the following two equations in two unknowns, w_s and w_u,

$$P_1 = \left(w_s + \frac{r_k}{a}\right)^{\gamma_1} w_u^{1-\gamma_1}\Gamma_1$$
$$P_2 = \left(w_s + \frac{r_k}{a}\right)^{\gamma_2} w_u^{1-\gamma_2}\Gamma_2$$

where $\Gamma_i = \gamma_i^{-\gamma_i}(1-\gamma_i)^{\gamma_i - 1}$ and is constant. This system of equations has a unique solution provided that there are no factor intensity reversals (see Feenstra, 2004), given by

$$w_s = P_1^{\frac{1-\gamma_2}{\gamma}} P_2^{-\frac{1-\gamma_1}{\gamma}} \Gamma_1^{-\frac{1-\gamma_2}{\gamma}} \Gamma_2^{\frac{1-\gamma_1}{\gamma}} - \frac{r_k}{a}$$
$$w_u = P_1^{-\frac{\gamma_2}{\gamma}} P_2^{\frac{\gamma_1}{\gamma}} \Gamma_1^{\frac{\gamma_2}{\gamma}} \Gamma_2^{-\frac{\gamma_1}{\gamma}}$$

where $\gamma = \gamma_1(1-\gamma_2) - \gamma_2(1-\gamma_1) = \gamma_1 - \gamma_2 > 0$. As measured by the ratio of the two factor prices, wage inequality is

$$\frac{w_s}{w_u} = P_1^{\frac{1}{\gamma}} P_2^{-\frac{1}{\gamma}} \left(\Gamma_1^{-\frac{1}{\gamma}} \Gamma_2^{\frac{1}{\gamma}} - \frac{r_k}{a} P_1^{-\frac{1-\gamma_2}{\gamma}} P_2^{\frac{1-\gamma_1}{\gamma}} \Gamma_1^{-\frac{\gamma_2}{\gamma}} \Gamma_2^{\frac{\gamma_1}{\gamma}}\right).$$

In order to analyse changes in real wages, i.e. w_s and w_u divided by $P = P_1^{\alpha_1} P_2^{\alpha_2}$, it is convenient to assume that $\alpha_1 = \alpha_2 = 0.5$ and that $\mathrm{d}\ln P_1 = -\mathrm{d}\ln P_2$, so that changes in nominal wages as determined above can be interpreted as changes in real wages. In the South, trade liberalisation causes P_1 to decrease and P_2 to increase because this country is relatively abundant in unskilled labour, which is used more intensively in sector 2, as well as a decrease in r_k. As in the Stolper-Samuelson theorem, the above equations show that w_s decreases and w_u increases, thus reducing wage inequality. However, the decrease in the price of equipment at Home partly offsets the decrease in w_s and, thus, wage inequality through a higher demand for equipment and hence for skilled labour.[1]

The decrease in the price of equipment can be interpreted as skill-biased technical change and is equivalent to factor-biased technical change in both sectors à la Jones (1965). Overall, wage inequality and skilled wages still decrease due to the magnification effect of the Stolper-Samuelson theorem, whose effect is therefore larger than that of the lower price of equipment. On the other hand, a reduction in the price of equipment in the North, caused by exogenous technical progress, tends to increase both skilled wages and wage inequality and has no substantial effect on real unskilled wages.[2]

Even though this simple framework is able to explain the increase in real unskilled wages that has occurred in some developing countries following trade liberalisation, it is not able to show other interesting patterns that are found in the data. In particular, it cannot explain the increase in the relative wages of skilled workers that has happened even in those developing countries where unskilled labour is relatively abundant. Moreover, it excludes the possibility of within-sector reallocation of resources, which has been shown to be an important part of the reallocation of resources following trade liberalisation (see Caselli, 2010; Bustos, 2009; and Meschi *et al.*, 2009). The next section provides a more complete framework.

[1]The effect is as if skilled workers had to buy their own computers and thus gained from them being cheaper.

[2]There might be some second-order effects through changes in the goods prices that are not considered here because they do not change the story qualitatively.

3 Equipment-skill complementarity with heterogeneous firms

This section extends the model to include equipment-skill complementarity within a 'new new' trade theory framework with heterogeneous firms and monopolistic competition. The model follows Bernard *et al.* (2007) and Vannoorenberghe (2008), but with substantial differences. Two cases regarding labour mobility across sectors are developed. The first case assumes that workers can move freely across sectors, as in standard HOS theory, which is relevant for analysis of the long run. The second case assumes that workers are immobile across sectors, even though they can still move across firms within industries, implying a move from an HOS model to a specific-factor model and to an analysis of the short run, focusing on within-sector reallocation of resources among firms.

There are several reasons why workers can move more easily across firms within industries than across industries. Labour legislation in most developing countries as well as many other things, including housing and family ties, can severely limit the possibility of labour mobility across sectors in the short and medium run (Goh and Javorcik, 2007). If sectors are geographically clustered, it also means that it is easier for workers to move across firms within an industry as all firms belonging to that industry are located close to each other. Industry-specific skills are an even more compelling reason for immobility of labour. Since it takes time and money to acquire the skills needed in a particular sector, it is more likely that a worker can find a new job within their industry than in a different sector.

The model retains the assumption that equipment and skilled labour are not only perfectly complementary, and that the relationship between the two is strictly linear, as assumed in the previous section (see equation (1)). The final section discusses the relaxation of this assumption.

3.1 Consumers

The model assumes that preferences are homothetic and that the representative consumer's utility depends on consumption of the output of the two industries, i, each of which contains a large number of differentiated varieties, ϕ, produced by heterogeneous firms. Country superscripts are omitted unless necessary. The upper tier of utility determining consumption of the two industries' output, C_i, is Cobb-Douglas as before,

$$U = C_1^{\alpha} C_2^{1-\alpha}.$$

The lower tier of utility determining consumption of varieties takes a constant elasticity of substitution (CES) form,

$$C_i = \left[\int_1^{\infty} c_i \left(\phi \right)^{\frac{\epsilon - 1}{\epsilon}} \mathrm{d}\phi \right]^{\frac{\epsilon}{\epsilon - 1}} \tag{2}$$

$$P_i = \left[\int_1^{\infty} p_i \left(\phi \right)^{1-\epsilon} \mathrm{d}\phi \right]^{\frac{1}{1-\epsilon}}, \tag{3}$$

where C_i is the consumption index defined over consumption of individual varieties, $c_i(\phi)$, with the dual price index, P_i, defined over prices of varieties, $p_i(\phi)$. $\epsilon > 1$ is the consumers' elasticity of substitution between different varieties and is assumed for simplicity to be the same in both sectors. Maximisation by consumers yields the standard condition stating that the relative demand of all varieties for which active firms have drawn productivities ϕ and ϕ' is inversely related to their relative prices:

$$\frac{c_i(\phi)}{c_i(\phi')} = \left(\frac{p_i(\phi)}{p_i(\phi')}\right)^{-\epsilon}. \tag{4}$$

3.2 Firms

In each sector $i = \{1, 2\}$ there is a continuum of firms, each producing a different variety ϕ, which also represents the firm-specific skilled-labour productivity parameter. Production uses three factors, skilled labour s, unskilled labour u and equipment k. Skilled and unskilled labour are both in fixed aggregate supply, i.e. there is no skill acquisition, and equipment is modelled as an intermediate good imported from abroad at a fixed price because the Home country is small relative to the Foreign country. Skilled and unskilled labour are combined in a CES production function:

$$y_i(\phi) = \left[\gamma_i^{\frac{1}{\sigma}} \phi^{\frac{1}{\sigma}} s_i(\phi)^{\frac{\sigma-1}{\sigma}} + (1-\gamma_i)^{\frac{1}{\sigma}} u_i(\phi)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}, \tag{5}$$

where ϕ appears in the first term because it affects the productivity only of skilled labour and $\sigma > 1$ is the elasticity of substitution between skilled and unskilled labour and, for simplicity, is assumed to be the same for all sectors.[3] By contrast, skilled labour and equipment are perfectly complementary in production,

$$s_i = a k_i. \tag{6}$$

Firms are heterogeneous in the productivity of their skilled labour and, thus,

[3] See Acemoglu (2002b) for a review of the empirical evidence estimating the parameter σ to be between 1 and 2. Behar (2009) estimates this parameter to be equal to 2.

also of their equipment, indexed by $\phi \in (1, \Phi)$, which is the realisation of a random variable, drawn from an exogenously given continuous distribution, $G(\phi)$. The assumption that $\phi \geq 1$ simplifies the analysis because it implies that skilled labour is at least as productive as unskilled labour. Intuitively, there exist different production technologies in a sector and firms choose how exactly they want to mix unskilled labour with skilled labour and equipment, depending on their skilled-labour productivity parameter value and on factor prices.

Firms can sell their product on their domestic market (subscript d), as well as on the export market (subscript x).[4] Production in each market involves fixed costs, which are equal across firms of the same country and sector. This generates increasing returns to scale, as in standard models of monopolistic competition. Firms pay fixed costs of domestic production, f_d, and of exporting, f_x, in terms of f, at a unit price r_f. Since this model is static, f should not be interpreted as capital, but rather as an initial payment to management consultants for the development of a business plan. These management consultants are a separate group of people whose other behaviour is not included in the present model. Fixed costs are such that $f_x > f_d$, which is a standard assumption given that the costs of doing business abroad are larger due to the extra costs of learning a legal system, language, etc. There are also variable international trade costs, $\tau_i \geq 1$, assumed to be of iceberg form (so that τ is the multiple of goods that must be produced in order for one unit of the good to arrive at its destination). These variable trade costs can be interpreted as tariffs and/or transportation costs and they can be levied on final goods (subscript o), or on imported equipment (subscript n). The Appendix

[4]The model assumes that there are only two countries, Home (superscript H) and Foreign (superscript F). Due to symmetry in the production processes, the focus of the following analysis can be put on exports from Home in order to analyse imports from Foreign.

shows how the model changes if trade costs are assumed to be "per-unit", i.e. non-proportional to prices and costs of production, following Wood (2007; 2008) and Irarrazabal *et al.* (2010).

The profits from selling on the domestic or on the export market are given by:

$$\pi_{im}(\phi) = p_{im}(\phi)c_{im}(\phi) - w_{si}s_{im}(\phi) - w_{ui}u_{im}(\phi) - r_{ki}k_{im}(\phi) - r_f f_m, \tag{7}$$

where $p_{im}(\phi)$ is the price at which a firm with characteristics ϕ in sector i sells its products in market $m = \{d, x\}$. w_{si} and w_{ui} are, respectively, the wages of skilled and unskilled labour in sector i, and $r_{ki} \equiv r_{ki}^H = r_{ki}^F \cdot \tau_{ni}^H$ is the price of equipment, equal to the price of this input in the foreign country times the iceberg variable trade cost. $c_{im}(\phi)$ denotes consumption in each market. Therefore, the goods market equilibrium implies:

$$y_{id}(\phi) = c_{id}(\phi) \tag{8}$$

$$y_{ix}(\phi) = \tau_{oi}^F c_{ix}(\phi), \tag{9}$$

where $y_{im}(\phi)$ denotes production aimed at each sector and market. Using either (8) or (9) together with (7) and (5), profit maximisation yields the following equations for prices:

$$p_{id}(\phi) = \frac{\epsilon}{\epsilon - 1}\left[\gamma_i\phi\left(w_{si} + \frac{r_{ki}}{a}\right)^{1-\sigma} + (1-\gamma_i)\, w_{ui}^{1-\sigma}\right]^{\frac{1}{1-\sigma}} = \frac{\epsilon}{\epsilon - 1} mc_i(\phi) \tag{10}$$

$$p_{ix}(\phi) = \tau_{oi}^F p_{id}(\phi). \tag{11}$$

Price is the marginal cost of production times a markup, which is a standard result in models with monopolistic competition. A decrease in the price of equipment, due to either an exogenous price reduction abroad or a decrease in tariffs at Home, leads to a lower unit cost of production and, thus, in the price of the good produced. This decrease is greater for a firm with a higher productivity level, ϕ, which is an important result in this model.

Firms which draw low ϕ may make negative profits and exit the market, either the export market only or both the domestic and export markets given the assumption that $f_x > f_d$. Thus, one needs to analyse the cutoff firm, i.e. the firm whose productivity draw allows it to break even. $\phi^{\star}_{id}$ is defined as the cutoff level of ϕ in the domestic market and $\phi^{\star}_{ix}$ as that in the export market in each sector i, such that

$$\pi_{id}(\phi^{\star}_{id}) \equiv 0$$
$$\pi_{ix}(\phi^{\star}_{ix}) \equiv 0$$

Using equations (5), (7), (8) and (10), input use and production level can be derived for the cutoff firm in the domestic market in each sector:

$$y_i(\phi^{\star}_{id}) = r_f f_d\,(\epsilon - 1)\, mc_i(\phi^{\star}_{id})^{-1} \tag{12}$$
$$u_i(\phi^{\star}_{id}) = r_f f_d\,(\epsilon - 1)\,(1 - \gamma_i)\, w_{ui}^{-\sigma} mc_i(\phi^{\star}_{id})^{\sigma-1} \tag{13}$$
$$s_i(\phi^{\star}_{id}) = r_f f_d\,(\epsilon - 1)\, \gamma_i \phi^{\star}_{id} \left(w_{si} + \frac{r_{ki}}{a} \right)^{-\sigma} mc_i(\phi^{\star}_{id})^{\sigma-1} \tag{14}$$
$$k_i(\phi^{\star}_{id}) = \frac{1}{a} r_f f_d\,(\epsilon - 1)\, \gamma_i \phi^{\star}_{id} \left(w_{si} + \frac{r_{ki}}{a} \right)^{-\sigma} mc_i(\phi^{\star}_{id})^{\sigma-1}, \tag{15}$$

where $mc_i(\phi^\star_{id}) = \left[\gamma_i \phi^\star_{id} \left(w_{si} + \frac{r_{ki}}{a}\right)^{1-\sigma} + (1-\gamma_i)\, w_{ui}^{1-\sigma}\right]^{\frac{1}{1-\sigma}}$ is the marginal cost for firm $\phi^\star_{id}$. Similar expressions can be derived for factor use and production for the cutoff firm in the export market by using (9) instead of (8) and (11) instead of (10) and, therefore, substituting f_x for f_d, $\phi^\star_{ix}$ for $\phi^\star_{id}$ and $mc_i(\phi^\star_{ix}) = \left[\gamma_i \phi^\star_{ix} \left(w_{si} + \frac{r_{ki}}{a}\right)^{1-\sigma} + (1-\gamma_i)\, w_{ui}^{1-\sigma}\right]^{\frac{1}{1-\sigma}}$ for $mc_i(\phi^\star_{id})$. Factor use and production of the cutoff firms increase with fixed costs because higher fixed costs require a firm to sell more in order to break even. A higher elasticity of substitution in the utility function puts downward pressure on the markup, which forces firms to sell more. A lower unit cost of production decreases the sales price more than it decreases costs due to the markup and forces the cutoff firm to produce more.

3.3 The goods market

Production and factor use of each firm can be expressed as a function of that of the cutoff firm in order to simplify the analysis and to describe the factor use and production schedules for the whole economy.

From the consumers' side of the economy, the relative consumption condition (4) for $\phi' = \phi^\star_{id}$ can be rewritten as

$$\frac{c_{id}(\phi)}{c_i(\phi^\star_{id})} = \left(\frac{p_{id}(\phi)}{p_i(\phi^\star_{id})}\right)^{-\epsilon}. \tag{16}$$

Using (8), (10) and (16), production for the domestic market in sector i of firm with productivity ϕ, $y_{id}(\phi)$, becomes

$$\frac{y_{id}(\phi)}{y_i(\phi^\star_{id})} = \left(\frac{mc_{id}(\phi)}{mc_i(\phi^\star_{id})}\right)^{-\epsilon}. \tag{17}$$

Using (12) for $y_i(\phi^\star_{id})$, one can rewrite the above expression for production for the domestic market, (17), as

$$y_{id}(\phi) = r_f f_d\,(\epsilon - 1)\,\frac{mc_{id}(\phi)^{-\epsilon}}{mc_i(\phi^\star_{id})^{1-\epsilon}}. \tag{18}$$

The higher the ϕ a firm draws, the lower is its marginal cost and the more it produces. The same procedure can be applied to the factor inputs:

$$u_{id}(\phi) = r_f f_d\,(\epsilon - 1)\,(1-\gamma_i)\,w_{ui}^{-\sigma}\frac{mc_{id}(\phi)^{\sigma-\epsilon}}{mc_i(\phi^\star_{id})^{1-\epsilon}} \tag{19}$$

$$s_{id}(\phi) = r_f f_d\,(\epsilon - 1)\,\gamma_i\phi\left(w_{si} + \frac{r_{ki}}{a}\right)^{-\sigma}\frac{mc_{id}(\phi)^{\sigma-\epsilon}}{mc_i(\phi^\star_{id})^{1-\epsilon}} \tag{20}$$

$$k_{id}(\phi) = \frac{1}{a} r_f f_d\,(\epsilon - 1)\,\gamma_i\phi\left(w_{si} + \frac{r_{ki}}{a}\right)^{-\sigma}\frac{mc_{id}(\phi)^{\sigma-\epsilon}}{mc_i(\phi^\star_{id})^{1-\epsilon}}. \tag{21}$$

Regarding production for the export market, (4) can be rewritten as

$$\frac{y_{id}(\phi)}{y_{ix}(\phi')} = \frac{c_{id}(\phi)}{\tau^F_{oi} c_{ix}(\phi')} = \left(\frac{p_{id}(\phi)}{p_{id}(\phi')}\right)^{-\epsilon} \tau_{oi}^{F\,\epsilon-1}\left(\frac{P^H_i}{P^F_i}\right)^{\epsilon-1}\left(\frac{E^H}{E^F}\right), \tag{22}$$

where E is total expenditure in the economy and is defined as

$$E = \sum_{i=1}^{2} P_i C_i. \tag{23}$$

Using equations (22), (10) and (11), the ratio of export sales to domestic sales for the same firm is therefore:

$$\frac{y_{ix}(\phi)}{y_{id}(\phi)} = \tau_{oi}^{F\,1-\epsilon}\left(\frac{P^F_i}{P^H_i}\right)^{\epsilon-1}\left(\frac{E^F}{E^H}\right) \qquad \forall\,\phi \geq \phi^\star_{ix} \tag{24}$$

This ratio is a positive function of the size of the Foreign market relative to the

Home market and a negative function of trade costs. Production for the export market can be expressed in terms of the export cutoff and condition (4) for $\phi' = \phi^\star_{ix}$ rewritten as

$$\frac{c_{ix}(\phi)}{c_i(\phi^\star_{ix})} = \left(\frac{mc_i(\phi)}{mc_i(\phi^\star_{ix})}\right)^{-\epsilon}. \tag{25}$$

Using this expression and the equivalent of (12) for the export market, the level of production for the export market becomes:

$$y_{ix}(\phi) = r_f f_x\,(\epsilon - 1)\,\frac{mc_i(\phi)^{-\epsilon}}{mc_i(\phi^\star_{ix})^{1-\epsilon}}. \tag{26}$$

Similarly to the expression for production for the domestic market, the higher the ϕ a firm draws, the more it produces for the export market because its marginal cost is lower. Expressions for the factor inputs can be derived in a similar fashion:

$$u_{ix}(\phi) = r_f f_x\,(\epsilon - 1)\,(1 - \gamma_i)\,w_{ui}^{-\sigma}\,\frac{mc_i(\phi)^{\sigma-\epsilon}}{mc_i(\phi^\star_{ix})^{1-\epsilon}} \tag{27}$$

$$s_{ix}(\phi) = r_f f_x\,(\epsilon - 1)\,\gamma_i\phi\left(w_{si} + \frac{r_{ki}}{a}\right)^{-\sigma}\frac{mc_i(\phi)^{\sigma-\epsilon}}{mc_i(\phi^\star_{ix})^{1-\epsilon}} \tag{28}$$

$$k_{ix}(\phi) = \frac{1}{a}r_f f_x\,(\epsilon - 1)\,\gamma_i\phi\left(w_{si} + \frac{r_{ki}}{a}\right)^{-\sigma}\frac{mc_i(\phi)^{\sigma-\epsilon}}{mc_i(\phi^\star_{ix})^{1-\epsilon}}. \tag{29}$$

In equations (26)-(29), variable trade costs affect not only the price of equipment at Home ($r_{ki} = r^F_{ki}\cdot\tau^H_{ni}$), but also the other factor prices because in general equilibrium these depend on variable trade costs.

From the above expressions for production and factor inputs for the domestic market, (18)-(21), and from (7) and (10), one can write profits from the domestic market as

$$\pi_{id}(\phi) = r_f f_d \left[\left(\frac{mc_i(\phi)}{mc_i(\phi^\star_{id})} \right)^{1-\epsilon} - 1 \right]. \tag{30}$$

A similar expression holds for profits in the export market, derived from the equivalent expressions for production and factor inputs,

$$\pi_{ix}(\phi) = r_f f_x \left[\left(\frac{mc_i(\phi)}{mc_i(\phi^\star_{ix})} \right)^{1-\epsilon} - 1 \right]. \tag{31}$$

Profits increase in ϕ and are equal to zero for the cutoff firm. This result holds for both the domestic and the export market. It ensures that only relatively productive, skill- and equipment-intensive firms export. Exporting firms employ proportionately more skilled labour and equipment than non-exporting firms and, therefore, pay higher wages on average to their workers and have a higher equipment-unskilled labour ratio.[5] This conforms with the empirical evidence presented by Bernard and Jensen (1995) and Leonardi (2007). Exporting firms also produce more, and have a higher ϕ, which is consistent with the evidence of Bernard and Jensen (1997) that they are more technology intensive.

Using (18), (26) and (24), one can derive an expression relating the two productivity cutoff levels:

$$\frac{f_d}{f_x} = \left(\frac{mc_i(\phi^\star_{id})}{mc_i(\phi^\star_{ix})} \right)^{1-\epsilon} \tau_{oi}^{F\,\epsilon-1} \left(\frac{P_i^H}{P_i^F} \right)^{\epsilon-1} \left(\frac{E^H}{E^F} \right). \tag{32}$$

[5]Given the simple relationship that I assume between equipment and skilled labour, I concentrate on the equipment-unskilled labour ratio. The same result applies for the equipment-labour ratio, but with a smaller magnitude.

The interval $(\phi^{\star}_{id}, \phi^{\star}_{ix})$ in which firms produce only for their domestic market increases with the difference between the fixed costs in the two markets and with higher variable trade costs. Both effects are due to the fact that higher barriers to international trade result in a lower proportion of exporters and a higher cutoff level for the export market. This leads to higher overall profits, which implies that more firms can break even in the domestic market, thus lowering the cutoff level in the domestic market and increasing the distance between the two cutoffs. Equivalently, a larger Home market relative to the Foreign market implies that only more productive firms are able to break even in the export market and, therefore, the interval increases.

3.4 Equilibrium conditions

As in Melitz (2003) and the following literature, the number of firms in the market is endogenous. An unbounded pool of ex-ante identical firms in each sector, $M_i = M$, decides to enter the market by paying a fixed sunk cost, f_e, equal across firms and sectors, paid in terms of f, at a unit price r_f. Upon entering the market, firms draw their productivity level, $\phi \in (1, \Phi)$. After drawing their firm-specific productivity parameter, firms decide whether to stay in the market and produce or exit the market, depending on their profits as described above. Therefore, there is net entry up to the point where the expected profits of entering are equal to the sunk entry cost. Equivalently, in equilibrium total industry profits, in both domestic and export markets, must equal total entry costs, including those of firms which have then exited, in each sector:

$$r_f f_e M = \int_{\phi^{\star}_{id}}^{\Phi} \pi_{id}(\phi)\mathrm{d}\phi + \int_{\phi^{\star}_{ix}}^{\Phi} \pi_{ix}(\phi)\mathrm{d}\phi. \tag{33}$$

Two alternative assumptions about labour mobility are explored. (1) When workers cannot move across sectors, labour market equilibrium is described by the following equations:

$$u_i = \int_{\phi_{id}^\star}^{\Phi} u_{id}(\phi)\mathrm{d}\phi + \int_{\phi_{ix}^\star}^{\Phi} u_{ix}(\phi)\mathrm{d}\phi \tag{34}$$

$$s_i = \int_{\phi_{id}^\star}^{\Phi} s_{id}(\phi)\mathrm{d}\phi + \int_{\phi_{ix}^\star}^{\Phi} s_{ix}(\phi)\mathrm{d}\phi. \tag{35}$$

Skilled and unskilled labour markets in each sector clear when the supply of each factor, fixed in each sector and denoted by u_i and s_i, is equal to total demand for that factor, arising from production for the domestic and the export markets and given by (19), (27), (20) and (28).

(2) When the two types of workers can move freely across sectors, the labour market clearing conditions become:

$$u = \sum_{i=1}^{2} \left[\int_{\phi_{id}^\star}^{\Phi} u_{id}(\phi)\mathrm{d}\phi + \int_{\phi_{ix}^\star}^{\Phi} u_{ix}(\phi)\mathrm{d}\phi \right] \tag{36}$$

$$s = \sum_{i=1}^{2} \left[\int_{\phi_{id}^\star}^{\Phi} s_{id}(\phi)\mathrm{d}\phi + \int_{\phi_{ix}^\star}^{\Phi} s_{ix}(\phi)\mathrm{d}\phi \right]. \tag{37}$$

Wages are equalised across sectors, which implies that the sector subscripts for factor prices can be dropped.

Similarly, the market for f, the initial payment to management consultants for the fixed production and entry costs, clears when demand is equal to the fixed supply:

$$f = \sum_{i=1}^{2} [(1 - G(\phi_{id}^\star))Mf_d + (1 - G(\phi_{ix}^\star))Mf_x] + 2Mf_e. \tag{38}$$

Thus, general equilibrium in this economy is defined by the goods market equilibrium in each sector (33) $\times$ 2, unskilled labour market clearing in each sector (34) $\times$ 2 or (36), skilled labour market clearing in each sector (35) $\times$ 2 or (37), market clearing for management consultants payments f (38), conditions relating the two productivity cutoffs in each sector at Home (32) $\times$ 2, definitions of sector price indices (3) that include prices of imported varieties and τ_{oi}^{H} $\times$ 2, definition of total expenditure at Home (23), a condition equating total expenditure to total income, and a trade balance condition that includes equipment imports. Total income includes payments to the management consultants f, who are assumed to be a separate group of agents in the economy. All the other variables of interest are functions of the above endogenous variable or, given the assumption of a small economy, are taken as exogenous since the effects would be too small to be measured, eg. P_i^F and E^F.

4 Numerical simulations

An analytical solution to this model was attempted by solving for relative skilled wages and relative cutoffs in the two sectors. However, the inclusion of equipment as a third factor of production and the fact that equipment enters additively with skilled wages made it impossible to find such solution.

The paper, therefore, relies on numerical simulations to analyse how trade liberalisation and cheaper equipment affect real and relative wages in this model. Numerical solutions have the advantage of providing a sense of the magnitude of the shocks analysed, but the results generated with them cannot be deemed general. In particular, the results that are described in this section are restricted to a small range of scenarios because finding a numerical solution becomes more difficult the further away the parameters are from the baseline case. Thus it cannot be ruled out that results change substantially with a different range of parameters, even though this does not seem likely.

Following the literature (see Melitz, 2003 and Bernard *et al.*, 2007), a generalised Pareto distribution for ex-ante firm productivity is assumed with probability density function

$$g(\phi) = \frac{1}{\varsigma}\left(1 + \frac{\xi\,(\phi - \mu)}{\varsigma}\right)^{-\frac{1}{\xi}-1},$$

where ξ is the shape parameter, ς is the scale parameter and μ is the location parameter. I assume that $\mu = 1$ and that $\varsigma = \xi = 0.168$, so that this is equivalent to a Pareto distribution. As shown in the above literature, this distribution provides a reasonable approximation to observed variation in firm productivity.

Following Bernard *et al.* (2007) and subsequent studies, the consumers' elasticity of substitution across varieties, ϵ, is set at 3.8 in both sectors. The elasticity of substitution between factors in the production function, σ, is set at 1.5 in both sectors, in the range suggested by Acemoglu (2002b). These values are also consistent with the assumption of Vannoorenberghe (2008) that $\epsilon > \sigma$. Fixed entry costs, f_e, are set equal to 1, fixed production costs for the domestic market, f_d, equal to 1, and fixed production costs for the export market, f_x, equal to 3 in both sectors. For simplicity, the factor of proportion between skilled labour and equipment, a, is set at 1. This is a strong assumption because it implies a linear relationship between skilled labour and equipment, but it simplifies the model significantly. The number of skilled and unskilled workers in the economy in the case when labour is immobile is set so that $\frac{s_1}{u_1} > \frac{s_2}{u_2}$, which is consistent with the assumption that sector 1 is the skill-intensive sector ($\gamma_1 = 0.6 > \gamma_2 = 0.4$). It is also assumed that, prior to the shocks that will be analysed, the economy is in long-term equilibrium so that factor prices are equalised across sectors. Prices in the Foreign country are set so that $\frac{P_1^H}{P_2^H} > \frac{P_1^F}{P_2^F}$, which is consistent with the assumption that Home is unskilled labour abundant, i.e. $\frac{s^H}{u^H} < \frac{s^F}{u^F}$, where $s = \sum_{i=1}^{2} s_i$ and $u = \sum_{i=1}^{2} u_i$. The price index P is a geometric mean of the two sector-level price indices with weights determined by α, the proportion of income spent on varieties of good 1, assumed to be equal to 0.5. Finally, the size of the Home economy is set at approximately one hundredth of that of the Foreign economy, consistent with the assumption that Home is a small, partially open, economy.

Given these assumptions, the paper next turns to the analysis of the response of real and relative wages to reductions in variable trade costs, τ, and in the price of equipment in the Foreign country, r_{ki}^F.

4.1 Trade liberalisation and cheaper equipment

The following tables analyse changes in real unskilled and skilled wages and relative skilled wages following trade liberalisation showing the results of several experiments in order to disentangle the various effects at work. The baseline case is when iceberg trade costs are equal to 1.5 in both sectors (subscripts 1 and 2) in both countries (superscripts H and F) and for equipment (subscript n) and final goods (subscript o). In table 1, trade liberalisation is modelled as a decrease of iceberg trade costs from 1.5 to 1.4, while table 2 shows the effects of assuming per-unit trade costs, which decrease from 0.5 to 0.4. It is further assumed that the foreign price of equipment, r_{ki}^F, stays the same and is equal to 1 in both sectors.

Table 1: Effects of general trade liberalisation with mobile and immobile labour.

	Baseline	**Mobile L**	**Immobile L**
τ_{ni}^{H}	1.5	1.4	1.4
τ_{oi}^{H}	1.5	1.4	1.4
τ_{oi}^{F}	1.5	1.4	1.4
w_{s1}	1.000	0.992	1.017
w_{s2}	1.000	0.992	0.976
w_{s1}/P	28.841	29.940	30.667
w_{s2}/P	28.841	29.940	29.471
w_{u1}	0.599	0.543	0.546
w_{u2}	0.599	0.543	0.541
w_{u1}/P	17.274	16.444	16.536
w_{u2}/P	17.274	16.444	16.379
$w_{i1}\ (w_{s1}/w_{u1})$	1.670	1.815	1.849
$w_{i2}\ (w_{s2}/w_{u2})$	1.670	1.815	1.794
$var(k/u)_1 * 100$	0.622	0.656	0.647
$var(k/u)_2 * 1000$	0.480	0.484	0.490
$(s(\phi \geq 3)/s)_1$	0.771	0.765	0.764
$(s(\phi \geq 3)/s)_2$	0.242	0.224	0.223
P	0.035	0.033	0.033

Table 1 shows how several key variables, including wages, change following trade liberalisation under the two alternative assumptions of labour mobility and immobility. The wage outcome in the two sectors when labour is mobile is simply a weighted average of the result in each sector when labour is immobile as workers move across sectors until wages are equalised. Therefore, the discussion and tables 3 onwards will focus on the case of immobile labour. Nominal skilled wages decrease slightly in sector 2, but increase on average by 4% in real terms due to substantial decreases in the price indices. Nominal unskilled wages decrease, which is in sharp contrast to the Stolper-Samuelson prediction for a developing country relatively abundant in unskilled labour. However, due to the decrease in the price indices, real unskilled wages decrease only by a small amount.

Price indices decrease for several reasons. The decrease in τ_{oi}^{D} makes prices of Foreign varieties lower, leading to lower price indices. The increase in Foreign varieties means that there are more varieties overall, which lowers price indices with a CES utility function, although this effect is offset by the decrease in Home varieties. Finally, the increase in average productivity, caused by less productive firms exiting the domestic market and consequently the rise in the domestic market cutoff, also leads to lower price indices since average prices go down. The decrease in the price indices due to the increase in Foreign varieties may be larger in this model than estimated for the US by Broda and Weinstein (2006) because the present result refers to a small country that trades with a large country with many more varieties.

It seems striking that real unskilled wages decrease in this model following trade liberalisation given that HOS theory predicts that they should increase in a developing country that is relatively abundant in unskilled labour.[6] This result is altered when trade costs are modelled per-unit rather than iceberg, as in table 2. In this case, not only is the increase in nominal and real skilled wages larger, but real unskilled wages rise too. The reason for this result is that larger firms are disproportionally penalised by per-unit trade costs, which add proportionally more to the costs and hence prices of higher productivity firms than of lower productivity firms. Unskilled labour intensive and lower-productivity firms produce and export more when variable trade costs are per-unit. This inefficiency is reduced when per-unit variable trade costs decrease, which leads wages of both types of workers

[6]Evidence shows that in some developing countries real unskilled wages have indeed decreased, as in Mexico during the period 1985-1990 (Caselli, 2010). However, a decrease in real unskilled wages would be predicted by HOS theory if the developing country in question were skill-abundant, as has been argued for Mexico (Wood, 1997).

Table 2: Effects of general trade liberalisation with mobile and immobile labour and per-unit trade costs.

	Baseline	**Mobile L**	**Immobile L**
t_{ni}^{H}	0.5	0.4	0.4
t_{oi}^{H}	0.5	0.4	0.4
t_{oi}^{F}	0.5	0.4	0.4
w_{s1}	1.000	1.053	1.063
w_{s2}	1.000	1.053	1.040
w_{s1}/P	26.019	28.746	29.011
w_{s2}/P	26.019	28.746	28.420
w_{u1}	0.699	0.686	0.688
w_{u2}	0.699	0.686	0.682
w_{u1}/P	18.187	18.794	18.832
w_{u2}/P	18.187	18.794	18.665
$w_{i1}\ (w_{s1}/w_{u1})$	1.431	1.532	1.543
$w_{i2}\ (w_{s2}/w_{u2})$	1.431	1.532	1.524
$var(k/u)_1 * 100$	0.620	0.631	0.627
$var(k/u)_2 * 1000$	0.728	0.836	0.831
$(s(\phi \geq 3)/s)_1$	0.668	0.662	0.662
$(s(\phi \geq 3)/s)_2$	0.116	0.107	0.107
P	0.038	0.036	0.036

to increase. This confirms the findings in Irarrazabal *et al.* (2010) that a reduction in per-unit trade costs is an additional source of gains from trade, since distortions are eliminated not only in international markets but also in the domestic market.

The increase in skilled wages combined with the tendency for a decrease or smaller increase in unskilled wages clearly leads to an increase in the skill premium and wage inequality, which is consistent with the evidence found in most developing countries, independent of whether they are skill abundant or skill scarce, in the last three decades (Anderson, 2005; Goldberg and Pavcnik, 2007).

The magnification of comparative advantage observed in Bernard *et al.* (2007) is not present in this model. In their model, this magnification effect is a consequence of low-productivity firms exiting the market in the comparative advantage sector. However, in the present model, the introduction of equipment as a third factor of production and the fact that firm heterogeneity is modelled in terms of productivity of skilled labour imply that there is more scope for productivity increases in the skill- and equipment-intensive sector as a consequence of low-productivity firms exiting the domestic market. This can be observed by the fact that the changes discussed above are larger in the skill- and equipment-intensive sector 1, which is the comparatively disadvantaged sector.[7]

In order to understand the reasons behind the increase in relative skilled wages, the next two tables show, respectively, the effects of lower variable trade costs only on imported equipment at Home and only on final goods in both countries. Table 3 simulates the effects of trade liberalisation with respect only to imported equipment at Home. In this table, substantial increases in nominal and real skilled wages and in the skill premium can be observed. Both real skilled wages and the skill premium increase on average by approximately 7.5%.

The reason for the increase in skilled wages, which pushes the skill premium up, is that as variable trade costs on equipment fall, the price of equipment decreases and demand for it increases. Firms with higher productivity are favoured because they use equipment more intensively and increase their demand for equipment by more. Since the model assumes equipment-skill complementarity, their demand for skilled workers, relative to unskilled workers, will also increase by more. As these large firms increase the demand for skilled labour, skilled wages increase.

[7] Table 5 in the Appendix shows the case in which trade liberalisation is carried out separately in the two sectors assuming immobile labour across sectors. The last column in this table shows that when trade liberalisation is carried out only in one of the two sectors, both skilled and unskilled wages tend to increase more in the skill- and equipment-intensive sector, confirming that the magnification of comparative advantage is not present in this model.

Table 3: Effects of lower variable trade costs on imported equipment at Home with immobile labour.

	Baseline	**Sector 1**	**Sector 2**	**Sector 1 & 2**
τ^H_{n1}	1.5	1.4	1.5	1.4
τ^H_{n2}	1.5	1.5	1.4	1.4
τ^H_{o1}	1.5	1.5	1.5	1.5
τ^H_{o2}	1.5	1.5	1.5	1.5
τ^F_{o1}	1.5	1.5	1.5	1.5
τ^F_{o2}	1.5	1.5	1.5	1.5
w_{s1}	1.000	1.090	0.990	1.083
w_{s2}	1.000	0.976	1.075	1.051
w_{s1}/P	28.841	31.528	26.659	31.431
w_{s2}/P	28.841	28.252	31.119	30.501
w_{u1}	0.599	0.596	0.596	0.594
w_{u2}	0.599	0.592	0.591	0.584
w_{u1}/P	17.274	17.245	17.251	17.238
w_{u2}/P	17.274	17.125	17.120	16.954
w_{i1} (w_{s1}/w_{u1})	1.670	1.828	1.661	1.823
w_{i2} (w_{s2}/w_{u2})	1.670	1.650	1.817	1.797
$var(k/u)_1 * 100$	0.622	0.623	0.622	0.623
$var(k/u)_2 * 1000$	0.480	0.480	0.481	0.481
$(s(\phi \geq 3)/s)_1$	0.771	0.772	0.771	0.772
$(s(\phi \geq 3)/s)_2$	0.242	0.242	0.243	0.243
P	0.035	0.035	0.035	0.034

Moreover, cheaper equipment lowers the unit cost of production, which decreases the sales price more than costs due to the markup. This forces the domestic cutoff firm to produce more, which pushes the low-productivity firms out of the domestic market.

Table 6 in the Appendix analyses changes in unskilled and skilled wages and relative skilled wages following an exogenous decrease in the world price of equipment r^F_{ki}. The simulations assume that the world price of equipment decreases from the initial value of 1 to 0.9, corresponding to a 10% drop. International variable trade costs remain equal to the baseline case of 1.5 and it is assumed that labour is immobile. Both nominal and real skilled wages increase following the decrease in the price of equipment, and the skill premium increases on average by approximately 11.5%. Slight decreases are observed in the real wages of unskilled workers. These results are similar to the case analysed in table 3, where variable trade costs on imported equipment decreased. The reason is that in both cases they lead to a decrease in the price of equipment at Home, with the only difference being that in the simulations in table 6 firms in the Foreign country can also access equipment at a lower price.

The new mechanism by which cheaper imported equipment increases skilled wages and the skill premium can be analysed in a different way by examining the variance across firms within each sector of the ratio of equipment to unskilled labour. This variable and its relatives, such as the within-sector variance in the equipment-labour ratio, are important determinants of relative skilled wages, as shown by Leonardi (2007), and can be interpreted as measures of skill-biased technical change. This paper uses the equipment to unskilled labour ratio because the model allows for more variation in this ratio. The variation in the equipment-labour ratio, on the other hand, is smaller because the model assumes perfect complementarity between skilled labour and equipment in order to remain more tractable. This assumption, however, implies that there is a perfectly linear relationship between equipment and skilled labour.

When the price of equipment decreases, high-productivity firms increase their demand for it. As mentioned above, this pushes low-productivity firms out of the domestic market because the domestic cutoff increases. This shows up in the data as an increase in the variance of the equipment-unskilled labour ratio ($var(k/u)$), even though in the sector as a whole the equipment-unskilled labour ratio stays the same. This mechanism can be interpreted as skill-biased technical change.

In tables 3 and 6, the change in the within-sector variance of the equipment-unskilled labour ratio is rather small compared to the change in the same variable in tables 1 and 4 (which simulates the effects of trade liberalisation in final goods only). This is a consequence of the simplistic assumption of perfect complementarity between skilled labour and equipment, which does not allow for as much intra-sectoral reallocation as it could be observed in reality and, thus, understates the effects analysed in this model.

The role of larger firms in increasing the demand for equipment can also be seen by examining the share of skilled workers employed by the largest firms, i.e. those with a productivity parameter $\phi \geq 3$, in each sector, defined as $(s(\phi > 3)/s)$ in the tables. While this variable tends to decrease in the case of a general trade liberalisation (table 1), it increases slightly when variable trade costs decrease only on equipment, which means that the larger firms get even larger and use a more skill-intensive mix of factors in production.

When variable trade costs decrease on final goods only (table 4), nominal and real skilled wages do not increase and instead a small decline is observed. Nominal and real unskilled wages decline too, but by a smaller amount, and thus the skill premium declines slightly. Moreover, the within-sector variance of the equipment-unskilled labour ratio increases by more than when a decrease in the price of equipment, either due to lower variable trade costs or cheaper world price, is simulated (tables 3 and 6). However, in table 4, the increase in the variance of the equipment-unskilled labour ratio is not caused by large firms increasing their demand for equipment but rather by the fact that firms in the middle of the distribution move from being domestic producers only to being exporters too. This

Table 4: Effects of lower variable trade costs on final goods in both countries with immobile labour.

	Baseline	**Sector 1**	**Sector 2**	**Sector 1 & 2**
τ_{n1}^{H}	1.5	1.5	1.5	1.5
τ_{n2}^{H}	1.5	1.5	1.5	1.5
τ_{o1}^{H}	1.5	1.4	1.5	1.4
τ_{o2}^{H}	1.5	1.5	1.4	1.4
τ_{o1}^{F}	1.5	1.4	1.5	1.4
τ_{o2}^{F}	1.5	1.5	1.4	1.4
w_{s1}	1.000	0.710	1.030	0.935
w_{s2}	1.000	1.124	0.967	0.926
w_{s1}/P	28.841	21.150	29.643	28.085
w_{s2}/P	28.841	33.172	27.837	27.808
w_{u1}	0.599	0.499	0.605	0.552
w_{u2}	0.599	0.638	0.585	0.556
w_{u1}/P	17.274	14.819	17.424	16.581
w_{u2}/P	17.274	18.833	16.837	16.701
$w_{i1}\ (w_{s1}/w_{u1})$	1.670	1.454	1.701	1.693
$w_{i2}\ (w_{s2}/w_{u2})$	1.670	1.767	1.654	1.665
$var(k/u)_1 * 100$	0.622	0.642	0.625	0.642
$var(k/u)_2 * 1000$	0.480	0.478	0.493	0.489
$(s(\phi \geq 3)/s)_1$	0.771	0.769	0.771	0.769
$(s(\phi \geq 3)/s)_2$	0.242	0.241	0.242	0.241
P	0.035	0.034	0.035	0.033

can be shown in the simulation by examining the share of skilled workers employed by the largest firms. Unlike in the case in which a decrease in the price of equipment is simulated, the largest firms employ relatively fewer skilled workers, although only slightly, because new exporters expand by more as they increase significantly their demand for all factors of production due to the new possibilities in the export market. Therefore, only decreases in the price of equipment, due to lower world prices or decreases in variable trade costs on equipment, cause exogenous or trade-induced skill-biased technical change, while trade liberalisation in final goods does not.

The reason why the variance of the equipment-unskilled labour ratio increases, even though the share of skilled labour used by the largest firms decreases, is that when variable trade costs decrease, more firms find it profitable to export, which leads to a smaller export cutoff. This leads to a decrease in average profits that pushes low-productivity firms out of the domestic market, thus raising the domestic cutoff. Therefore, not only there is a substantial reduction in the interval $(\phi^{\star}_{id}, \phi^{\star}_{ix})$ in which firms produce only for their domestic market, but also the variance of the equipment-unskilled labour ratio increases substantially, since the new exporters use equipment more intensively than those firms that exit the domestic market.

4.2 Alternative possible specifications

The paper so far has discussed the case of a small developing country that is unskilled labour abundant. The simulations in the previous section showed that, even in this case, trade liberalisation can lead to an increase in the skill premium in a model with equipment as a third factor of production and equipment-skill complementarity. This occurs even though trade liberalisation for final goods tends to reduce the skill premium, as would be expected in the case of an unskilled labour abundant country in standard trade theory.

Simulations for the case of a skill-abundant developing country have not been carried out, but it is fairly clear what they would show. The effect of a decrease in the price of equipment, due to either lower variable trade costs or a reduced world price, would still be to increase real skilled wages and therefore the skill premium, because this effect does not depend on which sector the country has a comparative advantage in. Moreover, a decrease in variable trade costs on final goods would most likely lead to an increase in the skill premium, for standard

Stolper-Samuelson reasons (in the simulations for a skill-scarce country a small decrease is observed). Therefore, the sum of all the effects would be an even stronger increase in the skill premium.

The empirical evidence in Anderson (2005) and Goldberg and Pavcnik (2007) shows that both skill abundant developing countries, such as most Latin American countries, and skill scarce developing countries, such as most East and South-East Asian countries, have experienced an increase in the skill premium in recent decades (though the phenomenon is better documented for Latin American countries). The present model is able to explain this set of facts and it is believed to be the first model to do so in a framework with two sectors, two diverse countries and, therefore, the possibility of Stolper-Samuelson effects.

Another specification change that merits investigation would be to replace the assumption of perfect complementarity between equipment and skilled labour. This assumption was adopted because it greatly simplifies the algebra. But in a more sophisticated model, the equipment-skilled labour ratio would be endogenous. In such a model, when equipment becomes cheaper, there could be effects pulling in two directions. Cheaper equipment would allow each skilled worker to use more of it and hence become more productive and earn more. Cheaper equipment could also cause it to be substituted for skilled workers, reducing the demand for them and hence causing them to earn less. But if the plausible assumption of complementarity is retained, the first of these effects would dominate, so the effects on the relative wage of skilled labour in the present model would be amplified. The accompanying increase in the intra-sectoral variance of the equipment-labour ratio would probably also be amplified, too.

5 Conclusion

This paper investigates the effects of trade liberalisation and skill-biased technical change caused by cheaper imported equipment on real and relative wages. Building on Bernard *et al.* (2007) and Vannoorenberghe (2008), the paper moves from a standard trade model with homogeneous firms and two countries, North and South, to a monopolistic competition framework with heterogeneous firms. This more elaborate model shows that, even in the presence of Stolper-Samuelson effects pushing in the opposite direction, a decrease in the price of equipment, due to a decrease in variable trade costs and/or a lower world price, can lead to an increase in the relative wages of skilled workers. It also shows that, depending on the assumption about variable trade costs, the increase in relative skilled wages can be accompanied by an increase in real unskilled wages in a developing country.

Therefore, this model is able to explain the increase in relative skilled wages that has been documented for many developing countries, regardless of whether they are abundant in unskilled or skilled labour. This model also allows for the possibility that real unskilled wages could be increased by trade liberalisation and cheaper equipment, as apparently has happened in many developing countries.

The model's explanation of these various empirical facts in a single framework comes at a cost. Since it is not possible to find an analytical solution, the paper has had to rely on numerical simulations. The numerical solutions provide a sense of the magnitude of the shocks analysed, but the results generated with them cannot be deemed general. However, the range of parameter values the results apply to is likely to be much larger than that actually analysed. To overcome this limitation, future research should explore an alternative modelling strategy for equipment, including its treatment as a capital good rather than an intermediate good. This research strategy would also make it possible to extend the model from its current static form into a more dynamic form.

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Appendix

A Model with per-unit trade costs

This Appendix shows how the main equations change when variable trade costs are assumed to be "per-unit", i.e. non-proportional to prices and costs of production, instead of the standard iceberg form. All equations relative to the domestic market stay the same and, thus, are not reported again unless necessary. Instead, the following text focuses on how the equations for the export market change.

Similarly to the case with iceberg trade costs, the profits from selling on the export market are given by:

$$\pi_{ix}(\phi) = p_{ix}(\phi)c_{ix}(\phi) - w_{si}s_{ix}(\phi) - w_{ui}u_{ix}(\phi) - r_{ki}k_{ix}(\phi) - f_x, \tag{39}$$

with the only difference given by the fact that the price of equipment $r_{ki} = r_{ki}^F + t_{ni}^H$, where t represents per-unit variable trade costs. The goods market equilibrium implies:

$$y_{ix}(\phi) = c_{ix}(\phi), \tag{40}$$

because no output is lost during the exporting process, but instead prices have to include the trade cost. Profit maximisation yields the following equations for prices:

$$p_{id}(\phi) = \frac{\epsilon}{\epsilon - 1}\left[\gamma_i \phi \left(w_{si} + \frac{r_{ki}}{a}\right)^{1-\sigma} + (1-\gamma_i)\, w_{ui}^{1-\sigma}\right]^{\frac{1}{1-\sigma}} = \frac{\epsilon}{\epsilon - 1} mc_i(\phi) \tag{41}$$

$$p_{ix}(\phi) = p_{id}(\phi) + \frac{1}{\epsilon - 1} t_{oi}^{F}. \tag{42}$$

As found previously, the price in the domestic market is the marginal cost of production times a markup, which is a standard result in models under monopolistic competition. The price in the export market now includes trade costs, but in additive rather than multiplicative form. The term $\frac{1}{\epsilon-1}$ in front of trade costs implies that prices do not increase to match the full amount of trade costs and, therefore, firms bear some of these costs in terms of lower per-unit profits.

It is possible to define the cutoff firm, i.e. the firm that draws a certain productivity ϕ, produces and just breaks even. The same term $\phi_{ix}^{\star}$ is used to define the level for which profits are zero in the export market in each sector i, such that

$$\pi_{ix}(\phi_{ix}^{\star}) \equiv 0$$

Using equations (5), (39) and (42), input use and production level can be derived for the cutoff firm in the export market in each sector:

$$y_i(\phi_{ix}^\star) = r_f f_x\,(\epsilon - 1)\,mc_i(\phi_{ix}^\star)^{-1}\left[1 + t_{oi}^F mc_i(\phi_{ix}^\star)^{-1}\right]^{-1} \tag{43}$$

$$u_i(\phi_{ix}^\star) = r_f f_x\,(\epsilon - 1)\,(1-\gamma_i)\,w_{ui}^{-\sigma} mc_i(\phi_{ix}^\star)^{\sigma-1}\left[1 + t_{oi}^F mc_i(\phi_{ix}^\star)^{-1}\right]^{-1} \tag{44}$$

$$s_i(\phi_{ix}^\star) = r_f f_x\,(\epsilon - 1)\,\gamma_i \phi_{ix}^\star \left(w_{si} + \frac{r_{ki}}{a}\right)^{-\sigma} mc_i(\phi_{ix}^\star)^{\sigma-1}\left[1 + t_{oi}^F mc_i(\phi_{ix}^\star)^{-1}\right]^{-1} \tag{45}$$

$$k_i(\phi_{ix}^\star) = \frac{1}{a} r_f f_x\,(\epsilon - 1)\,\gamma_i \phi_{ix}^\star \left(w_{si} + \frac{r_{ki}}{a}\right)^{-\sigma} mc_i(\phi_{ix}^\star)^{\sigma-1}\left[1 + t_{oi}^F mc_i(\phi_{ix}^\star)^{-1}\right]^{-1}. \tag{46}$$

The only difference in this set of equations when using per-unit trade costs is that trade costs levied on final goods now affect directly output and factor use of the cutoff firm as they are included in the last term of all the above equations. In particular, lower international trade costs decrease the price obtained by firms and force the cutoff firm in the export market to produce more to break even.

Having defined the cutoff firm, production and factor use of each firm can be expressed as a function of that of the cutoff firm in order to simplify the analysis and to describe the factor use and production schedule for the whole economy.

To find an expression for production for the export market, (4) for firm ϕ has to be rewritten as

$$\frac{y_{id}(\phi)}{y_{ix}(\phi)} = \frac{c_{id}(\phi)}{c_{ix}(\phi)} = \left(\frac{p_{id}(\phi)}{p_{ix}(\phi) + t_{oi}^F}\right)^{-\epsilon} \left(\frac{P_i^H}{P_i^F}\right)^{\epsilon-1} \left(\frac{E^H}{E^F}\right), \tag{47}$$

where P is the price index and E is total expenditure in the economy as previously defined. Using equations (22), (41) and (42), the ratio of export sales to domestic sales for the same firm is therefore:

$$\frac{y_{ix}(\phi)}{y_{id}(\phi)} = \left(1 + t_{oi}^{F} mc_i(\phi_{ix}^{\star})^{-1}\right)^{-\epsilon} \left(\frac{P_i^F}{P_i^H}\right)^{\epsilon-1} \left(\frac{E^F}{E^H}\right), \tag{48}$$

This ratio is a positive function of the size of the export market relative to the domestic market and a negative function of trade costs. Similarly, one can express production for the export market in terms of the export cutoff and rewrite condition (4) for $\phi' = \phi_{ix}^{\star}$ as

$$\frac{c_{ix}(\phi)}{c_i(\phi_{ix}^{\star})} = \left(\frac{p_{ix}(\phi) + t_{oi}^F}{p_i(\phi_{ix}^{\star}) + t_{oi}^F}\right)^{-\epsilon}. \tag{49}$$

Using this expression and (43), production and factor use for the export market becomes:

$$y_{ix}(\phi) = r_f f_x (\epsilon - 1) \frac{\left(mc_i(\phi) + t_{oi}^F\right)^{-\epsilon}}{\left(mc_i(\phi_{ix}^{\star}) + t_{oi}^F\right)^{1-\epsilon}} \tag{50}$$

$$u_{ix}(\phi) = y_{ix}(\phi)\,(1 - \gamma_i)\, w_{ui}^{-\sigma} mc_i(\phi)^{-\sigma} \tag{51}$$

$$s_{ix}(\phi) = y_{ix}(\phi)\,\gamma_i \phi \left(w_{si} + \frac{r_{ki}}{a}\right)^{-\sigma} mc_i(\phi)^{-\sigma} \tag{52}$$

$$k_{ix}(\phi) = y_{ix}(\phi)\,\frac{1}{a}\gamma_i \phi \left(w_{si} + \frac{r_{ki}}{a}\right)^{-\sigma} mc_i(\phi)^{-\sigma}. \tag{53}$$

Compared to the case with iceberg trade costs, international trade costs now affect directly output and factor use for the export market. Lower international trade costs allow firms to produce more thanks to lower prices in the export market.

Combined with (39) and (42), the above expressions for production and factor use for the export market can be used to find profits in the export market,

$$\pi_{ix}(\phi) = r_f f_x \left[\left(\frac{mc_i(\phi) + t_{oi}^F}{mc_i(\phi_{ix}^\star) + t_{oi}^F} \right)^{1-\epsilon} - 1 \right]. \tag{54}$$

Trade costs are now included in the expression for profits in the export market in such a way that lower trade costs increase profits as they allow to set a lower price and produce more.

Using (18), (50) and (48), the expression relating the two productivity cutoff levels becomes:

$$\frac{f_d}{f_x} = \left(\frac{mc_i(\phi_{id}^\star)}{mc_i(\phi_{ix}^\star) + t_{oi}^F} \right)^{1-\epsilon} \left(\frac{P_i^H}{P_i^F} \right)^{\epsilon-1} \left(\frac{E^H}{E^F} \right). \tag{55}$$

Even though trade costs now enter additively rather than multiplicatively, it is still the case that the interval $(\phi_{id}^\star, \phi_{ix}^\star)$ in which firms only produce for their domestic market increases with higher variable trade costs.

All the other assumptions used to find an equilibrium in this model with iceberg variable trade costs still apply, which implies that the equilibrium conditions do not change except for those relating to the export market, such as (55).

B Additional tables

Table 5: Effects of general trade liberalisation in different sectors with immobile labour.

	Baseline	**Sector 1**	**Sector 2**	**Sector 1 & 2**
τ_{n1}^H	1.5	1.4	1.5	1.4
τ_{n2}^H	1.5	1.5	1.4	1.4
τ_{o1}^H	1.5	1.4	1.5	1.4
τ_{o2}^H	1.5	1.5	1.4	1.4
τ_{o1}^F	1.5	1.4	1.5	1.4
τ_{o2}^F	1.5	1.5	1.4	1.4
w_{s1}	1.000	0.797	1.054	1.017
w_{s2}	1.000	1.101	0.979	0.976
w_{s1}/P	28.841	23.794	30.499	30.667
w_{s2}/P	28.841	32.605	28.349	29.471
w_{u1}	0.599	0.496	0.611	0.546
w_{u2}	0.599	0.631	0.566	0.541
w_{u1}/P	17.274	14.777	17.691	16.536
w_{u2}/P	17.274	18.696	16.377	16.379
w_{i1} (w_{s1}/w_{u1})	1.670	1.617	1.725	1.849
w_{i2} (w_{s2}/w_{u2})	1.670	1.748	1.729	1.794
$var(k/u)_1 * 100$	0.622	0.642	0.622	0.647
$var(k/u)_2 * 1000$	0.480	0.479	0.514	0.490
$(s(\phi \geq 3)/s)_1$	0.771	0.764	0.771	0.764
$(s(\phi \geq 3)/s)_2$	0.242	0.242	0.223	0.223
P	0.035	0.034	0.035	0.033

Table 6: Effects of a decrease in the world price of equipment with immobile labour.

	Baseline	**Sector 1**	**Sector 2**	**Sector 1 & 2**
r^F_{k1}	1.0	0.9	1.0	0.9
r^F_{k2}	1.0	1.0	0.9	0.9
w_{s1}	1.000	1.097	0.951	1.093
w_{s2}	1.000	0.969	1.117	1.078
w_{s1}/P	28.841	32.329	28.107	32.366
w_{s2}/P	28.841	28.618	32.920	31.936
w_{u1}	0.599	0.580	0.581	0.578
w_{u2}	0.599	0.588	0.587	0.575
w_{u1}/P	17.274	17.122	17.152	17.169
w_{u2}/P	17.274	17.350	17.331	17.060
w_{i1} (w_{s1}/w_{u1})	1.670	1.887	1.639	1.884
w_{i2} (w_{s2}/w_{u2})	1.670	1.649	1.900	1.870
$var(k/u)_1 * 100$	0.622	0.626	0.626	0.626
$var(k/u)_2 * 1000$	0.480	0.480	0.481	0.481
$(s(\phi \geq 3)/s)_1$	0.771	0.772	0.771	0.772
$(s(\phi \geq 3)/s)_2$	0.242	0.242	0.243	0.243
P	0.035	0.034	0.034	0.034