Trade, Wage Gaps, and Specific Human Capital Accumulation

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Abstract: We develop a new framework for the analysis of the impact of trade liberalization on the wage structure. Our model focuses on the decision of workers to accumulate firm-specific skills, by "on-the-job" training, knowing that this means their future wages will have to be negotiated, and that the outcome of negotiation will depend on the profitability prospect of firms operating in a new trading environment.

1 Introduction

The effects of trade liberalization on wage structure and employment have been a continuing topic of debate. (See, for example, Freeman (1995), Wood (1994), Krugman (1995), Davis (1998), Falvey (1998), Leamer (1998), Tyers and Yang (1999).) Economists participating in this debate typically use a modified version of the Heckscher-Ohlin model[1], with *fixed* endowments of skilled and unskilled workers. While that framework is a useful starting point, it neglects an important aspect: the decision to acquire skills *in response to* expected changes in trade regime is not modelled.

On the other hand, in the endogenous growth literature, human capital accumulation has received a great deal of attention. See Lucas (1988), Young (1991), Stokey (1991), and, for a survey of the trade and growth literature, see Long and Wong (1996). These authors however focused on long run considerations, and did not consider short-run issues such as the accumulation of industry-specific and firm-specific human capital, in response to trade liberalization. In this paper, we seek to fill that gap.

This paper presents a simple model of firm-specific human capital accumulation in a small open economy. We have two major goals in this paper. We want to find out if trade liberalization will (a) increase or decrease firm-specific human capital accumulation and (b) widen the wage gap between skilled and unskilled workers. This will have implications for the trade pattern, welfare and income distribution in both less developed countries (LDCs) and developed countries (DCs). We develop a new framework for the analysis of the impact of trade liberalization on the wage structure. Our model focuses on the decision of workers to accumulate firm-specific skills, knowing that this means their future wages will have to be negotiated, and that the outcome of negotiation will depend on the profitability of firms operating in a new trading environment.

We show that, for a less developed economy (one which imports the high-tech good), the expectation of trade liberalization leads to *less* human capital accumulation for skilled workers in the high-tech industry. In the absence of perfectly competitive labor markets (in our model wages are negotiated between management and workers with firm-specific skills), the effect of free trade on the supply of skills *may well be welfare-worsening.* (This is *proved* in

[1] For an important exception, see Neary (2000) who focused on oligopolistic competition, with *R&D* rivary in the first stage of the game.

Proposition 6 and Appendix 2B, under certain plausible assumptions). This argument has received some support from some section of the profession. In fact, the following quotation from Hirschman (1965, p. 5) is quite relevant:

"The opponents of free trade have often pointed out that for a variety of reasons it is imprudent and harmful for a country to become specialized along certain product lines in accordance with the dictates of comparative advantage. Whatever the merits of these critical arguments, they would certainly acquire overwhelming weight if the question arose whether a country should allow itself to become specialized not just along certain commodity lines, but along factor-of-production lines. Very few country would ever consciously wish to specialize in unskilled labor, while foreigners with a comparative advantage in entrepreneurship, management, skilled labor and capital took over these functions, replacing inferior "local talents."

Analysis of our model shows that, for a developed economy (high-tech good exporter), free trade leads to *more* human capital accumulation. In terms of wage gaps, the effect of free trade depends on the pattern of comparative advantage. The wage gap between high and low skill workers increases in the country that exports the high-tech good and decreases in the country which imports the high tech good. In section 4 we also briefly discuss the policy implications of these results as well as the effects of externalities and uncertainty.

2 A Basic Model of Human Capital Accumulation

2.1 Assumptions and Notation

We assume that there are two periods only. As a first step, let us consider a small open economy, consisting of two sectors, denoted by G, and H. (G and H stand for general and specific human capital respectively.) One can think of sector G, which produces Q_G, as the "low-tech" sector consisting of goods such as textiles and clothing. The "high-tech" sector's output, Q_H represents goods such as pharmaceuticals, software, computers, etc. Each individual in this economy possesses one unit of general human capital, and can accumulate firm-specific human capital. Sector G produces the numeraire good, which is exported (or imported) at the price $P_G = 1$. The only factor of production used to produce Q_G is general human capital. Production in sector G is under constant returns to scale: one unit of general human capital produces W_G units of good G. Thus the wage rate in this sector is W_G in both periods.

Sector H produces an output Q_H. Good H is produced using industry-specific physical capital, and human capital. There are N_H firms in sector H, each endowed with one unit of industry-specific physical capital. N_H is exogenously given. For the time being, the price of good H in period t, denoted by P_t , is taken as a parameter. In a subsequent subsection, we shall consider autarky equilibrium and show how P_t is determined endogenously.

We assume that, in sector H, to produce a positive output, a firm must have exactly one unit of industry-specific physical capital, and exactly one worker: a second worker would add nothing to output. If the worker (who works with one unit of industry-specific physical capital) has only one unit of *general* human capital, then the output is 1 unit of good H. If he has accumulated, in addition, h units of *firm-specific* human capital, then the output is $1+\mu h$, where μ is a positive parameter representing the *productivity* of firm-specific human capital in sector H. (Here, h is the worker's decision variable.) Since μ is only relevant in period 2, one may also interpret it as a measure of *technical progress embodied* in firm-specific human capital, and μh is firm-specific human capital measured in *efficiency units*.

Initially,workers in sector H have no firm-specific human capital. In period one each sector H worker decides on h, the amount of firm-specific human capital he wants to acquire. We assume that, without the firm's unit of specific physical capital, the worker cannot acquire firm-specific knowledge. The cost of acquiring firm-specific human capital depends on the amount h and on the learning ability of the worker. We model this by assuming that there is a parameter θ that represents learning ability, where θ is a positive real number, restricted to lie on the real interval $[\theta_a, \theta_b]$ where $0 < \theta_a < \theta_b$. Workers with higher θ have higher learning ability. The distribution function of θ is $F(\theta)$, where $F(\theta_a) = 0$ and $F(\theta_b) = 1$.

Our reason for introducing differences in learning ability is that we would like to model a *continuous* distribution of wages. On the other hand, it may be convenient, in some contexts, to talk about only *two* types of workers: skilled and unskilled. To accommodate both objectives, we find it useful to introduce a parameter z, a non-negative real number, which we use as an exponent for the parameter θ, and we assume that to obtain h, a worker of type θ must *directly incur* an effort cost which is denoted by $C(h)/\theta^z$, where $C(h)$ is convex and increasing, with $C(0) = 0$, and $z \geq 0$ is a useful parametrization of model type. So, workers with higher learning ability incur lower costs in acquiring human capital. A *special case* is obtained when we set $z = 0$ (or take the limit $z \to 0$). In this case, $\theta^z = \theta^0 = 1$ for all θ, so that effort cost is independent of learning ability, and the model reduces to one with only *two* types of worker: skilled and unskilled. We call the case with $z = 0$, the "benchmark case".

Each worker's θ is common knowledge. We assume for simplicity that for the worker, the cost $C(h)/\theta^z$ can be measured in terms of good G.[2] Let N be the number of individuals in this economy. We assume that $N > N_H$, so that when each firm in sector H employs one worker, there are enough workers left to produce some good G.

At the beginning of period two, a firm in sector H that has hired a worker of type θ in period 1 can rehire this worker, who has acquired $h(\theta) \geq 0$ units of firm-specific human capital, at a wage $W_2(\theta)$ (which is an outcome of a bargaining process between the firm and the worker, to be discussed below), or it can dismiss that worker, and employ a new worker, who, of course, does not have firm-specific human capital. If it takes the latter course of action, its profit is $\pi_R = P_2 - W_G$. This is the firm's reservation level of profit in its second-period bargaining with its worker. The experienced worker, on the other hand, can work in sector G in period two, at the wage W_G (since his firm-specific human capital is useless in other firms in sector H). This is his reservation wage in his bargaining with his existing employer.

2.2 Analysis of Wage Profiles

We now turn to the question of how bargaining determines the wage of the skilled worker of type θ in period two, *given* that the worker has acquired $h(\theta)$ units of firm-specific human capital. To do this, we use the theory of Nash cooperative bargaining, according to which the bargaining outcome in period 2 is a pair $(W_2(\theta), \pi_2(\theta))$ that maximizes the so-called Nash product, $(\pi_2(\theta) - \pi_R)^\beta (W_2(\theta) - W_G)^{1-\beta}$ subject to the constraint that

$$\pi_2(\theta) + W_2(\theta) = (1 + \mu h(\theta))P_2 \tag{1}$$

where $h(\theta)$ has been determined in period 1, and is *taken as given*[3] in the bargaining problem. The parameter β represents the relative bargaining

[2] Alternatively, we can interpret $C(h)/\theta^z$ as the cost of education, which uses up real resources, identified as good G.

[3] An alternative formulation, which would lead to a different result, is that the bargaining would take place in period 1, where the outcome would result in a contract that

power of the firm, where $0 \leq \beta \leq 1$. The constraint (1) may be written as

$$\pi_2(\theta) + W_2(\theta) = \pi_R + W_G + S(\theta)$$

where

$$S(\theta) \equiv \mu h(\theta) P_2 \tag{2}$$

is the surplus to be shared by the firm and the worker.

Solving this maximization problem yields the Nash-bargaining solution

$$W_2(\theta) = W_G + (1-\beta)S(\theta) = W_G + (1-\beta)\mu h(\theta) P_2 \tag{3}$$

and

$$\pi_2(\theta) = \pi_R + \beta S(\theta) \tag{4}$$

Equation (3) says that the skilled worker's wage consists of two components: a wage that he would earn elsewhere, plus a share of the surplus that his skills (together with the firm's capital stock) generate. Equation (4) indicates that firm's profit equals the sum of the profit it would earn if it were to employ a worker without firm-specific skills and its share of the surplus generated by the skilled worker.

We now show how $h(\theta)$ is determined in period one. Assume that there is no uncertainty, and that individuals can borrow and lend at a constant[4] rate of interest r. Then in period one, the worker of type θ in sector H chooses $h(\theta)$ to maximize his lifetime wage income, net of effort cost:

$$M(\theta) \equiv W_1(\theta) - \frac{C(h)}{\theta^z} + \frac{1}{(1+r)}\left(W_G + (1-\beta)\mu h P_2\right) \tag{5}$$

where he takes the first period wage, $W_1(\theta)$ as given. (Note that $\theta^z > 0$.because $\theta > 0$.) Solving this maximization problem yields the first order condition

$$\frac{(1-\beta)\mu P_2}{(1+r)} - \frac{C'(h(\theta))}{\theta^z} = 0 \tag{6}$$

and the second order condition

$$-C''(h(\theta)) < 0.$$

specifies how much human capital the worker must acquire, as well as wage rates $W_1$and W_2.

[4]The question of how r is determined will be addressed in a subsequent section.

Condition (6) says that a worker acquires firm specific human capital to the point where the discounted marginal gain in wage income in period two is equated to the marginal effort cost that the worker has to pay in period one to acquire the skills.

In order to get a closed form solution for $h(\theta)$ we assume a particular functional form for costs. We parametrize the cost function by

$$\frac{1}{\theta^z}C(h(\theta)) = \frac{Ah(\theta)^{1+v}}{(1+v)\theta^z} \qquad A > 0, v > 1 \tag{7}$$

The parameter A represents the non-idiosyncratic learning cost specific to an individual country. Comparing these costs across countries a large A might be associated with poor schools, inadequate libraries, or lack of access to the internet. Using this parameterization we can solve (6) for the worker's *optimal* level of firm-specific human capital, $h^*(\theta)$. Using (6) and (7)

$$\frac{Ah^*(\theta)^v}{\theta^z} = \frac{(1-\beta)\mu P_2}{1+r} \tag{8}$$

Solving we get

$$h^*(\theta) = h^*(P_2, \mu, \beta, A, r, \theta) = \left[\frac{\theta^z(1-\beta)\mu P_2}{A(1+r)}\right]^{1/v} \tag{9}$$

It will be useful to define

$$B \equiv \frac{(1-\beta)\mu}{A(1+r)} \tag{10}$$

so that

$$h^*(\theta) = [\theta^z B P_2]^{1/v} \tag{11}$$

From (8) and ((7), the optimized cost is

$$\frac{1}{\theta^z}C(h^*(\theta)) = \frac{[Ah^*(\theta)^v]h^*(\theta)}{(1+v)\theta^z} = \frac{(1-\beta)\mu P_2 h^*(\theta)}{(1+r)(1+v)} \tag{12}$$

Using (9) and considering for the moment the case in which the second period price is exogenous (the small country open economy case) we get a number of very intuitive results. First, in the case $z > 0$, workers with lower learning cost (i.e., higher θ) accumulates more human capital:

$$\frac{\partial h^*}{\partial \theta} = z\theta^{(z-v)/v}\left[BP_2\right]^{1/v} > 0 \text{ if } z > 0. \tag{13}$$

Higher second period prices and more productive technology result in workers accumulating higher levels of human capital:

$$\frac{\partial\left[h^*(\theta)\right]^v}{\partial P_2} = \frac{\theta^z(1-\beta)\mu}{A(1+r)} > 0, \qquad \frac{\partial\left[h^*(\theta)\right]^v}{\partial \mu} = \frac{\theta^z(1-\beta)P_2}{A(1+r)} > 0 \tag{14}$$

On the other hand, more bargaining power on the part of the firm and higher learning cost leads to less investment in human capital.

$$\frac{\partial\left[h^*(\theta)\right]^v}{\partial \beta} = \frac{-\theta^z\mu P_2}{A(1+r)} < 0, \qquad \frac{\partial\left[h^*(\theta)\right]^v}{\partial A} = \frac{-\theta^z(1-\beta)\mu P_2}{A^2(1+r)} < 0 \tag{15}$$

Using (3) and (11) we can solve for $W_2(\theta)$

$$W_2(\theta) = W_G + \mu(1-\beta)\left(\theta^z B\right)^{1/v} P_2^{(1+v)/v} = W_G + (1-\beta)\mu h^*(\theta)P_2 \tag{16}$$

thus $W_2(\theta)$ is increasing in P_2 and non-decreasing in θ.

Substituting (10) into (16) we get

$$W_2(\theta) = W_G + (1-\beta)\left[\theta^z B P_2\right]^{1/v}\mu P_2 \tag{17}$$

Another useful expression for W_2 is obtained by using (17), (10) and (11):

$$W_2(\theta) = W_G + \frac{(1+r)A}{\theta^z}h^*(\theta)^{1+v} \tag{18}$$

Next we determine the wage $W_1(\theta)$ of a sector-H worker of type θ in period one. To do this, we must first pin down the wages of the marginal worker $\widehat{\theta}$ (the one who is indifferent between being employed in the general sector, and being employed in the high-tech sector). We assume that prior to period 1 all workers are mobile. This means that in equilibrium the expected lifetime income (net of effort cost) of the marginal sector-H worker $\widehat{\theta}$ must be equal to the alternative lifetime income that he could obtain in sector G:

$$M(\widehat{\theta}) = W_G[1 + \frac{1}{1+r}] \tag{19}$$

Using (19), (5), for $\theta = \widehat{\theta}$, and (12),

$$W_G[1+\frac{1}{1+r}] = W_1(\widehat{\theta}) - \frac{(1-\beta)\mu P_2 h^*(\widehat{\theta})}{(1+r)(1+v)} + \frac{1}{1+r}\left(W_G + (1-\beta)\mu h^*(\widehat{\theta})P_2\right) \tag{20}$$

This simplifies to

$$W_1(\widehat{\theta}) = W_G + \left[\frac{(1-\beta)\mu P_2 h^*(\widehat{\theta})}{(1+r)(1+v)}\right] - \frac{1}{1+r}(1-\beta)\mu h^*(\widehat{\theta})P_2 \qquad (21)$$

Equation (21) says that in period 1, the employer pays the marginal worker $\widehat{\theta}$ his outside wage, plus the cost of firm-specific education (the expression inside the square brackets [...]), minus the discounted value of the surplus[5] that the employee can expect to capture in period 2.

We can write (21) as

$$W_1(\widehat{\theta}) = W_G - \frac{v}{(1+v)(1+r)}(1-\beta)\mu h^*(\widehat{\theta})P_2 < W_G \qquad (22)$$

From (18) and (22), we have the following relationship, for the *marginal* high-tech worker:

$$W_2(\widehat{\theta}) > W_G > W_1(\widehat{\theta}) \qquad (23)$$

To explain the second inequality in (23), that is, why the *marginal* high-tech worker gets a lower salary in period 1 than what he would get if he would work in the general sector G, we point to the fact that his employer offers him a lower wage in period 1 because she wants to extract from him, in period 1, the surplus that he expects to get in period 2 ($\beta\mu S(\widehat{\theta})$, net of his directly incurred effort cost), so that the marginal worker is indifferent between employment in sector H and in sector G. The worker is willing to accept a wage lower than W_G because his training would not be possible without access to the firm's unit of capital. His *total* cost of acquiring a positive h consists therefore of the firm's charge for access to capital, as reflected in lower period 1 wage) and his effort costs. Our result is consistent with the literature on "*on-the-job training*", see Gary Becker (1964).[6]

We now turn to the determination of $\widehat{\theta}$ itself. Recall that there are N_H units of capital. Due to our assumption of the Leontief-type technology, there can be at most N_H workers in sector H. We will focus on the case where all units of capital are used. Then $\widehat{\theta}$ must satisfy

$$\int_{\widehat{\theta}}^{\theta_b} f(\theta)d\theta = \frac{N_H}{N} \qquad (24)$$

[5]This equation reflects the theory of on-the-job training, developed by Gary Becker (1964).

[6]Clearly, in general, there exist intramarginal workers with lower learning costs than the marginal worker (those with $\theta > \widehat{\theta}$) for whom $W_G < W_1(\theta)$.

where $f(\theta)$ is the density function, with

$$\int_{\theta_a}^{\theta_b} f(\theta)d\theta = 1.$$

(For example, in the special case of a uniform density, $f(\theta) = 1/[\theta_b - \theta_a]$, (24) gives

$$\frac{\theta_b - \widehat{\theta}}{\theta_b - \theta_a} = \frac{N_H}{N} \equiv n_H$$

i.e., $\widehat{\theta} = \theta_b - n_H(\theta_b - \theta_a)$.)

Having determined $\widehat{\theta}$ and $W_1(\widehat{\theta})$, we can now determine the wage structure for workers who have *lower* learning costs than the marginal high-tech worker, i.e. all $\theta \geq \widehat{\theta}$. We first solve for the value of $W_1(\theta)$ for all $\theta \geq \widehat{\theta}$, by appealing to the equilibrium condition that all sector -H firms, by competing for workers, must earn the same discounted sum of profit:

$$\pi_1(\theta) + \frac{1}{1+r}\pi_2(\theta) = \pi_1(\widehat{\theta}) + \frac{1}{1+r}\pi_2(\widehat{\theta}) \equiv \Pi(\widehat{\theta}), \qquad \theta \geq \widehat{\theta} \tag{25}$$

where

$$\Pi(\widehat{\theta}) = P_1 - W_1(\widehat{\theta}) + \frac{1}{1+r}\left[\pi_R + \beta\mu h^*(\widehat{\theta})P_2\right] \tag{26}$$

and

$$\pi_2(\theta) = \pi_R + \beta\mu h^*(\theta)P_2$$

It follows that

$$-W_1(\theta) + \frac{1}{1+r}\beta\mu h^*(\theta)P_2 = -W_1(\widehat{\theta}) + \frac{1}{1+r}\beta\mu h^*(\widehat{\theta})P_2$$

i.e.,

$$W_1(\theta) = W_1(\widehat{\theta}) + \frac{1}{1+r}\beta\mu P_2\left[h^*(\theta) - h^*(\widehat{\theta})\right] \geq W_1(\widehat{\theta}) \tag{27}$$

where $h^*(\theta)$ is an increasing function of θ, by (13) for all $\theta \geq \widehat{\theta}$. Workers with lower learning costs earn higher first period wages. They also earn higher wages in the second period as well, as can be seen from (3) and (13).

Using (22) and (27)

$$W_1(\theta) = W_G - \frac{v}{(1+v)(1+r)}(1-\beta)\mu h^*(\widehat{\theta})P_2 + \frac{1}{1+r}\beta\mu P_2\left[h^*(\theta) - h^*(\widehat{\theta})\right] \quad (28)$$

Subtracting (28) from (3), we get a measure of the steepness of the wage profile, for $\theta \geq \widehat{\theta}$

$$\Delta W_t(\theta) \equiv W_2(\theta) - W_1(\theta) =$$

$$(1-\beta)\mu P_2\left[h^*(\theta) - h^*(\widehat{\theta})\frac{v}{(1+v)(1+r)}\right] - \frac{\beta\mu P_2}{1+r}\left[h^*(\theta) - h^*(\widehat{\theta})\right] \quad (29)$$

from which we get:

$$\frac{\partial\left[\Delta W_t(\theta)\right]}{\partial\theta} = (1-\beta)\mu P_2\left[1-\beta-\frac{\beta}{1+r}\right]\frac{\partial h}{\partial\theta}$$

This shows that the steepness is greater for workers with higher θ if and only if

$$\beta < (1+r)/(2+r). \quad (30)$$

Thus, *workers with higher θ earn higher wages in each period and, if $\beta < (1+r)/(2+r)$, they also have steeper wage profiles.*

Note that if P_2 is exogenous, then, we can easily compute the effect of technological progress (in the sense of an increase in μ) on the wage rates. Since, from (11),

$$\mu h^*(\theta) = \mu^{(1+v)/v}\left[\frac{\theta^z(1-\beta)P_2}{A(1+r)}\right]^{1/v} \quad (31)$$

$$\frac{\partial\left[\mu h^*(\theta)\right]}{\partial\mu} = \frac{1+v}{v}\left[\frac{\theta^z(1-\beta)\mu P_2}{A(1+r)}\right]^{1/v} = h^*(\theta)\left(\frac{1+v}{v}\right) > 0 \quad (32)$$

we obtain from (28)

$$\frac{\partial W_1(\theta)}{\partial\mu} = -\frac{(1-\beta)}{1+r}P_2 h^*(\widehat{\theta}) + \frac{\beta P_2}{1+r}\left(\frac{1+v}{v}\right)\left[h^*(\theta) - h^*(\widehat{\theta})\right]$$

Thus, for the marginal worker

$$\frac{\partial W_1(\widehat{\theta})}{\partial\mu} < 0 \quad (33)$$

(implying that, with a greater productivity parameter, the firm charges the *marginal* worker more for the use of capital in on-the-job learning). On the other hand, from (3) and (32),

$$\frac{\partial W_2(\theta)}{\partial \mu} = (1-\beta)P_2 h^*(\theta)\left(\frac{1+v}{v}\right) > 0, \qquad \theta \geq \widehat{\theta} \tag{34}$$

that is, a higher μ will increase the second period wage. Does a higher μ will *increase the steepness of the wage profile* in sector H ? From (29),

$$\frac{\partial\left[\Delta W_t(\theta)\right]}{\partial \mu} = (1-\beta)P_2\left[h^*(\theta)\frac{1+v}{v} - \frac{h^*(\widehat{\theta})}{1+r}\right] - \frac{\beta P_2}{1+r}\left(\frac{1+v}{v}\right)\left[h^*(\theta) - h^*(\widehat{\theta})\right] \tag{35}$$

Condition (30) is sufficient condition for this expression to be positive.

In the next subsection we determine autarky equilibrium. Here the complication is that the second period price is endogenous.

2.3 Autarkic Equilibrium

To solve for an autarkic equilibrium, we must specify the demand side. The question of how r is determined should also be addressed. This can be done most simply by assuming that individuals maximize life-time utility $U_1 + \delta U_2$ where U_t is quasi-linear, i.e., $U_t = V(X_{Ht}) + X_{Gt}$, and δ is a constant, $0 < \delta < 1$ and $V(.)$ is strictly concave and increasing. Then, in equilibrium, $1/(1+r) = \delta$. We assume that positive amounts of each good are consumed in each period.

The consumer of type θ solves the following intertemporal maximization problem

$$\max_{X(\theta)} X_{G1}(\theta) + V(X_{H1}(\theta)) + \delta X_{G2}(\theta) + \delta V(X_{H2}(\theta)) \tag{36}$$

subject to

$$X_{G1}(\theta) + P_1 X_{H1}(\theta) + \frac{1}{1+r}(X_{G2}(\theta) + P_2 X_{H2}(\theta)) = M(\theta) \tag{37}$$

where $M(\theta)$ is his life-time disposable income (net of learning effort cost) and $X(\theta) = (X_{G1}(\theta), X_{H1}(\theta), X_{G2}(\theta), X_{H2}(\theta))$. We consider interior solutions (i.e., $X_{Ht}(\theta) > 0$ and $X_{Gt}(\theta) > 0$ for $t = 1, 2$.)

For our purposes we are concerned with the demand for period two consumption[7]. Solving the consumer problem above yields the inverse demand function:

$$V'(X_{H2}(\theta)) = P_2$$

from which we obtain the demand function, for all $\theta \in [\theta_a, \theta_b]$,

$$X_{H2}(\theta) = D(P_2) \tag{38}$$

where $D' < 0$. Thus all consumers have the same demand for good H in period 2. (Differences in incomes affect only the levels of consumption of the numeraire good.)

Supply of period two goods by firm θ (for $\theta \geq \widehat{\theta}$) is given by

$$q_{H2}(\theta) = (1 + \mu h^*(\theta)) \tag{39}$$

where $\mu h^*(\theta)$ is given by (31). Since the probability density that a high-tech firm is matched with a worker of type θ, given that only those workers with $\theta \geq \widehat{\theta}$ work in the high-tech sector, is $f(\theta)/[1 - F(\widehat{\theta})]$, and since N_H is the measure of firms, total supply of good H in period 2 is

$$Q_{H2} = \int_{\widehat{\theta}}^{\theta_b} N_H q_{H2}(\theta) \frac{f(\theta)}{1 - F(\widehat{\theta})} d\theta$$

$$= N_H + N_H \mu \left[BP_2\right]^{1/v} R \tag{40}$$

where

$$R \equiv \int_{\widehat{\theta}}^{\theta_b} \frac{\theta^{z/v} f(\theta)}{1 - F(\widehat{\theta})} d\theta \equiv E\left[\theta^{z/v} \mid \widehat{\theta}\right]$$

is the conditional expectation of $\theta^{z/v}$, given $\widehat{\theta}$. (In the special case where $z = 0$ we have $R = 1$.) Notice that even though the number of firms is fixed and each firm employs only one worker, from (40), an increase in P_2 will increase supply, because a higher P_2 encourages human capital accumulation.

Let λ denote the ratio of capitalists to workers. Capitalists have equal shares in all firms of sector H. (There are no profits in sector G.) The total population is $(1 + \lambda)N$. We assume that capitalists have the same utility

[7]The problem of first period consumption is separable and has no impact on human capital decisions or on wages.

functions as workers. Then $D(P_{2A})$ is the representative agent's demand for good H in period 2. Equating demand to supply we obtain

$$(1+\lambda)ND(P_{2A}) = N_H + N_H\mu R\left[BP_{2A}\right]^{1/v} \tag{41}$$

This equation determines the equilibrium autarkic price P_2, which we denote by P_{2A}. Next we substitute P_{2A} into (28) to obtain the period one autarkic wage

$$W_{1A}(\theta) = W_G - \frac{v}{(1+v)(1+r)}(1-\beta)\mu h^*(\widehat{\theta})P_{2A} + \frac{1}{1+r}\beta\mu P_{2A}\left[h^*(\theta) - h^*(\widehat{\theta})\right] \tag{42}$$

where $\mu h^*(\theta)$ is given by (31). Finally, using (16) we have

$$W_{2A}(\theta) = W_G + \mu(1-\beta)\left(\theta^z B\right)^{1/v} P_{2A}^{(1+v)/v} \tag{43}$$

We are interested in finding out how our endogenous variables $(W_{1A}(\theta), W_{2A}(\theta), P_{2A})$ vary across countries. To do that we determine how these variables change with changes in our parameters (A, μ, β, n_H) where $n_H = N_H/N$.

2.4 Autarky Results

From (41), we get the autarkic equilibrium price P_{2A} of a country as a function of the parameters n_H, μ, A and β. Differentiating (41) totally, we obtain

$$JdP_{2A} = \left(1 + \mu RB^{1/v}P_{2A}^{1/v}\right)dn_H$$

$$+\frac{n_H}{v}\mu RP_{2A}^{1/v}B^{(1-v)/v}dB + n_H RB^{1/v}P_{2A}^{1/v}d\mu \tag{44}$$

where,

$$J \equiv \left((1+\lambda)D' - \frac{n_H}{v}\mu RB^{1/v}P_{2A}^{(1-v)/v}\right) < 0$$

and, using the definition of B given in (10),

$$\frac{dB}{B} = \frac{d\mu}{\mu} - \frac{d(1+r)}{1+r} - \frac{dA}{A} + \frac{d(1-\beta)}{1-\beta} \tag{45}$$

We can therefore state the following comparative statics results:

Proposition 1

(i) An increase in n_H will reduce the second period price P_{2A}

$$\frac{\partial P_{2A}}{\partial n_H} = \frac{1}{J}\left(1 + \mu R B^{1/v} P_{2A}^{1/v}\right) < 0 \tag{46}$$

(ii) An increase in A will increase the second period price P_{2A}

$$\frac{\partial P_{2A}}{\partial A} = -\frac{1}{J}\left(\frac{1}{A}\right)\frac{n_H}{v}\mu R P_{2A}^{1/v} B^{1/v} > 0 \tag{47}$$

(iii) An increase in μ will reduce the second period price P_{2A} :

$$\frac{\partial P_{2A}}{\partial \mu} = \frac{1}{J}\left(\frac{1+v}{v}\right) n_H R P_{2A}^{1/v} B^{1/v} < 0 \tag{48}$$

Remark: Result (i) is obvious because a higher n_H increases supply relative to demand, at any given price. Result (ii) is also plausible, because higher cost of human capital accumulation will result in *a lower rate of accumulation*, thus a fall in output at any given price. This entails a fall in the autarky equilibrium price. Finally, a higher μ will increase human capital accumulation at any given P_2, resulting in a greater supply of good H in period 2 at any given P_2 (i.e., a rightward shift in the supply curve), and hence the equilibrium price must fall in autarky (given that the demand curve is downward-sloping).

The effects of changes in the parameters μ, A, and n_H on second period wage can be computed from (16):

$$\frac{\partial W_{2A}(\theta)}{\partial n_H} = \frac{\partial W_{2A}}{\partial P_{2A}}\frac{\partial P_{2A}}{\partial n_H} < 0 \tag{49}$$

$$\frac{\partial W_{2A}(\theta)}{\partial \mu} = \frac{\partial W_{2A}(\theta)}{\partial \mu}\Big|_{P_{2A} const} + \frac{\partial W_{2A}}{\partial P_{2A}}\frac{\partial P_{2A}}{\partial \mu} \tag{50}$$

which is ambiguous in sign. Similarly, $\frac{\partial W_{2A}(\theta)}{\partial A}$ is also ambiguous in sign.

3 Direction of Trade and Wage Gaps

In this section, we assume that the economy under consideration is under autarky in period 1. We consider two scenarios. Under scenario 1, the economy remains under autarky in period 2, and everyone knows this in period 1. Under scenario 2, the economy will be open to free trade in period

2, and this is also known in period 1. We call the first scenario the autarky scenario, and the second one the free trade scenario. We assume that the country produces both goods in each period, under either scenario. (This is the *incomplete specialization* assumption.)

We consider a two-country world in which countries differ in endowments (n_H), technology (μ), and the cost of education (A).[8] If the two countries differ only in the parameter n_H, then, as shown in the Appendix, the country with a greater n_H will have a lower autarkic price P_{2A}. This country will therefore export the high-tech good under free trade. This is an *endowment-based* explanation of trade.

If the two countries have identical n_H, then, ceteris paribus, the country with a higher μ will have a lower autarkic price P_{2A}, and therefore export the high-tech good under free trade. This is a *technology-based* explanation of trade. Similarly, difference in A provides an *education-cost-based* explanation of trade.

More generally, for any given country, if its second period autarkic price P_{2A} of the high-tech good is smaller [respectively, greater] than the free trade world price P_{2T} of that good, then the opening of trade in period 2 (fully anticipated in period 1) will make that country an exporter[9] [respectively, importer] of the high-tech good in period 2. Let us denote variables of a country by a superscript e (m) if it exports (imports) the high-tech good after the opening of trade. We next determine the effects of free trade on wage gaps.

Let $W_{2T}^e(\theta)$ [respectively, $W_{2T}^m(\theta)$] be the second period wage of a type θ worker in the high-tech sector of a country that exports [respectively, imports] the high-tech good under the free trade scenario. Let $W_{2A}^e(\theta)$ [respectively, $W_{2A}^m(\theta)$] be the second period wage of a type θ worker in the high-tech sector of the same country under the autarky scenario.

We begin by considering *within-country* wage gaps. We call $W_{2T}^e(\theta)$ - W_G the wage gap (between skilled workers of type $\theta \geq \widehat{\theta}$ and unskilled ones) under free trade, of a high-tech exporting economy. We want to compare this gap to the corresponding wage gap under autarky, $W_{2A}^e(\theta) - W_G$. Similarly, $W_{2T}^m(\theta)$ -W_G is called the wage gap under free trade, of a high-tech importing economy. We want to compare this gap to the corresponding wage gap under

[8]The cost of education varies across individuals in each country, but differences in A reflect cross-country differences in education cost.

[9]See Appendix 1 for analysis of equilibrium world price P_{2T} in a two-country world.

autarky, $W_{2A}^{m}(\theta) - W_G$.

Proposition 2: (Effect of trade on wage gaps) For each type θ worker in the high-tech sector,

(i) free trade increases the wage gap in the high-tech exporting country (relative to its wage gap under autarky),

(ii) free trade reduces the wage gap of the high-tech importing country (relative to its wage gap under autarky), and

(iii) the increase (or decrease) is greater for workers who have a greater learning ability, θ.

Proof: For (i), we must show that $W_{2T}^{e}(\theta)$-W_G exceeds $W_{2A}^{e}(\theta) - W_G$. For an exporting country, $P_{2T}^{e} \geq P_{2A}^{e}$. Therefore, using (16),

$$W_{2T}^{e}(\theta) \geq W_{2A}^{e}(\theta) \tag{51}$$

For (ii), note that for an importing country, $P_{2A}^{m} \geq P_{2T}^{m}$. Therefore

$$W_{2A}^{m}(\theta) - W_G \geq W_{2T}^{m}(\theta) - W_G \tag{52}$$

For (iii), we must show that

$$\frac{\partial}{\partial\theta} W_{2T}^{e}(\theta) > \frac{\partial}{\partial\theta} W_{2A}^{e}(\theta) \tag{53}$$

Using (16),

$$\frac{\partial}{\partial\theta} W_{2T}^{e}(\theta) = (z/v)\theta^{(z/v)-1} B^{1/v}(1-\beta)\mu \left[P_{2T}^{e}\right]^{(1+v)/v} > 0$$

Similarly

$$\frac{\partial}{\partial\theta} W_{2A}^{e}(\theta) = (z/v)\theta^{(z/v)-1} B^{1/v}(1-\beta)\mu \left[P_{2A}^{e}\right]^{(1+v)/v} > 0$$

Thus (53) is proved. A similar argument applies to the importing country.

Remark: Proposition 2 shows that the effect of international trade on the wage gap between skilled and unskilled workers depends on the pattern of trade. Countries that export the high-tech good will see the wage gap increase, but importing countries will actually find that the wage gap decreases with the opening of trade. The intuition for these results is clear. For example, in the country that exports the high-tech good the opening of trade will increase the price of the high-tech good. This increases profits in that industry and since skilled workers bargain with firms over wages the workers will share in those increased profits through the bargaining process. We can also use these results to say something about *inter-country* wage gaps.

Corollary: The difference between the wage of skilled workers in the exporting economy and that in the importing economy under free trade, $W_{2T}^{e}(\theta) - W_{2T}^{m}(\theta)$, exceeds the autarkic difference, $W_{2A}^{e}(\theta) - W_{2A}^{m}(\theta)$.

Proof: From (52),

$$-W_{2T}^{m}(\theta) \geq -W_{2A}^{m}(\theta) \tag{54}$$

Adding (51) to (54),

$$W_{2T}^{e}(\theta) - W_{2T}^{m}(\theta) \geq W_{2A}^{e}(\theta) - W_{2A}^{m}(\theta) \tag{55}$$

Remark: Trade will also increase the wage gap between skilled workers across countries. Workers in the high-tech sector in the exporting country will see their wage rise relative to their counterparts in countries that import the high-tech good. This is a direct consequence of the fact that skill premia are increasing in the exporting country, but decreasing in the importing country.

When trade is *endowment-based,* equation (55) has a special interpretation as explained in the next proposition.

Proposition 3: (Wage equalization) If trade is *endowment-based*, second-period wages for type-θ workers are *equalized* (for a given θ) across countries under free trade, given the incomplete specialization assumption. The country that exports the high-tech good under free trade has low autarkic wages of skilled workers.

Proof: From (16), $W_{2T}^{e}(\theta) = W_{2T}^{m}(\theta)$ if countries differ only in n_H. With endowment-based trade, the left-hand side of (55) is zero, implying $W_{2A}^{e}(\theta) \leq W_{2A}^{m}(\theta)$.

Remark: On the other hand, if trade is *technology-based*, driven by, for example, the difference in μ, ($\mu^e > \mu^m$), then, as is clear from (16),

$$W_{2T}^{e} - W_{2T}^{m} = (1-\beta)\left[\frac{\theta^{z}(1-\beta)}{A(1+r)}\right]^{1/v}\left[(\mu^{e})^{(1+v)/v} - (\mu^{m})^{(1+v)/v}\right] P_{2T}^{(1+v)/v} \geq 0 \tag{56}$$

that is, under free trade, the wage of skilled workers in the exporting country is higher than in the importing country. Then the left-hand side of (55) is positive, and the right-hand side may be positive or negative.

We next turn to consideration of how trade affects the decisions of workers about how much human capital to accumulate.

Proposition 4: (Effect of trade on human capital accumulation) The opening of trade increases the accumulation of human capital in the country whose autarkic price $P_{2A}(\theta)$ is lower than the free-trade price $P_{2T}(\theta)$, and decreases the accumulation of human capital in the country whose autarkic price $P_{2A}(\theta)$ is higher than the free-trade price $P_{2T}(\theta)$.

Proof: From (9), and $P_{2A}^{e} < P_{2T}$

$$h_A^{*e}(\theta) < h_T^{*e}(\theta)$$

Similarly, $h_A^{*m}(\theta) > h_T^{*m}(\theta)$.

Remark: In addition to price effects trade also has an influence on human capital accumulation. Proposition 4 shows that trade enhances human capital accumulation in countries that export the high tech good and reduces human capital accumulation in the importing country. This result is important because it implies that, to some extent, *trade-induced wage gaps* are the result not only of direct price effects on wages but also due to the effect trade has on the *incentive* to accumulate human capital.

We next show that in the country that exports the high-tech good, favorable trade and technology changes tend to increase the wage gap. Define the wage gap for type θ in a high-tech exporting country for a given trade volume and level of technology to be $g(\theta) = W_2(\theta) - W_G$. Let us introduce *two disturbances* for this economy: it experiences a rise in μ (improved technology) and it confronts a flood of excess supply of good G from a collection of developing economies, which causes the relative price of good G to fall (i.e., the price P_2 rises, a favorable terms of trade shock.) Then the change in this economy's wage gap can be decomposed into two effects, namely the technology effect and the trade effect:

$$d\left(W_2(\theta) - W_G\right) = \frac{\partial\left(W_2(\theta) - W_G\right)}{\partial \mu} d\mu + \frac{\partial\left(W_2(\theta) - W_G\right)}{\partial P_2} dP_2$$

where, from (3), and (9), the technology effect is

$$\frac{\partial\left(W_2(\theta) - W_G\right)}{\partial \mu} \mid_{P_2=const} = (1-\beta)P_2\left[h^*(\theta) + \mu\frac{\partial h^*(\theta)}{\partial \mu} \mid_{P_2=const}\right] > 0 \quad (57)$$

and the trade effect is

$$\frac{\partial\left(W_2(\theta) - W_G\right)}{\partial P_2} \mid_{\mu=const} = \mu(1-\beta)\left[h^*(\theta) + P_2\frac{\partial h^*(\theta)}{\partial P_2} \mid_{\mu=const}\right] > 0 \quad (58)$$

Taken together equations (57) and (58) imply that favorable technology and trade shocks tend to increase the wage gap in the high-tech exporting country, while unfavorable shocks will reduce the wage gap. From these equations we can state proposition 5.

Proposition 5: In the country that exports the high-tech good, favorable (unfavorable) technology and trade shocks (i.e., increases in both μ and P_2, raise (reduce) the wage gap between skilled and unskilled workers. In the country that imports the high-tech good, a favorable technology shock (i.e., an increase in μ) combined with a favorable terms of trade trade shock (i.e., a fall in P_2, the price of the imported good) may increase the wage gap.

Remark: Notice that the increases in the wage gap will be larger for workers with higher θ.

4 Extensions

4.1 Income Distribution

In this subsection we analyze the effect of trade and capital accumulation on income distribution. We will first consider the case special case where $z = 0$, because it is simpler, and then we will consider the general case $z \geq 0$.

4.1.1 The special case where $z = 0$

In the *special case* where $z = 0$, the parameter θ has no effect on learning cost (because $\theta^z = \theta^0 = 1$), so workers within a given country are ex ante identical, and no matter which industry they choose to work in, their life-time income (net of effort cost), in terms of good G, is $W_G(1 + \frac{1}{1+r})$. By assumption of an interior solution, they consume both goods. Capitalists (owners of the physical capital stock) also consume. To keep the analysis clear we assume that workers are not shareholders. Then, when a country changes its trading status from autarky to exporter of the high-tech good, the domestic price P_2 rises, and workers are worse off. They would therefore prefer autarky to free trade. Capitalist's profit is increasing in P_2. Thus, capitalists in the high-tech sector prefer exporting to autarky, provided the increase in profit can overcompensate their loss of consumer surplus. (This condition is indeed satisfied; see Appendix 2.) For a country that would become an importer of the high-tech good under free trade, capitalists in the high-tech sector would prefer autarky to free trade, while the workers would prefer trade to autarky.

4.1.2 The general case where $z \geq 0$

In the general case, where z is not zero, to determine the effects of trade on welfare, we have to find out how the change in P_2 (from autarky to free trade) affects the real income of workers of type $\theta \geq \widehat{\theta}$. Let $M(\theta)$ denote the life time income net of effort cost. For the marginal worker $\widehat{\theta}$, $M(\widehat{\theta}) = W_G + W_G/(1+r)$ which does not change with trade. For $\theta \geq \widehat{\theta}$, let

$$W(\theta) = W_1(\theta) + \frac{1}{1+r} W_2(\theta)$$

then

$$M(\theta) = W(\theta) - \frac{1}{\theta^z} C(h^*(\theta)) \tag{59}$$

Using (27) and (16), we obtain, for $\theta \geq \widehat{\theta}$,

$$W(\theta) - W(\widehat{\theta}) = \frac{1}{1+r} \mu P_2 \left[h^*(\theta) - h^*(\widehat{\theta}) \right] \tag{60}$$

Thus, from (59), (60) and (12)

$$M(\theta) - M(\widehat{\theta}) = \left(\frac{1}{1+r} \right) \mu P_2 \left[h^*(\theta) - h^*(\widehat{\theta}) \right] \left[1 - \frac{1-\beta}{1+v} \right] \tag{61}$$

which, given that $z > 0$, is positive.

We need to modify the conclusions above since (61) implies that for workers of type θ sufficiently larger than $\widehat{\theta}$, income increases moving from autarky to free trade. We summarize this in the following proposition.

Proposition 6: (income distribution) For the high-tech good exporter, trade liberalization, by increasing the price P_2, makes workers in sector G and the marginal worker $\widehat{\theta}$ worse off in real terms, and makes some workers in sector H better off if their learning ability θ is sufficiently greater than $\widehat{\theta}$. Owners of high-tech capital are better off. (See Appendix 2A for a detailed proof.) For the the country that imports the high-tech good, with a marginal fall in P_2, if $z = 0$, all workers are better off and owners of capital in the high-tech sector are worse off, and *social welfare* falls. (See Appendix 2B.)

Remark: Proposition 6 implies that in the high-tech good exporting country, capitalists who own high-tech capital and highly skilled workers benefit from trade whereas less skilled workers (and capital owners in the general human capital sector, who earn zero profit) are worse off. For the country that imports the high-tech good, P_2 falls as compared to autarky, so , if $z = 0$, all workers are better off (recall that, with $z = 0$, they all earn $M(\widehat{\theta}) = W_G(1 + 1/r)$, which is unchanged) and capitalists are worse off, and it can be shown that *social welfare falls.* (See Appendix 2B.)

4.2 Externalities

We have assumed that the accumulation of human capital by a worker does not have direct spillover effects on other workers. In the endogenous growth literature, however, many authors argue that there exists significant spillovers. Let us indicate briefly how our model can be modified to take into account such beneficial externalities. An intuitively appealing formulation would be to modify our model by specifying that the parameter μ_i for individual i is an increasing function of the average amount $\bar{h}$ of accumulation of human capital in the industry and of N_H

$$\mu_i = \mu^0 + \phi(\bar{h}N_H), \qquad \phi' > 0 \tag{62}$$

The positive externality displayed in (62) implies that a laissez-faire regime would result in an inefficiently low level of accumulation of human capital. Since one person's investment in his human capital has a positive spillover effect on the human capital of others, the government of a small economy might want to pursue policies that increase the price of the high-tech good. This would mean that the country that imports the high tech good under free trade may have an incentive to prohibit such imports so as to raise the domestic price P_2, thus encouraging more human capital accumulation (as there is under-investment in human capital under laisez-faire). Of course, there would presumably be other policies that would be more efficient ways to deal with such externalities, but political or revenue considerations could lead to the adoption of protection.

4.3 Education Policy

In this subsection we briefly indicate how one might want to analyze education policy in the context of our model. One could think of education policy affecting two variables in our model, the cost of acquiring education, A or the productivity of education μ. Think of education policy as affecting μ. Let μ^0 denote the initial level of the variable μ. What is the marginal social benefit of a policy that directly gives rise to an increase in μ^0? Under free trade, for a small open economy, P_2 is exogenous and hence any increase in μ^0 to a higher value, say $\mu^0 + \varepsilon$, will increase h, i.e. increase human capital accumulation.

Under autarky, things are slightly different: any increase from μ^0 to $\mu^0+\varepsilon$ will cause the autarkic equilibrium price P_{2A} to fall to some level $\widetilde{P}_{2A} < P_{2A}^0$, and this may discourage human capital accumulation. Since the demand curve for good H is negatively sloped, this price fall means that the new equilibrium quantity consumed is greater than the old equilibrium quantity consumed. This in turns means that the new effective supply $(\mu^0 + \varepsilon)h(\mu^0 + \varepsilon, \widetilde{P}_{2A})$ exceeds the old $\mu^0 h(\mu^0, P_{2A})$, but we cannot be certain whether $h(\mu^0 + \varepsilon, \widetilde{P}_{2A})$ exceeds $h(\mu^0, P_{2A})$. Therefore, under autarky, a policy that directly increases μ may indirectly reduce h. If there are spillover effects in the economy, and if these effects depend on h rather than μh, then under autarky, a policy that increases μ could be harmful. To summarize, education policy that makes human capital more productive always improves welfare in a free trading economy. In an autarkic economy such an education policy may actually reduce welfare.

4.4 Uncertainty

We can introduce uncertainty about second period price, but the basic results go through. Let $s_1(\theta)$ be the amount of savings for a worker in period 1. At the beginning of period 2, when the uncertainty about period 2 price has been resolved, the worker knows that his second period wage is $W_G + \mu h(\theta) P_2$ and therefore his second period utility is

$$I_2 \left[P_2, h(\theta), s_1(\theta)\right] = \max_{X_{2H}} V\left(X_{2H}\right) + \left[s_1(\theta)(1+r) + W_G + (1-\beta)\mu h(\theta) P_2 - P_2 X_{2H}\right]$$

$$= V\left[D(P_2)\right] - P_2 D(P_2) + s_1(\theta)(1+r) + W_G + (1-\beta)\mu h(\theta) P_2$$

Notice that, since P_2 is not known in period 1, we cannot use the function $h^*(P_2, \mu, \beta, A, r, \theta)$ given in (9). We have, for any given $h(\theta)$,

$$\frac{\partial I_2}{\partial P_2} = -D(P_2) + (1-\beta)\mu h(\theta)$$

$$\frac{\partial^2 I_2}{\partial P_2^2} = -D'(P_2) > 0$$

$$\frac{\partial I_2}{\partial h(\theta)} = \mu P_2 > 0$$

$$\frac{\partial I_2}{\partial s_1(\theta)} = 1 + r$$

In the first period, before the uncertainty is resolved, the worker chooses $h(\theta)$ and $s_1(\theta)$ to maximize his expected two-period utility

$$EU = V(D_1(P_1)) + \left[W_1(\theta) - \frac{C(h(\theta))}{\theta^z} - s_1(\theta) - P_1 D_1(P_1)\right] + \delta E I_2\left[P_2, h(\theta), s_1(\theta)\right]$$

where E is the expectation operator (and the random variable is P_2).

It is clear from the above that in this simple formulation, uncertainty does not affect the decision on human capital investment: the worker simply chooses $h(\theta)$ to maximize

$$-\frac{C(h(\theta))}{\theta^z} + \delta(1-\beta)h(\theta)EP_2$$

which is the equivalent of (5).

5 Concluding Remarks

We have developed a model of firm-specific human capital accumulation and explored some of its implications. An important feature of our model is that human capital accumulation is endogenous: expectations of future trade liberalization would influence current decision on education. The effect of trade on the wage gap between high and low skill workers is shown to depend on whether a country is an exporter or importer of the high-tech good. We showed that trade liberalization *increases* the wage gap in the country that exports the high-tech good, and *decreases* the wage gap in the other country. In the country that exports the high-tech good, workers with low learning ability (low θ) and specific capital owners in the low-tech sector lose from free trade whereas high-tech specific capital owners and high learning ability workers gain from free trade. We also show that the wage gap may increase in an economy that imports the high-tech good, if that economy is subjected to two independent shocks: a technology shock and a terms of trade shock.

In the special case where all skilled workers earn the same net income (i.e., after subtracting education cost) as unskilled ones, we are able to show that a move from autarky to free trade will harm the country that imports the high-tech good under free trade. This "loss from trade" result [10] is due to the facts that (i) the labor market in period 2 is non-competitive: workers with firm-specific skills must bargain with their employers on second period wage, and (ii) firms and workers cannot enter into long-term contract conditional on the extent of human capital accumulation. Under these conditions, a fall in the price of the high-tech good, which discourages human capital accumulation, can be detrimental to welfare.

Other issues that can be considered within the framework of our model are: (i) a wage dispersion (Wood, 1994), (ii) political economy e.g., coalition of potential gainers and coalition of potential losers, (iii) brains drain, and migration e.g., since it is cheaper to accumulate high-tech human capital in advanced countries, there is an incentive to migrate to these countries.

APPENDIX 1
Determination of free trade equilibrium in a two-country world

Recall that, in the home country, the ratio of capitalists to workers is λ. Let the superscript f indicate variables of the foreign country. We assume that $\lambda^f = \lambda$. The home country's demand for good H in period two is $(1+\lambda)ND_2(P_2)$ and its supply of that good in period two is $Q_{H2}(P_2)$, where, using (40),

$$Q_{H2}(P_2) = N_H + N_H\mu R\,[BP_2]^{1/v} \tag{63}$$

Thus, the home country's excess supply function, $ES_2(P_2) \equiv Q_{H2}(P_2) - (1+\lambda)ND_2(P_2)$ is upward sloping, and intersects the price axis at a value denoted by P_{2A}.

The foreign country's demand for good H in period two is $(1+\lambda)N^fD_2(P_2)$ and its supply of that good in period two is $Q^f_{H2} = N^f_H + N^f_H\mu^f R^f\left[B^fP_2\right]^{1/v} \equiv Q^f_{H2}(P_2)$. Since $h^{*\prime}(P_2) > 0$ from (9), the foreign country's excess demand

[10] This contrasts with the standards "gains from trade" result (Kemp 1962,1995) which does not apply to models where workers and firms bargain over second period wage

function, $ED_2^f(P_2) = N^f D_2^f(P_2) - Q_{H2}^f(P_2)$ is downward sloping, and intersects the price axis at a value denoted by P_{2A}^f.

The free-trade equilibrium price P_{2T} must satisfy

$$ES_2(P_{2T}) = ED_2^f(P_{2T}) \tag{64}$$

Assume that $P_{2A}^f > P_{2A}$. Then there exists a unique free-trade equilibrium price P_{2T} , such that $P_{2A}^f > P_{2T} > P_{2A}$ and $ES_2(P_{2T}) = ED_2^f(P_{2T}) < 0$, indicating that the home country is the exporter of the high-tech good.

It is easy to see that in our model, $P_{2A}^f > P_{2A}$ if and only if, for all $P_2 \geq 0$,

$$n_H \left[1 + \mu R \left(\frac{(1-\beta)\mu}{A(1+r)}\right)^{1/v} P_2^{1/v}\right] > n_H^f \left[1 + \mu^f R^f \left(\frac{(1-\beta^f)\mu^f}{A^f(1+r^f)}\right)^{1/v} P_2^{1/v}\right] \tag{65}$$

Thus, if $n_H > n_H^f$ (with other parameters being the same for both countries), then the home country will be the exporter of the high-tech good; this is an *endowment-based* explanation of trade. Similarly, $\mu > \mu^f$ would give a *technology-based* explanation of home high-tech exports. $A < A^f$ would explain home exports of high-tech good in terms of lower *education cost.* $\beta < \beta^f$ would explain home exports of high-tech good in terms of lower *bargaining power* of home firms. $r < r^f$ would explain home exports of high-tech good in terms of *time preference* (a low interest rate encourages accumulation of human capital).

APPENDIX 2
Effects of free trade on income distribution

2 A: The impacts on the country that exports the high-tech good:

We first consider an open economy that *exports* the high-tech good under free trade. For this economy, the move from autarky to free trade may be represented by an increase in P_2 (relative to its autarkic P_{A2}). What are the effects of this increase on the welfare of workers and capital owners?

The indirect utility of a worker of type θ is obtained from the maximization problem described in section 2.3. This yields the demand functions

$$X_{H1}^*(P_1) = D_1(P_1),\ X_{H2}^*(P_2) = D_2(P_2) \tag{66}$$

where $D_t(.)$ is the inverse function of $V_t'(.)$. The demand for the numeraire good G can then be inferred from the budget constraint. Thus

$$X_{1G}^* + \frac{1}{1+r} X_{1G}^* = M(\theta) - P_1 D_1(P_1) - \frac{1}{1+r} P_2 D_2(P_2) \tag{67}$$

Substituting (66) and (67) into the direct utility function, and recalling that $\delta = 1/(1+r)$, we obtain the indirect life-time utility function

$$\mathcal{U}(P_1, P_2, M(\theta)) = V_1(D_1(P_1)) + \delta V_2(D_2(P_2)) + M(\theta) - P_1 D_1(P_1) - \delta P_2 D_2(P_2) \tag{68}$$

The effect of an increase in P_2 on the welfare of a worker of type θ is

$$\frac{d\mathcal{U}}{dP_2} = \delta V_2' D_2'(P_2) - \delta \left[P_2 D_2' + D_2 \right] + \frac{dM(\theta)}{dP_2} = -\delta D_2(P_2) + \frac{dM(\theta)}{dP_2}$$

For workers with $\theta \leq \widehat{\theta}$, their life-time income, net of education cost, is $M(\theta) = W_G(1 + \frac{1}{1+r})$ and therefore $\frac{dM(\theta)}{dP_2} = 0$. They are therefore made worse off by the rise in P_2. For workers with $\theta > \widehat{\theta}$, we use (31) and (61) to get

$$\frac{dM(\theta)}{dP_2} = \left(\frac{1}{1+r} \right) P_2^{1/v} \mu^{(1+v)/v} \left[\frac{1-\beta}{A(1+r)} \right]^{1/v} \left[1 - \frac{1-\beta}{1+v} \right] \left[(\theta)^{z/v} - \left(\widehat{\theta} \right)^{z/v} \right]$$

which is non-negative (positive if $z > 0$). Thus workers with sufficiently high learning ability will be better off under free trade.

For owners of capital in the high-tech sector, the indirect utility function is (68) with $M(\theta)$ replaced by the discounted sum of profits, which we denote by Π (which is the same for all firms in the high-tech sector, as we have argued in section 2.2, see equation (25) in particular.) From (26), (22) and (31),

$$\Pi(\theta) = \Pi(\widehat{\theta}) = P_1 - W_G + \left(\frac{1-\beta}{1+r} \right) \left(\frac{v}{1+v} \right) \mu h^*(\widehat{\theta}) P_2$$

$$+ \left(\frac{1}{1+r} \right) \left[P_2 - W_G + \beta \mu h^*(\widehat{\theta}) P_2 \right]$$

i.e.,

$$\Pi(\widehat{\theta}) = P_1 + \left(\frac{1}{1+r} \right) P_2 (1 + \mu h^*(\widehat{\theta})) - W_G \left(1 + \frac{1}{1+r} \right)$$

$$-\left(\frac{1-\beta}{1+r}\right)\left(\frac{1}{1+v}\right)\mu h^*(\widehat{\theta})P_2$$

It follows that

$$\frac{d\Pi(\widehat{\theta})}{dP_2} = \left(\frac{1}{1+r}\right)\left[(1+\mu h^*(\widehat{\theta})) + P_2\frac{d\mu h^*(\widehat{\theta})}{dP_2}\right]$$

$$-\left(\frac{1-\beta}{1+r}\right)\left(\frac{1}{1+v}\right)\left[\mu h^*(\widehat{\theta}) + P_2\frac{d\mu h^*(\widehat{\theta})}{dP_2}\right] > 0 \quad (69)$$

The term $1+\mu h^*(\widehat{\theta})$ is the second period output of firm $\widehat{\theta}$. In the usual text-book exposition of the theory of competitive firms, an increase in the price P_2 would raise profit by an amount equal to the output of the firm. That result does not apply here, because P_2 causes human capital accumulation, the fruit of which is shared between the firm and the worker. Here,

$$\frac{d\Pi(\widehat{\theta})}{dP_2} = \left(\frac{1}{1+r}\right)\left[1 + \left(1 - \frac{1-\beta}{1+v}\right)\frac{d\mu h^*(\widehat{\theta})P_2}{dP_2}\right]$$

where, from (31)

$$\frac{d\mu h^*(\widehat{\theta})P_2}{dP_2} = \left(\frac{1+v}{v}\right)\mu h^*(\widehat{\theta}) > 0$$

Thus

$$\frac{d\Pi(\widehat{\theta})}{dP_2} = \left(\frac{1}{1+r}\right)\left[1 + \left(\frac{v+\beta}{v}\right)\mu h^*(\widehat{\theta})\right] > 0 \quad (70)$$

The total profit gain to all capital owners in the high-tech sector is $\Omega \equiv N_H\left(\frac{1}{1+r}\right)\left[1+\left(\frac{v+\beta}{v}\right)\mu h^*(\widehat{\theta})\right]$, and, if $z=0$ so that $h^*(\theta) = h^*(\widehat{\theta})$ for all $\theta \geq \widehat{\theta}$, then Ω exceeds the (discounted) total output of the high-tech sector in period 2, which is $N_H(1+\mu h^*(\widehat{\theta}))/(1+r) = Q_2(P_{2A})/(1+r)$. Thus the gain in profits exceeds the loss of consumers surplus, $N(1+\lambda)D_2(P_{2A})/(1+r) = Q_2(P_{2A})/(1+r)$.

2 B: The impacts on the country that imports the high-tech good:

For a country that imports the high-tech good, the opening of trade amounts to a fall in P_2 relative to its autarkic price P_{2A}. A similar argument shows that, if $z=0$, the fall in P_2 will lead to a *net loss* of social welfare: the loss of profits outweighs the gains in consumers surplus.

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