*Training, Adverse Selection and Appropriate Technology: Development and Growth in a Small Open Economy**

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Abstract

Recent diffusion models cannot explain why the success of technology diffusion depends so critically on developing countries' human capital levels. This paper examines three main issues. First, we endogenize both appropriate technologies *and* human capital formation. Second, we refine the human capital accumulation process by introducing uncertainty about worker quality and training efficiency. Finally, we allow for international diffusion of technology as a function of the host country's endogenous ability to absorb technological spillovers. The resulting model is one of uneven growth where trade amplifies worker quality problems in laggard countries. In contrast, technology spillovers are shown to generate additional incentives to accumulate human capital in the laggard country, since this allows for faster adoption and diffusion of foreign technology in the future.

JEL: *O11, O31, O41.*
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1.0 Introduction

Recent refinements in the theory of economic growth examine the precise nature of technical change and human capital accumulation to better understand their influences on economic growth. For example, Barro and Sala-i-Martin (1997) model *costly imitation* instead of free foreign technology spillovers. Basu and Weil (1996), on the other hand, enriched the broad concept of technology by introducing *appropriate technologies* that are specific to particular input combinations. While continuous productivity increases based on technical change are important to development and growth, the recent empirical literature stresses that advanced countries' endogenously larger stocks of human capital are the result of their cumulative R&D activities (Coe, Helpman, and Hoffmaister, 1994). In response, Eicher (1996) suggested a model in which invention and adoption of technology require concurrent accumulation of human capital.

The above models cannot explain, however, why human capital build up is so crucial to the adoption of *foreign* technology as suggested by the empirical findings of Benhabib and Spiegel (1994), or why the success of technology diffusion depends so critically on the developing country's level of human capital (Borensztein, DeGregorio, and Lee, 1995). In Basu and Weil's (1996) AK model, adoption of appropriate technology takes time, but no skills. Barro and Sala-i-Martin (1997) assume workers with constant skill levels invent and imitate ever more sophisticated technologies, while Eicher (1996, 1998) does not allow for spillovers.

This paper examines three main issues. First, we endogenize both appropriate technologies *and* human capital formation. We assume that appropriate technologies are specific to particular skills, and that human capital is accumulated through firm training. Second, we refine the human capital accumulation process by introducing uncertainty about worker quality and training efficiency. Essentially, we combine an efficiency wage approach to labor markets with a model of endogenous accumulation of skills and technologies. We allow for trade and technological diffusion by extending an adverse selection model to the open economy, and by introducing an avenue for foreign technology spillovers. Here we are especially interested in how worker quality and informational asymmetries affect dynamic gains from trade. The uncertainty about training costs adds an additional dimension to the model that allows us to examine how changes in worker quality affect the efficiency wage, the production mix, the research effort, and therefore development and growth.

When we allow for international diffusion of technology, we specify that the size of the potential spillover is a function of the host country's endogenous ability to absorb new technology. In our examination of the diffusion process, we trace out not only the changes in technology as previous diffusion models have done; but we also examine the changes in domestic human capital accumulation in response to changes in the world rate of technical change.

We present a model of growth that is based on research effort and productivity increases in manufacturing production. Both research and production can only take place with appropriate technology, one that agents have been trained to master. Higher ability workers have a comparative advantage in learning about sophisticated technologies. However, firms' training costs are uncertain, because the quality of the worker applicant pool is unknown. Thus firms cannot ascertain workers' training efficiency ex ante, which renders hiring decisions to be subject to adverse selection problems. We assume that more sophisticated technologies generate higher training costs. This implies that technological progress and diffusion are constrained by the rate of training and human capital accumulation.

We find that relatively backward countries possess endogenously lower levels of human capital and technology. An increase in the relative price of the agricultural good then leads to a decline in research and in human capital accumulation beyond the well-known static contraction. First, we show that free trade amplifies (alleviates) the quality problems in manufacturing in the laggard (leader) country. This slows down (accelerates) the rate of training and contracts (expands) the manufacturing sector beyond the level indicated by the previous literature. In addition, the decreased amount of firm training provided in the laggard economy lowers the human capital growth in the economy. This implies that future technologies become even more costly to absorb into the manufacturing sector. Novel is that the slow down in human capital accumulation thus also lowers the country's ability to generate and absorb new technology, which forces yet an additional contraction of the manufacturing sector.

Once we allow for free spillovers of *appropriate technologies* from the rest of the world, we introduce an additional effect associated with diffusion. Beyond the well-known increase in technological change due to the free spillover, our model implies that diffusion may act as a powerful engine of development and growth through factor accumulation. Specifically, the fact that higher human capital investment today generates a more capable labor force that can absorb a greater amount of free technology spillovers in the future, accelerates human capital accumulation. Under these circumstances, firms are willing to pay higher efficiency wages to increase the quality of the manufacturing applicant pool, since more able workers have a comparative advantage at learning about new technologies. These gains from diffusion thus add significant new insights beyond those derived from previous costly imitation models.

Alternative models of technology transfer can be found in Grossman and Helpman (1991 Ch. 9), where time must elapse before technology can spread to laggard economies. In our model this time period is not arbitrarily fixed, but determined by the worker quality, training efficiency, and the endogenous level of human capital. Alternative mechanisms to slow down the rate of technological diffusion have been suggested by Parente and Prescott (1994) and by Eaton and Kortum (1994). Eaton and Kortum (1994) rely on patent protection, while Parente and Prescott (1994) present a model where technology diffuses slowly because countries might erect barriers that raise the cost of adoption. Barro and Sala-i-Martin (1995) present a summary of the diffusion discussion, but do not provide a model that allows for equilibria with ongoing innovation in all economies. In contrast, Keller (1997) provides evidence of the significant impact that "own" (domestic) R&D plays in OECD countries. Eaton and Kortum (1994) show that the five leading research economies do most of their research at home. Grossman and Helpman (1994) provide a survey of the literature.

The literature on the interrelationship between informational asymmetries and growth focuses almost exclusively on capital market imperfections (see, among others, Zeira, 1991, and Tsiddon, 1992). Eicher and Kalaitzidakis (1997) examine the effects of informational asymmetries in the labor market in a growth model with exogenous human capital. Labor market information asymmetries have not been extensively analyzed in the international trade literature.

Dixit (1989) models adverse selection problems between entrepreneurs and policy makers in an open economy. More frequent is, however, the moral hazard approach used to address commercial policy questions (e.g., Copeland, 1989, Bulow and Summers, 1986, Brecher, 1992, and Brecher and Choudhri, 1994). Informational asymmetries have been introduced into various other areas of the open economy. Markusen (1995) provides an exhaustive survey of the analysis of moral hazard problems associated with licensing agreements that multinationals face. Ethier (1986) examines incomplete contracts; and Dixit (1994) models migration decisions as a function of small open economy's stochastic terms of trade.

The empirical evidence for moral hazard in labor markets is scant. In contrast, Foster and Rosenzweig (1993) provide compelling evidence for the existence of adverse selection problems in labor markets. Their study concludes that higher productivity workers participate less in time-wage markets when the return to piece rate (self-employment) work increases. Foster and Rosenzweig also show that there is considerable ignorance among employers about workers' abilities in developing countries.

Section 2 introduces the model, Section 3.1 examines the adjustment when the country opens up to international trade and Section 3.2 examines the effects of international diffusion of knowledge. Finally, Section 4 concludes.

2.0 The Model

We assume a small open economy produces one agricultural and one manufacturing good with only one factor input, heterogeneous labor. Workers differ in their abilities to learn, but share the same level of general human capital. Worker quality is important to manufacturing firms because it determines the firms' training cost. Firms incur training costs because workers must learn to work with firm specific technologies, and firms must provide these skills through training. The training efficiency depends on worker quality, which contains both observable and unobservable components. Since firms cannot ascertain workers' training efficiencies with certainty ex ante, firms' hiring decisions are subject to adverse selection problems. The agricultural sector instead establishes a reservation wage through self-employment.

2.1 Agriculture

The agricultural sector is similar to Eicher and Kalaitzidakis (1997). Its purpose is to establish microeconomic foundations for a reservation wage. Alternatively, one could resort to the more prevalent assumption in adverse selection models and assume unemployment. Then, however, the model would collapse into one sector, and international trade extensions are far less interesting.

Two key assumptions pay tribute to the traditional notion of agricultural sectors. First, the sector is one of self-employment. Workers opt to work in agriculture when they do not find employment in manufacturing, or when the value of their marginal product in agriculture exceeds the wage they would receive in manufacturing. Second, we choose a linear production function not only to simplify matters, but also to reflect the traditional notion that the marginal product equals the average product in the agricultural sectors. The total output of the agricultural good, X, is given by

$$X_t = \sum_{i=0}^{L_t^X} H_t G[q(i)], \quad i \in [0, L], \quad G_q > 0, \tag{1}$$

Subscripts, except those referring to time, t, indicate partial derivatives. The total units of labor in the economy are represented by L, which divide themselves into agricultural and manufacturing employment, L_t^X and L_t^M, respectively. Productivity, $H_t G[q(i)]$ depends on the *quality* of the individual worker, which consists of two components: *observable human capital*, H_t, and *unobservable ability*, q. The average level of general human capital, H_t, (e.g., years of schooling) is observable to all.

Since each self-employed worker i knows her ability, q, there exist no informational asymmetries in the agricultural sector. Hence, the return to labor in agriculture is known with certainty to each individual. We label the value of the marginal product in agriculture the *reservation wage*, w_t^i, of worker i with human capital H_t at price p, or

$$w_t^i = H_t pG[q(i)] \qquad (2)$$

We choose manufacturing as the numeraire, so that *p* represents the relative price of the agricultural good. Given that higher quality workers have higher productivity, the following derivatives are straightforward: $¶w_t^i/¶H_t > 0$, $¶w_t^i/¶p > 0$, and $¶w_t^i/¶q > 0$. As we specify in detail below, general human capital increases endogenously over time, due to training spillovers in the manufacturing sector. Hence the reservation wage rises over time, while the human capital adjusted efficiency wage, w_t^i / H_t, is constant.

2.2 Manufacturing, Training and Innovation

To keep matters simple, we assume that each country possesses just one firm and one representative technology, A_t. The firm's production function for manufacturing output at time *t*, Y_t, is given by

$$Y_t = A_t L_t^Y \qquad (3)$$

Below, we suppress time subscripts unless they are necessary to avoid confusion. The productivity of labor depends on firm specific technology *A*. To be able to work with *A*, labor must possess sufficient firm specific skills. To acquire these skills, the employer provides and pays for training. Training introduces workers to the skills necessary to work with the technology that is used either in research or production. The training costs of the firm are assumed to be a function of quality. Specifically, we express the cost of training worker *i* as

$$C[q[q(i), H/A]], \quad \text{with } C'[.] < 0 \text{ and } C''[.] < 0, \qquad (4)$$

The training efficiency, $q[.]$, of worker *i* (i.e., how easily a worker attains new skills) is determined by three factors, ability, *q(i)*, general human capital, *H*, and the technology to be learned about, A. Since the individual ability, $q(i)$, is related to the reservation wage as specified in equation (2), we assume that we can write the training efficiency as $q[w^j,p,H/A]$, with $q_w > 0$, $q_{(H/A)} > 0$, and $q_p < 0$. The efficiency is thus still a positive function of the relative level of human capital to the technology at hand, since, given the same technology, workers with relatively higher human capital learn faster.

It is important to see that it is in the cost function (4) that the concept of appropriate technology is introduced for the first time. Instead of assuming with the previous literature that more sophisticated technologies increase output automatically, we specify that training costs are conditional on how the existing knowledge, H, relates to the specific technology that needs to be learned about.

The manufacturing sector is, however, marred by informational asymmetries. Firms hire workers whose training efficiency is not known with certainty to the employer. Manufacturers may observe general human capital level, H, relative to a technology A, but firms do not know the exact ability of each applicant, q (i.e., how fast an individual worker learns the technology). These informational asymmetries create an adverse selection problem. Firms realize, however, that the quality of the applicant pool deteriorates as the manufacturing wage declines, for any given level of observed human capital. While firms cannot observe the quality of worker i ex ante, they are capable of generating beliefs about the applicant pool's expected quality on the basis of workers' reservation wages. Since the reservation wage is increasing in q as seen in (2), firms may use the manufacturing wage, w, to influence the expected quality and training efficiency of their applicant pool.

Weiss [1980] first modeled adverse selection problems when firms hire heterogeneous workers with uncertain quality. He showed that such market imperfections lead employers to select workers on the basis of minimum cost per efficiency unit of labor. Nalebuff and Stiglitz [1982] extended the model to show that higher efficiency wages increase the expected ability of the applicant pool because lower quality applicants now have a smaller probability of being hired. Extending Weiss' [1990] model to technology and human capital accumulation, we assume firms base their hiring decisions on the *expected quality*, Q,

$$Q[w, H / A, p] = \frac{\int_0^w q[w^i, p, H / A]\Psi[w^i]dw^i}{\int_0^w \Psi[w^i]dw^i} \tag{5}$$

where $\Psi[w^i]$ gives the mass of workers with reservation wage ω^i. Equation (5) states that, given a given relative price, *p*, and a given wage offer, *w*, firms can expect an applicant with observable human capital, *H,* to possess quality, *Q*, when learning about technology *A*. From $q_w > 0$ and $q_p < 0$, it follows that $Q_w > 0$ and $Q_p < 0$. In addition, we assume that the expected quality increases in the level of observable human capital, or $Q_{(H/A)} > 0$, for a given technology and wage. Thus, the greater the workers' human capital level compared to the technology she has to learn about, the lower the training cost. We also assume that $Q_{pp} < 0$, $Q_{ww} > 0$, and $Q_{wp} = Q_{w(H/A)} = 0$, which implicitly imposes similar additional restrictions on the q[.] function.

We can now rewrite the firm's training cost per worker as

$$C[Q[w, H / A, p]] \tag{4'}$$

To simplify matters significantly, we assume that both *C*[.] and *Q*[.] exhibit constant elasticity of substitution.

In Eicher and Kalaitzidakis (1997) workers receive training, but each innovation was assumed to be drastic (Tirole 1988 p. 391), in the sense that new innovation caused total human capital depreciation. In this model we propose spillovers from specific skills and training to the general human capital pool of the economy. The simplest way to model this spillover is to assume that general human capital is a function of the fraction of workers that obtain training. The evolution of human capital can then be written as

$$\dot{H} = L^M H \tag{6}$$

where L^M is the total number of workers that the manufacturing sector hires and trains. The "dot" over variables represents time derivatives, or in the example above, $\dot{H} = ¶H / ¶t$.

Finally, we specify the means by which technology evolves. Once we allow for endogenous technological change, firms hire not only production workers, but also research workers, $\left(L^M - L^Y\right)$, to produce new technology. In line with our agenda of focusing on appropriate technologies, we specify that technology grows at the rate

$$\hat{A} = \left(L^M - L^Y\right)H / A, \tag{7}$$

where "^" represent proportional changes, or in the example above $\hat{A} = \dot{A} / A$. The rate of technological change thus depends not simply positively on either the level of technology or human capital as in previous R&D functions. Instead, the rate of change depends on how the human capital level relates to the level of technology in use. This captures the idea that, given a level of human capital, it becomes increasingly difficult to find innovations based on technologies that are relatively more unfamiliar to the researchers.

Since firms conduct research and produce with firm-specific technology, they must train not only production workers, but also researchers. In hiring for both positions, firms face an applicant pool with uncertain quality. To mitigate the informational asymmetry and to improve the quality of the applicant pool, the firm maximizes profits by offering an efficiency wage. Since the firm is large enough to recognize its effect on the general level of human capital, we write the present valued Hamiltonian as

$$AL^Y - \left(w + C\left[Q\left[w, H / A, p\right]\right]\right) \; HL^M + lH\left(L^M - L^Y\right) + mL^M H \tag{8}$$

where l represents the discounted shadow value of technology and m represents the discounted shadow value of human capital. Examining equation (8) from left to right, the first term represents total revenues and the last two terms are the accumulation constraints given in (6) and (7). The second term represents total labor costs, which are composed of wage plus training costs per efficiency unit of each worker hired into manufacturing. The Hamiltonian yields the following first order conditions:

$$l = A / H \tag{9a}$$

$$-1 = C'\left[Q\left[w, H / A, p\right]\right]Q_w\left[w, H / A, p\right] \quad (9b)$$

$$m = w + C[Q[w, H / A, p] - A / H \quad (9c)$$

$$\hat{l} = r - \frac{L^Y}{l} - \frac{L^M H^2 C'[w, H / A, p.]Q_A[w, H / A, p.]}{A^2 l} \quad (9d)$$

$$\hat{m} = r + \frac{L^Y l}{m} + \frac{L^M H^2 C'[w, H / A, p.]Q_H[w, H / A, p.]}{A^2 m} \quad (9e)$$

$$\lim_{t\to\infty} l_t A_t = 0, \lim_{t\to\infty} m_t H_t = 0 \quad (9f)$$

where r represents the rate of time preference.

Equation (9a) expresses that the shadow value of technology, l, depends not only on the *level* of technology, but also on how technology relates to the human capital necessary to use technology in production. The efficiency wage condition, (9b), determines the manufacturing wage as a function of the exogenous price, and of the endogenous human capital and technology levels. The equation replicates the typical condition that a unitary increase in the wage cost must generate an equal decrease in the equilibrium training cost. Most notably, the firm chooses the wage only to minimize its training costs, acting independently of the labor supply at any given wage.

The shadow value of human capital increases in the total (wage and training) cost per efficiency unit of labor employed, (9c). Along the balanced growth path, where variables grow at the same constant rate, the efficiency wage is constant from (9b). Total labor income, which consists of *wH*, however, increases throughout to keep pace with the reservation wage. This allows for a stable labor market equilibrium.

Our first point of interest is to establish how the efficiency wage responds to changes in (a) the human capital to technology level, *H/A*, and (b) the terms of trade, p. From equation (9b) we can show that the efficiency wage decreases as the level of general human capital declines, while it increases when the level of technology rises without an accompanying equiproportional increase in human capital:

$$\frac{\partial w}{\partial (H/A)} = -\frac{C''[.]Q_{(H/A)}Q_w}{C''[.](Q_w[.])^2 + C'Q_{ww}} < 0 \qquad (10)$$

Intuitively, as the ratio of human capital to technology increases, the efficiency wage may be lowered because the technology employed in manufacturing is relatively less demanding. We also assume that the elasticity, $-\left(\partial w/\partial (H/A)\right)\left((H/A)/w\right)$ does not exceed unity. This is to rule out that a decrease in the level of human capital, relative to the level of technology, can be associated with a greater increase in the efficiency wage rate. Since a higher efficiency wage attracts more able applicants who learn faster about new technologies and are relatively cheaper to train, an elasticity greater than 1 could generate ambiguities about worker quality. For example, a decline in H/A, but a greater increase in the wage, and thus the quality of the applicant pool, could yield perverse implications for the derived expected worker quality in equation (5).

To examine the effects of a terms of trade shock on the efficiency wage, we find from equation (9b) that

$$\frac{\partial w}{\partial p} = -\frac{C''[.]Q_p Q_w}{C''[.](Q_w[.])^2 + C'Q_{ww}} > 0 \qquad (11)$$

This implies that the efficiency wage must increase in the relative price of the agricultural good. This is intuitive, since it is in the firm's interest to raise the efficiency wage to counteract the decrease in the quality in the applicant pool. This decline in the worker quality in response to an increase in the relative price is due to the increase in the value of the marginal product in the agricultural sector.

2.3 Demand

The introduction of two qualitatively different sectors represents not only the differences in informational asymmetries across sectors, but also allows for a complete and standard demand side that permits a meaningful discussion of relative prices. We specify a simple demand structure, which will play a very passive role in our economy, however.

In each period, agents maximize utility, U, which is a function of their consumption of the agricultural and manufacturing good, X and Y,

$$U = a \ln X + \ln Y \tag{12}$$

Individual budget constraints are determined by the individuals' incomes derived from their ownership in firms, plus their efficiency wage income, or their income from self-employment in agriculture. There is no storage technology and goods perish if not consumed within a period. Utility maximization yields the standard relation between relative demand and relative price

$$a \frac{Y}{X} = p \tag{13}$$

which implies in the closed economy, when domestic supply must equal domestic demand, that

$$a \frac{AL^Y}{\sum_{i=0}^{L-L^M} HG[q(i)]} = p \tag{14}$$

Equation (14) thus renders the equilibrium relative price in the closed economy. Assuming that two countries possess identical labor forces, it is immediately clear from (14) that the country with the higher level of technology and employment in manufacturing production, possesses a comparative advantage in the manufacturing sector.

2.4 Stability

Our objective is to characterize the dynamics of the economy about a stationary growth path. Along such an equilibrium path, output, human capital and technology must grow at constant rates. To analyze the dynamics of the economy about the long run growth path, it is convenient to normalize key variables to attain stationarity. Defining

$$x \equiv H / A$$

we can transform the system in terms of stationary variables and the equilibrium dynamics can now be expressed by

$$\dot{l} = l\,r - L^Y - L^M x^2 C'[.]Q_x[.] \tag{15}$$

$$\dot{m} = mr + L^Y l + L^M xC'[.]Q_x[.] \tag{16}$$

$$\dot{x} = x\left(L^M - x\left(L^M - L^Y\right)\right) \tag{17}$$

Along the stationary state, where the labor market is in equilibrium, or $\dot{L}^Y = \dot{L}^M = \dot{L}^x = 0$, we can now determine the steady state values $\tilde{x}, \tilde{l}, \tilde{m}$. From (15) we find

$$\tilde{l} = \frac{\tilde{L}^Y + \tilde{L}^M \tilde{x}^2 C'[.]Q_x[.]}{r} \tag{18}$$

which we know from (9a) must be greater than zero. From (16) we can derive

$$\tilde{m} = -\frac{\tilde{L}^Y / \tilde{x} + \tilde{L}^M \tilde{x} C'[.]Q_x[.]}{r} \tag{19}$$

while the steady state ratio of human to physical capital is derived from (17) to be

$$\tilde{x} = \frac{\tilde{L}^M}{\tilde{L}^M - \tilde{L}^Y} \tag{20}$$

The linearized dynamics to this system can be expressed by the third order system

$$\begin{bmatrix} \dot{l} \\ \dot{m} \\ \dot{x} \end{bmatrix} = \begin{bmatrix} r & 0 & \tilde{L}^M \tilde{x} bC[.](1-b) \\ \tilde{L}^Y & r & \tilde{L}^M \tilde{x} C'[.]Q_x[.] \\ 0 & 0 & -\left(\tilde{L}^M - \tilde{L}^Y\right)\tilde{x} \end{bmatrix} \begin{bmatrix} l - \tilde{l} \\ m - \tilde{m} \\ x - \tilde{x} \end{bmatrix} \tag{21}$$

where

$$b \equiv \frac{dC}{dQ}\frac{dQ}{dx}\frac{x}{c} \tag{22}$$

represents the product of the cost and quality functions' elasticities of substitution with respect to x, and its value is assumed to exceed 2 to rule out ambiguous comparative static results below. It is straightforward to show that the determinant is negative and that the system possesses two positive eigenvalues and one negative eigenvalue. This implies saddle path stability, since we have two costate variables, l and m, and one state variable, x.

Along the balanced growth path, technology, human capital and output all grow at a common rate. From equation (6) it can be seen that this growth rate coincides with the number of those receiving training in the economy, L^M. This again underlines the idea of appropriate technologies. It is not the endogenous technological change that determines the growth rate, but it is the rate of human capital accumulation, since the latter constrains the use of technology.

3.0 Comparative Statics

3.1 Trade and Development

The purpose of the following sections is to analyze how the incentives to innovate in the small open economy are altered by international factors. We examine two possibilities. First, we analyze the case where the country moves from autarky to free trade. Second, we examine the effects of technology diffusion, by allowing for technological spillovers from the outside world. For both cases we investigate the resulting effects on the domestic incentives to innovate, and on the resulting level of human capital in the economy.

From the first order conditions (9) and from the steady state values (18) and (19) we can find two equations in L^Y and L^M. These two equations determine the equilibrium values of labor employed in manufacturing production and total labor hired in manufacturing

$$\frac{\tilde{L}^Y \tilde{x} + \tilde{L}^M \tilde{x}^2 C'[.] Q_x[.]}{r} = 1 \tag{23}$$

$$\tilde{x}^2(\tilde{w}+C[.])-\tilde{x}+1=0 \tag{24}$$

In the equations below we suppress the "~" that represent steady state values unless they are necessary to avoid confusion. Labor in production and in manufacturing uniquely determines *x* from (20), and the relative wage is a solely function of the human capital to technology ratio as determined in (9b). This renders L^Y and L^M uniquely determined by equations (23) and (24). From these two equations, we find that

$$\frac{\partial L^M}{\partial p}=-\frac{dx^3C'[.]Q_p[.]}{r|J|}\left(1-\left(-\frac{w_x x}{w}L^M-L^y\right)\frac{1}{L^M-L^Y}\right)<0 \tag{25}$$

$$\frac{\partial L^Y}{\partial p}=-\frac{C'[.]Q_p[.]dx^3}{L^M r|J|}\left(L^M bC[.]x-\left(-\frac{w_x x}{w}L^M-L^Y\right)\frac{L^Y}{\left(L^M-L^Y\right)}\right)<0 \tag{26}$$

$$\frac{\partial x}{\partial p}=\frac{\left(1-\left(C'[.]Q_w C/w\right)\right)x^2C'[.]Q_p[.]}{r|J|}>0 \tag{27}$$

The detailed derivation is provided in the appendix. The determinant $|J|>0$ and the constant $d>0$ are also defined in the appendix.

If a country starts with a comparative advantage in the agricultural good, its opening to world markets has two important consequences. First, it leads the laggard economy to increase its ratio of human capital to technological change. This does not signal a step forward in development, however, since it is accompanied by a decline in both research and human capital accumulation. In addition, once the model is enriched to allow for informational asymmetries, the manufacturing sector contracts even further than the static contraction in traditional trade models. The additional contraction is due to the fact that the rise in the relative price of the agricultural good aggravates the informational asymmetry and the worker quality problems in the manufacturing sector.

The detailed adjustment evolves as follows: as relative price of the agricultural good changes, the quality of the applicant pool for manufacturing jobs deteriorates because the opportunity cost in agriculture increased. Hence the cost of training increases. To maintain an acceptable quality of the applicant pool and to stem the increase in training cost, the firm would have to increase its wage offer. This increase in labor cost increases the cost of R&D, whose shadow value falls upon impact. The rate of technological change slows as firms seek to cut back on R&D investment. This increases the level of human capital relative to the level of technology.

The second part of the adjustment process comes as the human capital to technology ratio increases. At that time, the efficiency wage and training costs actually decline, since technological change decelerates and manufacturing workers need fewer skills to learn about new technology. The result is that the manufacturing firm chooses a less skill intensive and training intensive production process, resulting in lower worker productivity. As a result, the decrease in the quality of the applicant pool causes an additional incentive to contract the manufacturing sector. As technological change and productivity slow, employment in manufacturing production declines (26), and research employment declines for the above mentioned reasons. This results in a general contraction of the manufacturing sector, which finally implies a lower training level and a lower rate of human capital accumulation in the new equilibrium.

3.2 Spillovers from World Technology Markets

Simple models of diffusion specify R&D functions that allow for positive spillovers from foreign sources of innovation. Mankiw Romer and Weil [1992] have recently shown that an econometric model of the world in which world technology is assumed to evolve at an exogenous rate, and in which laggard countries catch up to that technology, fits the data surprisingly well. It simplifies our analysis greatly to assume an exogenously world growth rate of technology, and the analysis is also most compatible with our small open economy assumption. Consequently, we specify that world technology grows at a constant world growth rate of $\hat{A}*$, and we assume that domestic technology now grows according to

$$\hat{A} = \left(L^M - L^Y\right)H / A + H\frac{\hat{A}*}{A}, \tag{28}$$

As in Parente and Prescott (1994), $A*$, thus represents the "best practice" technology level of the rest of the world. Equation (28) implies that the domestic growth of technology is influenced by both domestic and foreign research efforts. Similar to previous diffusion functions, the greater the technological advance that can be copied from abroad, the greater the increase in domestic technology. This assumption relates, however, only to technology. In keeping with the theme of the paper, we assume that the effectiveness of foreign technology is weighted by its relation to the domestic human capital level. Specifically, the rate of diffusion is scaled by how favorably the level of domestic human capital relates to the foreign technology, $H/A*$. If the human capital level is high, relative to the foreign technology level, much new can be invented on the basis of the foreign spillover. If on the other hand, the level of foreign technology sophistication is large compared to the human capital level, not much technological progress follows from using the foreign technology in domestic research.

Following the analysis from above, we can rearrange the first order conditions to find

$$l = 1/x \tag{29a}$$

$$-1 = C'\left[Q[w,x,p]\right]Q_w[w,x,p] \tag{29b}$$

$$m = w + C[Q[w,x,p]] - 1/x \tag{29c}$$

$$\hat{l} = r - \frac{L^Y}{l} - \frac{L^M x^2 C'[w,x,p.]Q_x[w,x,p.]}{l} \tag{29d}$$

$$\hat{m} = r + \frac{\left(L^Y - \hat{A}*\right)l}{m} + \frac{L^M x^2 C'[w,x,p.]Q_x[w,x,p.]}{m} \tag{29e}$$

The only significant change in the first order conditions is that the growth rate of the shadow value of human capital accumulation, m, is now negatively related to the growth rate of foreign technology. From (29d), (29e), (28) and (6) we can find the new steady state values

$$\tilde{l} = \frac{\tilde{L}^Y + \tilde{L}^M \tilde{x}^2 c'[.]Q_x[.]}{r} \tag{30}$$

$$\tilde{m} = -\frac{\left(\tilde{L}^Y - A*\right) / \tilde{x} - \tilde{L}^M \tilde{x} C'[.]Q_x[.]}{r} \tag{31}$$

$$\tilde{x} = \frac{\tilde{L}^M}{\tilde{L}^M - \tilde{L}^Y + \hat{A}*} \tag{32}$$

This indicates that an increased rate of innovation abroad increases the shadow value of human capital accumulation, because more human capital is needed to learn about advanced technologies. Interestingly enough, *ceteris paribus*, the ratio of human capital to technology increases, which reflects the increase in the shadow value of human capital.

Following the above analysis it is easy to show that the system is again saddle path stable. Interesting is the adjustment if either the country opens up to world technology, or if the rate of technological change in the world increases. The second equation determining the equilibrium values of employment in manufacturing and production, (24), now becomes

$$x^2\left(w + C[.]\right) - x\left(1 + \frac{A*}{r}\right) + 1 = 0 \tag{33}$$

which allows us to derive the effects of an increase in diffusion as

$$\frac{\partial L^M}{\partial \hat{A}*} = \frac{x^2\left(L^M + L^Y x + (b-2)bL^M C[.]x^2\right)}{|J'|L^M r^2} > 0 \tag{34}$$

$$\frac{\partial L^Y}{\partial \hat{A}*} = \frac{2x^3(L^Y + bL^M C[.]\left(L^M + (b-2)L^Y x\right)}{|J'|\left(rL^M\right)^2} > 0 \tag{35}$$

$$\frac{dx}{dA*} = \frac{L^Y L^M x^2\left(-L^Y + bL^M xC[.]\right) + L^M\left(s_{L^M,A*} - 1\right)}{r\left(L^M - L^Y + \hat{A}*\right)^2} < 0 \tag{36}$$

where the assumption that the elasticity of manufacturing employment with respect to foreign technology, s_{L^M, A^*}, is smaller than unity, is a weak sufficient condition for *x* to decline in the foreign growth rate. If this condition would not hold, the virtuous cycle of ever more research causing ever more training would continue without bound.

The comparative statics show that both employment in manufacturing and employment in production increase due to the free technology spillovers from the rest of the world. However, the spillovers are not actually "free." We find that the ratio of domestic technology to domestic human capital falls. There are three reasons why the manufacturing firm is willing to increase its training activity despite the fact that training costs rise. First, the cost of future productivity increases has declined, since some of the technological change is a free spillover. Second, worker productivity increases in production, leading to higher revenues. Third, there is a positive intertemporal effect, where more training today generates more human capital, which allows for greater technology absorption in the future. The mechanism by which this growth rate increases is not simply a reflection of the spillover experienced by the R&D sector. Instead, the spillover raises also the incentive for training in the economy, which thus increases the future productivity in research and production.

4.0 Conclusion

The object of this paper was to endogenize both appropriate technology and human capital in order to examine their joint effect on trade and diffusion. Central to the paper, and to the endogeneity of human and physical capital are the informational asymmetries that we introduced to highlight the problems associated with providing the skills necessary to use and invent technology. Under these circumstances, we show that the incentives for training and human capital are also affected by the degree to which the quality of an applicant pool is uncertain.

The key results of the model are that opening up to international trade will not only result in reallocation of factors among sectors, but will also cause changes in the quality of workers across sectors. These quality changes can generate informational gains (or losses) in addition to the well-known static gains from trade. In fact, we show that the changes in worker quality in the training, innovating, and manufacturing sector have a lasting impact on the incentives to innovate and provide training in response to terms of trade changes in a small open economy.

In modeling technology and human capital we took a different approach than the previous literature. Most importantly, we relied on the concept of *appropriate technologies*, which we refer to when new technologies can only be invented or used if the human capital exits to apply these technologies to research and production. The concept of appropriate technologies thus turns out to be a crucial aspect in modeling international knowledge spillovers. In this model technology does not simply flow from one country to another at no cost, but the effectiveness of foreign technology is scaled by how it relates to domestic human capital. Without the knowledge to build on foreign technology inventions it is absurd to assume that an economy can use foreign blueprints in either production or research. Thus the model implies that international spillovers generate not only greater rates of technological change, but also increase human capital accumulation in order to absorb even greater fractions of foreign technology in the future.

Appendix

From (24) and (23) we can define the functions

$$\Xi_1[L^M, L^Y; p, r] = \frac{L^Y x + L^M x^2 C'[.]Q_x[.]}{r} - 1 = 0\,;\;\; \Xi_2[L^M, L^Y; p, r] = x^2\left(w + C[.]\right) - x + 1 = 0\,.$$

Totally differentiating the two we find

$$a11 = \frac{\partial \Xi_1}{\partial L^Y} = \frac{\dfrac{\left(L^Y\right)^2}{\left(L^M - L^Y\right)^2} + x\left(1 + (b-2)bL^M C[.]\dfrac{L^Y}{\left(L^M - L^Y\right)^2}\right)}{r} > 0\,;$$

$$a12 = \frac{\partial \Xi_1}{\partial L^M} = \frac{-\dfrac{L^Y L^M}{\left(L^M - L^Y\right)^2} - bC[.]x\left(x + (b-2)\dfrac{L^M L^Y}{\left(L^M - L^Y\right)^2}\right)}{r} < 0\,;$$

$$a21 = \frac{\partial \Xi_2}{\partial L^Y} = -\frac{\left(1 + (b-2)dC[.]x\right)L^M}{\left(L^M - L^Y\right)^2} < 0\,;\;\; a22 = \frac{\partial \Xi_2}{\partial L^M} = \frac{\left(1 + (b-2)dC[.]x\right)L^Y}{\left(L^M - L^Y\right)^2} > 0$$

$$d11 = -\frac{\partial \Xi_1}{\partial r} = \frac{L^Y x + L^M x^2 C'[.]Q_x[.]}{r^2} > 0\,;\;\; D12 = -\frac{\partial \Xi_1}{\partial p} = \frac{bL^M x^2 C'[.]Q_p[.]}{r} > 0$$

$$D21 = -\frac{\partial \Xi_2}{\partial r} = 0\,;\;\; D22 = -\frac{\partial \Xi_2}{\partial p} = -dx^2 C'[.]Q_p[.] < 0\,;$$

where $d = 1 - \left(C'[.]Q_w C/w\right) > 0$.

The positive determinant $|J| = \begin{bmatrix} a11 & a12 \\ a21 & a22 \end{bmatrix} = \frac{\left(1 + (b-2)dC[.]x\right)\left(L^Y x - bcx^2 L^M\right)}{r(L^M - L^Y)^2} > 0$ implies

$$\frac{\partial L^M}{\partial p} = \frac{a11d22 - a21d12}{|J|} < 0\,;\;\; \frac{\partial L^Y}{\partial p} = \frac{d12a22 - d22a12}{|J|} < 0\,;$$

$$\frac{\partial x}{\partial p} = \frac{-L^Y(\partial LM / \partial p) + LM\left(\partial L^Y / \partial p\right)}{\left(L^M - L^Y\right)^2} > 0\,.$$

For the comparative statics of a change in $\hat{A}*$ we replace (23) with (33) and define

$$\overline{\Xi}_1[.;A^*]=\frac{L^Y x+L^M x^2 C'[.]Q_x[.]}{r}-1=0\,;\ \overline{\Xi}_2[.;\hat{A}^*]=x^2\left(w+C[.]\right)-x\left(1+\frac{\hat{A}^*}{r}\right)+1=0\,.$$

Again the equations we differentiate totally to find

$$\bar{a}11=\frac{\partial\overline{\Xi}_1}{\partial L^Y}=a11>0\,;\quad \bar{a}12=\frac{\partial\overline{\Xi}_1}{\partial L^M}=a12<0\,;\quad \bar{a}21=\frac{\partial\overline{\Xi}_2}{\partial L^Y}=-\frac{\left(\hat{A}^*+r+(b-2)dC[.]x\right)L^M}{\left(L^M-L^Y\right)^2}<0\,;$$

$$\bar{a}22=\frac{\partial\overline{\Xi}_2}{\partial L^M}=\frac{\left(\hat{A}^*+r+(b-2)dC[.]x\right)L^Y}{\left(L^M-L^Y\right)^2}>0\,;$$

$$\left|\bar{J}\right|=\begin{bmatrix}\bar{a}11 & \bar{a}12\\ \bar{a}21 & \bar{a}22\end{bmatrix}=\frac{\left(A^*+r+(b-2)s_{c,Q}s_{Q,w}rC[.]x\right)\left(L^Y x-bC[.]x^2L^M\right)}{r(L^M-L^Y)^2}>0$$

$$\overline{D}13=-\frac{\partial\overline{\Xi}_1}{\partial A^*}=0\,;\ \overline{D}23=-\frac{\partial\overline{\Xi}_2}{\partial A^*}=x\,/\,r>0\,;\ \ \frac{\partial L^M}{\partial A^*}=\frac{\overline{D}23\bar{a}11}{\left|\bar{J}\right|}>0\,;\ \frac{\partial L^Y}{\partial A^*}=\frac{-\overline{D}23\bar{a}12}{\left|\bar{J}\right|}>0$$

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