E C O N O M I C S   B U L L E T I N

Wage inequality and welfare effects of domestic technological progress: a dual economy approach

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Abstract

This paper shows that technological progress caused by a domestic high-tech firm always increases the skilled-unskilled wage inequality, using a two-sector, two-labor model. Also, we derive a sufficient condition for the technological progress to be effective in increasing domestic welfare. In the Cobb--Douglas production function case, if the equilibrium relative wage is greater than a threshold level, domestic welfare unambiguously increases in response to the technological progress. Moreover, we also provide some policy implications of our results, in the context of developing countries.

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1. Introduction

How does the rapid pace of globalization affect the wage inequality between skilled and unskilled workers? Since the highly cited papers of Feenstra and Hanson (1996, 1997), an increasing number of studies have been undertaken to examine the same question.[1] The theoretical models constructed by Feenstra and Hanson (1996, 1997) assume that a single final good is produced from a continuum of intermediate inputs—each of these intermediate inputs differs in intensity of skilled labor. In these models, foreign direct investment (FDI) takes the form of outsourcing activities from developed countries (North) to developing countries (South). It is shown that an expansion of outsourcing activities widens the wage gaps between the skilled and unskilled in both North and South. In contrast to Feenstra and Hanson (1996, 1997), Das (2002) concludes that FDI reduces the skilled-unskilled wage inequality, using a two-sector, two-labor model. There are many other papers examining the relationship between wage inequality and trade liberalization (e.g. Das 2003, 2005). Also, various types of international factor movement are investigated by Chaudhuri and Yabuuchi (2006), Yabuuchi and Chaudhuri (2007), and Yabuuchi (2007), within both full-employment and underemployment frameworks. This paper is different from the above-mentioned papers in that *our analysis explicitly examines the effects of domestic technological progress* on wage inequality and domestic welfare.

The imperatives of globalization have been bringing genuine competition all over the world. The need of technological progress for competitiveness has been putting strong pressure on domestic firms that are exposed to the threat of foreign rivals. From the perspective of developing countries, it is partly true that globalization makes it easier to acquire advanced technologies from developed countries, and to achieve a rapid catch-up. This situation seems to be applicable to some emerging markets—especially, new economic giants such as China and India. However, we cannot overlook the presence of 'dualities'—the particular feature in developing countries. In fact, there exist a variety of different dualities—such as urban-rural, advanced-backward, formal-informal, and skilled-unskilled dualities. Some industries (e.g. computer software industry in India) have been rapidly increasing their international competitiveness, while some other industries *in the same country* have been stagnant. Thus, formal analyses of *unbalanced* technological progress with a dual economy model are necessary to capture the various facts in developing countries in the context of globalization.[2]

The purpose of this paper is to examine how *technological progress in a high-tech sector* affects skilled-unskilled wage differential and domestic welfare, using a two-sector (high-tech and low-tech), two-labor (skilled and unskilled) model. The high-tech sector has a duopolistic market structure, where a foreign firm employs domestic workers and competes with a domestic high-tech firm.[3] The low-tech sector is perfectly competitive and consists of

[1]Feenstra and Hanson (1997) provide empirical evidences of Mexico that show the wage gap between skilled and unskilled workers decreased between 1978 and 1985, then it turned to increase between 1985 and 1989. The expanding skilled-unskilled wage gaps are observed in Chile (Robbins, 1994), Argentina, Malaysia, the Philippines, Taiwan and Uruguay (Robbins, 1996). (For other empirical studies, see Wood, 1994, 1999; Beyer et al., 1999; Robbins and Gindling, 1999 and Arbache et al., 2004 among others.)

[2]Using cross-country data, Bourguignon and Morrisson (1998) find empirical evidences which show a positive correlation between inequality and the extent of duality. Also, Temple (2005) emphasizes that dual economy models deserve a central place in the analysis of growth in developing countries.

[3]There are a lot of empirical evidences, which show that FDI of foreign firms toward developing countries

domestic low-tech firms only. The high-tech sector is skilled-labor intensive and the low-tech sector is unskilled-labor intensive. Our main result shows that *an improvement in production efficiency caused by the domestic high-tech firm always increases the wage inequality* between skilled and unskilled workers, whereas its effect on domestic welfare is generally ambiguous. However, it is able to derive a sufficient condition for domestic technological progress to be effective in increasing domestic welfare. In the Cobb–Douglas production function case, the sufficient condition depends on whether the equilibrium relative wage is larger than a threshold level. *If the equilibrium relative wage is greater than the threshold level, domestic welfare unambiguously increases in response to domestic technological progress.* Otherwise it is possible that domestic technological progress decreases welfare.[4]

The remainder of this paper is organized as follows. Section 2 describes the model and its equilibrium solution. The framework of our model is based on that of Das (2002), but we highly simplify his model to focus on the effects of domestic technological progress. Section 3 examines the effects of technological progress caused by the domestic high-tech firm. Section 4 displays the welfare analysis. And the final section provides some concluding remarks.

2. The model

Consider an economy which consists of a high-tech sector (sector x, henceforth) and a low-tech sector (sector y, henceforth). Sector y, producing the *numéraire*, is perfectly competitive, while in sector x, duopolistic firms (one is domestic and the other is foreign) compete in the Cournot fashion. The foreign firm operates only in sector x. It sets up a local plant through FDI and employs domestic workers for its production. We put international trade away, thus each market clears domestically. Let the economy's demand side be represented by a Cobb–Douglas type social utility function:

$$U(D_x, D_y) = D_x^{\gamma} D_y^{1-\gamma}, \quad 0 < \gamma < 1, \tag{1}$$

where D_i $(i = x, y)$ denotes the consumption of good i and the constant γ represents the share of expenditure on good x. Maximizing (1) subject to the economy's budget constraint: $E = pD_x + D_y$, we obtain the following demand functions.[5]

$$D_x = \gamma E/p, \quad D_y = (1-\gamma)E, \tag{2}$$

where p is the relative price of good x and E denotes the national income (or expenditure).

There are two types of workers: skilled and unskilled; and their endowments are denoted by $\bar{L}_s$ and $\bar{L}_u$, respectively. The production of good y needs unskilled labor only. For simplicity, we assume that one unit of good y is produced from one unit of unskilled labor

is prevailing in oligopolistic market. A huge number of theoretical studies examining the 'strategic trade policy', pioneered by James Brander and Barbara Spencer, also use oligopolistic (or duopolistic) frameworks.

[4]In this context, our result is relevant to the literature of 'welfare reducing domestic innovation' (e.g. Takahashi, 2007; Mukherjee and Sinha, 2007). Takahashi (2007) shows that the private returns from innovation can be greater than the social returns, using the fixed fee license model. Mukherjee and Sinha (2007) examine the welfare effect of foreign firm's production strategy (i.e., strategic choice between FDI and export). They show that domestic cost reduction may reduce domestic welfare when the foreign firm switches its strategy from FDI to exporting.

[5]The price of good y, the *numéraire*, is assumed to be one.

employment. Therefore, the total output of sector y, denoted by Q_y, equals the total employment in this sector, denoted by L_y. Consequently, in this sector, the equilibrium wage rate in terms of the *numéraire* is given, and it can be normalized to unity.[6]

In sector x, as stated above, a domestic high-tech firm (firm d, henceforth) and a foreign firm (firm f, henceforth) compete in the Cournot fashion. Both types of labor, the skilled and unskilled, are indispensable to produce good x. Assuming that the production technology of good x is constant returns to scale and satisfies standard neoclassical properties. It is useful for our manipulation to represent this technology in the form of cost function. We represent the 'unit cost function' of firm f as $C(w_s, w_u)$, where w_s denotes the wage rate of skilled labor (skilled wage, henceforth) and w_u is the wage rate of unskilled labor (unskilled wage, henceforth). Recall that the unskilled wage in sector y always equals unity, and unskilled workers are assumed to be able to move freely between the two sectors; therefore the unskilled wage in sector x also equals unity. Since $C(w_s, w_u)$ is homogeneous of degree, it can be rewritten as

$$C(w_s, w_u) = w_u C(w_s/w_u, 1) \equiv w_u c(w) = c(w); \quad c'(w) > 0 > c''(w),$$

where w ($\equiv w_s/w_u$) denotes the relative wage.[7] The condition $w_u = 1$ implies that, in equilibrium, a change in the relative wage is represented by a change in the skilled wage (i.e., $\mathrm{d}w = \mathrm{d}w_s$). The input-coefficients of skilled and unskilled labor are shown to be $c'(w)$ and $c(w) - wc'(w)$, repectively, by applying Shephard's lemma.

The only difference between firm d and firm f is the degree of efficiency in production process. According to Das (2002), we simply formalize this feature by multiplying a parameter b to the unit cost function of firm f. Hence, the unit cost function of firm d takes the form

$$c_d(w; b) = bc(w); \quad b > 1.$$

In Section 3 and 4, we examine the impacts of technological progress caused by firm d. This technological progress is formalized in terms of a marginal improvement in production efficiency (i.e., a decrease in b).

Denoting the total output of sector x by Q_x, the market equilibrium condition of good x (i.e., $Q_x = D_x$) and (2) implies that the inverse demand function of good x is $p = \gamma E/Q_x$. Facing this function, each firm maximizes its profit, π_j ($j = f, d$), by choosing the quantity of its output, q_j, where the subscripts stand for 'firm f' and 'firm d', respectively. Solving the profit maximization problem for each firm yields the following first-order conditions:

$$\frac{\partial \pi_f}{\partial q_f} = 0 \;\Leftrightarrow\; \frac{p - c(w)}{p} = \frac{q_f}{Q_x}, \qquad \frac{\partial \pi_d}{\partial q_d} = 0 \;\Leftrightarrow\; \frac{p - bc(w)}{p} = \frac{q_d}{Q_x}. \tag{3}$$

The full employment conditions of skilled and unskilled workers are given by (4). And

[6] Throughout the paper, all wages are measured in terms of the *numéraire* and we will not explicitly mention that again.

[7] Without loss of generality, we assume that skilled workers enjoy a higher wage rate, that is $w_s > w_u = 1$ and $w > 1$.

the market equilibrium conditions for goods x and y are given by (5).[8]

$$\bar{L}_s = c'(w)(q_f + bq_d), \qquad \bar{L}_u = [c(w) - wc'(w)](q_f + bq_d) + L_y. \tag{4}$$

$$Q_x = D_x, \qquad Q_y = D_y + [p - c(w)]q_f. \tag{5}$$

Equilibrium Equations (3)-(5) are sufficient to jointly determine the endogenous variables, p, w, q_d, q_f and Q_y. (As already noted, $Q_y = L_y$ and $Q_x \equiv q_d + q_f$.) From these equations, Appendix A derives the output share of each firm in sector x:

$$\frac{q_f}{Q_x} = \frac{b}{1+b}, \qquad \frac{q_d}{Q_x} = \frac{1}{1+b}. \tag{6}$$

These equations imply that the output share of firm f increases and that of firm d decreases, as b increases. Moreover, in equilibrium, each firm produces a positive amount of output irrespective of the value of b.[9]

After some manipulations, the two full employment conditions in (4) can be rewritten as the following two equations which represent the two distinct relationships between w and Q_x (see Appendix B).

$$\textbf{SS curve:} \qquad \frac{2b}{1+b}Q_x = \frac{\bar{L}_s}{c'(w)}, \tag{7}$$

$$\textbf{UU curve:} \qquad \left[\frac{(1-\gamma)(1+b)}{\gamma} + \frac{b^2}{1+b}\right] Q_x = \frac{1}{c(w)}\left\{\bar{L}_u - \left[\frac{c(w) - wc'(w)}{c'(w)}\right]\bar{L}_s\right\}. \tag{8}$$

The SS and UU curves essentially capture full employment of skilled and unskilled workers, respectively; and these curves include only two endogenous variables, Q_x and w.[10] Figure 1 depicts that the SS and UU curves uniquely determine the equilibrium value of Q_x and w, denoted by Q_x^* and w^*. (Appendix C analytically examines the slopes of SS and UU curves.) Substituting w^* and Q_x^* into (6), (A1) and (A5), we obtain the equilibrium values of p, q_f, q_d and Q_y (see Appendix D).

3. The effects of domestic technological progress

This section examines the impacts of technological progress caused by firm d (the domestic high-tech firm).[11] As far as our specification in the unit cost function used here, we cannot

[8] The last term of the second equation in (5), $[p - c(w)]q_f$, is the profit of firm f, assumed to be remitted to the home country in terms of the *numeraire*.

[9] In Das (2002) model, it is necessary to put an upper limit on the value of b to assure a positive amount of output for the domestic firms (see page 60 of Das, 2002). Furthermore, he assumes $b = 1$ (i.e., no technology gap case) to simplify the welfare analysis (see Section 4 of Das, 2002). The need to put these constraints on the value of b arises from the generality on the number of firms (existing in his model). This is the main reason why we choose a simple duopolistic structure in the current analysis, because we would like to focus on considering the technology gap between the domestic and the foreign firms.

[10] For the detailed explanations of the SS and UU curves, see pages 61 and 62 of Das (2002).

[11] As described above, the technological differential between firms d and f is represented in the parameter b. Thus, in our model, domestic technological progress is expressed in an exogenous marginal decrease in b.

explicitly solve for Q_x^* from (7) and (8). For this reason, we employ a graphical analysis to show the effect of domestic technological progress on Q_x^*. Appendix E shows that an increase in b shifts both the SS and UU curves leftward.[12] Thus, it is apparent from Figure 2 that the new equilibrium value, denoted by $\widetilde{Q}_x^*$, is unambiguously lower, while the change in w^* seems unclear.

In turn, an analytical approach must be employed to check the relationship between w^* and b. Appendix F shows the following result:

$$\frac{\mathrm{d}w^*}{\mathrm{d}b} = \left[\frac{(b+1)(b-1)+\gamma}{2\gamma b^2}\right] \Big/ \left[\frac{(\bar{L}_u + \bar{L}_s w)c(w^*)c''(w^*) - L_y[c'(w^*)]^2}{\bar{L}_s[c(w^*)]^2}\right] < 0. \tag{9}$$

These observations complete the following proposition.

Proposition 1. *Technological progress in production efficiency caused by the domestic high-tech firm (i.e., a decrease in b) increases the relative wage and the total output of the high-tech sector (and vice versa); that is* $dw^*/db < 0$ *and* $dQ_x^*/db < 0$.

The widening gap between the skilled and unskilled wages caused by the domestic technological progress is a notable result. Intuitively, this result comes from the demand-side factor of the labor market. A drop in b increases the total output of high-tech sector at any given value of w. Since the high-tech sector is skilled-labor intensive, an expansion in this sector increases the relative demand of skilled labor. Thus, the relative wage must rise to absorb the excess demand for skilled labor.

A change in b also affects the other equilibrium variables derived in (A10)-(A13). The impacts on p^* and q_f^* are ambiguous, while the effects on q_d^* and Q_y^* can be summarized by the following proposition (see Appendix G).

Proposition 2. *Technological progress in production efficiency caused by the domestic high-tech firm (i.e., a decrease in b) increases its own output and decreases the total output of the low-tech sector (and vice versa); that is* $dq_d^*/db < 0$ *and* $dQ_y^*/db > 0$.

4. Welfare analysis

This section examines the welfare effect of technological progress caused by firm d, using a standard duality approach. Consider the following aggregate expenditure function:

$$E(p,u) = \min_{D_x, D_y} \left\{ pD_x + D_y \mid \; U(D_x, D_y) \geq u \right\}, \tag{10}$$

where u denotes arbitrary given level of utility. Since the total output of the economy in terms of the *numéraire* is allocated to the wage incomes of the skilled and unskilled and the profits of firms d and f (i.e., $pQ_x + Q_y = w\bar{L}_s + \bar{L}_u + \pi_d + \pi_f = E + \pi_f$), another way of expressing the aggregate expenditure (or national income) is

$$E(p,u) = w\bar{L}_s + \bar{L}_u + \pi_d = w\bar{L}_s + \bar{L}_u + [p - bc(w)]q_d. \tag{11}$$

[12]Note that an increase in b stands for technological *deterioration* of firm d. If we only reverse the result, we can analyze the effects of domestic technological *progress*.

Totally differentiating this equation and defining a change of welfare by $\mathrm{d}W \equiv (\partial E/\partial u) \times \mathrm{d}u$,[13] we obtain

$$\mathrm{d}W \equiv \mathrm{d}u = \mathrm{d}E = \bar{L}_s \mathrm{d}w + [p - bc(w)]\mathrm{d}q_d + q_d \mathrm{d}p - q_d bc'(w)\mathrm{d}w.$$

Thus, the following equation shows how a change in b affects the equilibrium welfare level.

$$\frac{\mathrm{d}W^*}{\mathrm{d}b} = \bar{L}_s \frac{\mathrm{d}w^*}{\mathrm{d}b} + [p^* - bc(w^*)]\frac{\mathrm{d}q_d^*}{\mathrm{d}b} + q_d^* \frac{\mathrm{d}p^*}{\mathrm{d}b} - q_d^* bc'(w^*)\frac{\mathrm{d}w^*}{\mathrm{d}b} \tag{12}$$

$$= \bar{L}_s \frac{\mathrm{d}w^*}{\mathrm{d}b} + [p^* - bc(w^*)]\frac{\mathrm{d}q_d^*}{\mathrm{d}b} + q_d^* \left[c(w^*) + c'(w^*)\frac{\mathrm{d}w^*}{\mathrm{d}b}\right], \tag{13}$$

where the above second equality comes from substituting (A14) into (12). The first and second terms of (13) are negative, while the third term of (13) is ambiguous. Hence, the sufficient condition for $\mathrm{d}W^*/\mathrm{d}b$ to be negative is

$$c(w^*) + c'(w^*)\frac{\mathrm{d}w^*}{\mathrm{d}b} \leq 0 \;\Leftrightarrow\; \frac{c(w^*)}{c'(w^*)} \leq -\frac{\mathrm{d}w^*}{\mathrm{d}b}. \tag{14}$$

If the condition (14) is satisfied, technological progress in production efficiency caused by firm d unambiguously increases welfare. In what follows, we specify the production function as the Cobb–Douglas form, and then reexamine the above condition (14).

Cobb–Douglas case Assume that the production function of firm f takes the Cobb–Douglas form:

$$q_f = AN_s^{\alpha} N_u^{1-\alpha}, \qquad 0 < \alpha < 1, \tag{15}$$

where $A\,(> 0)$ denotes a technological parameter, N_s is the employment of skilled workers and N_u is that of unskilled workers. Using this production function, we obtain the following unit cost function (see Appendix H):

$$c(w) = A^{-1}\alpha^{-\alpha}(1-\alpha)^{\alpha-1}w^{\alpha}. \tag{16}$$

Using this specific unit cost function, the condition (14) can be reduced to the following condition (17), and then we obtain Proposition 3 (see Appendix I).

$$w^* \geq \Psi \quad \text{with} \quad \Psi \equiv \frac{\bar{L}_u}{\Gamma \bar{L}_s} \equiv \frac{2\gamma b^2}{(b+1)(b-1)+\gamma} \cdot \frac{\bar{L}_u}{\bar{L}_s}. \tag{17}$$

Proposition 3. *In the Cobb–Douglas case (specified by (15)), technological progress in production efficiency caused by the domestic high-tech firm (i.e., a decrease in b) increases welfare if the condition (17) is satisfied. If condition (17) is violated, however, the welfare effect of technological progress is ambiguous.*

In other words, whether domestic technological progress is certain to increase welfare or not depends on magnitude relation between the endogenous value of the equilibrium relative

[13] $\partial E/\partial u$ is the reciprocal marginal utility of income and, without loss of generality, we assume that it is normalized to unity.

wage, w^*, and the exogenous value of Ψ. Since we already assumed $w > 1$, if only $\Psi \leq 1$, then (17) must hold. In this case, domestic technological progress is certain to increase welfare.

The value of Ψ is increasing in $\bar{L}_u$ and γ, and decreasing in $\bar{L}_s$ and b. Among these effects on Ψ, considering exogenous changes in the 'skilled-unskilled ratio of labor endowment', (i.e., $\bar{L}_s/\bar{L}_u$), is the most important matter to examine, because any attempts to increase it—e.g. education policy—are at the top of the policy agendas in many developing countries.[14] An increase of the skilled-unskilled ratio ($\bar{L}_s/\bar{L}_u$) decreases the value of Ψ, then it makes a domestic innovation to be more likely to raise welfare. This is a straightforward relationship between domestic innovation and the skilled-unskilled ratio, simply because the larger the relative amount of skilled workers who benefit from innovation, the more innovation contributes to welfare.

5. Concluding remarks

This paper examines the impacts of technological progress caused by the domestic high-tech firm within a two-sector, two-labor framework. Proposition 1 states our first main result, which shows that the equilibrium wage differential increases in response to the domestic technological progress. This result comes from only the demand-side factor of labor market, because we do not allow endogenous changes in labor supply. This is the crucial assumption in this paper and it is also relevant to Proposition 3, our second main result.

Proposition 3 states that if the equilibrium relative wage is greater than the threshold level (Ψ), domestic technological progress increases welfare. However, one of the most distinctive features of developing economies is abundant supply of unskilled labor. Taking this feature into account, Ψ in our model probably takes a larger value. Then, in that case, what is possible to happen is domestic technological progress will decrease welfares.

Hence, when the actual amount of unskilled labor is extremely larger than that of skilled labor, policymakers in such economy should give the first priority to policies that will encourage unskilled workers to improve their skill (e.g., subsidies for basic education, on-the-job training, scholarship foundation, etc.). Otherwise, any rapid, but unbalanced technological progress would benefit only a small number of skilled workers and it would be unlikely to contribute to increase domestic welfare.

This paper assumes a constant skilled-unskilled ratio of labor endowment. Therefore, the present analysis is applicable to short-run equilibrium. To examine long-term educational effects on workers' abilities, we must remove the assumption of fixed labor endowment in our future study.

[14] In this footnote, we examine the value of $1/\Gamma$ which also affects the value of Ψ. As a numerical example, let us assume $\gamma = 0.5$. Then, as b increases from 1.5 to 10, $1/\Gamma$ monotonically decreases, approximately, from 1.3 to 1.

References

Arbache, J. S., A. Dickerson and F. Green (2004) "Trade Liberalisation and Wages in Developing Countries" *Economic Journal* **114**, F73-F96.

Beyer, H., P. Rojas and R. Vergara (1999) "Trade Liberalisation and Wage Inequality" *Journal of Development Economics* **59**, 103-123.

Bourguignon, F. and C. Morrisson (1998) "Inequality and Development: the Role of Dualism" *Journal of Development Economics* **57**, 233-257.

Chaudhuri, S. and S. Yabuuchi (2006) "Economic Liberalization and Wage Inequality in the Presence of Labour Market Imperfection" *International Review of Economics and Finance*, forthcoming.

Das, S. P. (2002) "Foreign Direct Investment and the Relative Wage in a Developing Economy" *Journal of Development Economics* **67**, 55-77.

Das, S. P. (2003) "Trade and Relative Wage in a Global Economy" *Review of International Economics* **11**, 397-411.

Das, S. P. (2005) "Gradual Globalization and Inequality between and within Countries" *Canadian Journal of Economics* **38**, 852-869.

Feenstra, R. C. and G. H. Hanson (1996) "Foreign Investment, Outsourcing and Relative Wages" in *Political Economy of Trade Policy: Essays in Honor of Jagdish Bhagwati* by R. C. Feenstra and G. M. Grossman, Eds., The MIT Press: Cambridge, MA, 89-127.

Feenstra, R. C., and G. H. Hanson (1997) "Foreign Direct Investment and Relative Wages: Evidence from Mexico's Maquiladoras" *Journal of International Economics* **42**, 371-393.

Mukherjee, A. and U. B. Sinha (2007) "Welfare-reducing Domestic Cost Reduction" *Review of International Economics* **15**, 294-301.

Robbins, D. J. (1994) "Worsening Relative Wage Dispersion in Chile During Trade Liberalisation, and its Causes: is Supply at Fault?" Development Discussion Papers No. 484, Harvard Institute for International Development, Harvard University.

Robbins, D. J. (1996) "HOS Hits Facts: Facts Win; Evidence on Trade and Wages in the Developing Countries" Development Discussion Paper No. 557, Harvard Institute for International Development, Harvard University.

Robbins, D. J. and Gindling, T. H. (1999) "Trade Liberalisation and the Relative Wages for More-Skilled Workers in Costa Rica" *Review of Development Economics* **3**, 140-154.

Takahashi, S. (2007) "Fixed Fee Licenses and Welfare Reducing Innovation: A Note" *Economics Bulletin* **15**, 1-12.

Temple, J. (2005) "Dual Economy Models: A Primer for Growth Economists" *Manchester School* **73**, 435-478.

Wood, A. (1994) *North-South Trade, Employment and Inequality. Changing Fortunes in Skill-Driven World*, Clarendon Press: Oxford.

Wood, A. (1999) "Openness and Wage Inequality in Developing Countries: The Latin American Challenge to East Asian Conventional Wisdom" in *Market Integration, Regionalism and the Global Economy* by R. E. Baldwin, D. Cohen, A. Sapir and A. Venables, Eds., Cambridge University Press: Cambridge.

Yabuuchi, S. (2007) "Unemployment and International Factor Movement in the Presence of Skilled and Unskilled Labor" *Review of Development Economics* **11**, 437-449.

Yabuuchi, S. and S. Chaudhuri (2007) "International Migration of Labour and Skilled-unskilled Wage Inequality in a Developing Economy" *Economic Modelling* **24**, 128-137.

Appendices

Appendix A This appendix shows how to derive (6) in the text. First, adding the two equations in (3) together, we obtain

$$\frac{2p-(1+b)c(w)}{p}=\frac{q_f}{Q_x}+\frac{q_d}{Q_x}=1,$$

where the last equality is from the definition: $Q_x \equiv q_f + q_d$. Next, combining the first and last terms of the above equation makes

$$p=(1+b)c(w). \tag{A1}$$

Then rearranging this equation yields

$$\frac{p-c(w)}{p}=\frac{b}{1+b}, \tag{A2}$$

$$\frac{p-bc(w)}{p}=\frac{1}{1+b}. \tag{A3}$$

(A1) shows that the relative price, p, is greater than the marginal cost, $c(w)$, and the difference positively depends on b—the degree of domestic firm's productive efficiency. Last, substituting (A2) and (A3) into the two equations in (3), we obtain (6). □

Appendix B This appendix shows how to derive (7) and (8) in the text. First, let us look at the derivation of (8). From (A1) and the output share of firm f in (6), the profit of firm f can be expressed as

$$[p-c(w)]q_f=\frac{b^2}{1+b}Q_x c(w). \tag{A4}$$

Next, eliminating $(q_f + bq_d)$ from the two equations in (4), we obtain

$$(Q_y =)\, L_y = \bar{L}_u - \left[\frac{c(w) - wc'(w)}{c'(w)}\right]\bar{L}_s \tag{A5}$$

Thus, from (5), (A4), (A5) and the economy's budget constraint $(E = pD_x + D_y)$, we have

$$\begin{aligned} E &= pD_x + D_y \\ &= pQ_x + Q_y - [p - c(w)]q_f \\ &= pQ_x + \bar{L}_u - \left[\frac{c(w) - wc'(w)}{c'(w)}\right]\bar{L}_s - \frac{b^2}{1+b}Q_x c(w). \end{aligned} \tag{A6}$$

Using (A6) and the inverse demand function of good x, $(E = pQ_x/\gamma)$, we have

$$\frac{p}{\gamma}Q_x = pQ_x + \bar{L}_u - \left[\frac{c(w) - wc'(w)}{c'(w)}\right]\bar{L}_s - \frac{b^2}{1+b}Q_x c(w). \tag{A7}$$

Substituting (A1) into (A7), we obtain (8).

Deriving (7) is very straightforward. It can be derived from substituting the two equations of (6) into the first equation of (4). □

Appendix C This appendix analytically examines the slopes of SS and UU curves. Totally differentiating (7) with respect to w and Q_x, we can show that the SS curve displays a positive relationship between w and Q_x:

$$\left.\frac{\mathrm{d}w}{\mathrm{d}Q_x}\right|_{\mathrm{SS}} = -\left(\frac{2b}{1+b}\right)\frac{\bar{L}_s c''(w)}{[c'(w)]^2} > 0.$$

Similarly, totally differentiating (8) with respect to w and Q_x, we have

$$\left.\frac{\mathrm{d}w}{\mathrm{d}Q_x}\right|_{\mathrm{UU}} = \left[\frac{(1-\gamma)(1+b)}{\gamma} + \frac{b^2}{1+b}\right] \Big/ \left[\frac{\bar{L}_s[c(w) - wc'(w)] - \bar{L}_u c'(w)}{[c(w)]^2} + \frac{\bar{L}_s c''(w)}{[c'(w)]^2}\right], \tag{A8}$$

where the sign of the derivative is indeterminate. Now rewriting (A5) in Appendix B as

$$\bar{L}_s[c(w) - wc'(w)] = [\bar{L}_u - L_y]c'(w), \tag{A9}$$

and applying this equation to (A8) makes the following clear result:

$$\left.\frac{\mathrm{d}w}{\mathrm{d}Q_x}\right|_{\mathrm{UU}} = \left[\frac{(1-\gamma)(1+b)}{\gamma} + \frac{b^2}{1+b}\right] \Big/ \left[\frac{-L_y c'(w)}{[c(w)]^2} + \frac{\bar{L}_s c''(w)}{[c'(w)]^2}\right] < 0.$$

□

Appendix D Each of the following variables with asterisk, '∗', stands for its equilibrium value.

$$p^* = (1+b)c(w^*), \tag{A10}$$

$$q_f^* = \frac{b}{1+b}Q_x^*, \tag{A11}$$

$$q_d^* = \frac{1}{1+b}Q_x^*, \tag{A12}$$

$$Q_y^* = \bar{L}_u - \left[\frac{c(w^*) - w^*c'(w^*)}{c'(w^*)}\right]\bar{L}_s. \tag{A13}$$

Appendix E This appendix shows the reason why the both curves shift leftward in Figure 2. First, let us consider the SS curve describing (7). Since we have

$$\frac{\mathrm{d}\left(\frac{2b}{1+b}\right)}{\mathrm{d}b} = \frac{2}{(1+b)^2} > 0,$$

the LHS of (7) increases as b increases. Thus, at any given value of w, Q_x must decrease to satisfy the equality in (7). This relationship is illustrated by the leftward shift of SS curve in Figure 2.

Next, take a look at the terms enclosed within the square brackets in the LHS of (8). Since we obtain

$$\frac{\partial\left[\frac{(1-\gamma)(1+b)}{\gamma} + \frac{b^2}{1+b}\right]}{\partial b} = \frac{1-\gamma}{\gamma} + \frac{2b+b^2}{(1+b)^2} > 0,$$

the LHS of (8) increases as b increases. Thus, at any given value of w, Q_x must decrease to satisfy the equality in (8). This relationship is illustrated by the leftward shift of UU curve in Figure 2. □

Appendix F This appendix derives (9) in the text. First, eliminating Q_x from (7) and (8), we obtain

$$\frac{b^2 + 2(1-\gamma)b + 1 - \gamma}{2\gamma b} = -1 + \left(\frac{\bar{L}_u}{\bar{L}_s} + w^*\right)\frac{c'(w^*)}{c(w^*)},$$

where the value of w^* is implicitly determined. Totally differentiating this equation with respect to w^* and b, we obtain

$$\frac{\mathrm{d}w^*}{\mathrm{d}b} = \left[\frac{(b+1)(b-1)+\gamma}{2\gamma b^2}\right] \Big/ \Lambda \qquad \text{with}$$

$$\Lambda \equiv \left[\frac{\bar{L}_u\{c(w^*)c''(w^*) - [c'(w^*)]^2\} + \bar{L}_s\{c'(w^*)[c(w^*) - w^*c'(w^*)] + w^*c(w^*)c''(w^*)\}}{\bar{L}_s[c(w^*)]^2}\right].$$

Applying (A9) to the numerator of Λ makes (9). □

Appendix G This appendix contains the proof of Proposition 2. Totally differentiating (A10), (A11), (A12) and (A13), with respect to p^* and b, respectively, we obtain

$$\frac{\mathrm{d}p^*}{\mathrm{d}b} = c(w^*) + (1+b)c'(w^*)\frac{\mathrm{d}w^*}{\mathrm{d}b}, \tag{A14}$$

$$\frac{\mathrm{d}q_f^*}{\mathrm{d}b} = \frac{Q_x^* + b(1+b)\frac{\mathrm{d}Q_x^*}{\mathrm{d}b}}{(1+b)^2}, \tag{A15}$$

$$\frac{\mathrm{d}q_d^*}{\mathrm{d}b} = \frac{-Q_x^* + (1+b)\frac{\mathrm{d}Q_x^*}{\mathrm{d}b}}{(1+b)^2} < 0, \tag{A16}$$

$$\frac{\mathrm{d}Q_y^*}{\mathrm{d}b} = \bar{L}_s\left[\frac{c(w^*)c''(w^*)}{[c'(w^*)]^2}\right]\frac{\mathrm{d}w^*}{\mathrm{d}b} > 0. \tag{A17}$$

Since $\mathrm{d}w^*/\mathrm{d}b < 0$ and $\mathrm{d}Q_x^*/\mathrm{d}b < 0$, deriving $\mathrm{d}q_d^*/\mathrm{d}b < 0$ and $\mathrm{d}Q_y^*/\mathrm{d}b > 0$ are straightforward, while the signs of $\mathrm{d}p^*/\mathrm{d}b$ and $\mathrm{d}q_f^*/\mathrm{d}b$ are indeterminate. □

Appendix H Consider the following cost minimization problem:

$$\min_{N_s, N_u} \; w_s N_s + w_u N_u \qquad \text{s.t. } A N_s^{\alpha} N_u^{1-\alpha} \geq q_f.$$

From the first-order conditions, it is straightforward to derive the optimal employment of the skilled and unskilled:

$$N_s = \frac{q_f}{A}\left[\frac{\alpha w_u}{(1-\alpha)w_s}\right]^{1-\alpha}, \qquad N_u = \frac{q_f}{A}\left[\frac{(1-\alpha)w_s}{\alpha w_u}\right]^{\alpha}.$$

Substituting these equations into the objective function makes the cost function:

$$K(w_s, w_u, q_f) = w_s \frac{q_f}{A}\left[\frac{(1-\alpha)w_s}{\alpha w_u}\right]^{\alpha-1} + w_u \frac{q_f}{A}\left[\frac{(1-\alpha)w_s}{\alpha w_u}\right]^{\alpha};$$

and the unit cost function:

$$C(w_s, w_u) \equiv \frac{K(\cdot)}{q_f} = \frac{w_s}{A}\left[\frac{(1-\alpha)w_s}{\alpha w_u}\right]^{\alpha-1} + \frac{w_u}{A}\left[\frac{(1-\alpha)w_s}{\alpha w_u}\right]^{\alpha}.$$

Recalling that $w_u = 1$ and $w_s = w$ in the equilibrium, we obtain (16) in the text. □

Appendix I This appendix provides the proof of Proposition 3. Using (16), the two terms in the second inequality of (14) can be rewritten as

$$\frac{c(w^*)}{c'(w^*)} = \frac{w^*}{\alpha} \equiv F(w^*)$$

and

$$-\frac{\mathrm{d}w^*}{\mathrm{d}b} = \frac{\Gamma \bar{L}_s}{\alpha \bar{L}_u} w^{*2} \equiv G(w^*) \quad \text{with} \quad \Gamma \equiv \frac{(b+1)(b-1)+\gamma}{2\gamma b^2}.$$

Figure 3 shows $F(w^*)$ and $G(w^*)$ graphically. These two curves intersect at two points, that is, at $w^* = 0$ and $w = \bar{L}_u/(\Gamma \bar{L}_s) \equiv \Psi$. Thus, under the specifications of (15) and (16), the condition (14) can be reduced to (17). □

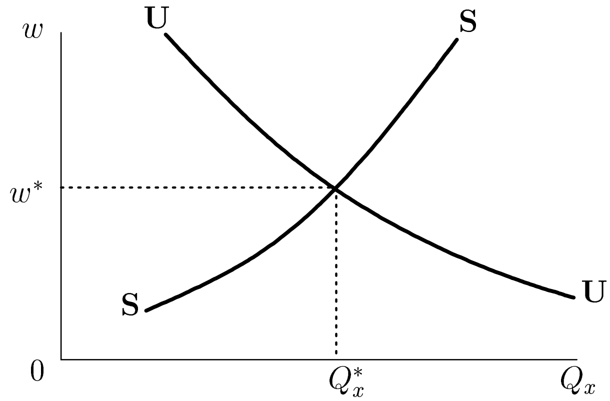

Figure 1: The SS and UU curves determine the unique equilibrium

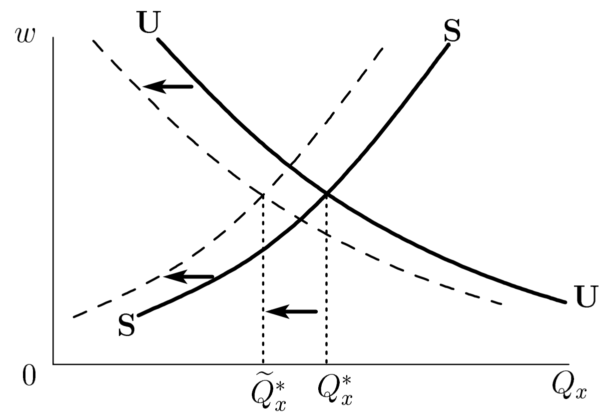

Figure 2: The effects of an increase in the parameter b

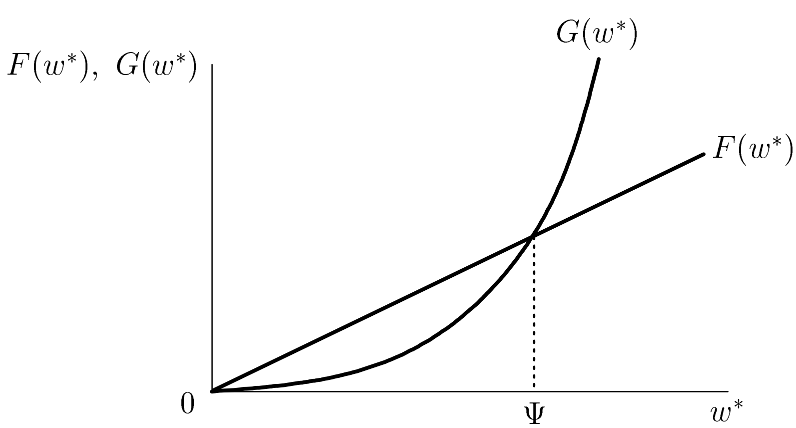

Figure 3: The determination of the value of Ψ