INTERNATIONAL PRODUCTIVITY DIFFERENCES IN MANUFACTURING INDUSTRY PROBLEMS WITH EXISTING THEORY AND SOME SUGGESTIONS FOR A THEORETICAL RESTRUCTURING

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INTERNATIONAL PRODUCTIVITY DIFFERENCES IN MANUFACTURING INDUSTRY - PROBLEMS WITH EXISTING THEORY AND SOME SUGGESTIONS FOR A THEORETICAL RESTRUCTURING

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Part I of this study examines certain important difficulties with existing formal theory purporting to explain international differences in output per worker in manufacturing, particularly differences between developed and underdeveloped countries. Part II presents a theoretical case for abandoning two central assumptions of that theory -- that all firms can be considered as on the same neoclassical production function, and that factor markets are perfect and competitive. Basically the argument will be that manufacturing development should be modeled as an inter- and intra-national diffusion process. Part III presents an empirical analysis of Colombian-United States productivity differences which supports the argument of Part II.

I. PROBLEMS WITH EXISTING THEORY

Over the past decade a considerable literature has developed attempting to explain cross-country differences in output per worker

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Several of the ideas presented in this paper are the result of, or have been significantly sharpened by, discussions with Donald Keesing, Edward Mitchell, and Sidney Winter. The data on Colombia, used in the final section, were obtained in the course of a study under contract to AID and reported in [4].

in manufacturing industry. The differences to be explained are substantial. If one believes the published figures, value added per worker in manufacturing in India is only about one-tenth that in the United States; in countries like Colombia, Japan, and Mexico, about one-quarter; in Western Europe roughly sixty percent. These kinds of differences exist industry-by-industry, as well as for manufacturing as a whole.[1]

The descriptive and qualitative literature has discussed a wide variety of variables which may explain the differences, and has employed (implicitly) a wide variety of models. However in the more quantitative literature employing a formal model, the theoretical analysis almost invariably starts from two assumptions. The first is that within an industry, all firms, both within a country and in different countries are, in some basic sense, employing the same neoclassical production function. Differences in output per worker therefore ought to be explainable by differences in the supply of complementary factors per worker. The second assumption is that factors are homogeneous and perfectly mobile within an industry in a country, and factor prices are determined on competitive markets. Prices or returns of different factors are the same for all firms in the country and can be used to estimate marginal productivity. Together these two assumptions imply that in each country the industry is the representative firm writ large. Inter-country productivity differences reflect differences in factor proportions employed by the representative firms.[2]

The point of view presented later in this paper breaks significantly from these assumptions. I have been led to adopting a quite different point of view in large part because of growing awareness that the early attempts to employ the model empirically suggested some basic problems with the neoclassical framework. It is useful therefore to set the stage by describing these problems.

The most useful point of departure is the study of Arrow, Chenery, Minhas, and Solow, which, within the above framework, attempted to relate cross country differences in value added per worker to differences in the capital labor ratio.[3] Capital and labor were defined so that their returns added up to value added; thus other factors implicitly were assumed to influence average quality or effectiveness of one or both of these two basic inputs.

For our purposes the pertinent questions to which their research pertains can be posed as follows: Given the observed level of value added per worker and of capital per worker in an industry in a less developed country, and assuming they stay on the same (common to all countries) production function, what would their value added per worker be if they had a capital labor ratio equal to that in a developed country? How much of the observed difference in value added per worker can be explained, in the sense above, by the difference in the capital labor ratio?

The answers, of course, depend on the "shape" of the production function. The basic assumptions constrain the shape. Output per worker, $\frac{Q}{L}$, must be an increasing and concave function of the capital labor ratio, $\frac{K}{L}$, given other factors that will be denoted by Y. Thus:

$$\frac{Q}{L} = F\left(\frac{K}{L}, Y\right) \quad F_1 > 0 \ , \ F_{11} < 0 \tag{1}$$

Or, for a constant Y :

$$\frac{Q}{L} = f\left\{\frac{K}{L}\right\} \ f' > 0, \ f'' < 0. \tag{1a}$$

Notice that f(·) may differ across countries if Y differs.

Observation of output and capital per worker, and of either the rate of return on capital or capital's share, permit quantitative specification of a point on the function, and the slope or elasticity of the function at that point. For if we assume that the marginal productivity of capital, f' , equals the interest rate:

$$\left\{\frac{Q}{L}\right\}_o = f\left[\left\{\frac{K}{L}\right\}_o\right]$$

$$f'\left[\left\{\frac{K}{L}\right\}_o\right] = r_o \quad \text{or} \quad \frac{f'\left[\left\{\frac{K}{L}\right\}_o\right]\left\{\frac{K}{L}\right\}_o}{f\left[\left\{\frac{K}{L}\right\}_o\right]} = r_o \left\{\frac{K}{Q}\right\}_o = S_K^o \tag{2}$$

This information suffices for estimation of the effect on output per worker of small changes in the capital labor ratio. For large changes something must be known about the degree of concavity of the function -- the rate of diminishing returns. This can be measured by the elasticity of substitution between capital and labor which determines how the elasticity of the function changes as the capital labor ratio changes:[4]

$$\frac{dS_k}{d(\frac{K}{L})} = S_k(1-S_k)\left(\frac{E-1}{E}\right)\frac{L}{K} \qquad (3)$$

In general E will not be a constant, but will itself change with $\frac{K}{L}$. However, in the Arrow, et al., specification, the production function is assumed to have a constant elasticity of substitution. Thus, if one knows a point on the curve, its elasticity or slope there, and the elasticity of substitution, one can specify the entire (partial) production function. One then can answer direc.ly the two questions posed above.

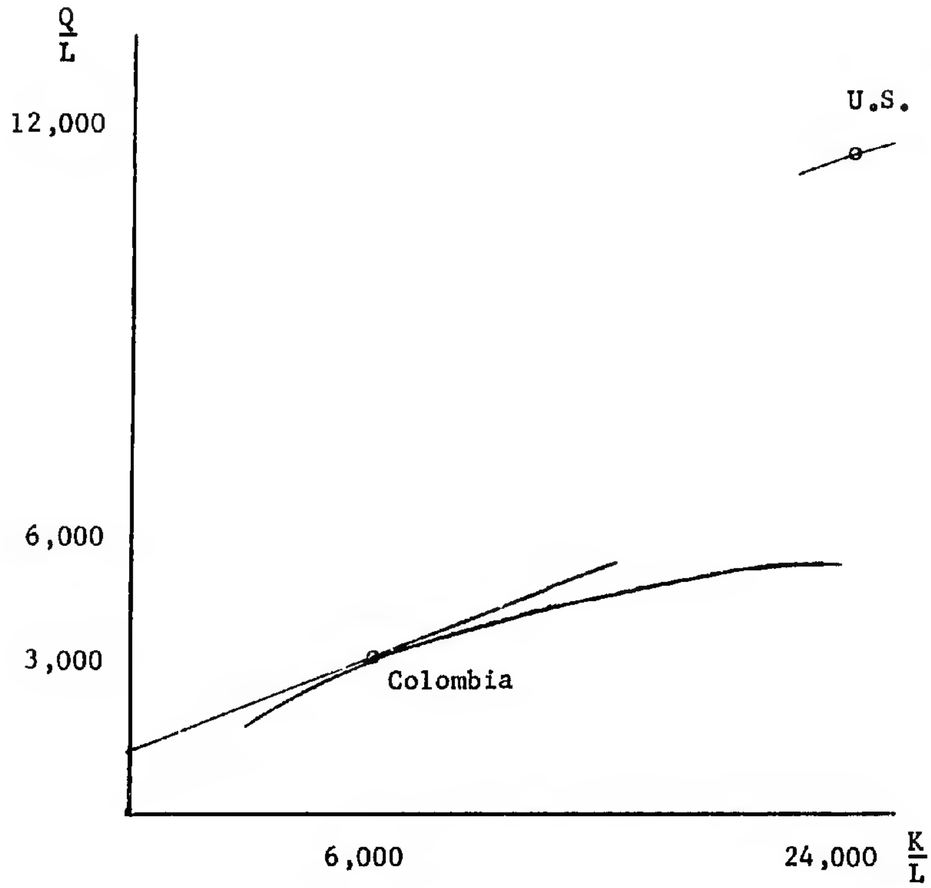
As an example let us ask: how much larger would value added per worker be in Colombian manufacturing industry if Colombia had a capital stock per worker roughly comparable to that in the United States (but no other changes affecting productivity were made)? As of 1964 value added per worker in Colombia was about \$3,000 (compared with \$12,000 in the United States) and the capital labor ratio was about \$6,000 (compared with \$24,000 in the United States).[5] This is a point on the production function. The elasticity of the function at that point can be estimated by capital share -- about .7. Let us take an estimate of the elasticity of substitution from Arrow, et al., at about .6. (Later I shall discuss how they arrived at that figure.) Assuming a constant elasticity of substitution between capital and labor, equation 1a can be written:[6]

$$\frac{\frac{Q}{L}}{\left(\frac{Q}{L}\right)_o} = \left[S_K^o \left[\frac{\left\{\frac{K}{L}\right\}}{\left\{\frac{K}{L}\right\}_o} \right]^{\frac{E-1}{E}} + S_L^o \right]^{\frac{E}{E-1}} \qquad (4)$$

Calculations show that if this function holds, output per worker would be slightly more than twice as great -- approximately $6,900 -- if the capital labor ratio was the same as that in the United States, but other variables that influence relative productivities were not changed from existing levels in Colombia. Or, differences in the capital-labor ratio alone explain only about one-third of the observed productivity difference. It also should be noted, for future reference, that the rate of return on capital, which at Colombia's existing capital-labor ratio is somewhat greater than in the United States would be significantly lower at a higher capital-labor ratio, if nothing else changed. All this is depicted in Fig. 1.

What was just done is <u>not</u> exactly what Arrow, et al., did. It is illuminating to examine the differences, which show why the result that there are significant unexplained productivity differences between countries has been largely unnoticed, and at the same time see how they obtained an estimate of the elasticity of substitution.

Arrow, et al., were interested in explaining productivity differences among a number of countries, and for many of these reliable capital stock data did not exist. However, if one assumes, for the moment, that capital-labor ratio differences are the only distinquishing differences between rich and poor countries, from the general neo-classical production function and the assumption that labor is paid



Calculations assume that the elasticity of the function at $\frac{K}{L}$ = 6,000 is .7, and the Elasticity of Substitution is .6.

FIGURE 1

CES CALCULATIONS FOR A COLOMBIA-U.S. COMPARISON its marginal product, one can obtain a monotonic increasing relationship between the wage rate and the capital-labor ratio.

$$w = g\left\{\frac{K}{L}\right\} \tag{5}$$

This relationship provides an indirect measure of the capital-labor ratio, and permits (1a) to be written as follows:

$$\frac{Q}{L} = f\left[g^{-1}(w)\right] = h(w) \tag{1a}$$

Given a specification of the basic form of $f(\cdot)$, say CES, then this relationship is directly estimable. For the CES there will be three parameters, one of these (a function of) the elasticity of substitution. This is how Arrow, et al. obtained their estimate of the elasticity of substitution.

Notice that in reality what is happening is that the elasticity of substitution is being estimated so as to fit the observed differences in labor share (or capital share) between high and low wage countries. Dividing both sides of (1a) by w and inverting yields

$$\frac{Lw}{Q} = \frac{w}{h(w)} \tag{6}$$

or

$$S_L = j(w)$$

It is an empirical fact that the share of labor is higher in high wage countries than low wage areas, and this will show up in the estimated parameters of (1a). Since w is assumed to be related only to $\frac{K}{L}$, this means that, by 5 and (1a), the equation will imply that wage share decreases as the capital labor ratio increases. This means that, as the model is specified, the statistical results will be interpreted as showing an elasticity of substitution between capital and labor of less than unity.

But there clearly is something misspecified about the model. For where capital data are available it is possible to go back and estimate what output per worker would be at a different capital labor ratio. The result should be that lifting the capital labor ratios in poor countries to a level comparable to that in the United States should yield an output per worker estimate equal to that in the United States, plus a random error. As we have seen, it does not. Arrow, et al., did not show this negative result the same way I did. Instead they used a factor price frontier argument that will be discussed, and employed, later. But first let us try to see what is misspecified about the model.

Let us maintain the key assumptions of the Arrow model -- the common linear homogeneous production and competitive factor pricing -- but drop the special assumption used in equation (1a) that differences in capital labor ratios are the only differences between countries. Instead, let us admit, as before, that there may be other factors, Y, that also may vary across countries. Let us assume that $\frac{K}{L}$ and Y are both related to the level of development, a concept with no independent definition, but indexed by Z. Both $\frac{Q}{L}$ and w will be systematically related to Z as follows:

$$\frac{Q}{L} = F\left[\frac{K}{L}(Z) \ , \ Y(Z)\right] = F(Z) \qquad (7)$$

$$w = G\left[\frac{K}{L}(Z) \ , \ Y(Z)\right] = G(Z) \qquad (8)$$

Then, although Z (like $\frac{K}{L}$) is not observable directly, it is observable indirectly.

$$\frac{Q}{L} = F\left[G^{-1}(Z)\right] = H \ (w) \qquad (7a)$$

exactly as before.

If this is what is going on, it explains why Arrow, et al., can get such a good fit for equation (1a), and yet it also be true that differences in capital labor ratios alone can explain only a small portion of intercountry productivity differences. The equation that they actually fitted is consistent with a wide variety of factors, not just higher capital labor ratios, that distinguish rich countries from poor. While something that might be called an elasticity of substitution can be derived, there is no reason why the number so estimated need have anything at all to do with an elasticity of substitution (holding other factors constant) between K and L.[7]

One implication of the above is that there is no reason why the Arrow, et al., estimate of the "elasticity of substitution" should be employed in equation (4). However, if the "share equals elasticity" assumption is maintained, there is little explanatory leverage in the elasticity of substitution. If the elasticity of substitution is higher than .6 then diminishing returns will set in less rapidly and a higher capital labor ratio will contribute more to higher output. But, as shown in Table 1, even with a very high elasticity of substitution, it still is not possible to explain more than half of the observed differences in value added per worker in this way. If a common-to-all nations linear homogeneous production function is assumed, and competitive factor pricing as well, then differences between rich and poor countries must transcend differences in the capital labor ratio.

Let us return to how Arrow, et al., deduced that differences in the capital-labor ratio could not be the whole study. A neoclassical production function with two factors of production, say capital and labor, implies a factor price frontier, if we assume competitive factor pricing. Thus, the general model:

$$\frac{Q}{L} = f\left\{\frac{K}{L}\right\} \; ; \; f' > 0 \; f'' < 0 \tag{9}$$

$$w = \frac{\partial Q}{\partial L} \, , \; r = \frac{\partial Q}{\partial K}$$

implies a factor price frontier which can be characterized as follows:

$$1\ (w,\ r) = 0,\ \frac{\partial w}{\partial r} > 0 \tag{10}$$

Both factor prices are uniquely related to $\frac{K}{L}$, one positively and one negatively. If the wage rate is higher in one country than another (because of more capital per worker) the rate of return on capital must be lower. Recall that the slope of $f\left\{\frac{K}{L}\right\}$ declined with $\frac{K}{L}$ in Fig. 1

Table 1

$$\frac{\left\{\frac{Q}{L}\right\}}{\left\{\frac{Q}{L}\right\}_o} \text{ as a function of E, and } \frac{\left\{\frac{K}{L}\right\}}{\left\{\frac{K}{L}\right\}_o}$$

$\dfrac{\left\{\frac{K}{L}\right\}}{\left\{\frac{K}{L}\right\}_o}$ \ E	.4	.6	.8	1.0	1.5
2	1.49	1.57	1.60	1.63	1.65
4	1.88	2.28	2.50	2.64	2.81
6	2.02	2.73	3.21	3.51	3.88

Calculations made using equation (4) in the text, assuming $S_K^o = .7$

However, several studies have shown little difference across countries in the rate of return on capital in a given industry, despite the very great differences in real wage rates.[8] In particular, it is clear that the rate of return on capital in high wage countries is nowhere near as low, in comparison with the rate of return on capital in low wage countries, as is implied by the factor price frontier, given the specification of the production function. It is this fact that led Arrow, et al., to recognize that something else, as well as differences in capital labor ratios, must distinguish high from low wage countries.

One might have expected this result. After all, there are international capital markets. The question then becomes, why does the rate of return on capital in less developed countries fall to roughly world levels at such a low capital labor ratio? What are the key differences between less and more developed countires that repress both output per worker and the return to capital in the former?

Mitchell's study is the obvious next step: an attempt to put into the model some other factor that seems positively related to value added per worker.[9] His candidate is a measure of skill or educated endowments. His particular formulation is in terms of an index of skill mix of the labor force -- which he designates by the ratio of skilled labor, L_1 , to total labor, L .

$$\frac{Q}{L} = F(\frac{K}{L}, \frac{L_1}{L}, Y^*) \qquad (11)$$

His model has considerably more explanatory power than the simpler one of Arrow, et al., and further, is able to deal with certain phenomena that the simpler model cannot, such as systematic differences across countries in the capital labor ratio associated with a given rate of return on capital (referred to above) and systematic differences across industries in the average wage rate.

It is unclear how much of the differences across countries in value added per worker the augmented model can explain. Some clues can be provided, as with the simpler model, by considering the factor price frontier. The Mitchell model implies a factor price frontier as follows:

$$1\left\{w_1, w_2, r\right\} = 0 \qquad \left.\frac{\partial w_i}{\partial r}\right|_{w_j} < 0 \quad \left.\frac{\partial w_i}{\partial w_j}\right|_{r} < 0 \tag{12}$$

where w_1 and w_2 are the wages of skilled and unskilled labor. If one assumes $r = \bar{r}$ (rates of return on capital do not differ much across countries), then if unskilled workers are paid more in high income countries, skilled workers must be paid less, not just relatively but absolutely. For the result on the factor price frontier for a two factor model is easily generalized to a 3 or indeed an n factor model. If one factor is paid less in one situation (country) than in another, there must be at least one other factor that is paid more.[10] What limited data I have seen suggests that, if we exclude managerial personnel (which will be discussed later) this is not the case. Engineers, scientists, doctors, lawyers, skilled mechanics, all tend to be paid less, not more, in less developed countries than in more developed ones. In part there may be quality differences. But the so-called brain drain shows that many of these people can go from a country where they are "scarce" to one in which they are "plentiful" and earn more money.

If one drops the assumption of constancy across countries in rates of return on capital, and admits higher rates of return in low wage countries, the conclusion is less clear. However, I suspect that there certainly are differences that transcend capital and skill endowments per worker. As other factors are progressively brought into the analysis the unexplained residual will be further reduced. And clearly there are some important measurement errors that need to be treated. But the point that will be stressed in the remainder of this paper is that there are no reasons why the two basic assumptions of the model -- a common linear homogeneous production function and perfect competitive factor markets -- should be held sacrosanct.

II. THE CASE FOR ABANDONING THE BASIC ASSUMPTIONS: MANUFACTURING DEVELOPMENT AS A DIFFUSION PROCESS

The assumptions of a common production function, and perfect and competitive factor markets, have proved both convenient and fruitful for modeling many economic phenomena. However, they would appear to get in the way of understanding international differences in productivity -- particularly differences between advanced and underdeveloped economies.

It has been clear for some time that growth and structural transformation of the manufacturing sector in advanced economies is, in considerable part, the result of technological advance and not simply the result of increases in the various factors of production. Because of the accounting identity between the value of output and the returns to inputs, it always is possible to "explain" output changes by input changes (suitably measured); however many of these input changes themselves must be attributed to technological advances. Technological advance itself probably can be attributed in some part at least to inputs invested for the purpose of advancing technology, hence in some sense perhaps changes in output can be attributed to changes in inputs (although the relationship almost certainly will not be linear homogeneous). However, no one would deny that in advanced countries in a quite fundamental sense production functions have changed and are changing over time. While this is a statement about growth over time within a country, it has important implications regarding differences, at any moment of time, across countries.

Recent research by Keesing, Vernon, Hufbauer,[11] and others, suggests strongly that trade patterns in manufactured products reflect more than differences in resource endowments. A considerable portion of U.S. manufacturing exports is in new products that other countries have not yet begun to produce in quantity. Vernon and Hufbauer go on to show that, with a lag, the other major manufacturing nations pick up and employ U.S. technology (and gradually cut the United States out of export markets). With a greater lag, eventually less developed countries begin to adopt and employ the technology.

The technological lead, product cycle theory suggests a quite different analysis of international differences in productivity than is implied by the model discussed in the preceding section. The engine of manufacturing development is technological advance in the developed countries -- particularly the United States. While the fact that the United States is the leading country in creating new products can, at least partially, be attributed to its "endowments" of managers, scientists, engineers, and just plain innovative and flexible people, it is clear that the United States has a real technological "lead." More generally, the position of any country in the diffusion hierarchy may well be a function of factor endowments, particularly supply of sophisticated managers, technicians, and easily trainable labor. But there is no reason to believe that these factors enter in the way that one would try to force them to enter the analysis if one followed the conventional approach. For viewing the economic development process as a diffusion process naturally leads one to abandon the two basic assumptions of the neoclassical model --

that all firms in all countries are on the same production function, and that markets are in full equilibrium.

Within the country where the inventing is going on, the firms doing it have at least a potential head start over the others. Other firms may themselves have been close to making the invention, and be able to follow quite quickly. Other firms may lag considerably. Within the adopting countries, firms may differ greatly in their ability to adopt quickly; some are subsidiaries of the innovating firms in the countries doing the inventing, and among the domestically owned firms there may be great variation in technical and managerial capability to adopt new technology. Various studies of diffusion show that in general it takes a considerable time for a new technique to spread to most of the firms in an industry. Thus at any given time one would expect to find considerable variation among firms with respect to the vintage of their technology, certainly between countries, but even within a country.[12]

Variation among firms with respect to vintage of technology is certainly compatible with perfect factor markets. The Solow embodiment model and various versions of the putty clay model,[13] for example, involve both differences among forms in the vintage of their technology, and perfect factor markets. But such models require perfect knowledge and foresight on the part of firm managers, and perfect knowledge and mobility on the part of factors. The studies of diffusion, while consistent with the assumption that entrepreneurial decisions move the systems in the direction of equilibrium, do not indicate that the adjustment rate is so rapid that, for all practical purposes, all firms always have the same rate of return on capital. Clearly they don't. Similarly, the various studies of labor mobility, while indicating that labor moves from poorer to better paying jobs, far from indicate a perfect labor market.[14]

It would appear, therefore, that data on value added per worker in a particular industry represent the weighted average of a distribution that may have considerable range and variance.

$$\frac{Q}{L} = \sum_{(\frac{Q}{L})_{min}}^{(\frac{Q}{L})_{max}} (\frac{Q}{L})_i \frac{L_i}{L} \qquad (13)$$

Comparing less with more developed countries it is clear that $(\frac{Q}{L})_{max}$ is likely to be smaller in the former both because of differences in factor prices and because some firms in the more developed countries, where the inventing is going on, are simply ahead technically. And $(\frac{Q}{L})_{min}$ is likely to be smaller in the less developed country, for factor price reasons if for no other.

It also is likely that the range or variance of productivity will be greater in the less developed country. There are two basic reasons. First, the responsiveness of investment to a new, even highly profitable, technological opportunity, although positive, is likely to be less strong. Managerial talent is more limited and it is likely that differences in management capabilities show up more sharply in ability to appraise and exploit new opportunities than in any other way. There are likely to be more in the way of specific input bottlenecks -- particular skills, and machinery that must be purchased from abroad. Second, imperfect domestic factor markets, another well-known characteristic of less developed countries, further tends to slow the adoption process by increasing the cost of expanding firms. Slow adoption not only reduces the density of the distribution in equation 13 at the top; it also reduces pressure on lagging firms. Slow adoption, in Sidney Winter's terms, makes survival space less constraining.[15]

To develop a sophisticated fully articulated model to formalize the kinds of relationships discussed above probably will prove to be a major task. While I think the game is worth the candle, I cannot undertake it here. However, it is possible, and seems worthwhile, to illustrate how some of these relationships work by the following highly stylized and simplified model.

Assume that initially at time t_o full competitive equilibrium exists on product and factor markets, all firms have the same (linear homogeneous) production functions and (within any country) face the same factor prices, have the same costs, and are making a normal profit. Any initial differences in output per worker across countries will then be a function of relative factor endowments which in turn will be reflected in relative and absolute factor prices. To simplify matters assume that capital and labor are the only factors (one can interpret capital as broadly as one wishes): Thus at time t_o :

$$(\frac{Q}{L}) = f(\frac{K}{L}) = g(w, r) \qquad (14)$$

where $f(\cdot)$ is homogeneous of degree one and $g(\cdot)$ homogeneous of degree zero.

Assume that at time t_o a new technology is invented that is α times more productive for every factor mix. At time $t_o + \theta$ the new technology is first brought into use at a level comprising ϵ percent of total output. The lag between invention and introduction, θ, may differ across countries. After time $t_o + \theta$ productivity will be:

$$(\frac{Q}{L}) = g\ (w_1, r_1)\ \frac{L_1}{L} + \alpha\ g\ (w_2, r_2)\ \frac{L_2}{L} \qquad (14a)$$

In the formulation above the subscript (1) refers to the old technology and the subscript (2) to the new technology. The use of the subscript for factor prices indicates that factor prices may differ for firms using the two technologies, although they are assumed equal initially.[16]

Unit costs for the two technologies will be:

$$C_1 = h_1\ (w_1, r_1) \qquad (16)$$

$$C_2 = h_2\ (w_2, r_2) = \frac{h_1\ (w_2, r_2)}{\alpha}$$

$h_i\ (\cdot)$ is a linear homogeneous function of factor prices.[17] It is assumed that, initially, price is equal to C_1, and hence exceeds unit cost using the new technology.

Instead of assuming full equilibrium throughout the diffusion process, assume rather that the system moves toward equilibrium. Let the rate of expansion (or contraction) of output from a particular technology be proportional to unit profits (or losses).

$$\left(\frac{\dot{Q}}{Q}\right)_i = \lambda \ (P - h_i \ (w_i, r_i)) \quad \lambda > 0 \qquad (17)$$

$$Q_1 + Q_2 = Q$$

Assume that profitable (and expanding) firms have to pay more for their factors than firms breaking even or losing money (and hence declining). Without specifying at the moment the relative (dynamic) elasticities of supply of the two factors, let the cost equations be:

$$h_i \ (w_i, r_i) = h_i \ (\bar{w}, \bar{r}) + b \ (P - h_i \ (\bar{w}, \bar{r}))$$

$$0 \leq b < 1 \qquad (18)$$

where $\bar{w}$ and $\bar{r}$ are the factor prices firms just breaking even have to pay, and b is, in a sense, a "sharing" factor determining the split of rents between profits and factor payments. There may or may not be a trend in $\bar{w}, \bar{r}$. Like θ , λ and b may differ across countries.

Finally, let the demand equation be:

$$P = P\ (Q) \qquad P' \leq 0 \qquad (1a)$$

As we shall see, either a positive trend in factor prices or a downward sloping demand curve provides the required squeeze on the profitability of "old technology."

It is easy to see that the system will move toward a new equilibrium in which $(\frac{Q}{L})$ equals $(\frac{Q}{L})_2$, P equals $\frac{h_1(\bar{w},\bar{r})}{\alpha}$, and old technology is completely eliminated. If $\bar{w}$ and $\bar{r}$ change over the period this too, of course, would be reflected in the new equilibrium. In any case real factor returns, in terms of the good in question, will be higher in the new equilibrium. All this is obvious.

What is interesting about the model is what it tells us about the path to the new equilibrium, and characteristics of the industry along the path.

The relative importance of the old and new technology will be changing as follows:

$$\frac{d}{d\,t} \log \left(\frac{Q_2}{Q_1}\right) = \lambda\,(1 - b) \left[h_1\,(\bar{w},\,\bar{r}) - \frac{h_1\,(\bar{w},\,\bar{r})}{\alpha} \right] \qquad (19)$$

The rate of growth of Q_2 relative to Q_1 will be greater, the greater is λ , the smaller is b (the sharing factor) and the greater the efficiency advantage of new technology over old. If we assumed no change in $\bar{w}$ and $\bar{r}$ and plotted $\frac{Q_2}{Q}$ over time the curve would be S shaped, specifically it would be a logistic.

$$\frac{Q_2}{Q} = \frac{1}{1 + \left(\frac{Q_1}{Q_2}\right)_o e^{-ct}} \qquad (20)$$

where $c = \lambda (1 - b) \left[h_1 (\bar{w}, \bar{r}) - h_1 \frac{(\bar{w}, \bar{r})}{\alpha}\right]$

This is consistent with what we know about diffusion patterns.[18]

As the diffusion process proceeds productivity will be rising. If we assume that profitable firms pay either the same factor prices or more for both factors in the same proportion, then noting that $g(\cdot)$ is homogeneous of degree zero, the productivity equation has the simple form:[19]

$$\frac{Q}{L} = g(\bar{w}, \bar{r}) \left[1 + (\alpha - 1) \frac{L_2}{L}\right] \qquad (14b)$$

But under these assumptions, since $\frac{Q_2}{Q}$ is a logistic so is $\frac{L_2}{L}$.[20] Therefore the time path of productivity will also be a (shifted upwards) logistic with slow growth initially, then acceleration, and finally a slowing down of the rate of productivity growth as new technology becomes dominant.

More realistic assumptions about the factor cost adjustment equations blur the neatness of the above result. For example, it seems reasonable to assume that while the expanding (and profitable) firms have to pay more for labor, they may have no disadvantage at all relative to less profitable firms in gaining access to capital. In this case firms employing new technology would have a labor productivity differential over firms using the older technology that exceeds α, reflecting the higher wage to interest rate ratio they face. In this case, of course, the productivity growth equation is much more complicated, nor can it any longer be assumed that $\frac{L_2}{L}$ and $\frac{Q_2}{Q}$ move in lock step. But the simpler result is quite suggestive.

The thrust behind growth of output per worker will be growth of "total factor productivity" in a very real sense. If $\bar{r}$ and $\bar{w}$ stayed constant over the period and if, during the transition period, the factor price ratio facing expanding and declining firms is the same, there will be no change at all in the capital labor ratio, while output per worker would be growing.

Under more realistic assumptions, complementing growth of output per worker due to increase in total factor productivity (the progressive shift to use of more productive technology) there would be a rise in the capital labor ratios which would further increase output per worker. For the diffusion period would be marked by a relatively high capital share. Positive quasi rents would be being made in the expanding modern subsector and more than offsetting negative quasi rents in the contracting craft sector. Letting r stand for the average interest rate, capital's share will be:

$$S_K = \frac{r\ K}{P\ Q} + \frac{Q/Q}{P\ \lambda} \qquad (21)$$

The first term of (21) is a measure of the static elasticity of output with respect to capital, the second a reflection of net quasi rents which will be particularly large when output is growing most rapidly.

Thus the industry as a whole will be able to afford higher wages. And it is reasonable to assume that there will be an upward drift of $\bar{w}$ reflecting the inability of the modern sector to cut wages as their growth rate slows, or a tendency for the equilibrium wage to rise when there are large net quasi rents. Thus:

$$\frac{d}{d\,t}(\bar{w}) = Z\,(S_K - \frac{r\,K}{P\,Q}) \qquad Z' > 0 \qquad (22)$$

If we assume that $\bar{r}$ doesn't change much, this mechanism will induce a rise in the capital labor ratio. The high capital share will enable firms to "afford" and "finance" such a rise. This mechanism of course would lead to a smaller fall in P between the new equilibrium and the old.

Notice what is happening is that the factor price adjustment mechanism during the diffusion process is inducing a rise in the capital-labor ratio associated with a rise in $\bar{w}$. Implicitly what is being assumed is a more elastic supply of capital (to the country in question) than labor.

The above model is highly oversimplied and in many ways mis-specified.[22] However, it does seem to capture the spirit of a diffusion point of view with respect to international productivity differences, and it certainly generates some interesting implications regarding differences between less and more developed countries.

Consider two countries, one a "highly developed" one in the sense that the diffusion process started a long time ago (θ is small) and is complete or nearly complete (large λ, small b), the other "under developed" in which the diffusion process started only recently (large θ) and which is characterized by a small λ and a large b. Assume the product is traded internationally and world prices obtained in both countries, and that $\bar{r}$ is roughly the same in both countries because of international capital mobility. Productivity per worker would be higher in the more developed country and so would be the wage rate. And so, therefore, would be the capital-labor ratio. Part of the productivity and wage difference would reflect the higher capital labor ratio, the difference would be greater than the capital-labor ratio difference could explain and this would show up when the factor price frontier was considered. If the elasticity of substitution between capital and labor was not greater than one, the wage share would be higher in the more developed countries. An econometrician fitting a CES would ascribe the reason to be a less than unitary elasticity of substitution, but a large share of the difference would not be due to that but to the existence of large quasi rents in the less developed country. If one disaggregated one would find that a key factor explaining the productivity differentials would be the existence in the less developed countries of a large subsector of firms using older technology, which had been largely eliminated in the more developed countries. One also would find a "dual" wage structure in the less developed country.

In short, the model seems capable of explaining quite easily certain phenomena that the neoclassical model has trouble with. It also generates some other specific implications of considerable interest.

III. A COLOMBIAN-U.S. COMPARISON

The ideas presented in the preceding section can be made more concrete, and evidence provided to support them, by examining in detail some of the differences between the United States and Colombia in value added per worker in manufacturing as a whole, and in the various two-digit manufacturing industries.[23]

As reported earlier, in 1964 productivity in Colombian industry averaged about one-quarter that of the United States. This was roughly the same ratio as obtained in 1958 and it will be convenient to orient the discussion around 1958 data. The year 1958 provides a vantage point from which one can look forward as well as backwards.

As shown in Table 2, lower productivity was a phenomenon that held across the board industry-by-industry. Further, there was a tendency for the same industry to stand relatively high or low with respect to value added per worker in the two countries. Nonetheless, there was still a considerable variance across industries in value added per worker in a Colombian industry as a fraction of that in the United States. The ratio was relatively high in tobacco, textiles and petroleum (valued added per worker between one-third and one-half that in the United States). The ratio was relatively low in the wood products and metal processing industries (less than one-seventh that of the United States). These are the kinds of observations to be explained.

These are the kinds of observations the model discussed in part I of this paper purports to explain. But a glance at Table 2, which shows great variation in productivity among firms within an industry -- particularly between large and small firms -- suggests that the model is inapplicable. Its "representative firm" implication is clearly violated.

Table 2

VALUE ADDED PER WORKER BY FIRM SIZE AND INDUSTRY, UNITED STATES AND COLOMBIA, 1958[a]

(in 1958 $U.S.)

Industry	Average Value Added	Firm Size (employees) 1-9	10-19	20-49	50-99	100-249	250+
United States							
Food	$10,321	$ 8,326	$ 7,859	$ 8,753	$ 9,979	$10,277	$11,691
Tobacco	16,733	4,833	2,886	7,038	6,286	7,404	19,338
Textiles	5,387	8,842	7,017	6,038	5,562	5,549	5,172
Clothing & footwear	5,086	8,853	6,922	5,386	4,659	4,424	4,878
Lumber	5,465	4,330	4,252	5,308	5,855	6,117	6,265
Furniture	6,759	6,788	6,449	6,477	6,627	6,521	7,144
Paper & paper products	10,276	7,979	4,479	7,793	8,704	9,588	11,237
Printing	9,169	8,100	7,798	8,329	8,883	9,362	9,962
Chemicals	17,550	12,126	12,474	13,333	14,387	16,776	19,189
Petroleum	14,056	14,108	13,561	12,454	12,033	17,408	13,773
Rubber products	9,420	8,143	7,741	8,112	8,009	8,167	10,157
Leather products	5,436	7,235	5,883	5,532	5,388	5,234	5,442
Minerals, non-metallic	9,979	8,757	8,620	8,894	8,634	10,627	10,763
Basic metals	10,646	7,866	7,495	7,726	8,697	8,877	11,105
Metal products	8,896	8,308	8,038	8,234	8,642	8,878	9,320
Machinery, excl. elec.	9,191	8,852	8,326	8,816	9,032	9,208	9,351
Electrical machinery	9,263	8,114	7,930	8,067	8,038	8,421	9,551
Transportation equipment	9,811	7,727	7,553	8,[illegible]	8,110	8,418	10,002
Other	6,320	7,500	6,777	6,735	6,581	7,189	9,432

Industry	Average VA	1-9	10-19	20-49	50-99	100-199	200+
Colombia							
Food	$ 2,029	$ 1,019	$ 1,177	$ 2,177	$ 2,330	$ 3,526	$ 2,837
Beverage	5,187	1,308	1,519	2,053	6,019	7,124	4,826
Tobacco	7,153	416	556	986	2,971	12,243	17,575
Textiles	1,967	560	1,282	1,105	1,363	1,436	2,174
Clothing & footwear	826	600	670	720	831	960	1,414
Lumber	864	828	811	927	797	640	1,104
Furniture	890	782	684	856	975	1,028	1,511
Paper & paper products	1,958	1,230	1,223	1,993	1,611	884	3,027
Printing	1,403	869	803	1,601	1,834	1,335	1,762
Chemicals	2,983	1,863	1,562	2,818	2,667	3,364	3,855
Petroleum	6,578	3,961	3,973	2,681	--	--	7,105
Rubber products	2,185	1,047	1,475	1,256	1,403	--	2,335
Leather products	1,379	838	1,020	1,029	832	1,018	2,433
Minerals, non-metallic	1,276	578	679	857	1,235	1,141	2,117
Basic metals	1,914	1,027	2,436	2,052	1,040	2,128	1,954
Metal products	1,304	818	871	1,356	1,313	1,233	2,347
Machinery, excl. elec.	1,172	832	943	1,105	1,076	--	1,946
Electrical machinery	1,959	945	1,062	1,669	2,325	1,689	2,777
Transportation equipment	949	746	930	1,026	1,081	1,030	961
Other	1,687	1,052	1,117	1,685	2,019	1,782	1,939

Notes: -- indicates no observations reported.

[a]Exchange rate: 6.9 pesos = 1 dollar.

Sources:
United States: U.S. Department of Commerce, 1958 Census of Manufactures (USA), General Summary, Washington, D.C., 1961;
Colombia: DANE (central statistical bureau).

I want to argue that a diffusion, evolution point of view is much more consistent with the data. And the relatively simple "two" technologies version can carry one pretty far.

With the exception of a few industries (textile mill products and certain parts of the food processing industry) Colombia's adoption of modern technology did not really begin until after World War II. This did not mean that Colombia had no firms in other industries. In 1944 about 135,000 people were employed in Colombian industry, and there were a number of firms in almost all industries.[24] However, it would appear that in most of these industries these firms were craft or semi-craft, producing for a local or regional market and protected by high transport cost and the absence of a modern distribution system generally. In the early postwar period many factors, including the improvement in transport, the import shortage experience of World War II, and the ready availability of foreign exchange due to good coffee prices, increased the perceived profitability of establishing modern industry. The resulting wave of industrialization was superimposed upon the traditional structure of craft industry.[25]

By the mid-1950s, when coffee prices broke and industrial growth slowed until it was refueled by foreign credit, most Colombian industries contained two roughly separable groups of firms. One group, generally newcomers or old firms that had transformed themselves, consisted of firms that were roughly similar to typical firms in the same industry in more developed countries -- somewhat smaller, with somewhat lower value added per worker, capital per worker, and labor quality -- but using roughly the same kind of technology and recognizable as the same kind of animal. The other group was composed of the traditional small craft firms using significantly less in the way of modern equipment, and quite different (and less related to formal education) skills, and creating a far lower value added per worker. To a considerable degree these two groups differed in terms of their product. Within the so-called metal products industry the craft firms produced pots and pans, the more modern firms produced some parts for and assembled washing machines and refrigerators. But in many cases there was more direct competition. Craft firms produced shoes and furniture largely by hand or with simple power tools; modern firms produced similar products using much more power equipment and mass production organization of work. But in either case, both craft firms and more modern firms were included in almost every two- or three-digit industry, and it is differences across countries at the two- or three-digit level that so much recent research has sought to explain.[26]

In part the survival of a significant craft sector in Colombia, but not in a more developed country, can be explained by neoclassical considerations. The differences between modern and craft technology do not appear to be neutral; the former is much more requiring of capital and skilled labor than the latter. Thus, craft technology is economically more viable in a country where unskilled and uneducated workers are cheap relative to educated workers and capital.

But a good part of the explanation seems consistent with the "diffusion" model rather than the neoclassical model. The late start is clear. Shortages of skilled managers and technicians clearly limited the pace of the adoption process after it started out, and as we shall see, at least after the mid-1950s, adoption of modern technology was foreign exchange limited.[27] Particularly where markets were protected from foreign competition by restrictions or transport costs, there was room in domestic demand for craft firms to survive. Finally, survival was facilitated by factor market imperfections. Minimum wage legislation and labor union organization kept wages high in the modern subsector, but did not extend effectively to small firms. Thus small craft firms had a significant labor cost advantage, as is shown in Table 3.

Let us consider various empirical implications of the dualism model. First, differences in value added per worker between the countries should be a function of the relative size (as measured by percent of employment) of the craft subsector in Colombia. Second, reasonably well-managed firms using modern technology should be earning a very high rate of return, even when paying wage rates significantly higher than the average in Colombia (but far less than in the United States). Third, the situation in Colombia should be in flux; the modern sector should be expanding relative to the craft sector and driving it out of busin s in some fields.

To test any of these implications it of course is necessary to identify the craft and modern subsectors. It is reasonable that to a first approximation craft firms tend to be small and modern firms tend to be large in Colombian industry. This relation should not hold for the United States. Thus there should be much greater differences

Table 3

WAGE RATES BY INDUSTRY AND FIRM SIZE, COLOMBIA, 1958
(in pesos)

Industry	Firm Size (employees)						
	Average	1-9	10-19	20-49	50-99	100-199	200+
Food	3,193	1,957	2,504	3,174	3,570	3,446	4,569
Beverages	5,627	2,561	3,142	4,100	5,365	5,854	6,186
Tobacco	3,791	938	1,184	1,426	2,836	5,725	7,245
Textile	4,118	1,789	2,982	3,006	3,439	3,238	4,388
Clothing & footwear	2,433	2,000	2,129	2,225	2,513	2,679	3,289
Lumber	2,792	2,589	2,641	2,907	2,811	2,494	3,321
Furniture	3,297	3,704	2,899	3,216	3,557	3,578	4,704
Paper & paper products	4,452	2,908	3,014	3,291	4,253	2,648	6,898
Printing	4,247	2,730	3,259	3,782	5,419	4,764	5,057
Chemicals	4,710	2,906	3,174	4,696	4,629	5,096	5,391
Petroleum	12,288	2,889	4,430	7,885	--	--	13,087
Rubber products	4,993	2,707	3,114	3,867	4,039	--	5,253
Leather & leather prod.	3,436	2,128	2,461	2,983	2,964	3,653	4,615
Minerals, non-metallic	3,266	1,992	2,337	2,677	3,109	3,367	4,379
Basic metals	5,431	3,118	3,533	3,619	3,759	6,932	5,881
Metal products	3,605	2,613	2,888	3,721	4,052	3,535	4,540
Machinery, excl. elec.	3,895	3,213	3,438	3,918	4,294	--	4,571
Electrical machinery	3,994	2,947	3,628	3,827	3,828	3,599	4,871
Transportation equip.	4,500	2,791	3,310	4,356	4,505	4,541	5,414
Other	4,180	3,529	3,584	3,673	3,881	3,478	6,587

Note:
-- indicates no observations reported.

Source:
DANE.

in value added per worker between small firms and large in Colombia than in the United States. Table 2 presents the data for 1958. Data for 1964 will be presented later. Notice that in the United States, with the striking exception of the tobacco products industry (where the giant firms are highly mechanized cigarette companies and the smaller firms cigar manufacturers), while value added per worker is positively related to size, value added per worker in the giants is seldom more than 50 percent larger than in the smaller firms. In Colombia, on the other hand, the difference in value added per worker between large and small firms tended to be substantial except in those industries, like lumber, where even the large firms had very low productivity suggesting they too were "craft." Thus the association of craft with small and large with modern seems roughly valid, but not always so.

To permit testing of the first implication, Table 4 presents value added per worker in Colombia as a fraction of that in the United States by industry and by firm size within an industry. Notice how much closer the large Colombian firms were to their U.S. counterparts in terms of value added per worker than were the small Colombian firms. In industries where value added per worker in Colombia was a relatively large percent of that in the United States two conditions tended to hold. First, the ratio was .4 or greater for large firms (suggesting similar technology). Second, employment in these firms comprised a large share of total employment (see Table 5). Where Colombian value added per worker was small as a fraction of that in the United States, the large Colombian firms did

Table 4

RATIO OF COLOMBIAN VALUE ADDED PER WORKER TO U.S. VALUE ADDED PER WORKER, BY INDUSTRY AND FIRM SIZE, 1958

Industry	Firm Size (employees)						
	Average	1-9	10-19	20-49	50-99	100-199[a]	200+[a]
Food[b]	.28	.12	.15	.25	.30	.52	.33
Tobacco	.43	.09	.19	.14	.47	1.65	.91
Textiles	.37	.06	.18	.18	.25	.26	.42
Clothing & footwear	.16	.07	.10	.13	.18	.22	.29
Lumber	.16	.19	.19	.18	.14	.11	.18
Furniture	.13	.12	.11	.13	.15	.16	.21
Paper & paper products	.19	.15	.27	.26	.19	.09	.27
Printing	.15	.11	.10	.19	.21	.14	.18
Chemicals	.17	.15	.13	.21	.19	.20	.20
Petroleum	.47	.28	.29	.22	.00	.00	.52
Rubber & rubber prod.	.23	.13	.19	.16	.18	.00	.23
Leather products	.25	.12	.17	.19	.15	.20	.45
Minerals, non-metallic	.13	.07	.08	.10	.14	.11	.20
Basic metals	.18	.13	.33	.27	.12	.24	.18
Metal products	.15	.10	.11	.17	.15	.14	.25
Machinery, excl. elec.	.13	.09	.11	.13	.12	.00	.21
Electrical machinery	.21	.12	.13	.21	.29	.20	.29
Transportation equipment	.10	.10	.12	.13	.13	.12	.10

Notes:

[a] U.S. size groups are actually 100-249 and 250 and up.

[b] U.S. includes food and kindred products; Colombia, food and beverage industries combined.

Source:
Table 4.

Table 5

DISTRIBUTION OF COLOMBIAN LABOR FORCE BY FIRM SIZE, 1958 AND 1964

(percent of totals)

Industry	Firm Size (employees)											
	1-9		10-19		20-49		50-99		100-199		200+	
	1958	1964	1958	1964	1958	1964	1958	1964	1958	1964	1958	1964
Total industry	13.8	12.2	11.1	9.8	15.9	13.0	11.8	11.7	11.9	12.7	35.5	40.6
Food	23.8	23.9	14.5	13.6	19.2	15.2	16.0	11.4	10.6	12.1	15.9	23.8
Beverages	3.5	2.9	3.1	2.7	8.6	5.6	9.4	7.5	31.1	27.2	44.2	54.1
Tobacco	15.8	14.9	13.3	11.8	18.8	11.3	12.1	11.2	10.3	12.8	29.6	37.9
Textiles	2.6	2.4	2.5	2.4	5.7	6.1	4.0	4.6	6.6	5.7	78.5	78.8
Clothing & footwear	23.2	22.6	14.7	13.7	21.5	15.8	15.8	16.7	10.6	9.4	14.2	21.8
Lumber	30.1	22.7	22.9	15.3	12.9	14.0	13.2	6.6	5.8	13.4	15.2	28.0
Furniture	28.4	29.9	19.4	18.5	21.0	22.8	10.4	9.8	12.4	5.2	8.3	13.7
Paper & paper products	3.1	2.6	9.3	8.8	21.5	16.0	18.2	13.0	17.1	16.9	30.9	42.8
Printing	13.3	11.6	15.4	16.0	19.6	17.5	7.2	8.7	15.5	13.6	28.9	32.6
Chemicals	8.6	6.7	8.8	5.7	17.3	14.9	19.4	15.2	18.1	23.0	27.8	34.4
Petroleum	.5	2.7	3.3	3.3	9.2	4.6	--	5.7	--	9.4	87.0	74.3
Rubber products	1.7	1.5	5.6	2.7	5.7	8.9	2.1	4.9	--	--	85.0	82.1
Leather products	15.8	19.2	11.6	14.2	14.3	12.1	12.4	6.9	16.8	17.1	29.1	30.4
Minerals, non-metallic	14.2	13.1	13.9	10.2	16.8	13.0	8.8	11.1	13.6	10.0	32.7	42.5
Basic metals	2.4	.6	4.9	6.1	10.6	1.8	7.7	5.9	10.7	20.0	63.7	65.6
Metal products	12.2	8.5	15.0	11.6	28.3	19.3	15.1	20.6	17.9	16.3	11.6	23.7
Machinery, excl. elec.	18.5	16.5	22.1	17.5	24.7	18.9	15.8	15.8	--	6.6	18.8	24.7
Electrical machinery	10.4	5.9	11.4	9.3	21.4	12.2	21.5	15.8	8.9	16.5	26.4	40.3
Transportation equip.	15.8	12.5	12.6	13.4	15.0	11.1	9.5	13.1	6.7	10.1	40.4	39.7
Other	9.7	9.5	14.0	10.6	19.5	21.6	25.9	25.0	14.4	23.1	16.6	10.2

Source: DANE.

poorly relative to U.S. firms (suggesting that many of them were not using modern technology), or employment in large firms was a small fraction of the total in the industry, or both.

Regarding the second implication, interviews with accountants suggest that after tax (and adjusted for inflation), rates of net return on capital of 30 percent or more are typical for large firms. Colombia may be one less developed country where the average rate of return on capital in manufacturing is higher than in the developed countries, but it is clear that the average rate of return is significantly lower than the rate of return in large firms.

A high rate of return in the large modern firms, together with access to credit at reasonable terms (which seems the case when there is not a balance of payments squeeze) would provide a strong inducement for the modern manufacturing sector to expand -- the third implication of the dualism model. As mentioned earlier, the fall in export earnings greatly slowed Colombian manufacturing growth in the mid-1950s. By 1958, however, various loans permitted a new surge of imports and industrial growth. The pattern of post-1958 growth is revealing. Table 6 shows that firms of over 200 employees, which in 1958 accounted for about 35 percent of employment, accounted for over 65 percent of the increase in employment achieved by the manufacturing sector as a whole between 1958 and 1964. They accounted for roughly the same percent of the increase in value added. These very large firms, together with those in the 100-200 employee range, accounted for about 75 percent of the growth in output and employment over the 1958-1964 period.

Table 6

DISTRIBUTION OF COLOMBIAN LABOR FORCE
BY FIRM SIZE, 1958-1964

Year	Firm Size (Employees)						
	Total	1-9	10-19	20-49	50-99	100-199	200+
1958	236,748	32,569	26,341	37,672	27,985	28,077	84,104
1959	248,540	30,938	25,863	37,741	30,183	31,301	92,514
1960	254,000	30,150	24,917	37,460	29,238	31,190	101,045
1961	264,107	30,931	25,201	39,197	31,313	31,726	105,739
1962	277,012	32,051	26,427	40,604	31,870	34,695	111,365
1963	280,520	33,252	26,792	37,321	33,794	35,638	113,723
1964	283,841	34,767	27,697	36,885	33,121	36,157	115,214

Source:
DANE.

At the same time there was a significant relative decline in employment in small firms. As employment in firms of over 200 expanded from 35 to 40 percent of the total, employment in firms of under 50 fell from 41 to 35 percent. As the precent of value added in large firms increased from 49 to 54 percent, that in small firms decreased from 23 to 17 percent.

Table 5 shows that these phenomena were pervasive. In most Colombian industries there was a significant increase in the percent of employment accounted for by large firms, and a decrease in small firms. The phenomena were particularly apparent in industries like metal products, where growth of output and employment were particularly great and the percentage of employment in large firms initially was quite small.

Not only were the bulk of employment and output increases over the period accounted for by the large firms. Roughly one-fifth of the increase in value added per worker achieved over the period was the result of a shift in the composition of the work force toward the higher productivity (larger) firms and away from the small craft firms. The shift was a particularly important contributor to productivity growth in the food processing industry (about 30 percent), tobacco products (25 percent), lumber and wood products (productivity would have fallen without the shift), furniture (35 percent), paper (35 percent), chemicals (most of the total), non-metallic minerals (30 percent), and metal products (more than half).

In addition, productivity growth in the large (greater than 100 employees) and medium-sized (50 to 100) firms tended to be significantly greater than in the small firms; indeed, productivity in the smallest firms would appear to have declined over the period (see Table 7. Thus the productivity gap between large and small firms actually widened. While this breaks from the dualism model narrowly conceived, it is roughly what one might expect in a more realistic analysis. Productivity growth in the large and medium size firms probably reflects three factors -- a growing percentage of these firms using modern technology, a growth of experience in operation both by management and labor, and the incorporation of more modern and/or more equipment per worker in the already modernized firms. In contrast, craft technology and productivity tends to be static.

It is interesting to note that most of the surge of expansion of employment in manufacturing and in the large firm subsector occurred between 1958 and 1962. During this period, when employment growth in manufacturing averaged over 3 percent a year, firms of over 100 employees accounted for better than 90 percent of the total increase. Employment in firms of under 20 workers actually fell. Since 1962 there has been a significant fall-off in the rate of growth of manufacturing employment, which averaged only about 1.5 per cent a year in the 1962-64 period and probably has not accelerated since. To a considerable degree this has been the result of a drastic decline in the rate of employment growth in large firms, which fell from about 5 percent a year to about 1.5 percent. At the same time employment in the smallest firms began to expand again. During the 1961-1966 period there would appear to have been a significant rise in ur ban unemployment, suggesting that in considerable part the resurgence of

Table 7

PRODUCTIVITY GROWTH BY FIRM SIZE (VALUE ADDED PER WORKER), 1958-1964
(thousands of 1963 pesos)

Year	Firm Size (employees)						
	Total	1-9	10-19	20-49	50-99	100-199	200+
1958	26.01	11.02	12.75	19.12	24.47	36.81	35.96
1959	27.30	10.70	13.49	19.29	24.79	39.22	36.76
1960	28.60	11.57	14.51	19.75	25.83	40.19	37.67
1961	29.28	11.40	14.98	20.55	28.07	42.06	37.67
1962	30.41	12.37	15.44	20.99	25.90	43.85	39.70
1963	31.25	9.93	14.34	21.13	27.02	45.87	41.47
1964	32.83	10.05	14.80	23.54	30.31	46.97	43.29

Source:
DANE.

small craft firms reflects the desperate effort of people to find any kind of work.

The basic reason would appear to be the balance of payments bind that again closed in on Colombia after 1961, and consequent stopping of the growth of capital goods imports to permit the expansion of the modern sector. Analysis of these developments is beyond the scope of this paper. However the effects are strikingly in accord with the model.

FOOTNOTES

1. The principal source of data for international manufacturing comparisons is the United Nations [1].

2. For a survey of much of the relevant literature see Nerlove [2].

3. See Arrow, et al. [3].

4.

$$S_k = \frac{f_k K}{Q} = \left\{\frac{f_k}{f_L}\right\}\left\{\frac{K}{L}\right\} S_L = \left\{\frac{f_k}{f_L}\right\}\left\{\frac{K}{L}\right\}\left\{1-S_k\right\} \qquad (1)$$

$$\frac{dS_k}{d\frac{K}{L}} = -\left[\frac{f_k}{f_L}\;\frac{K}{L}\right]\frac{dS_k}{d\frac{K}{L}} + \frac{f_k}{f_L}\left\{1-S_k\right\} + \left\{1-S_k\right\}\frac{K}{L}\,\frac{d\left\{\frac{f_k}{f_1}\right\}}{d\frac{K}{L}} \qquad (2)$$

Noting that $E = -\left(\frac{d\frac{K}{L}}{d\frac{f_k}{f_L}}\right)\left(\frac{\frac{f_k}{f_L}}{\frac{K}{L}}\right)$, that

$\frac{f_k K}{f_L L} = \frac{S_k}{1-S_k}$ and $1 + \frac{S_k}{1-S_k} = \frac{1}{1-S_k}$, and regrouping:

$$\frac{dS_k}{d\left\{\frac{K}{L}\right\}}\left\{\frac{1}{1-S_k}\right\} = \frac{f_k}{f_L}\left\{1-S_k\right\}\left[1-\frac{1}{E}\right] \qquad (3)$$

Since from Eq. (1) $\frac{f_k}{f_L}\left\{1-S_k\right\} = \frac{L}{K} S_k$

$$\frac{dS_k}{d\frac{K}{L}} = S_k\left\{1-S_k\right\}\left\{\frac{E-1}{E}\right\}\frac{L}{K} \qquad (4)$$

5. The general CES can be written:

$$Q = A\left[\delta K^{\frac{E-1}{E}} + \left\{1-\delta\right\} L^{\frac{E-1}{E}}\right]^{\frac{E}{E-1}} \quad (1)$$

or, dividing by L

$$\frac{Q}{L} = A\left[\delta\left\{\frac{K}{L}\right\}^{\frac{E-1}{E}} + 1-\delta\right]^{\frac{E}{E-1}} \quad (2)$$

The ratios of the factor shares can be shown to be

$$\frac{S_k}{S_L} = \frac{\delta}{1-\delta}\left[\frac{K}{L}\right]^{\frac{E-1}{E}} \quad (3)$$

Rewriting Eq. (2)

$$\frac{Q}{L} = A\left[\delta\left\{\frac{K}{L}\right\}_o^{\frac{E-1}{E}}\left[\frac{\left\{\frac{K}{L}\right\}}{\left\{\frac{K}{L}\right\}_o}\right]^{\frac{E-1}{E}} + 1-\delta\right]^{\frac{E}{E-1}} \quad (4)$$

Substituting from Eq. (3)

$$\frac{Q}{L} = A\left[\left\{1-\delta\right\}\frac{S_k^o}{S_L^o}\left[\frac{\left\{\frac{K}{L}\right\}}{\left\{\frac{K}{L}\right\}_o}\right]^{\frac{E-1}{E}} + 1-\delta\right]^{\frac{E}{E-1}} \quad (5)$$

$$\frac{Q}{L} = \frac{A\left\{1-\delta\right\}}{S_L^o}\left[S_k^o\left[\frac{\left\{\frac{K}{L}\right\}}{\left\{\frac{K}{L}\right\}_o}\right]^{\frac{E-1}{E}} + S_L^o\right]^{\frac{E}{E-1}} \quad (6)$$

Recognizing that $\left\{\frac{Q}{L}\right\}_o$ must equal $\frac{A\left\{1-\delta\right\}}{S_L^o}$,

$$\frac{Q}{L} = \left\{\frac{Q}{L}\right\}_o \left[S_k^o \left[\frac{\left\{\frac{K}{L}\right\}}{\left\{\frac{K}{L}\right\}_o}\right]^{\frac{E-1}{E}} + S_L^o \right]^{\frac{E}{E-1}} . \qquad (7)$$

6. See Nelson [4].

7. For example, consider two countries with exactly the same capital labor ratio, but with one with a higher output per worker because of, say, higher educational attainments. Assume that the rate of return on capital the same in both countries with the wage rate and, hence, wage share higher in the high income country. From the CES calculations described above the statistician would come up with with an estimate of the elasticity of substitution between capital and labor (less than one), despite that there is in fact no difference in the capital-labor ratios in the two cases.

8. See Mitchell [5].

9. For a summary, see Mitchell, op. cit.

10. Assume a linear homogeneous production function $Q = f\left\{X_1 \ldots X_n\right\}$. Assume price equals marginal and average cost equals one, and cost minimization so that $w_i = f_i$ for all i. Assume the isoquants are strictly convex, and at least some of each factor is needed to produce any output. The linear homogeneity assumption guarantees that one can calculate the nature of possible variations

in factor price compatible with these assumptions by considering only one isoquant. Using vector notation, consider two such compatible factor price vectors, W_o and W_1, and their associated minimum cost factor inputs, X_o and X_1. We know:

$$\min_{X} W_o X = W_o X_o = 1 < W_o X_1 \qquad (1)$$

$$\min_{X} W_1 X = W_1 X_1 = 1 < W_1 X_o \qquad (2)$$

Thus:

$$W_o X_o < W_1 X_o \quad \text{or} \quad W_o \ngtr W_1 \qquad (3)$$

and

$$W_1 X_1 < W_o X_1 \quad \text{or} \quad W_1 \ngtr W_o \quad . \qquad (4)$$

That is, neither factor price vector, compatible with the assumptions, can be strictly greater than the others. If one observes two such systems of factor prices, if one of the components of one is greater than the same component in the other, some other component must be less.

11. See references [6], [7], and [8], for an introduction to a rapidly growing literature.

12. For a survey of the diffusion literature see Nelson, Peck, and Kalachek [9], Chapter 5.

13. See Solow [17], and Salter [18].

14. Nelson, Peck, and Kalachek [9], Chapters 5 and 7.

15. See Winter [10].

16. The intra-manufacturing dualism model obviously has a kinship with the Ranis-Fei agricultural-manufacturing dualism model [15]. Houthakker has an interesting distribution of firms model in which, like in the present one, looking at its aggregate obscures what is really going on [16].

17. A linear homogeneous production function plus cost minimization imply a cost function linear homogeneous in factor prices.

18. For a survey see Nelson, Peck, and Kalachek [9], Chapter 5. Equation (20) is derived once one notes that

$$\frac{Q_2}{Q} = \frac{1}{1 + \frac{Q_1}{Q_2}} \qquad \text{and} \qquad \frac{Q_1}{Q_2} = \left(\frac{Q_1}{Q_2}\right)_o e^{ct}$$

19. $\frac{Q}{L} = g\,(w_1, r_1)\,\frac{L_1}{L} + \alpha\, g\,(w_2, r_2)\,\frac{L_2}{L}$

But if $\frac{w_i}{r_i} = \frac{\overline{w}}{\overline{r}}$ then $g\,(w_i, r_i) = g\,(\overline{w}, \overline{r})$

Noting that $\frac{L_1}{L} = 1 - \frac{L_2}{L}$ equation (14b) follows.

20.

$$\frac{L_2}{L} = \frac{1}{1 + \frac{L_1}{L_2}}$$

but

$$\frac{L_1}{L_2} = \frac{\left(\frac{Q_2}{L_2}\right) Q_1}{\left(\frac{Q_1}{L_1}\right) Q_2} = \alpha \left(\frac{Q_1}{Q_2}\right)$$

Thus $\frac{L_2}{L}$ is the same function as $\frac{Q_2}{Q}$, except for a different constant before the exponential term.

21.

$$1) \quad S_K = \frac{P\,Q - w_1\,L_1 - w_2\,L_2}{P\,Q}$$

$$= \frac{P\,Q - C_1\,Q_1 - C_2\,Q_2 + r_1\,K_1 + r_2\,K_2}{P\,Q}$$

(using 16)

$$= \frac{r\,K}{P\,Q} + \frac{(P - C_1)\,Q_1/Q + (P - C_2)\,Q_2/Q}{P}$$

$$= \frac{r\,K}{P\,Q} + \frac{\dot{Q}_1/Q_1\;Q_1/Q + \dot{Q}_2/Q_2\;Q_2/Q}{P\,\lambda}$$

(from 17)

$$= \frac{r\,K}{P\,Q} + \frac{\dot{Q}/Q}{P\,\lambda}$$

22. First, the assumption (implicit) of independent national markets should be relaxed. One effect of some countries introducing the new technology earlier may be to exert downward pressure on price in the other countries as well. This modification, perhaps, could be handled by introducing a shift factor to the demand curve.

Second, the assumption of the same λ for expanding and declining firms, or more generally that of a "portional" adjustment mechanism should be dropped and replaced by a more sophisticated relationship.

Third, the assumption that new technology is neutrally better than old is very bothersome. There is considerable reason to believe that technology invented in the high wage countries is labor saving.

Perhaps this could be handled by having the shift factor be a function of factor prices, thus $\alpha(\frac{w}{r})$, $\alpha' > 0$. This would imply (as seems reasonable) that new technology has less of a cost saving advantage in low wage than high wage countries.

Fourth, for many purposes one would want to drop the assumption of just two competing technologies and consider a steady flow of new technology. Formally this is not hard to do. But the resulting complication of the model appears to make drawing of sharp implications very difficult.

Fifth, the model would be significantly enriched by a more explicit modeling of factor markets, in particular, analysis of the determinants of $\bar{w}$ and $\bar{r}$. One might want to relate movements in $\bar{w}$ to shifts in demand for labor relative to supply domestically, and, perhaps, assume $\bar{r}$ is constant and equal in old countries reflecting international capital mobility. But if one were to go in this direction one would have to be more explicit about the factor demand implications of the profit pull adjustment equation (17). Probably one would want to pose equation (17) explicitly in terms of incremental demand for factors as a function of differences between their marginal value product and their price. This, as the modification above, seriously complicates the model.

23. For a more complete analysis see Nelson [4].

24. See United Nations [1].

25. For a discussion of the industrialization process in the early and mid-1950s, see United Nations [11], and Carne [12].

26. See C. Alejandro [13], and Staley and Morse [14], for evidence of dualism in other less developed countries.

27. For a more complete discussion, see Nelson [4].

REFERENCES

1. United Nations, The Growth of World Industry: National Tables, Vol. I, New York, 1963.

2. Nerlove, M., "Recent Empirical Studies of the CES and Related Production Functions" in M. Brown (ed.), The Theory and Empirical Analysis of Production, National Bureau of Economic Research, Colombia University Press, 1967.

3. Arrow, K. J., H. B. Chenery, B. S. Minhas, and R. M. Solow, "Capital-Labor Substitution and Economic Efficiency," Review of Economics and Statistics, August 1961.

4. Nelson, R. R., A Study of Industrialization in Colombia: Part I, Analysis, The RAND Corporation, RM-5412-AID, August 1967.

5. Mitchell, E., An Econometric Study of International and Interindustrial Differences in Labor Productivity, The RAND Corporation, RM-5125-PR, December 1966.

6. Keesing, D., "The Impact of Research and Development in U.S. Trade," Journal of Political Economy, February 1967.

7. Vernon, R., "International Investment and International Trade in Product Cycles," Quarterly Journal of Economics, June 1966.

8. Hufbauer, G. C., Synthetic Materials and the Theory of International Trade, Gerald Ruckworth, London, 1966.

9. Nelson, R. R., M. J. Peck, E. Kalachek, Technology, Economic Growth, and Public Policy, Brookings Institution, Washington, 1967.

10. Winter, S., "Economic National Selection and the Theory of the Firm," Yale Economic Essays, Spring 1964.

11. United Nations, Analysis and Projections of Economic Development-Part III-The Economic Development of Colombia, ECLA, Geneva, 1957.

12. Currie, L., et al., The Basis of a Development Program for Colombia, published for the International Bank for Reconstruction and Development by Johns Hopkins Press, Baltimore, 1950.

13. Alejandro, C. D., "Industrialization and Labor Productivity Differentials," The Review of Economics and Statistics, May 1965.

14. Staley, E., and R. Morse, Modern Small Industry for Developing Countries, McGraw Hill, New York, 1965.

15. Ranis, G., and J. Fei, "A Theory of Economic Development" American Economic Review, September 1961.

16. Houthakker, H., "The Pareto Distribution and the Colb-Douglas Production Function in Activity Analysis," The Review of Economic Studies, 1955.

17. Solow, R. M., "Investment and Technical Progress," in Mathematical Methods in the Social Sciences, Stanford, 1960.

18. Salter, W. E. G., Productivity and Technical Change, Cambridge, 1960.