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A B S T R A C T

A general equilibrium production model is developed where technologies are embodied in capital goods of different vintage indexed in a continuum. Difference in the 'extent' of existing knowledge determines a wage gap between a developed (north) and a developing region (south), With free flow of technology, relatively 'backward' technologies move to the south. With innovation in the north, a 'technology cycle' is created by which some of the technologies are pushed out of the north into the south. This also tends to widen the wage-gap between the rigions. A distinction is made between 'standard technical progress' and 'Innovations' and both of them are shown to have different implications for the world equilibrium.

INTRODUCTION

International transfer of technology has emerged as an important issue in the literature on international trade and economic development. In recent years there have been quite a few papers on Vernon's (1966) 'product-cycle' hypothesis. Krugman (1979)[1] discusses a formal model of technology transfer and product-cycle when 'new' goods are innovated in the north and continuously passed on as 'old' goods to the south. This is also related to the models of trade in used machines as developed by Sen (1962) and Smith (1974). The later-models tried to explain why the south and the north might gain when relatively obsolete machines are exported to the developing countries with low wage. Essentially they talk about trade in machines of different vintages. More recently Grossman and Helpman (1989a, 1989b) in a series of papers have discussed innovation and growth when firms actively invest in R and D for product development. They also addressed the problem of endogeneous product cycle. [Grossman and Helpman (1991)] where there are endogenous product innovation and endogeneous technology transfer. Innovation is undertaken only by the northern capitalists whereas their southern counterparts engage in 'reverse-engineering' to adopt recently innovated technologies. Krugman (1979) and Grossman-Helpman papers (in a more complete manner) focus on the genesis of the product-cycle hypothesis[2]. Parallel to this set of ideas, one can bring in the issue of trade in second hand machines since a large part of LDC (Less developed country) imports constitute purchase of capital equipments from the developed countries. Operative conditions of such machines vary in the south vis-a-vis the north. The purpose of this paper is to discuss technology transfer in a simple general equilibrium vintage capital model. Here the technological progress is embodied, so that technology transfer occurs with capital mobility. We shall try to explain a pattern of technology-cycle (as the product-cycle in the existing literature) where 'new' machines are innovated in the north and when they are 'old', they are transferred to the south. The paper points out the role for comparative advantage in technology trade and performs comparative statics of technology transfer.

The Grossman-Helpman approach to the problem of product-cycle is based on the assumption that the northern capitalists can not directly produce in the south. Therefore, the southern entrepreneurs will be carrying out imitative activities. This paper caters to the situations where northern capitalists are free to go to the south and establish their plants and the southern producers are not allowed to imitate the northern technologies. (by guaranteering some sort of patent rights to the northern capitalists). Given this set up, the paper addresses the problem of technology-transfer by the northern capitalists to the south. This paper endogeneizes the equilibrium wage-gap between the two countries and then argue why all types of capital embodying various technologies do not move to the low-wage south. As in the Grassman and Helpman (1991), this paper assumes that the innovation occurs only in the north. However it is closer to Krugman (1979) since the innovation is exogeneous and as in Krugman (1979) it stresses the comovement of relative wage rates and rate of innovations in the north.

The paper will show, that under a very general set of conditions, relatively obsolete machinaries will have 'comparative advantage' in being located in the south[3]. In other words, even if wages are low in the south, 'better' machinaries will not be relocated away from the source country. With the arrival of new machines oldest ones become globally obsolete but the 'not-so-old' ones tend to fly to the south. This will also be associated with a widening of the wage gap between the north and the south. On the other hand standard technical progress in the existing technology set of the north might lead to an exactly opposite result.

The paper proceeds as follows. In the first section we describe the basic theoretical structure of the closed economy and discuss free trade in goods. In the second section technology transfer equilibrium is analyzed. In the penultimate section comparative static results are highlighted and in the concluding section we discuss possible generalizations and robustness of the results derived in the paper.

Section 1 Free Trade in Goods

Our economy consists of two sectors-traditional (X) and modern manufacturing (Y). Traditional sector uses land and labor with typical neo-classical technology characterized by constant returns to scale and diminishing returns to inputs. The modern manufacturing sector uses different types of capital and labor to produce a homogeneous good. Each capital is indexed by $z \in [0, \bar{z}]$ and the labor-output ratio $a_y(z)$ is a declining function of z i.e. capital types of higher order are also more efficient. One unit of output requires one unit of capital of type z and $a_y(z)$ units of labor. $\bar{z}$ is the upper limit of the index signifying the extent of the knowledge set. Although productive capacity of each technology is identical, varying labor productivities will determine the rent for each type of capital-embodied technology. We do not allow substitution between capital and labor within a technology. We assume that the markets are perfectly competitive, labor and land are fully employed and capital types earning positive rent in the market are also fully employed. As is evident, the last assumption hints at the presence of obsolete machines earning negative rates of return in the resultant general equilibrium of the system.

Following symbols will be used throughout the paper.

$K(z) = K$ - Given stock of capital for each technology.

T - Given stock of land

L - Given volume of the labor force

a_x - labor-output ratio in the traditional sector

a_T - land-output ratio in the traditional sector

W - Wage rate

R - Return to land

$r(z)$ - Return to the zth type of capital.

$\tilde{z}$ - minimum viable technology level in the manufacturing sector (i.e. $r(\tilde{z}) = 0$)

P - Relative price of the manufacturing good in terms of the traditional product.

$D(P)$ - Homothetic relative demand function for the manufacturing product, with $D' < 0$.

The pre-trade general equilibrium of the system ean be summarized by the following set of equations.

Competitive pricing implies,

$$wa_x + Ra_T = 1 \qquad (1)$$

$$wa_y(z) + r(z) = P \qquad (2)$$

$$wa_y(\tilde{z}) = P \qquad (3)$$

Full-Employment conditions

$$K = Y(z) \qquad (4)$$

$$a_x X + \int_{\tilde{z}}^{\bar{z}} a_y(z) Y(z)\, dz = L \qquad (5)$$

$$a_T X = T \qquad (6)$$

(1) - (6) describe the supply side of the systems, (4)-(6) can be reduced to the following equation.

$$L = L_{dx}(w,T) + K \int_{\tilde{z}}^{\bar{z}} a_y(z)\, dz \qquad (7)$$

Where $L_{dx}(w,T)$ denotes the demand for labour in the traditional sector. Now, (3) and (7) define two relationships in $(w,\tilde{z})$ given P and resource endowments. From (3), as w goes up, $\tilde{z}$ must go up since $a_y' < 0$ and P is held constant. From (7), as $\tilde{z}$ goes up $\int_{\tilde{z}}^{\bar{z}} a_y(z)$ goes down since $a_y(z) > 0 \; \forall z$. Therefore, traditional sector's demand for labor must go up to absorb excess labor. This will imply a decline in w. Figure 1 summarizes these two relationships which determine $(w^o, \tilde{z}^o)$ as the equilibrium pair, Once $(w^o, \tilde{z}^o)$

are determined, (1) and (2) will determine R and $r(z)$ for $z \in (z^0, \bar{z}$

As P goes up, for a given $\tilde{z}$, w must go up and in the new equilibrium $\tilde{z}$ must go down and w should go up. The exact expressions are given by,

$$\frac{d\tilde{z}}{dP} = \frac{\frac{-\partial L}{\partial w}dx}{\Delta} < 0, \quad \frac{dw}{dP} = \frac{-Ka_y(z)}{\Delta} > 0 \quad \text{where}$$

$$\Delta = [\, -Ka_y^2(z) - \frac{\partial L}{\partial w}dx \; a_y'(z)\, w \,] < 0$$

(see appendix).

Now, total supply of Y is given by $K \int_{\tilde{z}}^{\bar{z}} dz$.

$$\text{Therefore,} \quad \frac{d(\,K \int_{\tilde{z}}^{\bar{z}} dz\,)}{dP} = \frac{dK\,(\bar{z} - \tilde{z}\,)}{dP}$$

$$= -K\frac{d\tilde{z}}{dP} > 0 \quad \text{as} \quad \frac{d\tilde{z}}{dP} < 0$$

Relative supply of the manufacturing output is given by,

$$S\,(\bar{z},P) \equiv \frac{K\,(\bar{z}-\tilde{z}(P))}{X\,(P)} \text{ with } \frac{\partial S}{\partial \bar{z}} > 0,\ \frac{\partial S}{\partial P} > 0 \quad \ldots\ldots\ldots(8)$$

The equilibrium relative price can be derived from the following equation,

$$D(P) = S\,(\bar{z},\, P\,) \quad \ldots\ldots\ldots\ldots\ldots\ldots (9)$$

To highlight the role of technology in international trade, we shall assume two economies identical in every respect except one having $\bar{z}$ (the extent of knowledge) > $\bar{z}^*$ initially, where variables with '*' will be related to the foreign country[4]. Given the structure of the model one can prove the following proposition.

Proposition 1

For any given P, the home country's supply of manufacturing will dominate the foreign country's manufacturing output.

Proof : We have to a show that for any P,

$$S(\bar{z},P) > S^*(\bar{z}^*, P)$$

First note that $\dfrac{d[K(\bar{z} - \tilde{z})]}{d\bar{z}} > 0$

$$\text{i.e., } K[1 - d\tilde{z}/d\bar{z}] = K\left[1 - \frac{Ka_y(\bar{z})}{Ka_y(\tilde{z}) + \frac{\partial L}{\partial w}dx \quad \frac{\partial a_y}{\partial \tilde{z}} \cdot \frac{1}{a_y}}\right]$$

$$\text{since } \frac{d\tilde{z}}{d\bar{z}} = \frac{Ka_y(\bar{z})}{Ka_y(\tilde{z}) + \frac{\partial L}{\partial w}dx \quad \frac{\partial a_y}{\partial \tilde{z}} \quad \frac{1}{a_y}} \quad \text{(see appendix)}$$

$$\text{and} \quad \frac{d\tilde{z}}{d\bar{z}} < 1$$

as, $a_y(\tilde{z}) > a_y(\bar{z})$, $\frac{\partial L_{dx}}{\partial w} < 0$, $\frac{\partial a_y}{\partial z} < 0$.

Also, $\frac{\tilde{d}x}{d\bar{z}} = \frac{\partial L_{dx}}{\partial w} \cdot \frac{dw}{d\bar{z}} < 0$, as $\frac{dw}{d\bar{z}} > 0$ (see appendix)

Therefore, X is lower also. Hence, higher $\bar{z}$, ceteris paribus, will increase manufacturing output and lower traditional output implying an unambiguous increase in $S(\bar{z}, P)$.

Proposition 2. The home country will export manufacturing good in free trade and the free trade wage rate in the home country will be greater than that of the foreign country.

Proof :

The autarkik relative price of the home country P_A can be solved from

$$D(P_A) = S(\bar{z}, P_A)$$

and for P_A^* ,

$$D(P_A^*) = S(\bar{z}^*, P_A^*)$$

Since $D' < 0$, and $P_A < P_A^*$, the home counrty will export the manufactureing good. Free trade in goods will imply same price, P for each region. But $\bar{z} > \bar{z}^*$ will imply $\tilde{z} > \tilde{z}^*$ (proposition 1).

Competitive equilibrium condition for the marginal technology in each country gives us,

$$wa_y(\tilde{z}) = P = w^* a_y(\tilde{z}^*)$$

$$a_y(\tilde{z}) < a_y(\tilde{z}^*) \quad (\text{as } \tilde{z} > \tilde{z}^*) \Rightarrow w > w^* \qquad \underline{\text{QED}}$$

Section II Technology Transfer Equilibrium

The home country 'henceforth called the north) with greater number of technologies at its disposal enjoys a comparative advantage in the manufacturing good and also earns higher wage rate than the foreign country (the south). It is obvious that the northern capital will have a natural tendency to move to the south. The process of technology transfer as embodied in the capital would usually require certain 'set-up' cost to be incurred in the south for accomodating hitherto unknown advanced methods of production. Typically technologies currently available to both countries should not require any technology-specific investment in the south. But it would be resonable to assume that for $\bar{z} > \bar{z}^*$, there should be some cost of transfer. One example will be installation of sophisticated computers which require continuous air-conditioning of rooms where the computers are located. We shall assume that such costs will be incurred through the employment of the southern labour specifically for this purpose. One can also visualize such costs as costs of training the southern laborers. During the time of training each of them has to be paid a common wage rate. It seems more logical to make the training costs as increasing function of the level of technologies. But we shall see that our result will hold even with the same fixed costs of training or installation across different types of superior technologies.

Since the 'set-up' costs will be sunk, the question arises is how to internalize it in the current returns to capital. We can think of the following scenario. A northern capitalist is fully informed about the time path of the parameters guiding his decision and he takes the initial equilibrium values to be given for all time periods to come. Therefore, to him only discounted flow of profits matters where the discount rate is given by $0<\sigma<1$. Difference between the discounted stream of profits at home and abroad should at least pay for the sunk cost. If the capitalists are not sure about future changes in the parameters, situations might arise such that they have to come back to the north before the 'sunk-cost' is recovered. That will be a net loss. Having an extremely pessimistic view, earlier he can recover the cost better it is. In this case period under consideration may be only the period in which the capital moves to the south. However, we shall assume that future certainty induces firms to discount their pay-offs ad infintum. There is no harm in assuming that for a single atomistic northern capitalist relevant variables assume initial equilibrium values.

Let z_T be defined as a technology which earns the same rate of return irrespective of its location.

i.e.

$$P - wa(z_T) = P - w^* a^*(z_T) - \frac{w^* F^*(z_T)(1-\sigma)}{Y} \qquad (10)$$

(where $w^*F^*(z_T)$ is the set-up cost).

Our assumption implies that $\bar{F}^*(z_T) = 0$ for $z_T \leq \bar{z}^*$. In other words, as $w > w^*$ and $a(z_T) = a^*(z_T)$, (10) will imply all $z_T < z^*$ should move to the south. Now, consider $\bar{z} > z_T > \bar{z}^*$, then slight manipulation of (10) yields,

$$\frac{w}{w^*} = 1 + \frac{\bar{F}^*(z_T)(1-\sigma)}{a(z_T)Y} = 1 + \frac{\bar{F}^*\,(1-\sigma)}{a(z_T)Y} \qquad (11)$$

Let $1 + \frac{\bar{F}^*(1-\sigma)}{a\,(z_T)Y} = \lambda\,(z_T, \bar{F}^*, Y, \sigma)$

It is easy to check that $\lambda(.)$ has the following properties.

a) $\lambda = 1$ for $0 \leq z_T \leq \bar{z}^*$ (as $\bar{F}^* = 0$)

b) $\frac{\partial \lambda}{\partial z_T} > 0$ as $a'(z_T) < 0$

c) $\lambda > 1$ for $\bar{z}^* < z_T \leq \bar{z}$

$\lambda(.)$ describes the relative cost of technology transfer for any technology. Infact increasing λ tells us that better technologies are more costly to transfer given the fixed set-up/training costs. Here is an example of a simple comparative advantage argument. Better technologies have comparative advantage in being located in the high wage north. Since $\frac{w}{w^*}$ should be endogenerously determined, one has to solve the full general equilibrium model in the post-transfer situation to get an exact value of $\frac{w}{w^*}$ and z_T.

The following set of equations describe the world competitive equilibrium in the post-transfer situation.

$$w = \lambda(z_T)\, w^* \qquad (12)$$

$$w^* a_y(\hat{z}^*) = P \qquad (13)$$

$$K \int_{z_T}^{\bar{z}} a_y(z)dz + L_{dx}(w, T) = L \qquad (14)$$

$$K \int_{\hat{z}^*}^{z_T} a_y(z)dz + L^*_{dx}(w^*, T) + F^*(z_T - \bar{z}^*) = L \qquad (15)$$

$D(P) = S(P, \bar{z})$ (This is the aggregated world relative demand and supply functions) .... (16)

These five equations will determine w, w^*, z_T, $\hat{z}^*$ and P. z_T denotes the extent of transfer from the north to the south. Given the above structure following proposition is immediate.

<u>Proposition 3. In the resultant post-transfer equilibrium a) w can never be lower than w^*. (b) with $w > w^*$ in the new equilibrium, it is likely that, relatively obsolete technologies will be transferred to the south.</u>

<u>Proof</u> : a) Since $\lambda(z_T) \geq 1$, from (12) $w \geq w^*$

b) If $w > w^*$, then $\lambda(z_T) > 1$, which implies $z_T \in (\bar{z}^*, \bar{z})$. For all possible equilibria in this case, z_T (except one where $z_T=\bar{z}$) is strictly less than $\bar{z}$ and technologies in the region $(z_T, \bar{z})$ will not be transferred.

If in the resultant equilibrium w is less than w^*, there should be reverse technology flow increasing w and reducing w^*, till they match. On the other hand an interior equilibrium for z_T will imply that further transfer increases $\frac{\bar{F}^*(1-\delta)}{a(z)}$ and reduces the rate of return for the relevant technology. Such possibility as the others have been shown in figure 2.

Possibility of an interior equilibrium where z_T lies between $\bar{z}^*$ and $\bar{z}$ raises an interesting question. Given that there exists some fixed set up cost for transferring better technologies to the south, better technologies will have a comparative advantage in staying back in the north. Essentially the relevant comparative cost ratio is measured by $\frac{\bar{F}^*(1-\delta)}{a_y(z)Y}$ and with increasing z such a relative cost increases. Transferring relatively obsolete technologies is an outcome of the trade-off between the fixed costs of transfer and variable cost of production. Later we shall explore the generality of such a result with varying F^* across technologies, and allowing for the use of northern labor in the setting-up/training activity in the south.

Section III Innovation, Technology Transfer and Obsolescence

Following the tradition in the literature we shall assume that innovation takes place only in the north. Innovation of new technologies can be captured by an incre4ase in the index $\bar{z}$ implying introduction of superior technologies without affecting the labor-output ratio of the existing set of technologies. An increase in $\bar{z}$,ceteris paribus, will increase the demand for labor in the north pushing up w. For any $z_T < \bar{z}$, this will mean an incentive to go to the south. This in turn will increase w^*. A higher w^* will make some of the pre-existing technologies in the south globally obsolete. The resultant general equilibrium will show, among other things, an increase in $\frac{w}{w^*}$ and z_T. This particular result is quitesimilar to Krugman (1979) where innovation of a new good necessarily increases relative wage rate of the north and transfers the production of some of the goods erstwhile produced in the north to the south. However, we get the result in a different framework.

The exact expression for a change in z_T can be derived by differentiating (12) - (16) with respect to $\bar{z}$ and finding out. $\frac{dz_T}{d\bar{z}}$, which is given by

$$\frac{dz_T}{d\bar{z}} = \frac{-(D_p - S_p)\, K^2\, a_y^2\,(z^*)\, a_y\,(\bar{z})}{\Delta} > 0$$

as $D_p < 0$, $S_p > 0$ and $\Delta > 0$ [Δ has been derived to be positive in the appendix).

It can also be shown that

$$\Delta > -(D_p - S_p)\, K^2\, a_y^2\,(z^*)\, a_y\,(\bar{z})$$

So that $\frac{dz_T}{d\bar{z}} < 1$. This should be expected as an initial increase in $\bar{z}$ induces z_T to increase but not by so much as to negate the initial impact of a net increase in the demand for northern labor. As is evident, the comparative statics are done assuming $\bar{z}^* < z_T < \bar{z}$. However, an initial equilibrium with $z_T \leq \bar{z}^*$ can eventually get transformed into an equilibrium where $z_T > \bar{z}^*$ and $w > w^*$, through a process of continuous innovations in the north[5]. From equation (12) it follows that as z_T goes up $\frac{w}{w^*}$ must also go up as $\chi' > 0$. Since manufacturing production increases in the world and P goes down, $\hat{z}^*$ must go up implying global obsolescence for some of the pre_existing technologies in the south.

Another way of visualizing technical progress in the north is through the standard notion of technical progress where $a_y(z)$ goes down for each $z \in [z_T, \bar{z}]$. This will imply a lowering of demand for northern labor at a given wage rate and hence a process of reverse technology transfer. In a dynamic world more meaningful interpretation of the above result can be given. One can think of two possible types of northern countries. One which is more 'innovative' in the sense of having higher $\bar{z}$ and the other being more efficient in the existing set of technologies. The first category of the northern countries will be transferring technology to the south to a greater degree than the other type with relatively lower wage rate. In real life one would expect to see the northern region to be a mix of boththese types. With more efforts being spent on innovatingtotally new methods of production rather than fine tuning the existing methods, a higher wage rate should emerge, and therefore it is likely that a 'technology-cycle' will be initiated between the north and the south. The above structure also high-lights the fact that sectors where innovations are not kept up must suffer through the rising wage rate caused by higher- labour -demand generated through innovations in other sectors.

Proposition 4. An expansion in the knowledge-set of the north (denoted by increase in $\bar{z}$) will lead to an increase in the set technologies transferred to the south and a widening of the wage gap between the north and the south.

Proof :-

Follows from $\frac{dz_T}{d\bar{z}} > 0$ and $\frac{d(\frac{w}{w^*})}{d\bar{z}} > 0$

(see appendix). QED.

Proposition 5. A North with a more productive manufacturing technology set will transfer fewer technologies to the south.

Proof : Lowering of required labor-output ratio for a given $\bar{z}$ pushes down $\frac{w}{w^*}$. If θ is the measure of the decline in the labor coefficient then $\frac{\partial a_y(z,\theta)}{\partial\theta} < 0$ for any given $z \in [0,\bar{z}]$. This reduces total demand for labor in the north and hence $\frac{w}{w^*}$. On the other hand (12) shows $\lambda = \lambda(z_T, \theta)$, $\frac{\partial\lambda}{\partial\theta} > 0$, i.e. the relative cost of transfer also increases. Therefore, z_T should be lower. Infact $\frac{dz_T}{d\theta} < 0$ (see appendix). Figure 3 summarizes the above situation. QED

Fine tuning of the existing set of technologies will lower the number of technologies transferred to the south. As $\frac{w}{w^*}$ goes down initially, there is a reverse technology transfer and relative cost of transfer as measured by $\lambda(z_T)$ also tends to go up leading to a fall in z_T. It is hard to predict what would happen to the $\frac{w}{w^*}$ ratio in the resulting equilibrium. Unlike the case with increasing $\bar{z}$, one can find lowering z_T along with higher $\frac{w}{w^*}$. There are essentially- two offsetting effects. First, $\frac{w}{w^*}$ goes down initially given $\lambda(z_T)$ and then with increasing $\lambda(z_T)$ and reverse transfer, demand for labor is pushed up. Even with higher $\frac{w}{w^*}$ it is possible to conceive a lower value for z_T because of an upward shift in $\lambda(z_T)$. Therefore, both type of technical progress might end up increasing the wage-gap between the north and the south[6].

The comparative static results derived in this section depends on $\lambda(z_T)$ which is an increasing function of the level of technology. It is interesting to note that some modifications in the structure of the transfer cost do not alter the nature of $\lambda(.)$ function. Suppose the process of transfer requires not only southern labor but also northern labor and the northern capitalsits have to pay them the northern wage rate. The situation might be one where foreign managers or personnel are required to supervise installation of new machines and they haveto be paid their home salaries. Let $\bar{F}$ number of northern laborers be required for, such purpose. Following (11), one can derive a relationship such as

$$\frac{w}{w^*} = 1 + \frac{\bar{F}^*(1-\delta)}{a(z_T)Y} + \frac{w}{w^*}\,\frac{\bar{F}\,(1-\sigma)}{a(z_T)Y} \qquad (17)$$

$$\text{or } \frac{w}{w^*} = \frac{a(z_T)Y + \bar{F}^*(1-\sigma)}{a(z_T)Y - \bar{F}\,(1-\delta)} \qquad (18)$$

Note that the r.h.s. in (18) is an increasing function of z_T. Therefore, modified $\lambda(\cdot)$ should not qualitatively differ from our earlier specification.

Section IV

Conclusion

This paper has been an attempt to model international transfer of technology in a competitive general equilibrium structure where the 'extent' of technology transfer can be discussed rigorously. Technologies have been characterized by different capital goods of varying vintages. There are three major points of the paper. First, one could give a 'comparative advantage' argument to justify why relatively obsolete technologies will be transferred to the developing nations. Second, continuous innovations in the developed countries generate a kind of 'technology cycle'. Third, the paper could endogenise the 'wage_gap' between the north and the south. In the pre-technology trade situation the south starts with a lower wage than the north. With technology transfer wage rates tend to come closer but innovations in the north not only increase the rate of transfer but also widen the wage-gap between the two regions.

The paper can be extended to two directions. One way should be to endogeneize the process of innovation in this framework. Assuming different capitalists earning differential returns will be willing to reduce the labour costs further, one should build up a theory of innovations in such a competitive structure. This should then be applied to model differential rates of innovations between the north and the south. One may mention in this context that none of the existing models explain why innovations must originate in the north. Future research on this structure proposes to analyse such issues in greater detail. One has a feeling that to model problems on technology choice or technology transfer the vintage capital model can serve a very useful purpose. However, it has to be modified and reconstructed to fit and issue in question. In this way one can derive meaningful and interesting results somewhat comparable to the ones developed in the innovative contributions of Krugman (1979) and Grossman and Helpman (1991).

Footnotes

1. Few other papers on the product-cycle hypothesis are by Dollar (1986), Marjit (1989) and Segerstrom, Anant and Dinopoulos (1991).
2. Other papers on export of technology are by Jones (1970), Findlay (1978), Succar (1987).
3. See Marjit (1988) for a partial-equilibrium explanation of this phenomenon.
4. Greater $\bar{z}$ amounts to having more capital relative to land and labor. Subsequently propositions 1 and 2 in effect result from a Ricardo-Viner model where both countries have equal amount of land and labor but one has more capital. Thanks are due to a referee for pointing thisout.
5. For an earlier treatment on trade and vintage capital see Bardhan (1970). It is difficult to use the notion of technical progress, as in a vintage capital structure, in this model primarily because introduction of new machines increases demand for labor at the going wage rate even if productivity of new machines is higher than the old ones. One can not characterize 'innovation' just by a declining

labour-output ratio but also by increasing $\bar{z}$. If existing machines become more productive in the north, different results will appear as would be evident in the subsequent discussion. Arrival of new machines increase the wage rate, wipe out some of the old ones and the new ones keep start getting much higher rents than the existing old machines by virtue of having low labor-output ratios.

6. In a pioneering paper on the continuum approach in the Ricardian structure, Dornbusch, Fisher and Samuelson (1979) have discussed the effects of technological progress. In their model reduction of labor-output rations through competitive conditions unambiguously improve the wage rate of the country concerned. Here, with fixed capacities, lowering of labor-output ratios for all $z \in [0,\bar{z}]$ reduces the aggregate demand for labor required to produce the given level of output. Hence, the wage rate is reduced. But interestingly in equilibrium total output must increase as previously obsolete machines now come into operation and the total productive capacity in the economy expand. Thanks are due to one of the referees for drawing my attention to the Dornbusch, Fisher and Samuelson (1977) paper in this context.

APPENDIX

1. Determination of $\frac{d\tilde{z}}{dp}$, $\frac{dw}{dp}$

Differentiating (3) and (5) in the text we get,

$$\frac{dw}{dp} a_y(\tilde{z}) + \frac{d\tilde{z}}{dp} a_y'(\tilde{z}) w = 1 \qquad (1A)$$

$$\frac{\partial L_{dx}}{\partial w} \frac{dw}{dp} - K a_y(\tilde{z}) \frac{d\tilde{z}}{dp} = 0 \qquad (2A)$$

$$\frac{d\tilde{z}}{dp} = \frac{-\frac{\partial L_{dx}}{\partial w}}{\Delta} < 0 \quad , \quad \frac{dw}{dp} = \frac{-K a_y(\tilde{z})}{\Delta} > 0$$

where $\Delta = -K a_y^2(\tilde{z}) - \frac{\partial L_{dx}}{\partial w} a_y'(\tilde{z}) \frac{d\tilde{z}}{dp} < 0$

2. Determination of $\frac{d\tilde{z}}{d\bar{z}}$

Proceed as in 1. by differentiating (3) and (5) with respect to $\bar{z}$ and use the fact that $\frac{d\left[\int_{\tilde{z}}^{\bar{z}} a_y(z)\,dz\right]}{d\bar{z}} = a_y(\bar{z})$

to get
$$\frac{d\tilde{z}}{d\bar{z}} = \frac{K a_y(\bar{z})}{K a_y(\tilde{z}) + \frac{\partial L_{dx}}{\partial w} \cdot \frac{\partial a_y}{\partial \tilde{z}} \cdot \frac{1}{a_y}} < 1$$

3. Determination of $\frac{dz_T}{d\bar{z}}$, $\frac{d\left(\frac{w}{w^*}\right)}{d\bar{z}}$ and $\frac{dz_T}{d\theta}$

Differentiating (12) - (16) in the text we get,

$$\frac{dw}{d\bar{z}} - \lambda' \frac{dz_T}{d\bar{z}} w^* - \lambda \cdot \frac{dw^*}{d\bar{z}} + 0 \cdot \frac{d\tilde{z}^*}{d\bar{z}} + 0 \cdot \frac{dp}{d\bar{z}} = 0 \qquad (3A)$$

$$0 \cdot \frac{dw}{d\bar{z}} + 0 \cdot \frac{dz_T}{d\bar{z}} + a_y(\tilde{z}^*) \frac{dw^*}{d\bar{z}} + w^* a_y'(\tilde{z}^*) \frac{d\tilde{z}^*}{d\bar{z}} + 0 \cdot \frac{dp}{d\bar{z}} = 0 \qquad (4A)$$

$$L_{dx}' \frac{dw}{d\bar{z}} - K a_y(z_T) \frac{dz_T}{d\bar{z}} + 0 \cdot \frac{dw^*}{d\bar{z}} + 0 \frac{d\tilde{z}^*}{d\bar{z}} + 0 \cdot \frac{dp}{d\bar{z}} = -K a_y(\bar{z}) \qquad (5A)$$

$$0 \cdot \frac{dw}{d\bar{z}} + \left\{ K a_y(z_T) + \bar{F}^* \right\} \frac{dz_T}{d\bar{z}} + L_{dx}^{*\prime} \frac{dw^*}{d\bar{z}} - K a_y(\tilde{z}^*) \frac{d\tilde{z}^*}{d\bar{z}} + 0 \cdot \frac{dp}{d\bar{z}} = 0 \qquad (6A)$$

$$0 \cdot \frac{dw}{d\bar{z}} + 0 \cdot \frac{dz_T}{d\bar{z}} + 0 \cdot \frac{dw^*}{d\bar{z}} - 0 \cdot \frac{d\tilde{z}^*}{d\bar{z}} + (D_p - S_p) \frac{dp}{d\bar{z}} = \frac{\partial S}{\partial \bar{z}} \qquad (7A)$$

$$\begin{vmatrix} 1 & -\lambda' & -\lambda & 0 & 0 \\ 0 & 0 & a_y(\tilde{z}^*) & w^* a_y'(\tilde{z}^*) & 0 \\ L_{dx}' & -K a_y(z_T) & 0 & 0 & 0 \\ 0 & (K a_y(z_T) + \bar{F}^*) & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & D_p - S_p \end{vmatrix} \equiv \Delta = (D_p - S_p) \Big[K a_y(\tilde{z}^*) \left\{ a_y(\tilde{z}^*) \left(-K a_y(z_T) + \lambda' L_{dx}' \right) \right\}$$
$$+ w^* a_y'(\tilde{z}^*) \left\{ -K a_y(z_T) L_{dx}^{*\prime} + L_{dx}' \lambda' L_{dx}^{*\prime} - \lambda L_{dx}' \left(K a_y(z_T) + \bar{F}^* \right) \right\} \Big] > 0$$

Therefore, $$\frac{dz_T}{d\bar{z}} = \frac{-(D_p - S_p) K a_y^2(\tilde{z}^*) K a_y(\bar{z})}{\Delta} > 0 \ (<1), \quad \frac{d\left(\frac{w}{w^*}\right)}{d\bar{z}} = \lambda' \cdot \frac{dz_T}{d\bar{z}} > 0$$

Follow the argument in the text for $a_y = a_y(z, \theta)$ and change the full-employment of labor condition in the north as follows,

$$L_{dx}(w, T) + \phi(K, z_T, \bar{z}, \underline{\theta}) = L \qquad (8A)$$

Also note that

$$w = w^* \lambda(z_T, \theta) = w^* \left[\frac{a(z_T)}{a(z_T, \theta)} + \frac{\bar{F}^*(1-\delta)}{a(z_T, \theta) K} \right] \qquad (9A)$$

One has to differentiate (8A), (9A) to replace (3A) and (5A) and follow the previous method to find out,

$$\frac{dz_T}{d\theta} = \frac{(D_P - S_P)\left[-Ka_y(\tilde{z}^*)\left\{K\frac{\partial\phi}{\partial\theta}a_y(\tilde{z}^*) + L'_{dx}\left(w^*\frac{\partial\lambda}{\partial\theta}a_y(\tilde{z}^*)\right)\right\} - L^{*\prime}_{dx}\left\{-wa'_y\left(-K\frac{\partial\phi}{\partial\theta} - L'_{dx}w^*\frac{\partial\lambda}{\partial\theta}\right)\right\}\right]}{\Delta} < 0$$

4. <u>Property of $\lambda(.)$ with modified transfer cost.</u>

$$\frac{w}{w^*} = \frac{a(z_T)Y + \bar{F}^*(1-\delta)}{a(z_T)Y - \bar{F}(1-\delta)} = \lambda(z_T) \qquad (10A)$$

$$\frac{\partial\lambda}{\partial z_T} = \frac{a'.Y\left[a(z_T)Y - \bar{F}(1-\delta)\right] - a'Y\left[a(z_T)Y + \bar{F}^*(1-\delta)\right]}{\left[a(z_T)Y - \bar{F}(1-\delta)\right]^2}$$

$$= \frac{-a'.Y(\bar{F} + \bar{F}^*)(1-\delta)}{\left[a(z_T)Y - \bar{F}(1-\delta)\right]^2} > 0$$

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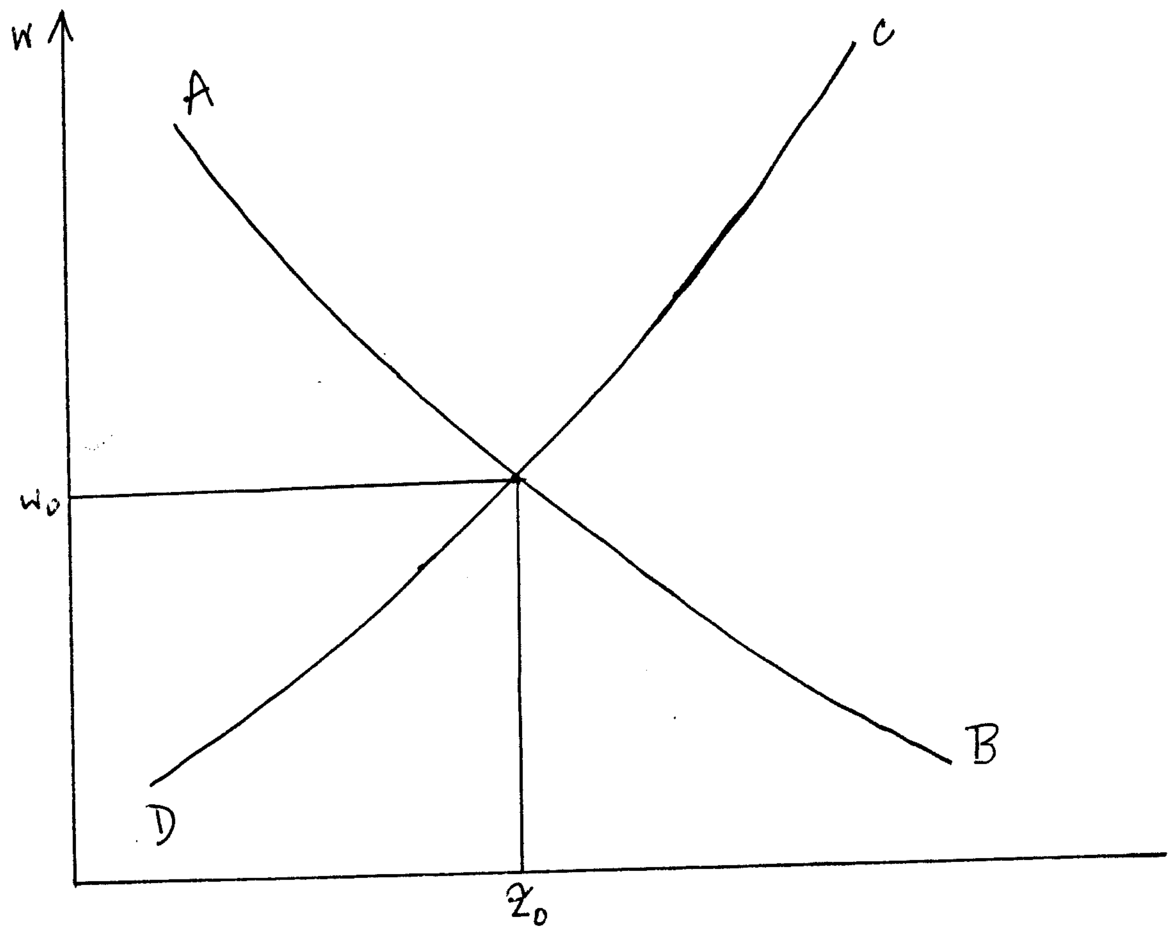
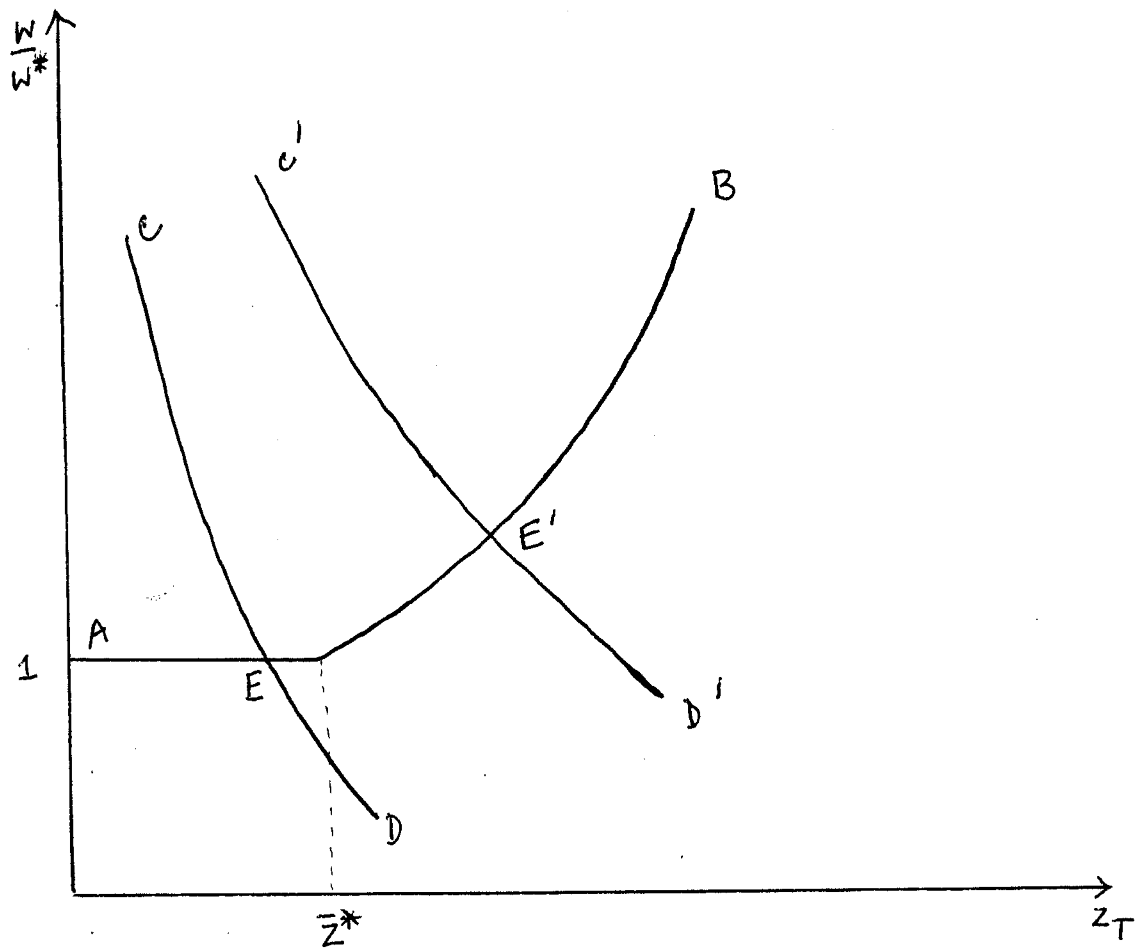


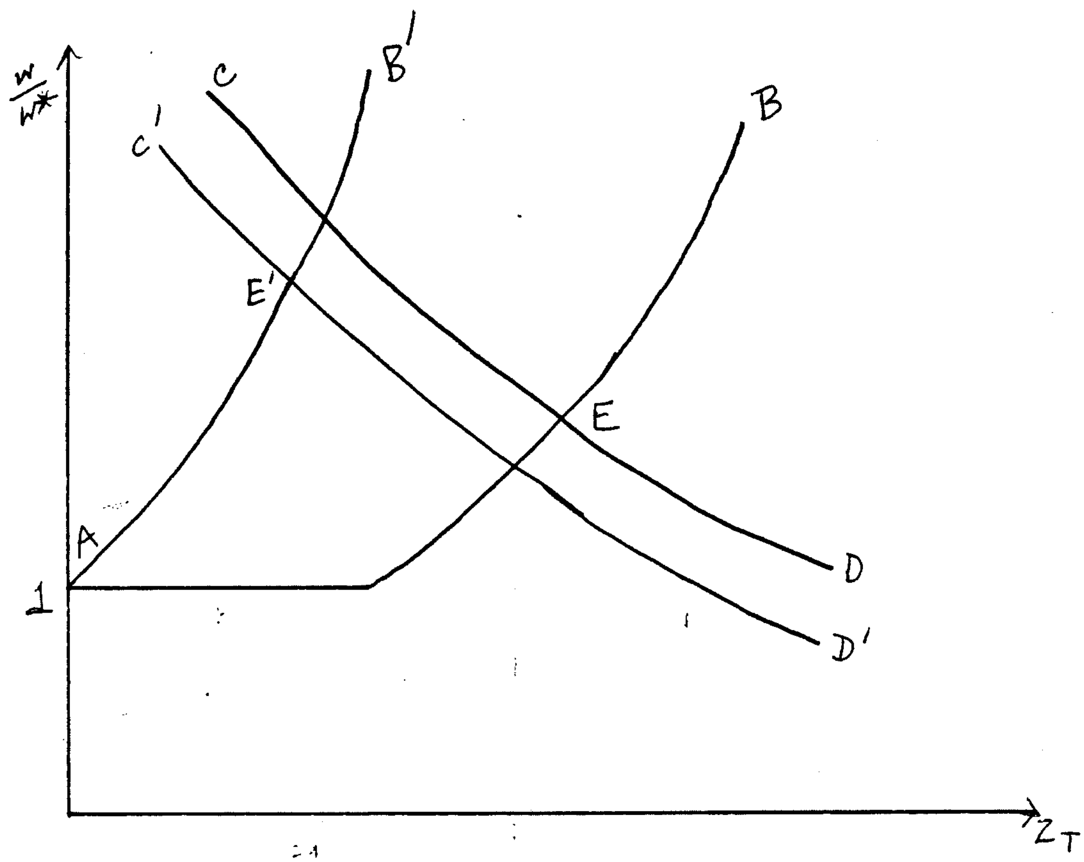
AB denotes (7) and CD denotes (3) in the text.

FIGURE - 1



AB denotes $\lambda(z_T)$, CD describes $\frac{w}{w^*} = f(z_T)$. At E, $w = w^*$ and at E', $w > w^*$.

FIGURE - 2



At E, z_T is higher than at E', $\frac{w}{w^*}$ has gone up. But $\frac{w}{w^*}$ can go down.

FIGURE - 3