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Green Revolutions and Miracle Economies : Agricultural Innovation, Trade and Growth

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Abstract

The purpose of this paper is to develop a simple model of an economy in which growth is driven by a combination of exogenous technical change in agriculture as well as by a rising world demand for labor-intensive manufactured exports. We explore the relative roles of agricultural innovation and rising export demand in a model with two traded industrial goods and a non-traded agricultural good, food. When the non-traded sector uses a specific factor, we show that technical change in agriculture may be the key to sustained factor accumulation in industry, in particular driving intersectoral labor migration. A key assumption is a less than unitary price elasticity of demand for food. Our results could form a crucial link in capturing the story of labor-abundant economies which experienced structural transformation and growth through labor-intensive manufactured exports, without prior technology breakthroughs in industry. They contribute to explaining the massive growth in factor accumulation which shows up in some growth accounting studies : they may also imply that some of the contribution of “technical progress” is mistakenly attributed solely to factor accumulation.

JEL Classification : O3, O4, F1.

Keywords : Structural change, agricultural productivity, labor migration, terms of trade.

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GREEN REVOLUTIONS AND MIRACLE ECONOMIES: AGRICULTURAL INNOVATIONS, TRADE AND GROWTH

1. Introduction

Why did certain regions of the world embark on phases of rapid growth at certain points in time? Economists analyzing such growth spurts sought the answer in terms of growth accounting exercises comparing the respective contributions of factor accumulation and productivity growth. For instance Alwyn Young's (1995) exercises for East Asia, contrary to the World Bank's findings of spectacular productivity growth, found that improvements in industrial productivity were largely illusory and that rapid factor accumulation accounted for the bulk of the growth that these countries had experienced.

In this paper we take a step back from such studies. A conclusion that a growth miracle was driven by factor accumulation begs the question : why did such rapid factor accumulation take place ? This supplies our motivation. In any economy in which food prices are not totally insensitive to domestic supply and demand, the process of structural transformation - a move out of agriculture into manufacturing and services - cannot be accomplished without technical progress. Such an economy, if technologically stagnant, would run into Ricardian diminishing returns, a spiral of rising food prices and wages eroding industrial profits and accumulation. It has of course been argued that, with a growing industrial sector, labor could migrate a la Arthur Lewis [1954] from agriculture into industry without generating wage-price pressures as long as surplus labor persists in agriculture. But surplus labor in itself is a questionable theoretical concept, and in any case, rising food prices would pose an insuperable barrier even if surplus labor existed. What then explains cases of industrialization driven by mass intersectoral labor migration, where significant industrial productivity growth was absent?

In quest of a possible answer we construct a simple model of an economy in which growth is driven by two factors - exogenous technical change in a closed agricultural sector and a rising world demand for labor-intensive manufactured exports. What governed our choice of these factors? We turn to agricultural innovation as a natural candidate which could facilitate the release of factors,

particularly labor, from agriculture for industrial employment. As Kuznets (1958) pointed out, a precondition for industrial growth is a sufficient rise in agricultural productivity. An example of a dramatic rise in agricultural productivity would be the aftermath of the "Green Revolution" which transformed the rice economies of the East. Agricultural innovation could keep diminishing returns from setting in even in the absence of technical progress in industry. This would be all the more crucial in a closed agricultural sector where the price of food is not determined by international prices - which happens in our model due to a factor specific to the non-traded sector, land (a point explained at length later). Clearly, in the absence of any innovation, food prices would run the danger of rising in Ricardian fashion. Innovation in the agricultural sector could be a crucial link in explaining the massive growth in factor accumulation which seems to show up in some growth accounting studies : it may also imply that some of the contribution of "technical progress" - albeit in agriculture, not industry, is mistakenly attributed solely to factor accumulation.

In the initial part of our paper we find that exogenous technical change in agriculture could drive industrialization by inducing migration of labor from agriculture into industry. We consider an economy with two traded industrial goods, labor-intensive "light" and more capital-intensive "heavy" manufactures, and one non-traded good, food. While the industrial sector behaves like a Heckscher-Ohlin economy using labor and capital, the agricultural sector uses a specific factor, land, in addition to labor. Before turning to a comparison of our models with other studies in the literature, we briefly outline the intuition underlying the last section of our paper where in addition to agricultural innovation, we also model the effect of rising world demand for labor-intensive manufactured exports. Apart from rises in the productivity of the agricultural sector, a second factor which has often been important for growth is a rise in trading opportunities. We recall the role played by expanding trade opportunities in fueling the Industrial Revolution of Western Europe. A similar expansion in the trading opportunities faced by the developing or middle income countries of today occurred in the mid-sixties, with a series of improvements in ocean transport (containerization, deep-draught carriers), communication costs (the Information Revolution), and warehousing costs ('just-in-time' management technology). At the same time, other factors, such as the dismantling of old tariff barriers beginning with the Kennedy round of trade negotiations and the rise of new affluent markets in the middle east and the Pacific which reduced the distances that developing country exports had to travel, also facilitated penetration of foreign markets. Some developing countries took longer than others to begin to benefit from this process because until recently they followed autarkic policies (eg South Asia). But the demand stimulus provided by the new developments described above and the international division of labor they gave rise to, made it possible for developing countries to access foreign markets, reducing the disadvantage of not being able to realize domestic scale economies.

The labor-abundant economies were the major potential beneficiaries of the growth of trade because of the massive wage-differential between the rich and the poor countries. We model a rise in demand for labor-intensive manufactured exports as a rise in the f.o.b prices that such exports could fetch.

Hazari and Sgro (2004) examine a wide class of models of the generalized Harris-Todaro variety. It is possible to draw parallels between our model and theirs, treating our model as a variant of a special case of their generalized model. The generalized model they consider involves an urban and a rural region, each producing one traded and one non-traded good. The factors of production are labor and region-specific capital. In our model, we have two traded goods in an industrial sector, and one non-traded good in an agricultural sector. The factors of production are labor (mobile between all sectors as in Hazari and Sgro), capital which is used for the two industrial goods, and a specific factor, land, confined to food production. If we think of food as being the non-traded rural sector good in Hazari and Sgro, and if we set the production of both the non-traded urban good and the traded rural good in the H-S model to zero, we derive a special case of the H-S model. The difference of this special case from our model is that in ours the industrial sector (corresponding to the urban sector in H-S) has two traded goods. This point is also relevant to a comparison of our paper with Matsuyama (1992). Matsuyama has only one manufactured and one agricultural good in his model, and therefore cannot accommodate our case of a closed agricultural, and an open industrial market. Instead he analyzes the impact of agricultural innovation on industrialization in the distinct contexts of a closed and an open economy and concludes that it is favorable in the former but unfavorable in the latter. Industrial production in his model uses only labor, while we use standard two-factor neoclassical production functions. In contrast to the learning by doing in Matsuyama, we analyze the case of no technical progress in industry - our purpose being to interpret in stark terms the studies which find little evidence of industrial productivity growth in fast-growing economies. While Matsuyama assumes a rather specific utility function, the logarithmic form of the Stone-Geary function with a subsistence term for food, we postulate a much more general utility function. Finally, the openness of the industrial sector in our model allows us to analyze the impact of terms-of-trade changes even as the food market remains closed. Given the differences in our models, it is interesting to observe that our conclusions converge with Matsuyama's on the question of the favorable effect of an agricultural revolution on industry in a closed food market.

Another model which relates to ours is Komiya (1967). Komiya introduces a non-traded good into the standard Heckscher-Ohlin framework with its two traded goods. But all three commodities are produced using the same two factors - thus, the price of the non-traded good is locked in by the internationally determined traded good prices. However, unlike in Komiya's model, we use a flexi-price

framework along with fixed prices for traded goods (except in the last section of our paper where we also allow for change in the relative prices of traded goods, i.e, terms of trade changes). The crucial assumption which makes this possible is the use of a specific factor in our model. Land is specific to the production of the non-traded good, food. Had this not been the case, and had food and industrial goods production shared the same set of intersectorally mobile factors, then the price of food could not be determined independently of the world prices of the industrial goods - in which case our model would become like Komiya's. As it is the assumption of a specific factor allows us to treat food prices as an independent variable with flexibility - thus avoiding a major problem of the Komiya model.

In sum, therefore, our paper represents a contribution to the literature on growth through structural transformation. In particular we focus on labor-abundant economies as we believe this captures the story of the economic transformation of a very large proportion of the world's population. The focus on labor-abundant economies also allows us to explore the story of growth through labor-intensive manufactured exports. We highlight the roles of agricultural innovation as well as a rise in world demand for labor-intensive manufactures. Our assumption of a specific factor in the production of the non-traded good, food, buys us the advantage of allowing for flexible food prices independent of the fixed world prices for traded goods. Our assumption of two traded industrial goods, in addition to the closed agricultural sector, also allows us to study the case of economies with open industrial but closed agricultural markets. This continues to be of relevance as barriers on international trade in food remain much higher than corresponding barriers on trade in other goods.

2. Assumptions

1. We use a modified version of the Jones 'specific factor' model in which food production requires land and labor while manufacturing requires labor and capital. There are however two manufactures, one labor-intensive, and the other capital-intensive – with factor intensity reversals assumed away for simplicity.

2. Capital is assumed to be perfectly malleable and freely transferable between industries; labor likewise between agriculture and both industries.

3. We eliminate distributional considerations by using a 'representative agent' model. This, together with the assumption of a constant population, enables us to treat aggregate demand functions as scale blow-ups of individual demand functions.

4. The own-price-elasticity of food demand η is assumed to be less than

unity.

5. There is no foreign trade in food.
6. All goods are gross substitutes.

3 . The Model

The structure of our model has parallels with Hazari and Sgro (2004). We have two goods being produced in the manufacturing sector, using labor and capital, both goods being traded, and one non-traded good, food, produced in the closed agricultural sector using labor and land. In the H-S model, as mentioned in the introduction, there is a rural sector which produces a non-traded good, which could be considered to be food. However in H-S unlike in our model, there is also a traded rural sector good and one traded and one non-traded good in the urban sector - while in our model both goods in the industrial sector are traded. In our model as well as H-S, labor is internally mobile - between sectors in H-S and between manufacturing and food in our model. The specificity of land for agricultural production in our model is also similar to the use of "region-specific capital" in the production of the rural non-traded good in H-S. However in H-S this capital can also move into the production of the rural traded good, while in our model land is truly specific to the non-traded sector.

We now come to the specifics of our model. Food output depends on labor, land and an agricultural productivity parameter: it is represented by $AF(L_a, N)$ where A is the Hicks-neutral productivity parameter, L_a is labour in agriculture and N land. The demand for food depends on income I and relative prices p (of food) and p_1 (the 'terms-of-trade' of light manufactures, the exportable of a labor-abundant economy), all in terms of heavy manufactures. Heavy manufacture is thus the numeraire with price 1. Hence the demand function for food is represented by $D(I, p, p_1)$. As there is no foreign trade in food, in equilibrium, supply equals domestic demand:

$$AF(L_a, N) = D(I, p, p_1) \tag{1}$$

The specificity of N in food production is a crucial feature of our model. We know that p_1 , the relative price of traded goods (manufactures), is determined by world prices. If all factors of production were perfectly mobile between manufacturing and food production, the price of food p could no longer be determined independently of world prices. It would instead be "locked in" by p_1 . Specificity of N thus permits flexibility of food prices.

We assume CRS production functions for light and heavy manufactures, respectively. The CRS feature will help to simplify our calculations. We do not impose any such assumption on the food production function. The production

functions for light and heavy manufactures are given by (2) and (3) respectively.

$$G(K_1, L_1) = L_1 g(k_1) = X_p \quad (2)$$

and

$$H(K_2, L_2) = L_2 h(k_2) = Y_p \quad (3)$$

where K_i and L_i denote the supply of capital and labor to the i -th industry and k_i the capital-labor ratio in it ($i=1,2$).

In equilibrium, the value of the marginal product of capital (the rental R) should be equal in the two industries:

$$p_1 g'(k_1) = h'(k_2) = R \quad (4)$$

Similarly, the value of the marginal product of labor (the wage W) should be equal in both industries and agriculture:

$$W = pAF_L(L_a) = p_1[g(k_1) - k_1 g'(k_1)] \quad (5)$$

$$= h(k_2) - k_2 h'(k_2) \quad (6)$$

The demand functions for manufactures are

$$X = X(I, p, p_1) \quad (7)$$

$$Y = Y(I, p, p_1) \quad (8)$$

and the balanced trade equation is

$$p_1(X_p - X) = Y - Y_p \quad (9).$$

The full-employment equations for labor and capital are

$$L_a + L_1 + L_2 = L \quad (10)$$

and

$$k_1 L_1 + k_2 L_2 = K \quad (11)$$

and the income identity is

$$I = pAF(L_a) + p_1 X_p + Y_p \quad (12).$$

By Walras' law, one of these equations is redundant – and we discard (8) – the demand function for capital-intensive manufactures – as implied by the other two demand functions, the income identity and the balanced trade equation. We note that we are using I to denote nominal income : to denote real income, we use U (which can be thought of as utility).

There is an alternative way of looking at this model. We can express the prices of manufactures and of food in terms of factor prices and input coefficients. Thus we get:

$$a_{LX}(w) + a_{KX}(r) = p_1 \quad (13)$$

$$a_{LY}(w) + a_{KY}(r) = 1 \quad (14)$$

$$a_{LA}(w) + a_{NA}(\Pi) = p \quad (15)$$

Here w and r represent the wage rate and the rental rate on capital while Π is the rental rate on land. The coefficients in (13) and (14) represent the input-output coefficients of labor and capital in the production of the light and heavy manufactures respectively. The coefficients in (15) represent the input-output coefficients of labor and land in agricultural production. Since p_1 is predetermined by world prices, and as technology and therefore the input-output coefficients are known, we can solve (13) and (14) for w and r . This then leaves us with two unknowns, Π , the rental on land, and p , the price of food in terms of heavy manufactures. In addition to (15), we need another equation to solve for these and we can use (1), our supply-demand equation for the closed food market. Using the fact that nominal income, I , in terms of heavy manufactures is given by $I = pAF + p_1X_p + Y_p$, we can solve for p from (1), and then use this value of p in (15) to solve for Π

Figure 1 helps illustrate equations (13) and (14). Here the curve for p_1 shows the possible combinations of w and r that could lead to a price of p_1 for good X, given techniques of production. Similarly the curve for $p_2 = 1$ shows the possible combinations of w and r that would result in a numeraire price of 1 for the heavy industry, given that techniques of production are known. The equilibrium w and r are determined by the intersection point of these two curves, which represents the solution of equations (13) and (14).

Alternatively, we can focus on equations (1)-(12) to understand and solve the system. This economy is then determined by the parameters L , K , A , and p_1 ; and one of its endogenously determined characteristics is the degree of industrial specialization. For given values of the parameters L , K and p_1 and of L_a , the industrial production economy can be regarded as a small open economy with fixed factor endowments K and $(L - L_a)$ and a fixed commodity price ratio p_1 . If the capital/labor ratio in such an economy lies within a certain 'diversification zone' $\bar{k}(p_1) \geq K/(L - L_a) \geq \underline{k}(p_1)$, both industries will operate, the factor price ratio, the techniques of production k_1 and k_2 and the productivities of factors in both industries will be determined by p_1 alone. Further, $k_1(p_1) = \underline{k}(p_1)$ and $k_2(p_1) = \bar{k}(p_1)$. Outside the diversification zone, however, there will be perfect specialization and the factor price equalization results will break down.

This can be understood by referring to Figure 2. Here the slope of $OA = k_1(p_1)$ represents the capital-labor ratio in the production of the light manufacture while the slope of $OB = k_2(p_1)$ represents the (higher) capital-labor ratio in the production of the heavy manufacture. The horizontal line shows the capital resource constraint : the total capital available for both goods sums to K . The cone

Oe_2e_1 formed by the rays OA, OB and the capital resource constraint, is a "diversification cone". Labor allocation is not fixed and depends on the residual $(L - L_a)$ which is the total supply available to the manufacturing sector. If a solution can be found within the diversification cone, there is incomplete specialization with both light and heavy manufactures being produced. This happens if $k_2(p_1) > K/(L - L_a) > k_1(p_1)$. If, however, $k_2(p_1) = K/(L - L_a)$ - that is if the ratio of total capital to the labor available to industry equals the slope of the ray OB, then there is complete specialization in the capital-intensive manufacture, Y. Similarly, if $K/(L - L_a) = k_1(p_1)$, there is complete specialization in the labor-intensive manufacture, X.

Static Equilibrium

We study the static equilibrium of this economy in terms of a migration equilibrium condition and a commodity market equilibrium (although the migration equilibrium condition derives from the labor market, the labor market itself is derived from the commodity market, therefore all the results are basically derived using the commodity market). The migration equilibrium $p = \phi(L_a)$ for any set of parameters K, L, A and p_1 is the set of pairs of food prices and agricultural labor allocations determined by the marginal productivity equations. Along this locus of food prices and agricultural labor allocations, there is no migration of labor between sectors as the marginal productivity of labor in different sectors is equalized. We note that the marginal productivity equations are themselves derived from the commodity market in food and the production functions of the manufactures - reinforcing the point that it is possible to derive our results using the commodity market alone. Under imperfect specialization, the marginal productivity equations are given by (4), (5) and (6) with $k_1 = \underline{k}(p_1)$ and $k_2 = \bar{k}(p_1)$. Under complete specialization (say in the labor-intensive industry 1), equation (6) (for industry 2) disappears and the relevant equation is (5) with $k_1 = K/(L - L_a)$.

The commodity market equilibrium, on the other hand, is the food price that equates the supply and demand for food, given any allocation of labor to agriculture $p = \varphi(L_a)$. Under imperfect specialization, this is the solution of the equations (1), (2), (3), (7), (9) and (12) with $k_1 = \underline{k}(p_1)$ and $k_2 = \bar{k}(p_1)$. Under complete specialization in industry 1, equation (3) drops out, Y_p vanishes in equations (9) and (12) and k_1 in equation (2) becomes $k_1 = K/(L - L_a)$.

Since we assume our basic functions to be all continuous and differentiable, $p = \phi(L_a)$ and $p = \varphi(L_a)$ can be easily seen to be continuous. This is so even at \underline{L}_a and \bar{L}_a , the points of transition from incomplete to complete specialization: it can be checked that in the limit $L_a = \bar{L}_a$ (or $L_a = \underline{L}_a$), the equation system under

perfect specialization becomes identical with that under diversification. We can therefore represent migration equilibrium and commodity market equilibrium by continuous curves in (L_a, p) space as shown in Figure 3.

Proposition 1: There is a unique static equilibrium, given the following set of assumptions:

- (1) $F(0)=0$; no agricultural production is possible without labor:
- (2) $D(I, p, p_1) > 0, \forall I > 0, p < \delta < \infty$. : there will be some positive demand for food at all positive incomes and upper-bounded food prices.
- (3) $I - pD(I, p, p_1) > 0, \forall I > 0, p > 0$: there will be some positive demand for manufactures at all positive incomes and food prices.

Proof: In the appendix.

Comparative statics with productivity shocks

Now we introduce positive productivity shocks in agriculture ($dA > 0$).

Proposition 2: With $\eta < 1$, (a less than unitary own price elasticity of demand for food), a positive productivity shock in agriculture results in labor moving out of agriculture into industry. This holds even if we control for changes in the price of food, that is, if we consider changes in real as opposed to nominal income.

Proof:

We confine ourselves here to the incomplete specialization case. Details about the complete specialization case are available on request.

We now consider changes in real income, U , as opposed to nominal income I . Differentiating (1), we note that the total change in food demand can then be split into two components : the first due to a change in food price p keeping U constant, and the second due to a change in U keeping p constant. (These are akin to the substitution and income effects of any price change). We then have:

$$AF_L dL_a + F dA = [D_p]_{const.utility} dp + [D_U]_{pconst} dU \quad (16)$$

Equations (4) and (6) are unaffected, because, with terms of trade p_1 assumed unchanged, $\underline{k}(p_1)$ and $\bar{k}(p_1)$ must also be constant. Differentiating (5)

$$pF_L dA + AF_L dp + pAF_{LL} dL_a = 0 \quad (17).$$

From (10) and (11), abstracting from population growth and capital accumulation,

$$k_1 dL_1 + k_2 dL_2 = 0 \quad (18)$$

$$dL_a + dL_1 + dL_2 = 0 \quad (19).$$

Now it is possible to show that with a productivity shock of dA ,

$$dU = pFdA \quad (20).$$

This measures the change in real income. We can briefly derive (20) as follows: Since U is a function of domestic demand for all three goods, D (food demand), X and Y , then since Y is the numeraire good, changes in real income can be expressed as:

$$dU = \frac{\partial U/\partial D}{\partial U/\partial Y} dD + \frac{\partial U/\partial X}{\partial U/\partial Y} dX + dY = p dD + p_1 dX + dY$$

Now

$$pD + p_1 X + Y = pAF + p_1 X_p + Y_p$$

(equating the value of national expenditure and the value of national product).

Total differentiation yields

$$p dD + p_1 dX + dY + D dp = pFdA + pAdF + p_1 dX_p + dY_p + AF dp$$

or

$$p dD + p_1 dX + dY = pFdA + pAdF + p_1 dX_p + dY_p$$

as $AF=D$ (domestic supply and domestic demand in the food market are always equal). Now if we measure the change in real income, then we have

$$\begin{aligned} dU &= p dD + p_1 dX + dY = pFdA + pAdF + p_1 dX_p + dY_p \\ &= pFdA + pAF_L dL_a + p_1 g'(k_1) dK_1 + p_1 [g(k_1) - k_1 g'(k_1)] dL_1 + h'(k_2) dK_2 \\ &\quad + [h(k_2) - k_2 h'(k_2)] dL_2 \\ &= pFdA + pAF_L [dL_a + dL_1 + dL_2] + h'(k_2) [dK_1 + dK_2] \quad (\text{from (4), (5) and (6)}) \\ &= pFdA \end{aligned}$$

(using (10) and (11), the full employment equations for labor and capital).

Now if and only if $dL_a = 0$ (there is no intersectoral labor migration), (17) implies

$$pF_L dA + AF_L dp = 0 \Rightarrow dp/p = -dA/A. \quad (17b)$$

With the agricultural labor force constant, the proportionate rate of growth of food supply is dA/A . What about the proportionate rate of growth of food demand? Looking at the right hand side of (16), using the fact that $p[D_p]_{const.utility} = -\sigma D$ where σ is the Hicks-compensated own price elasticity of food demand, and using (20) and (1), the proportionate rate of growth of food demand works out to be

$$\begin{aligned} dD(p, U)/D(p, U) &= -\sigma dp/p + pD_U dA/A = (\sigma + pD_U) dA/A \quad (\text{from (17b)}) \\ &= \eta dA/A \end{aligned}$$

where η is the standard Marshallian own price elasticity of demand for food. The own price elasticity incorporates both substitution and real income effects on demand.

We have assumed that $\eta < 1$ (a reasonable assumption - food being a necessity faces a relatively inelastic demand curve). Therefore, the above tells us that food supply increases faster than food demand: the excess supply of food will drive food prices down faster than implied by (17 b).

Thus, for $\eta < 1$, $dA/A + dp/p < 0$, which implies, from (17), that

$$dL_a = -\frac{F_L}{F_{LL}}[dA/A + dp/p] < 0$$

– labor migrates from agriculture into industry.

Substituting this last expression for dL_a and equation (20) above in (16), dividing through by $AF = D$, and collecting terms,

$$-[F_L^2/F_{LL} + p[D_p]_{const.utility/D}]dp/p = [F_L^2/F_{LL} + pD_U F - F]dA/A.$$

Since $p[D_p]_{const.utility/D} = -\sigma$,

$$dp/p = -dA/A \frac{F_L^2/F_{LL} + pD_U F - F}{F_L^2/F_{LL} - \sigma F}$$

Both the numerator and the denominator of this fraction are negative, as $F_{LL} < 0, \sigma > 0$ and pD_U (the marginal propensity to consume food) is less than 1. Moreover, the numerator is less than the denominator (more negative) iff $1 - pD_U > \sigma$, or equivalently, iff $\eta < 1$. This establishes that as $\eta < 1$, we have

$$dp/p < -dA/A.$$

Thus,

$$dL_a = -F_L/F_{LL}[dA/A + dp/p] < 0.$$

The intuition for labor migrating into industry is that in a no-migration situation, p falls as fast as A rises; however, if the own price elasticity of food demand is less than unity, food demand rises less than food supply. Thus for equilibrium in the food market, p must fall faster, necessitating labor migration out of agriculture for labor market equilibrium. Meanwhile, the inflow of labor into industry has a Rybczynski effect on production, raising labor-intensive outputs and lowering capital-intensive ones – as long as techniques in both industries remain constant (due to the constancy of the terms of trade).

Thus, agricultural innovation by itself can drive industrialization if terms of trade within industry are stable: it will also of course drive down the price of food. The crucial condition is a less-than-unit own-price-elasticity of food demand. The closed character of the agricultural market actually stimulates industrial development by forcing labor which may otherwise have been producing agricultural export surpluses into manufacturing.

Further, agricultural innovation stimulates not only industrial expansion generally, but industrial exports in particular. By inducing labor migration into industry, it intensifies the comparative advantage of the industrial economy in labor-intensive production and export through a Rybczynski effect. Thus, the Green Revolution could have supplied the momentum for both sustained industrialization and industrial export growth even without either productivity improvement in manufacturing or favorable changes in the world economy.

It is of course true that, since food prices would fall during this process, agricultural innovation could continue only if it were exogenous. Endogenous technical progress may well be self-limiting under such circumstances – though it

could be argued that even this may not happen. Agriculture being highly competitive, the well-known incentives to innovation under competition – the carrot of temporary profits for the pioneer and the stick of assured losses for the laggard – may well have worked efficiently.

4. Comparative statics with productivity and terms of trade shocks

This section incorporates the effect of an improvement in the terms of trade into the framework of Section 2. The reason for investigating this is to model an improvement in trading opportunities as a drastic fall in transfer costs, which would raise the f.o.b. prices exports could fetch.

Proposition 3: When terms of trade improvements and technical progress in agriculture occur simultaneously, the latter continues to stimulate migration to manufacturing for $\eta < 1$ while the former independently induces migration into manufacturing– under conditions of both perfect and imperfect specialization.

Proof: In the appendix.

Industrialization without agricultural innovation: If $dA = 0$, $\frac{dL_a}{dp_1} < 0$ and $\frac{dp}{dp_1} > 0$ as can be seen by substitution of $dA=0$ into appendix equations (30) and (31). Terms-of-trade improvement by itself attracts migrants into industry – but at the cost of rising food prices. Food scarcity is the consequence both of swelling demand and of dwindling supply. If we examine changes in real income, the terms of trade effect by itself still induces labor migration out of agriculture. However the effect is reinforced by agricultural innovations subject to our condition of less than unitary own price elasticity of demand for food. Moreover agricultural innovation can halt the rise in food prices that would definitely result in its absence.

This last point may be clarified by referring to the commodity market equilibrium curve $\varphi(L_a)$. If there is an irreducible minimum to food demand at $D = D_{\min}$ there is a corresponding minimum $(L_a)_{\min}$ below which the agricultural labor force cannot be driven without generating excess demand for food. $(L_a)_{\min}$ is given by $AF((L_a)_{\min}) = D_{\min}$. In that case, the $\varphi(L_a)$ curve will be asymptotic to the ordinate $L_a = (L_a)_{\min}$. Equilibrium will necessarily lie to the right of this. As agricultural labor approaches this limit, exploding food prices will halt industrialization in its tracks. This is the Ricardian limit on growth, set by the closure of the agricultural market and by technological stagnation in agriculture. As in Ricardo's England, 'repeal of the Corn Laws' would revive industrial growth as

would further innovation in agriculture.

5. Some Possible Extensions : Technical Progress in Other Non-Tradeables

While we have explicitly focussed on the role of exogenous technical progress in agriculture in the release of labor for industrial expansion, the same analysis is amenable to a broader interpretation. Autonomous innovation in any non-tradeable and labor-intensive activity would have essentially the same effect. Technological progress in the production of household services is a particularly important example. It is possible that it significantly accelerated the migration of labor, particularly female labor, into industry, and this is one explanation for the rising female labor participation that seems to be a corollary of development. Of course, other factors (e.g. the fall in birth rates) may have contributed to the same effect.

In this context, the role of freer trade as the vehicle of technical progress should not perhaps be ignored. It could have been the import of labor-saving household gadgets that led, both directly and through their learning effects on domestic production, to the crucial changes in household technology. Modelling this however would take us too far afield into complexities beyond the scope of the present paper.

Appendix

Proof of Proposition 1:

Assumptions (1) and (2) suffice to ensure that as L_a diminishes, $\varphi(L_a)$ rises without bound and so exceeds $\phi(0)$. Assumption (3) ensures that as L_a reaches L , so that only food is produced and all income is agricultural, food will be in excess

supply at all positive prices, driving the equilibrium food price down to zero. Thus $\varphi(L) = 0$. In contrast, the marginal physical product of labor in both agriculture and manufactures will be positive in this limit; and so accordingly will be the food price that equilibrates the two: so $\phi(L) > 0$, i.e. $>\varphi(L)$.

Given the continuity of the functions $\varphi(L_a)$ and $\phi(L_a)$, they must intersect. To show that the intersection is unique, we need to show monotonicity of the slopes of these functions.

We determine the slopes of these curves by differentiating the relevant equations. Here we only consider the incomplete specialization cases as being of more interest. Details on the complete specialization case are available on request.

First consider $\phi'(L_a)$. Differentiating equation (5) yields

$AF_L dp + pAF_{LL} dL_a = 0$; (the fact that p_1 and k_1 remain constant accounts for the RHS being 0).

$$\Rightarrow dp/dL_a = -pF_{LL}/F_L > 0.$$

So the slope of the no-migration curve $\phi'(L_a) > 0$.

To get $\varphi'(L_a)$ we differentiate (1). Rather than look at changes in nominal income, we focus on changes in real income, U . Then the change in food demand is decomposed into two components: a change due to changes in p keeping U constant, and a change due to changes in U keeping p constant. In this case, the latter component is zero. Thus we have:

$$\begin{aligned} AF_L dL_a &= [D_p]_{const.utility} dp = -\sigma D dp/p \\ &= -\sigma AF dp/p \end{aligned} \tag{A1}$$

where σ is the Hicks-compensated own price elasticity of demand for food. Thus the slope of the CMC is

$$\varphi'(L_a) = dp/dL_a = -\frac{pF_L}{\sigma F} < 0.$$

So the commodity market equilibrium curve CMC is downward-sloping in (p, L_a) space.

The monotonically upward sloping $\phi(L_a)$ and the monotonically downward sloping $\varphi(L_a)$ obviously have a unique intersection.

Proof of Proposition 3:

Total differentiation yields different results now from Section 2: as p_1 is variable, so are k_1 and k_2 . Again, we use changes in real income, dU . Thus, we now have

$$FdA + AF_L dL_A = [D_U]_{const.prices} dU + [D_p]_{const.utility} dp + [D_{p_1}]_{const.utility} dp_1 \tag{21}$$

$$g'(k_1) dp_1 + p_1 g''(k_1) dk_1 = h''(k_2) dk_2 \tag{22}$$

$$[g(k_1) - k_1 g'(k_1)] dp_1 - p_1 k_1 g''(k_1) dk_1 = -k_2 h''(k_2) dk_2 \tag{23}$$

$$pF_L dA + AF_L dp + pAF_{LL} dL_a = -k_2 h''(k_2) dk_2 \tag{24}$$

$$L_1 dk_1 + k_1 dL_1 + L_2 dk_2 + k_2 dL_2 = 0 \tag{25}$$

$$dL_a + dL_1 + dL_2 = 0. \tag{19}$$

As in section 3, we can find dU . Total differentiation of the income-expenditure identity now yields

$$pdD + p_1dX + dY + Ddp + Xdp_1 = pFdA + pAdF + p_1dX_p + dY_p + AFdp + X_pdp_1$$

or

$$pdD + p_1dX + dY + Xdp_1 = pFdA + pAdF + p_1dX_p + dY_p + X_pdp_1$$

as $AF=D$. Now if we measure the change in real income, omitting the change attributable to changing food prices, then we have

$$\begin{aligned} dU &= pdD + p_1dX + dY = pFdA + pAdF + p_1dX_p + dY_p + (X_p - X)dp_1 \\ &= pFdA + pAF_LdL_a + p_1g'(k_1)dK_1 + p_1[g(k_1) - k_1g'(k_1)]dL_1 + h'(k_2)dK_2 \\ &\quad + [h(k_2) - k_2h'(k_2)]dL_2 + (X_p - X)dp_1 \end{aligned}$$

$$= pFdA + pAF_L[dL_a + dL_1 + dL_2] + h'(k_2)[dK_1 + dK_2] + (X_p - X)dp_1$$

(from (4), (5) and (6))

$$= pFdA + (X_p - X)dp_1$$

(using (10) and (11), the full employment equations for labor and capital).

$$= pFdA + E_Xdp_1 \tag{26}$$

where we use the notation $E_X = X_p - X$ to denote exports of the labor-intensive manufacture. Thus the change in real income is different from that in the previous section due to the terms of trade effect in the exports.

From (23) above,

$$dk_2 = \frac{1}{k_2h''(k_2)} [p_1k_1g''(k_1)dk_1 - \{g(k_1) - k_1g'(k_1)\}dp_1]. \tag{27}$$

Substituting this in (22),

$$g'(k_1)dp_1 + p_1g''(k_1)dk_1 = p_1k_1g''(k_1)dk_1/k_2 - \{g(k_1) - k_1g'(k_1)\}dp_1/k_2$$

$$\Leftrightarrow \left[\frac{k_2 - k_1}{k_2} g'(k_1) + g(k_1)/k_2 \right] dp_1 = -p_1g''(k_1) \frac{k_2 - k_1}{k_2} dk_1$$

$$\Leftrightarrow dk_1 = -\frac{1}{p_1g''(k_1)} \left[g'(k_1) + \frac{g(k_1)}{k_2 - k_1} \right] dp_1 \tag{28}$$

$$dk_2 = \frac{1}{k_2h''(k_2)} \left[-k_1 \left\{ g'(k_1) + \frac{g(k_1)}{k_2 - k_1} \right\} dp_1 - \{g(k_1) - k_1g'(k_1)\} dp_1 \right]$$

$$= -\frac{g(k_1)}{h''(k_2)} \frac{dp_1}{k_2 - k_1}. \tag{29}$$

Both dk_1 and dk_2 are positive. The rise in p_1 has a Stolper-Samuelson effect that not only increases the wage rate but also results in the expansion of the labor-intensive industry. Factors move out of the capital-intensive into the labor-intensive industry in such a manner as to increase the capital-intensities in both (this could be accomplished by the heavy industry releasing K and L in proportions between the original k_2 and k_1).

$$\text{Now } dw = d[h(k_2) - k_2h'(k_2)] = -k_2h''(k_2)dk_2 = \frac{k_2g(k_1)}{k_2 - k_1} dp_1 \quad [\text{from (29)}]$$

$$\text{and } dr = d[h'(k_2)] = h''(k_2)dk_2 = -\frac{g(k_1)}{k_2 - k_1} dp_1$$

Also, substituting from (29) into (24),

$$pF_LdA + AF_Ldp + pAF_{LL}dL_a = \frac{k_2g(k_1)}{k_2 - k_1} dp_1$$

$$\Rightarrow dL_a = \frac{k_2g(k_1)}{pAF_{LL}(k_2 - k_1)} dp_1 - \frac{F_L}{pF_{LL}} dp - \frac{F_L}{AF_{LL}} dA$$

Using this and (26) in (21), and substituting $p[D_p]_{const.utility} = -\sigma D = -\sigma AF$

$$\begin{aligned}
& FdA + AF_L \left[\frac{k_2 g(k_1)}{pAF_{LL}(k_2-k_1)} dp_1 - \frac{F_L}{F_{LL}} \left\{ \frac{dp}{p} + \frac{dA}{A} \right\} \right] \\
&= -\sigma AF dp/p + [D_1]_{const.utility} dp_1 + D_U [pFdA + E_X dp_1] \\
&\Rightarrow -\left[\frac{\{F_L\}^2}{F_{LL}} - \sigma F \right] \frac{dp}{p} = \left[\frac{\{F_L\}^2}{F_{LL}} + pD_U F - F \right] \frac{dA}{A} + \left[[D_1]_{const.utility} - \frac{k_2 g(k_1) F_L}{pF_{LL}(k_2-k_1)} + D_U E_X \right] \frac{dp_1}{A} \\
&\Rightarrow \frac{dp}{p} = -\frac{dA}{A} \left[\frac{\{F_L\}^2/F_{LL} + pD_U F - F}{\{F_L\}^2/F_{LL} - \sigma F} \right] - \frac{dp_1}{A} \left[\frac{[D_1]_{const.utility} - \{k_2 g(k_1) F_L/pF_{LL}(k_2-k_1)\} + D_U E_X}{\{F_L\}^2/F_{LL} - \sigma F} \right] \quad (30)
\end{aligned}$$

Exactly as in the previous section, the numerator and denominator of the fraction multiplying $-dA/A$ are both negative so food prices tend to fall with agricultural innovation. As before, the fall is more than proportionate given our assumption that $\eta < 1$. As $[D_1]_{const.utility} > 0$, and as $F_{LL} < 0$ and $E_X > 0$, $D_1 - \frac{k_2 g(k_1) F_L}{pF_{LL}(k_2-k_1)} + D_U E_X > 0$. This shows that the terms of trade effect tend to boost the demand for food, raising p .

From (30) and the expression for dL_a ,

$$dL_a = \frac{k_2 g(k_1)}{pAF_{LL}(k_2-k_1)} dp_1 + \frac{F_L}{F_{LL}} \left[\frac{dp_1}{A} \left\{ \frac{[D_1]_{const.utility} - \{k_2 g(k_1) F_L/pF_{LL}(k_2-k_1)\} + D_U E_X}{\{F_L\}^2/F_{LL} - \sigma F} \right\} + \frac{dA}{A} \left\{ \frac{\{F_L\}^2/F_{LL} + pD_U F - F}{\{F_L\}^2/F_{LL} - \sigma F} \right\} - \frac{F_L}{F_{LL}} \frac{dA}{A} \right]$$

Simplifying,

$$dL_a = -\frac{F_L}{F_{LL}} \frac{(1-\eta)F}{\{F_L\}^2/F_{LL} - \sigma F} \frac{dA}{A} + \frac{F_L}{F_{LL}} \left[\frac{[D_1]_{const.utility} - \{\sigma F k_2 g(k_1)/pF_L(k_2-k_1)\} + D_U E_X}{\{F_L\}^2/F_{LL} - \sigma F} \right] \frac{dp_1}{A} \quad (31)$$

As $F_{LL} < 0$, $\frac{\{F_L\}^2}{F_{LL}} - \sigma F < 0$, we see that the crucial condition for $\frac{dA}{A}$ to have a negative effect on dL_a , ie to induce industrialization, remains $\eta < 1$. As for the effect of dp_1 on L_a , it is negative iff

$$\frac{\sigma F k_2 g(k_1)}{pF_L(k_2-k_1)} > [D_1]_{const.utility} + D_U E_X$$

We show below that this always holds. Multiplying both sides by $\frac{p_1}{D} = \frac{p_1}{AF}$ this inequality becomes

$$\sigma \frac{p_1 k_2 g(k_1)}{p_1(k_2-k_1)[g(k_1)-k_1 g'(k_1)]} > \frac{p_1 [D_1]_{const.utility}}{D} + \frac{p_1 D_U}{D} E_X \quad [\text{using (5)}]. \quad (32)$$

Now from the homogeneity of demand in all prices and nominal income,

$$\frac{p_1 D_1}{D} + \frac{ID_I}{D} + \frac{pD_p}{D} + \frac{D_2}{D} = 0 \quad [\text{where } D_2 = \frac{\partial D}{\partial p_2} \text{ at } p_2 = 1]$$

$$\Leftrightarrow \frac{p_1 D_1}{D} + \frac{[D_1]_{const.prices}}{D} [pD + p_1 X_p + Y_p] + \frac{pD_p}{D} + \frac{D_2}{D} = 0$$

$$\Leftrightarrow \frac{p_1 D_1}{D} + \frac{p_1 D_U}{D} X_p = -pD_U - \frac{D_I}{D} Y_p + \eta - s_2$$

$$= \sigma - \frac{D_I}{D} Y_p - s_2 \quad (33)$$

where $s_2 = \frac{D_2}{D}$ is the cross elasticity of demand for food with respect to heavy manufactures: $s_2 > 0$ by a gross substitution assumption.

Now as $k_2 > k_2 - k_1$ and $g(k_1) > g(k_1) - k_1 g'(k_1)$, the left hand side of (32) $> \sigma > \sigma - s_2 - \frac{D_U}{D} Y_p = \frac{p_1 D_1}{D} + \frac{p_1 D_U}{D} X_p > \frac{p_1 [D_1]_{const.utility}}{D} + \frac{p_1 D_U}{D} E_X$ (which is the right hand side of (32)). Thus, the terms of trade effect always tends to induce labor migration into industry.

The analysis for the complete specialization case is available on request.

Therefore the inequality (32) always holds – the effect of a terms of trade improvement on L_a is unambiguously negative.

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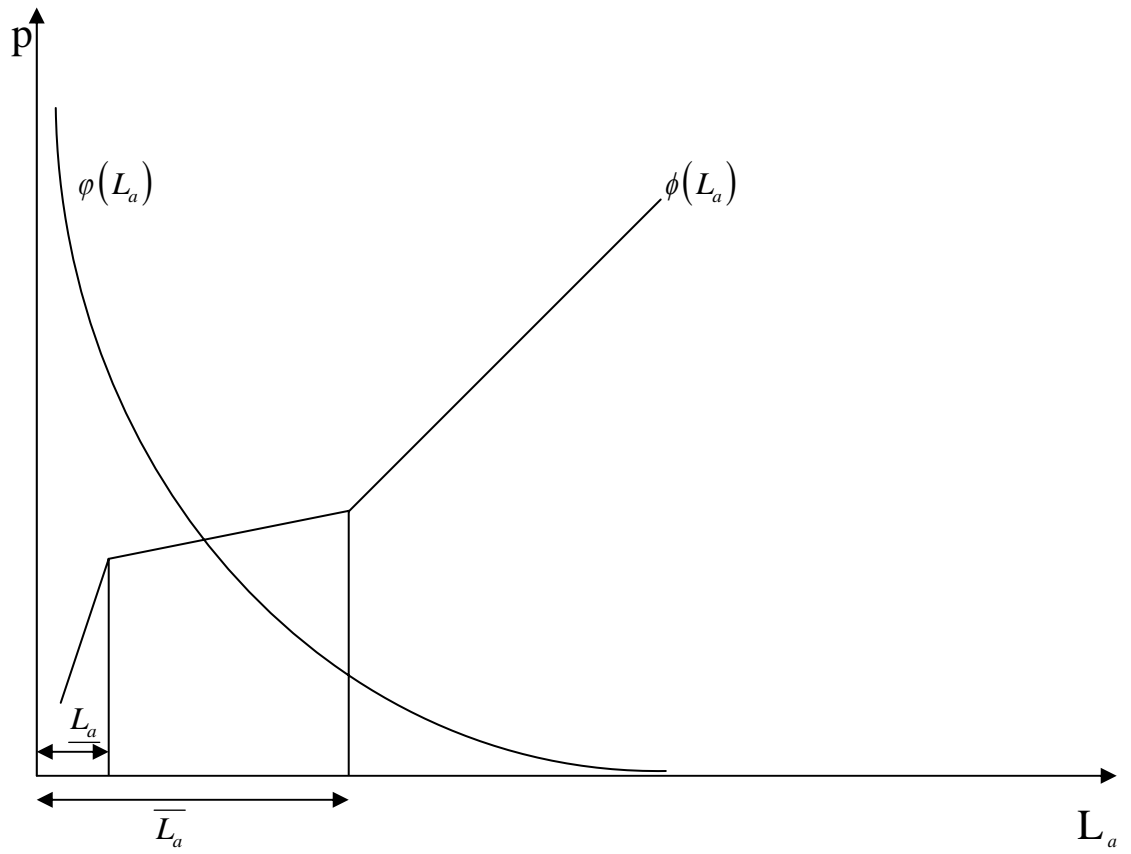


FIG. 3