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INDUCED INNOVATION:
A CRITICAL REVIEW OF THE THEORY AND CONCLUSIONS FORM NEW EVIDENCE

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Introduction

1) The formal analysis of economic growth has started as an analysis of the accumulation of factors of production, in particular of capital. The simple Harrod-Domar models regarded increases in the capital-labor ratio as the only source of increases in per capita income. Therefore, increases in investment into physical capital (through increases in the savings rate) were considered the single most important policy goal for countries trying to achieve growth.

However, with the work of Solow (1957) and others it soon became apparent that increases in the physical capital-labor ratio could explain only a very small part of the increases in per capita incomes. What the capital-labor ratio could not explain was termed technical change, although the more neutral term "efficiency increases" might have generated less controversy or misunderstanding. Since then Denison (1969), Jorgensen and Griliches (1967) and others have made great effort to allocate "technical change" to various elements of efficiency increases or quality changes of traditional factors: Increases in education, quality changes of capital equipment and land, changes in utilization rate of capital and economies of scale, etc.

The ultimate source of these changes is always some sort of investment, although not the traditional investment of the Harrod-Domar model into new units of already developed physical capital. Schultz (1966) therefore stresses that less developed countries will not be able to obtain growth by investing more into capital goods of traditional form. Instead they will have to create new institutions capable of providing improved inputs into production such as better educated labor force, better intermediate inputs (e.g. seeds) and new capital equipment adapted to the local conditions. Some institutions (extension, information) and the proper market incentives for the diffusion of the new inputs will also be required. Government activity in the production and diffusion of new techniques is necessary because private firms will be unable to capture all the benefits of their investments. Schultz argues that only if the less developed countries are successful in this endeavor will they obtain growth.

2) Suppose a country is successful in obtaining efficiency growth. The rate of growth of labor income and employment (not necessarily the wage rates) will not only depend on the rate of efficiency growth but also on whether the ensuing efficiency growth will be biased, i.e. labor saving or labor using.* If the countries simply import techniques from the developed countries without adapting them to their own factor endowments, their efficiency growth will be labor saving and labor incomes and employment

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*The terms factor saving and factor using biases are unfortunate because efficiency gains will most often reduce the absolute amount used per unit of output of all factors. However, the terms factor saving and using do not refer to the absolute requirements, but to the relative speed with which the requirements are reduced. Efficiency gains are said to be saving the factor which has its input requirements reduced in the highest proportion at constant factor prices. Absolute changes of factor productivity are not considered.

will not rise fast or may even decline. On the other hand if they could develop their own techniques or adapt advance techniques such that, for a given increase in total factor efficiency (or productivity), they would use substantially lower capital-labor ratios than the techniques of the developed countries, then labor incomes and employment would rise faster. The induced innovation hypothesis maintains that this is possible and will occur if the necessary institutions exist and factor prices reflect the true opportunity cost of factors.

The basic idea of the induced innovation hypothesis is that the biases are not determined outside of the economic system but depend on the conditions prevailing within each economy. In the Hicks-Ahmad version (Ahmad 1966) the biases depend on changes in relative factor prices while in the Kennedy-Samuelson version (Samuelson 1965) they depend on the level of the factor shares. Only with empirical evidence can we decide which inducement mechanism is the correct one and whether the induced innovation hypothesis is relevant at all.

This paper first presents the theoretical models of induced innovation and discusses their weaknesses. The second part of the paper is devoted to a review of the empirical evidence now available.* The conclusions of this paper are that the evidence strongly supports the view that biases are determined within the economic system and are not exogenous to it. On the other hand it is not yet clear how the economic variables interact to

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*In particular Hayami and Ruttan (1970), Fellner (1972) and Binswanger (1972). The last reference discusses the measurement of biases in Japanese and U.S. agriculture. These measurements underly the empirical conclusions on induced innovation of this paper.

determine the biases. To know more about this problem, a better theoretical model of induced innovation is needed. Such a model should be based on the theory of investment rather than on a simple one period model of cost minimization on which the previous models have been based.

The concept of Hicks neutrality is used in this paper.* But it is used in a slightly amended version which leads to a definition of biases in terms of factor shares.

$$B_i\Big|_{\text{relative factor prices}} = \frac{d\alpha_i^*}{dt}\,\frac{1}{\alpha_i} \lesseqqgtr 0 \quad \text{Hicks} \begin{cases} \text{i-saving} \\ \text{i-neutral} \\ \text{i-using} \end{cases} \quad (1)$$

where α_i is the share of factor i in total costs. This definition has the advantage that it leads to a single measure of bias for each factor in the n-factor case while Hicks definition would lead to n-1 measures of bias for each factor.**

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*Hicks' definition is as follows (see Nadiri 1970 for a good discussion). Technical change is said to be neutral, labor-saving or labor-using depending on whether, at a constant capital-labor ratio, the marginal rate of substitution stays constant, increases or decreases. Mathematically this can be expressed as follows:

$$\frac{d}{dt}\,\text{MRS}\Big|_{\frac{K}{L}} = \frac{d}{dt}\left(\frac{f_K}{f_L}\right) = -\frac{d}{dt}\left(\frac{dL}{dK}\right) \gtreqqless 0 \rightarrow \text{Hicks} \begin{cases} \text{labor-saving} \\ \text{neutral} \\ \text{labor-using} \end{cases} \quad (1a)$$

where f_K and f_L stand for the marginal products. Neutrality is therefore a homothetic inwards shift of the unit osoquant. If at a constant factor ratio the marginal rate of substitution (or the ratio of the capital price to the labor price) is rising, then the labor share is declining. This leads immediately to definition (1).

**To estimate biases it is, however, not possible to simply look at historic factor share changes. The observed share changes have come about through biased technical change and through ordinary factor substitution in response to changes in the prices of the factors. The basic problem is, therefore, to sort out to what extent the share changes have been due to biased technical change and to what extent to price changes. This can only be done, in a graphic sense, if the curvature of the isoquant is known. The substitution parameters of the production process have to be estimated before any biases can be measured.

Induced Innovation as an Investment Problem

One way of thinking of the biases and, more generally of the rate of efficiency gains, is to treat them as given from outside of the economic system. This view in a way likens the discovery of new methods of production to geographic discoveries. The physical, chemical, and biological world has certain properties which are given and can be discovered. Once they are discovered they will uniquely determine both the rate and the biases of technological change. Similarly, in geographic exploration you can only find what is there: Columbus set out for India; what he found was America.

While it is certainly true that one can only discover the existing properties of the real world, technological possibilities of these properties might be much more flexible than the view of exogenous determination of rate and biases of technological change might hold. Given a certain amount of research expenditures, one can develop a large variety of processes, each one with different impact on the cost of production and on factor intensities. If this view is true, then the rate and the biases would be determined within the economic system and to find out more about it, one would need an investment theory of technological change. Schmookler (1966) and Nelson (1959a and b) have loosely discussed invention in such a framework, but not much progress has been made in this area to develop a rigorous model. To facilitate the later discussion therefore, the elements which such a model should include are sketched out, first in terms of the rate of technological change or innovation in a particular industry and then in terms of the biases.

Leaving product innovation aside, the rate of efficiency growth would be governed by the following elements to which one can assign pseudo-mathematical symbols for further reference.

1. Physical, chemical and biological possibilities, i.e., the state of the basic sciences, which one might assume to be exogenous. Let this complex be denoted by S.
2. The cost of developing actual production processes from S, i.e., the research and development costs, C.
3. The expected returns obtainable from the innovation, which will be governed by
   a) The size of the process to which an innovation is applied, M. The bigger the process, the larger the market potential of the innovation.
   b) The prices of other factors of production, P.
   c) The interest rate, r.
   d) Other factors such as the state of competition in the industry, patentability or other protection of the innovators rights, etc. Denote this by O.

One can then write the rate of efficiency growth as the following general relationship:

$$T = f(S,C,M,P,r,O). \tag{2}$$

This is a framework which is very similar to the human capital approach of labor quality improvements or to investments into soil improvements.

Given such an investment theory the question of endogeneity or exogeneity of the rate is an empirical question of the relative importance of the different variables in f. If the S complex dominates all other elements, then the rate will be mainly exogenous while it will be endogenous if the economic variables are more relevant than the S complex.* In an outstanding empirical investigation of U. S. patent statistics and of hundreds of important inventions in four industries, Schmookler (1966) has come to the conclusion that the rate of return to inventions is of far greater importance than the state of knowledge. He shows that market forces and not the availability of all the necessary elements of S trigger off the inventions. While the availability of all necessary basic knowledge may be a necessary condition, he has found no instance where this alone has brought about an important invention. In most cases considered, the necessary basic knowledge was available decades before the innovation was actually made.

It is a small step from the function (2) to the formulation of an analogous investment model of the biases:

$$\text{Biases} = g(S,C,M,P,r,0) \tag{3}$$

In the actual world the biases and the rate will be determined simultaneously, but it is analytically convenient to separate the two.

The questions to be asked in this investment model are the same as before: Does S constrain the possibilities for biases such that all other arguments become empirically irrelevant? If that is the case, biases (or

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*S is assumed to grow exogenously. While this may be questionable in the case of the U.S., it is certainly quite a good assumption for most other countries.

neutrality) are given exogenously, even if enterpreneurs tried to allocate their research expenditures according to an investment model. Another way to have de facto exogeneity would be if the cost of achieving a labor saving biases was small while the cost of capital saving biases was exorbitant.*

The theoretical discussions of induced biases in the mid-sixties and the empirical research based on it have centered on the following aspects:

1. They consider only biases due to technological change and not biases which might result from investments in human capital or soil improvements. Any measured biases, however, result from all sources of efficiency gains.
2. The discussions have centered on whether the S elements determine the biases exclusively or not.
3. They have neglected the cost aspects.
4. On the return side they have only considered factor prices and factor shares

The first reference to factor prices as a source of biases has been made by Hicks (1964) in his Theory of Wages (originally published in 1932). He argues that changes in factor prices will induce biases which will save the progressively more expensive factor. (Of course, the biases themselves will influence the factor prices.) Hicks did not specify the mechanism by which this would occur.

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*This is similar to the problem of planting bananas in Quebec. While it is not impossible to build vast heated greenhouses there, no one will do it commercially because of the exorbitant costs associated with it.

Ahmad (1966) has a very careful exposition of this idea. He uses the concept of a historic innovation possibility curve (IPC) defined as follows: At a given time there exists a set of potential production processes to be developed. This set might be thought of as determined by the state of the basic sciences. Each process in the set is characterized by an isoquant with a relatively small elasticity of substitution, and each of the processes in the set requires a given amount of resources to be developed to the point where it actually can be used. The IPC is the envelope of all unit isoquants of the subset of those potential processes which the entrepreneur might develop with an exogenously given amount of research and development expenditures. The determination of the rate of technological change is therefore not considered in this model. Figure 1 taken from Ahmad's publication explains the model.

For time t the process I_t had been developed. The IPC corresponding to it was IPC_t. Given the relative factor prices of the line P_tP_t, this process was the cost minimizing one. Once I_t is developed the remainder of its IPC becomes irrelevant because, for period t + 1, the IPC has shifted inwards to IPC_{t+1}. If factor prices remain the same, entrepreneurs will develop the process I_{t+1} for the next period. If the IPC has shifted neutrally, the technical change will be neutral. (But Ahmad recognizes that it is possible that the IPC shifts inwards nonneutrally, which would result in biases even at constant factor prices.) If, however, factor prices change to P_{t+1} P_{t+1}, then it is no longer optimal to develop I_{t+1} but the process corresponding to I'_{t+1} becomes optimal. In the graph P_{t+1} P_{t+1}

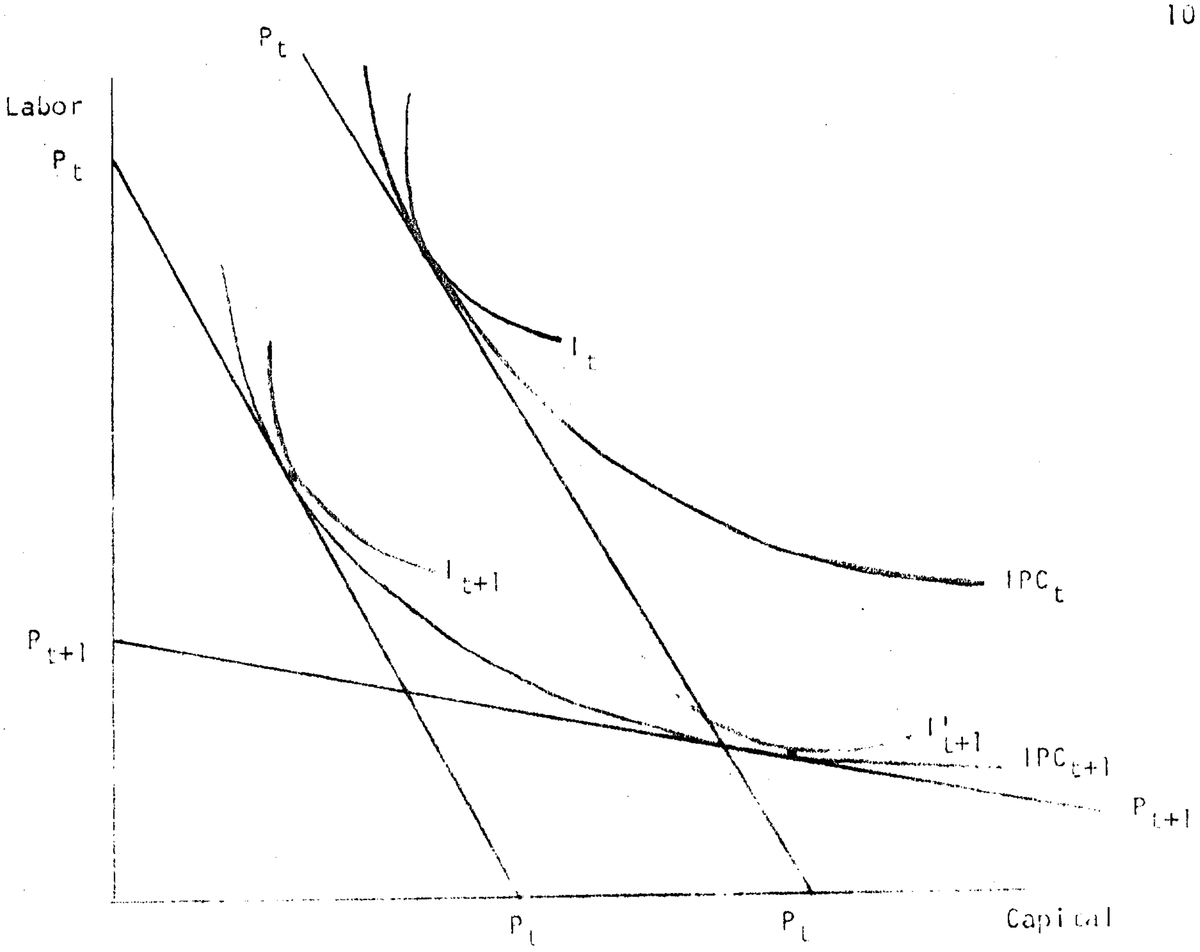

Figure 1. Ahmad's Induced Innovation Hypothesis (Ahmad 1966, Figure 1).

corresponds to a rise in the relative price of labor. If the IPC has shifted neutrally, I'_{t+1} will be relatively labor saving in comparison to I_t.

Because of the way in which IPC is defined, and given full knowledge of entrepreneurs about factor prices and all possible alternative processes, induced innovation will certainly occur. But the assumptions have to be examined.

First, the theory assumes that the further shift of the IPC is independent of the process which was developed in period t. This may or may not be true.

Second, the theory does not consider the possibility of spending resources to influence the shift of the IPC. It is conceivable that resources could be spent either to increase the elasticity of substitution of the IPC or to have it shift nonneutrally.

Further, the theory might become irrelevant, if the elasticity of the IPC were not much larger than the isoquants corresponding to the individual processes. If, moreover, the IPC was biased, a fundamental bias would result.

Jumping a little bit ahead: to test the relevance of the induced innovation hypothesis requires that one test whether the IPC has a substantially larger elasticity of substitution than the individual processes. Even if the IPC was fundamentally biased, a larger elasticity of substitution would still make induced innovation empirically relevant because it would allow endogenous forces to increase or offset the fundamental biases to a large extent. A direct measure of the elasticity of substitution of the IPC is not attempted. However, I obtained indirect evidence by considering the biases in Japanese and U.S. agriculture (Binswanger 1972, 1973). Since Japan and the U.S. had differing trends in factor prices and other economic variables, they must have had differing biases in the same time periods, if the elasticity of substitution of the IPC is large and induced innovation is empirically relevant. The differences in the biases must, moreover, be large, if the theory is also to be relevant.

Other shortcomings of Ahmad's theory are that no other economic factors governing the rate of return to biases are considered and that the time dimension of the benefits to biases is neglected. In particular, if biases were only obtainable at a cost, the relative importance of a factor, to which a given savings applies, would make a difference in the rate of return.

Kennedy's (1964) and Samuelson's (1965) version of the induced innovation theory takes account of the relative importance of factors and, in some sense, of the cost of obtaining biases, and treats the time dimension more satisfactorily. The basic idea of this theory can best be explained with an example. Suppose it were equally expensive to develop a new technology which reduced labor requirements by 10 percent as one which reduces capital requirements by 10 percent. If the capital share is equal to the labor share, the entrepreneurs will be indifferent between the two and half will choose the one and the other half the other. The outcome will be neutral technical change. If, however, the labor share were 60 percent, then all would choose the labor-reducing version. If the elasticity of substitution were less than 1, this would go on until the labor and the capital shares became equal again, provided the induced biased technical change does not alter the tradeoff relationship between labor requirement and capital requirement reducing (augmenting) technical change.

Therefore shares can be stable even if the capital-labor ratio changes historically. This implication of shares stability is what interested the authors.

The following section discusses assumptions in mathematical detail and the objections which might be raised against it.

Write total unit costs as follows:

$$U = KR + LW \qquad \text{s.t.} \quad Y(A_K K,\ A_K L) = 1 \qquad (4)$$

where W is the wage rate and R the capital rental rate and the **A**'s are augmentation coefficients.* The instantaneous proportional rate of reduction in unit costs can be written

$$\dot{u} = \frac{\dot{U}}{U} = -\dot{a}_K\alpha_K - \dot{a}_L\alpha_L + \text{terms involving price changes} \qquad (5)$$

(see Samuelson 1965 for derivation) where α_K and α_L are the factor shares,

$$\dot{a}_K = \frac{1}{A_K}\,\frac{\partial A_K}{\partial t} \quad \text{and} \quad \dot{a}_L = \frac{1}{A_L}\,\frac{\partial A_L}{\partial t}$$

Now assume:

1. given factor prices
2. an exogenously given budget for research and development of new techniques, and
3. a fundamental trade-off between the rate of proportional reduction in labor requirements, $\dot{a}_L$, and the rate of proportional reduction in capital requirements, $\dot{a}_K$.

Assumption (3), which is simply an assumption about the underlying possibilities of technical change, can be written as:

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*See Solow (1967) for a discussion of factor augmentation. The production function in factor augmenting form is

$$Y = f[(X_1A_1), (X_2A_2), \ldots, (X_nA_n)]$$

(X_1A_1) is the effective quantity of factor X_1. An increase in A_1 has the same effect on output as an equiproportional increase in X_1 would have had prior to the increase in A_1. Therefore factor augmentation restricts technical change so that it cannot alter the form or the parameters of the production function. It enters by changing the quantity of effective factor supply. It is immaterial whether effective factor supplies can be measured or not, because producers will react to changes in marginal productivities of the factors and alter input quantities according to the unchanged parameters of the production or cost function. It is, however, important to note that an increase in the quality of factor i does not raise the augmentation coefficient of factor i alone but may affect the A's of all cooperating factors. (See page 34 for more on this.)

$$\dot{a}_L = f(\dot{a}_K)$$

or (6)

$$\emptyset(\dot{a}_K, \dot{a}_L) = 0.$$

Assume that this "Transformation" function or as Kennedy (1964) called it, this "Innovation Possibility Frontier" (IPF) has the usual characteristic of economic transformation functions, i.e.,

$$\frac{d\mathring{a}_K}{d\mathring{a}_L} < 0, \quad \frac{d^2\mathring{a}_K}{d\mathring{a}^2_L} < 0.$$

Graphically, this transformation function will look as follows (Figure 2) (Samuelson 1965):*

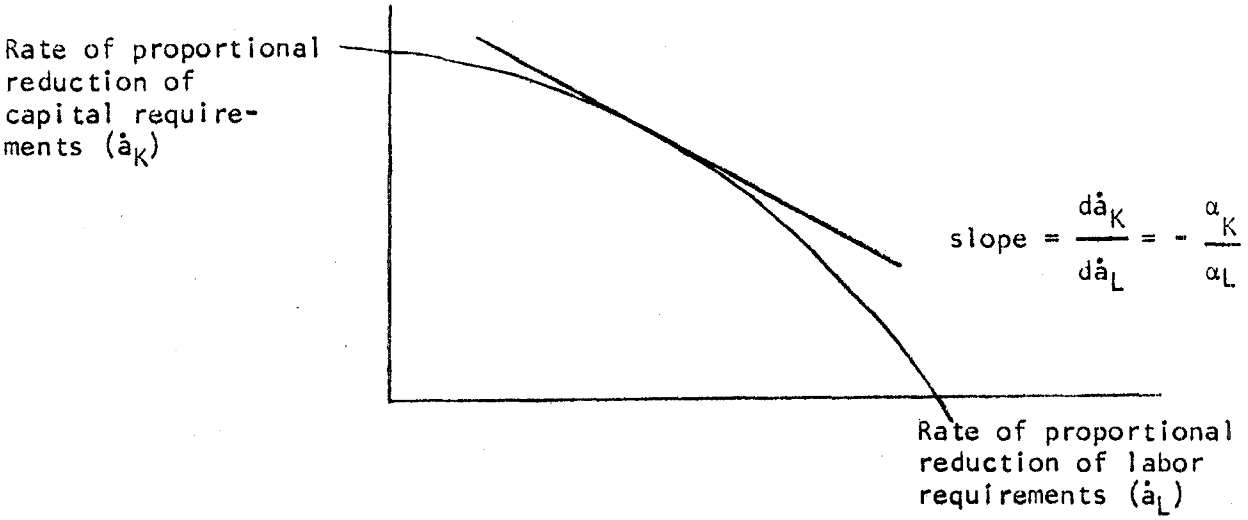

Figure 2: Kennedy's Innovation Possibility Frontier

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*The IPF is assumed to be invariant over time. Neither Kennedy nor Samuelson discuss in detail what determines the position of the IPF, which, in a way, governs the growth rate. The farther out the IPF lies, the faster will be the reduction in input requirements per unit of output at a given ratio of $\mathring{a}_K$ to $\mathring{a}_L$.

Given equation (5) and equation (6), one can set up a maximization problem. Maximize the rate of instantaneous unit cost reduction subject to the trade-off relation of factor augmentation.

$$\text{Minimize } \dot{u} = - \dot{a}_K \alpha_K - \dot{a}_L \alpha_L \tag{7}$$

$$\text{subject to } \phi(\dot{a}_K, \dot{a}_L) = 0.$$

The solution is completely analogous to the solution of the similar system of minimizing cost subject to a given output, where α_K and α_L now have the same rôle as factor prices. Hence, the rate of cost reduction is maximized at a point where

$$\frac{d\dot{a}_K}{d\dot{a}_L} = - \frac{\alpha_L}{\alpha_K} . \tag{8}$$

The slope of the IPF has to be equal to the inverse ratio of the shares (see Figure 2). Hence, the higher the labor share, the higher will be $\dot{a}_L$ relative to $\dot{a}_K$ or technical change will be relative labor-augmenting. It will be labor saving if, in addition, $\sigma < 1$.

The mechanism implied in equation (8) can explain the constancy of relative factor shares even if the capital-labor ratio increases, provided that σ of the individual production process is less than 1. In the absence of technical change, an increase in the capital-labor ratio would increase the labor share. But as the labor share increases, resources are shifted by the above mechanism to the development of labor-augmenting technology, which will offset the tendency of the labor share to increase. Dynamic properties of this system under various assumptions can be found in Samuelson (1965) and Drandakis and Phelps (1966). The basic weakness of this approach lies in the assumption that the rate of proportional reduction of labor requirements ($\dot{a}_L$) is a function of ($\dot{a}_K$) independent of the initial levels of capital and labor inputs (assumption 6). Ahmad (1966) shows graphically that this independence assumption implies that the IPC corresponding to this IPF is of the Cobb Douglas form. The "metaproduction function" corresponding to this IPC isoquant (Hayami and Ruttan, 1970) is therefore a Cobb Douglas function.*

Under these circumstances, it is clear that any theory of induced innovation based on the assumption (6) must result in shares stability: If the meta-production function is Cobb-Douglas, it will shift meutrally over time. Even if individual subprocesses have elasticities of substitution of less than one, factor ratios and shares are determined by the Cobb-Douglas meta-production function in the long run. Even with apparently nonneutral technical change shares will be stable. This shares stability will obtain whether the inducement mechanism is factor prices or factor shares. In a way this latter approach just replaces the concept of neutral shifts of the individual production process with another more hidden form of fundamental neutrality.** Ahmad's framework is therefore more general

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*For a mathematical proof see Binswanger (1973).

**The strange results which are obtained with the Kennedy-Sanuelson approach when the elasticity of substitution of the individual production processes is larger than one have no importance at all since then there cannot exist a trade-off relationship (5). It makes no sense to assume that individual processes have larger elasticities of substitution than the meta-production function, which in this case is Cobb-Douglas with an elasticity of substitution of one.

because his IPC can have any functional form and shift neutrally or non-neutrally. Both versions of the induced innovation hypotheses have to be considered starting points for a more general theory.

Empirical Evidence on Induced Innovation

Solow (1957), Sato (1970) and Fellner (1971) consider the question of whether there has been an aggregate labor saving bias in technological change in the U.S. economy. All three attempts impute biases, if any, to the effect of technical change alone and neglect the human capital aspect as a possible source of bias. But for their argument it is immaterial whether human capital is a source of bias or not. Solow's test is based on the mathematical fact that, if biases occur, the rate of technological change (his residual) cannot be independent of the capital labor ratio. Since he fails to find such a relationship, he concludes that technical change must have been neutral.

Drandakis and Phelps (1966) show that, if the production function is CES and technical change is factor augmenting, the Hicks bias, (Ia) defined in terms of a change in marginal rates of substitution at constant factor prices, can be measured as follows:

$$Q_{\left|\frac{K}{L}\right.} = \frac{1-\sigma}{\sigma}\,(\dot{a}_L - \dot{a}_K) \;\overset{>}{\underset{<}{=}}\; 0 \;\begin{cases}\text{L-saving}\\ \text{L-neutral}\\ \text{L-using}\end{cases} \qquad (9)$$

with $\dot{a}_K$ and $\dot{a}_L$ defined as before.*

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*This equation shows the important fact that relatively labor-augmenting technical change need not be labor-saving. Three cases exist:

<u>Cases</u>: (1) $\sigma = 1$ Technical change is always neutral;
(2) $\sigma < 1$ Technical change is labor-saving if $\dot{a}_L > \dot{a}_K$, it is capital-saving if $\dot{a}_L < \dot{a}_K$;
(3) $\sigma < 1$ Technical change is labor-saving if $\dot{a}_L < \dot{a}_K$, it is capital-saving if $\dot{a}_L > \dot{a}_K$.

(continued on page 18)

Sato (1970) showed that the rate of proportional change in the augmentation coefficient ($\dot{a}_i$) can be measured as follows:

$$\dot{a}_i = \frac{\sigma \dot{w}_i - (\dot{y} - \dot{x}_i)}{\sigma - 1} \qquad \begin{matrix} \sigma \neq 1 \\ i = 1,\ 2 \end{matrix} \qquad (10)$$

where lower case letters with dots are logarithmic time derivatives i.e. rates of change of

W_i = wage of factor i

Y = output

X_i = quantity of factor i.

He uses the discrete change equivalent of these formulas to derive factor augmentation series for capital and labor for the U.S. private nonfarm sector from 1910 to 1960 assuming that σ is less than 1.

He finds that technical change has been almost exclusively labor augmenting. If σ is less than one, this implies that technical change has been labor saving (equation 9), which contradicts Solow's finding.

Sato's conclusion is supported by Fellner (1971) who shows that during the period 1948-1957 the labor share rose from approximately 60% to 65%, while it remained constant during the rest of the period 1920-1966. Between 1948 and 1957 the capital-labor ratio rose at a much faster rate (3.7% per annum) than during any part of the period 1920-1966. This is interpreted as follows: Given an elasticity of substitution of less than

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That relatively labor-augmenting technical change ($\dot{a}_L > \dot{a}_K$) is labor-using for $\sigma > 1$, is explained as follows: The increase in efficiency of labor allows entrepreneurs to reduce the amount used. But with higher marginal product at a constant price, there is now an incentive to substitute labor for capital. And the elasticity of substitution is so large that the incentive to use less labor due to its efficiency increase overrides the initial saving made possible by the efficiency increase.

one, the rise in the capital labor ratio during the whole of the period 1920-1966 should have had a tendency to increase the labor share during the entire period. That it did not do so must have been due to an exactly offsetting labor saving bias, except between 1948 and 1957. In this subperiod, the rise in the capital labor ratio was so large that the bias was not sufficient any more to hold shares constant.

The exactly offsetting bias except between 1948 and 1957 would be consistent with a share induced innovation process according to Kennedy and Samuelson. It is, however, also consistent with the idea of a fundamental bias during the entire period.

Also, the fact that the labor share actually increased between 1948 and 1957 and stayed constant afterwards would indicate that the inducement mechanism to hold shares stable did either not work at all during that period or was so weak as to have only a small impact. If the share inducement mechanism had been very responsive, the labor share would not have risen between 1948 and 1957 despite the strong rise in the K/L ratio. But constancy of the labor share throughout the period might then again have been consistent with the opposing hypothesis that technical change was neutral throughout the period. This is just an example of the impossibility of inferring something about the source of biases on the basis of actual share behavior in only one country without measuring the biases first.

Solow's finding of neutrality is inconsistent with Sato's and Fellner's finding of nonneutrality. If Sato and Fellner are right then we still do not know whether the bias was fundamental or not.

Hayami and Ruttan (1970) followed an entirely different approach: They compared agricultural time series data on labor, land and capital (machinery) productivity in Japan and the U.S.. The differences in the development of these series between the two countries is so striking that they conclude that the differences must be due to biases rather than to ordinary factor substitution along the production function of the neutrally changing production process.

To test whether their impression is right Hayami and Ruttan then assume that at each moment of time the elasticities of substitution among factors in agricultural production is very small so that almost fixed proportions prevail. As support they cite evidence from experimental studies on fertilizer response which indicate that the optimal fertilizer use in each crop does not change very much with changes in prices. Examples of mechanical processes such as harvesting of grain are also presented. However, while it may be true that for individual crops or tasks the elasticities of substitution are quite small, this may no longer hold for the farm level where much more flexibility is likely to exist, as linear programming studies in general show.

Given the assumption of almost fixed proportions of individual production processes, the induced innovation hypothesis can be proved as follows: Estimate the elasticities of substitution using time series data. If they are large then the ex post observed substitution must have been due to biased technical change rather than to substitution along a given production function which was assumed to be very difficult. The advantage of this method is that it would prove both the endogeneity of the biases and the predominant role of factor prices in explaining them.

The estimation equation which Hayami and Ruttan use to estimate the elasticities of substitution has certain problems which are reviewed in Binswanger (1973). Their largest measured elasticities of substitution is 1.3 between machinery and labor in the U.S.. All other elasticities of substitution are estimated to be less than one. Therefore, if one rejects their hypothesis of almost fixed proportions at each moment of time one cannot consider their estimates as conclusive evidence for the induced innovation hypotheses.

In the light of this it seemed to be necessary to actually measure the biases for the U.S. and the Japanese agriculture. This was the starting point for my own work of measuring biases in the many factor case.*

Instead of the a production function the transcendental logarithmic per unit cost function is used (Christensen, Jorgensen and Lau 1970). The function is a logarithmic Taylor series expansion of an arbitrary twice differentiable cost function to the second term. It is therefore less restrictive than the production and cost functions currently in use. In particular it allows arbitrary and variable elasticities of substitution among all factors. The cost function contains all the information about the production process which its dual production function contains.

In logarithmes it is written as follows:

$$\ln U = \nu_0 + \sum_i \nu_i \ln W_i + \frac{1}{2} \sum_{ij}\sum \gamma_{ij} \ln W_i \ln W_j \qquad (11)$$

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*Details of the procedure and a rigorous derivation of the approach in terms of a factor augmenting framework can be found in (Binswanger 1972, 1973). The derivation presented here is a heuristic short cut.

where U is per unit cost and W_i are factor prices. Because of Shephard's lemma $(\frac{\partial U}{\partial W_i} = X_i)$,

$$\frac{\partial \ln U}{\partial \ln W_i} = \alpha_i = \nu_i + \sum_j \gamma_{ij} \ln W_j, \qquad i = 1 \ldots n \tag{12}$$

where α_i are the factor shares. Equation (12) explains the shares at a moment of time in terms of factor prices. Differentiating totally and assuming ν_i and γ_{ij} to be constant we have:

$$d\alpha_i = \sum_j \gamma_{ij} \, d\ln W_j, \qquad i = 1 \ldots n \tag{13}$$

which explains the share changes due to factor price changes. If (13) is taken over time, there will, however, be another reason of factor share changes, namely the biases. Call these share changes $d\alpha^*$, which would occur in the absence of factor price changes. Then (13) becomes

$$d\alpha_i = \sum_j \gamma_{ij} \, d\ln W_j + d\alpha^*_i, \qquad i = 1 \ldots n \tag{14}$$

If we have data on actual share changes $d\alpha$, on the changes in factor prices $d\ln W$, and if we know the γ_{ij} parameters then we can solve

$$d\alpha^*_i = d\alpha_i - \sum_j \gamma_{ij} \, d\ln W_j \tag{15}$$

i.e., subtract from the actual share changes that part which has been due to price changes, or factor substitution along a given cost function. The discrete time equivalent of (15) can then be substituted into the discrete time equivalent of (1) to obtain measures of biases.

This framework was applied to the agricultural sector. Five factors were distinguished: land, labor, machinery (including animal power for the time series data), fertilizer and all other. The parameters of the cost function were estimated cross sectionally in the U.S. with state data. Four cross sections for the years 1949, 1954, 1959 and 1964 were constructed from USDA data.*

The estimated values of the γ_{ij} are used for both the U.S. and Japan. They were assumed to be constant over time as well. This is the key assumption of the whole approach. It derives from the concept of factor augmenting technical change.**

Time series data were then constructed for the U.S. (USDA data) and Japan (Okawa et al., 1966). The variables construction tried to achieve close correspondence of the definitions of the factors for all three data sets. Complete correspondence was, of course, impossible to achieve. The U.S. time series data covered the years 1912-1968 while the Japanese series covered the period 1893-1962, with the years 1941-1953 missing. The series of the biases are presented graphically. The figures will compare the Japanese and the U.S. biases for land, labor, machinery and fertilizer. Biases for "other" imputs are not presented because they do not show any independent information (the sum of the biases has to be zero). The graphs

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*Considerable data transformations on the cross section data as well as on 2 time series data sets was necessary. For a full discussion of the sources of the data and the transformation see (Binswanger 1973).

**The assumption does not imply that the countries are on the same production or cost function. Difference in the augmentation coefficient is sufficient to place the unit isoquants of the two countries in entirely different positions in the positive orthant.

will also show standardized series of actual share behavior except where the indices of biases and actual shares move closely together.

Figure 3 may help interpret the graphs. Suppose the line OA depicted the Japanese series of fertilizer bias, while the line OBC represented the fertilizer bias in the U.S.. The slope of the line is the measure (1) of B while the whole line represents cumulative biases. Both series originate at t at a level of 100, which corresponds to the level of the actual factor share in each country at that time. The actual shares at t will in general be different between the countries. This initial difference is not explained. It may result from differences in factor prices at that time and from differences in biases which occurred prior to the investigation. The graph would tell us that Japan had experienced a fertilizer using bias at constant rate during the entire period which would have tended to double the actual factor share if price changes had not deviated the actual share from that path. The U.S., on the other hand, would first have experienced a fertilizer saving bias with a corresponding tendency of the actual share to decline by 30%.

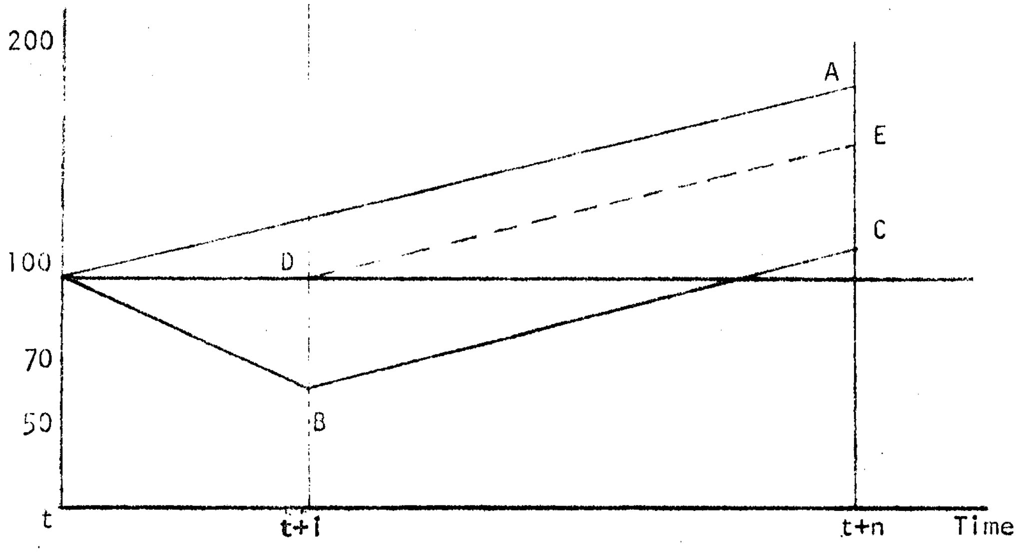

Figure 3: Example of graph, semi-log scale.

After time t + i, however, the bias would have been positive with an equal rate (equal slope) as the Japanese bias. The total impact of the U.S. bias during the period would have been a tendency of the share to rise by 10%.

Suppose we only had the data from t + i to t + n. Then both series would originate at the level of 100 at t + i and be presented by an identical line DE with equal slope as the other ones. From that evidence alone we would conclude that both countries had experienced identical fertilizer biases, which would lead us to believe that the bias was exogenous. Given, however, the strong divergence of the biases between t and t + i, we would reach the opposite conclusion that biases have been endogeneous, at least between t and t + i.

This example is given to show that equal development of biases for one factor share during a long period does not necessarily disprove the endogeneity hypothesis. The economic forces on that particular factor during that time might have been similar and caused similar biases. A strong case for exogeneity could, however, have been made if all biases showed similar slopes during most of the time.*

Turning on to the evidence (Figures 4, 5, 6, and 7) note that the Japanese series start in 1893 while the U.S. series start only in 1912.** Both series are standardized for the 1912 value of the actual share. Note also that there is a data break for the Japanese series from 1940 to 1954.

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*By a similar reasoning, it is clear that neutrality of a bias for one factor alone does not mean that this neutrality is exogenous. If an induced innovation process has occurred long before t, the rate of return to further saving or using biases in this factor might have been no larger than the rate of return to neutral efficiency growth of this factor, i.e., the possibilities of further biases might have come close to exhaustion precisely because induced biases have previously been strong.

**Numerical values reported in the appendix.

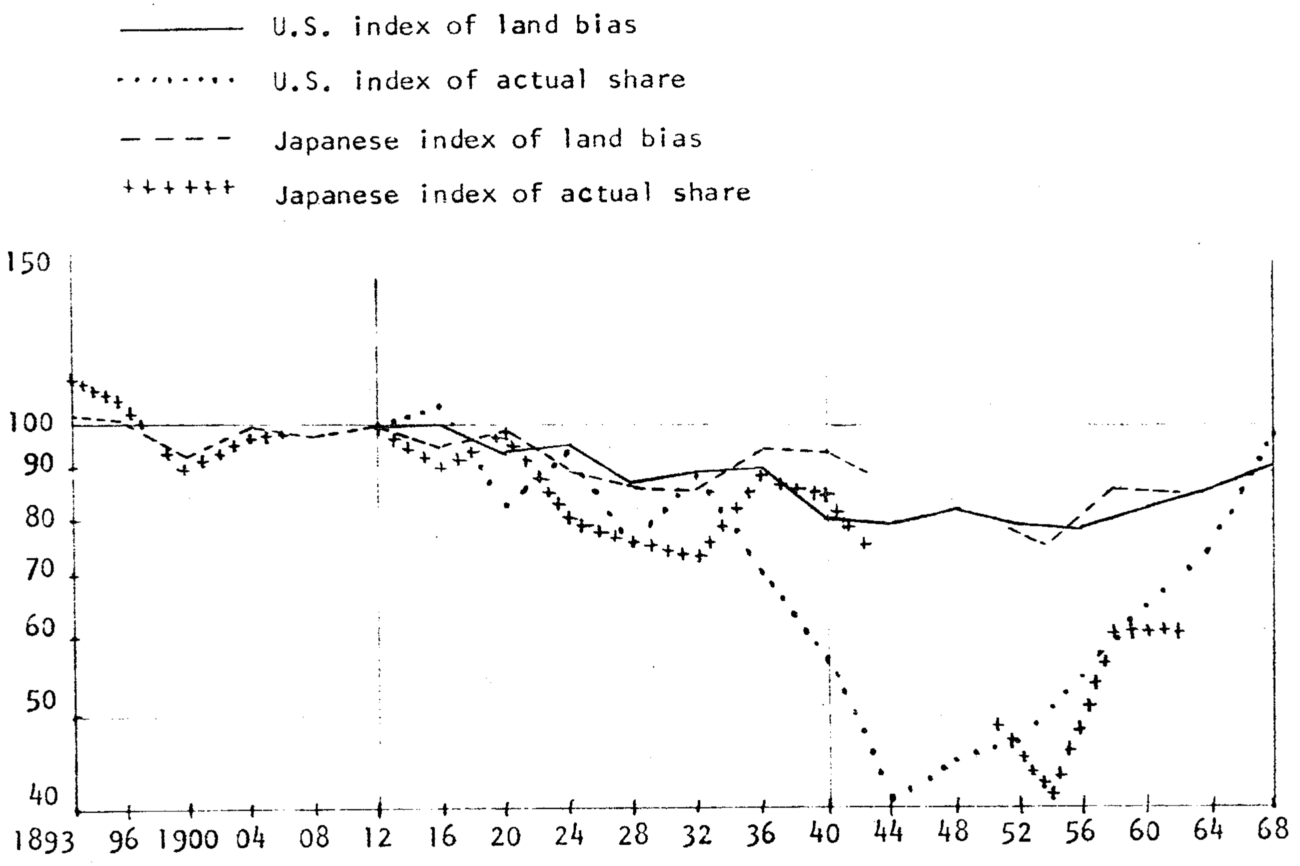

Figure 4: Comparison of U.S. and Japanese Land Biases
Semilog Scale, 1910 - 1912 = 100

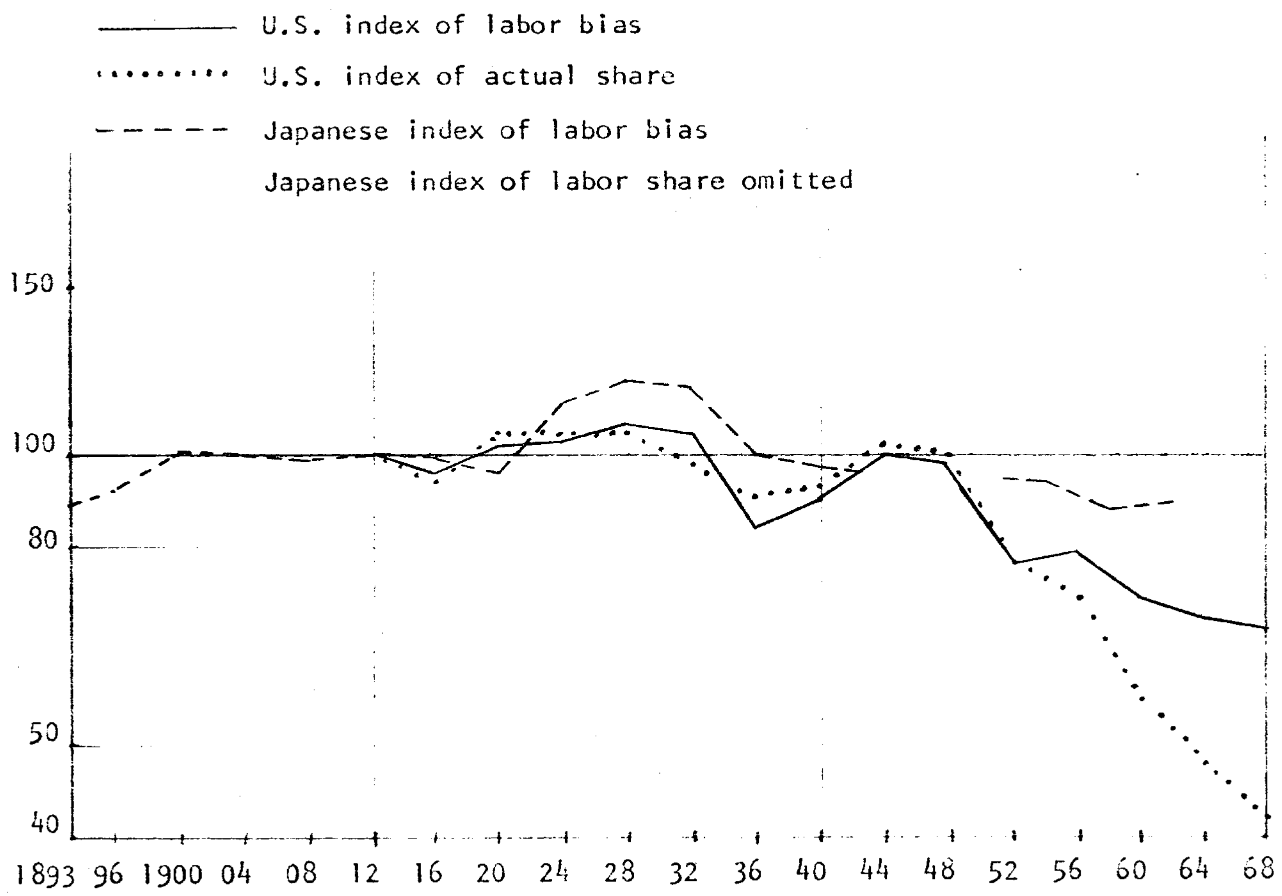

Figure 5: Comparison of U.S. and Japanese Labor Biases
Semilog Scale, 1910 - 1912 value = 100

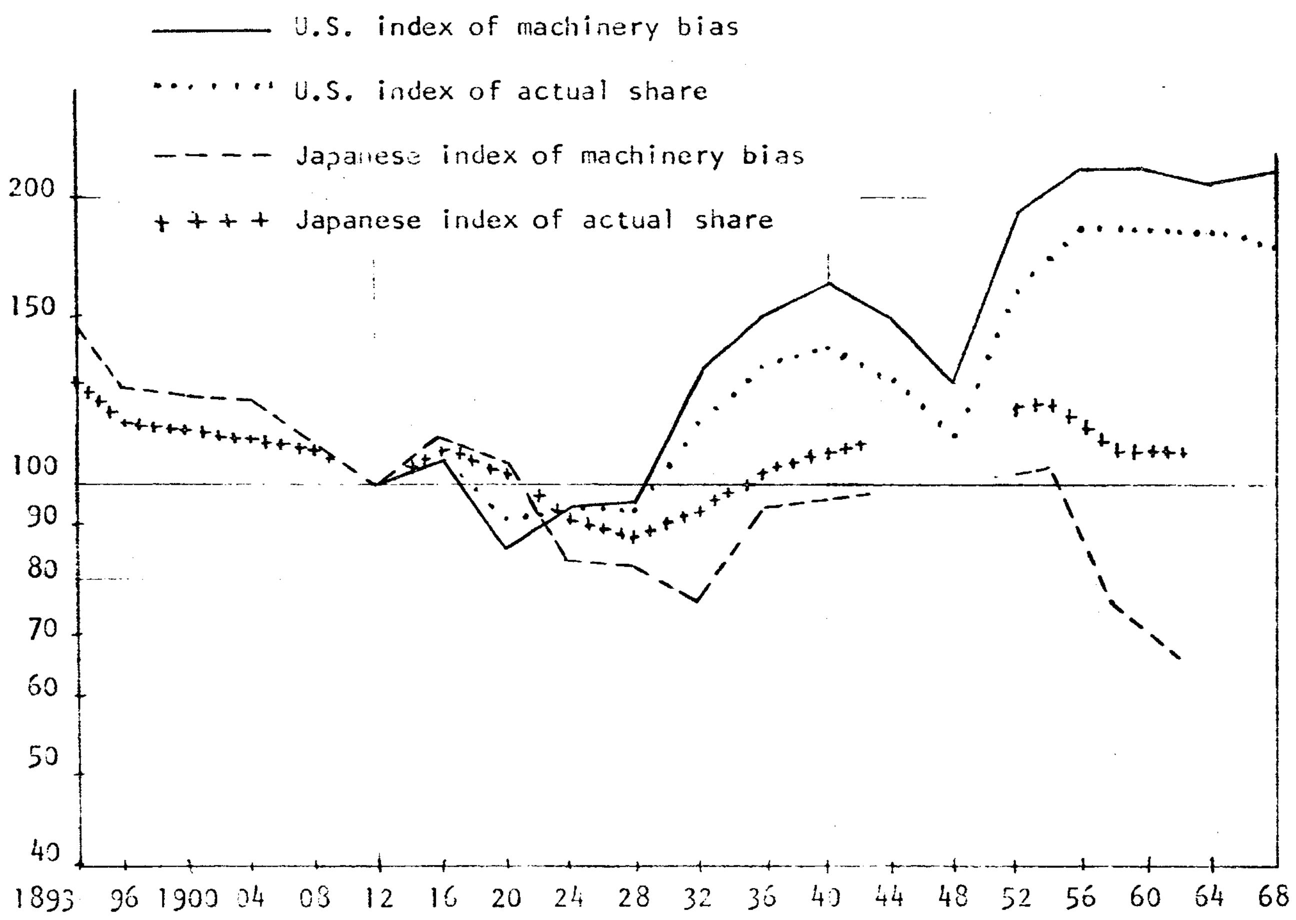

Figure 6: Comparison of U.S. and Japanese Machinery Bias
Semilogarithmic Scale, 1910 - 1912 = 100

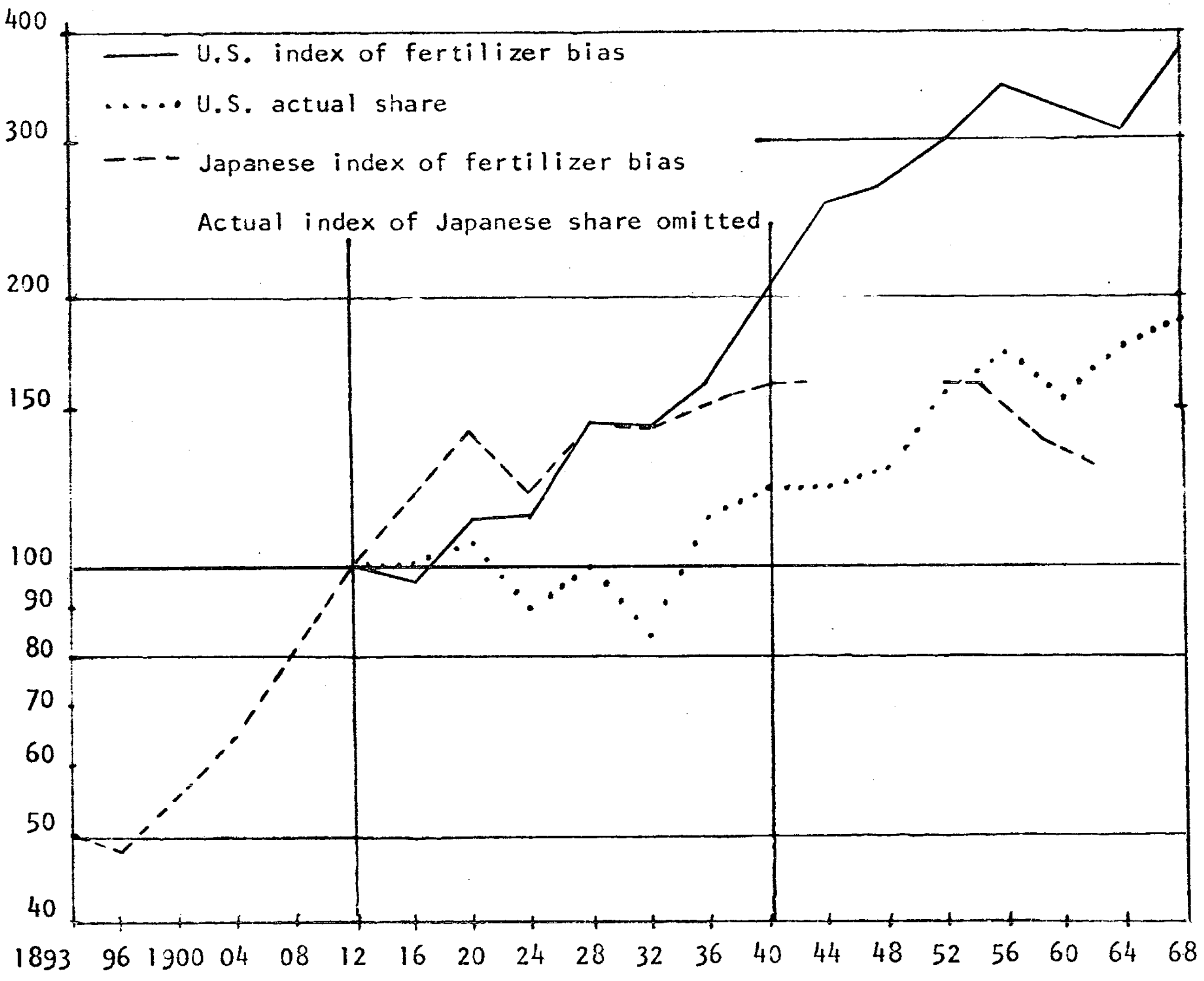

Figure 7: Comparison of U.S. and Japanese Fertilizer Bias
Semilog Scale, 1910 - 1912 = 100

While we still know what the total impact of the bias has been in this interval, possible departures from a straight line during this time are unknown.

From the evidence for land and labor alone, the conclusion would probably have been that, while biases did occur, they were of essentially the same nature in both countries during the period of overlap. This would have led to a conclusion that some exogenous force was at work. The only evidence for endogeneity would have been the following observations: In both countries the labor biases were labor saving after the second World War which coincides with a strong wage rate rise in both countries. Also, the labor saving bias in the U.S. was much stronger than in Japan, which tends to confirm the endogeneity because labor price rises were stronger in the U.S. than in Japan during the fifties. But this would be only weak evidence for the endogeneity hypothesis. Also the biases, contrary to what one might expect initially, were rather weak. A priori we might have expected a strong land saving bias in Japan. The only ex post explanation that this did not occur might be that Japan started in 1893 already at a point where land saving biases had occurred previously and driven the rate of return from further biases down or the cost of the biases up.

Turning now to the evidence from machinery and fertilizer, it becomes clear that the biases were endogenously determined to a very large extent. The U.S. experienced a strong machinery using bias while Japan experienced a machinery saving one. This is what would be expected from the induced innovation hypothesis.

The fertilizer biases strengthen this conclusion. From 1932 to 1962 the U.S. experienced a strong fertilizer using bias while Japan had neutral fertilizer efficiency growth. This can only be explained if biases are endogenous. It is also interesting to note that the Japanese period of neutrality followed after a period of strong fertilizer using bias. This lends support to the hypothesis, that after a prolonged period of bias in one direction, further gains from biases become exhausted, despite a further drop in the input price. This in turn suggests that not too much should be made of the almost neutrality of the labor and land series.

How would one, a posteriori, explain the fact that biases were much weaker for labor and land (except for labor in the period after World War II). Both fertilizer and machinery went through strong structural changes in their form and production methods. Before the period under consideration the source of plant nutrients was primarily organic fertilizer produced by farmers themselves. Chemical fertilizer changed the form of plant nutrients and their production takes place outside the farm sector. This releases farm labor for other purposes. Essentially the same is true for machinery. This factor consisted originally of draft animals and tools and implements which could be produced on the farm or in small scale rural industry. Towards the end of the period, mechanical traction replaced the animals, the tools and machinery became more complex and were produced largely outside the farm economy. It seems clear that the strongest biases would be expected with respect to factors undergoing such strong changes. But this is an a posteriori explanation which was not considered at the outset.

Anotner conclusion can be made from the series: Where strong biases occurred, the absolute difference between the Japanese and the U.S. cumulative bias is equal to or larger than the larger of the absolute cumulative biases. This means that the total extent of the large biases must be explained by endogenous forces rather than a fundamental bias in any direction. This not only strengthens the endogeneity hypothesis but means that endogenous biases are empirically important in explaining shares and wage rates of factors.

Conclusions with respect to the precise inducement mechanisms are negative. Which element is most important in terms of function (2), the factor prices, interest rates, size of markets, or cost of obtaining the innovation? Data are only available on changes in factor prices and factor shares and both fail if considered to be the sole empirical relevant source of bias. From the graphs no clear relationship emerges between actual shares and biases. When the price data are inspected, the following conclusions emerge (Appendix Tables 3 and 6): The price of fertilizer relative to the output price declined dramatically in both countries. This is consistent with the observed biases. After World War II the price of labor rose in both countries which is consistent with labor saving biases during that period as well. But the puzzle lies in the behavior of machinery prices and machinery biases: Machinery prices rose as fast in the U.S. as labor prices while they declined in Japan. But it was the U.S. which experienced machinery using biases while Japan experienced a machinery saving bias. If changes in relative factor prices had been the single most important force determining the biases, this would not have been possible. Other variables, such as the absolute level of relative factor prices, interest rates, size of market etc, must have been important as well.

CONCLUSIONS

This section briefly summarizes the empirical and theoretical conclusions of this paper for the induced innovation hypothesis and tries to show some policy implications.

The comparison of the biases in the agricultural sectors of Japan and the United States shows that the biases are endogeneous to a very large extent. This does not mean that advances in basic sciences are unimportant. Without such advances the fertilizer using biases in both countries would not have been possible. But the basic sciences are only a necessary condition for technical change. They leave the options open as to the timing of technical change and the direction of the biases which are determined by economic forces.

Does this conclusion generalize to the economy as a whole. Sato's work on measuring biases of the U.S. private nonfarm sector seem to support this. The labor saving biases which he measured are clearly consistent with induced innovation because the rise in wage rates has been one of the most important features of recent U.S. economic history. So the burden of the proof is now on those who argue that biases are exogeneously determined.

On the other hand it has not been possible to find out how the different economic variables interact in determining the biases. Simple hypotheses that just one set of variables is all important seem to be doomed to failure. Therefore it will be necessary to build a better formal model of induced innovation capable of generating refutable empirical hypotheses. Such a model will have to be an investment model. Ahmad's graphical technique is unable to take into account the time dimension of the costs and benefits of efficiency gains. I also believe that attempts to generalize Kennedy's innovation possibility frontier will not lead anywhere for the following reasons: Factor augmenting technical change has a tremendous appeal because of its mathematical simplicity. Changes in the factor augmenting coefficients have the same effect on output than an equiproportional increase in the corresponding factor of production. All one has to know is the changes in the factor augmenting coefficients and the parameters of the production function to determine what will happen to output. But the problem with this approach is that, while we may be able to measure the changes in factor augmenting coefficients a posteriori, we have no way to know how they have been generated. Have they been due to investments in human capital, quality improvements in capital equipment or intermediate inputs, new production techniques or organizational improvements? There is no simple relationship between any one of these changes and particular augmentation coefficients. Human capital does not only affect the augmentation coefficient of labor but of all cooperating factors, but we do not know to what extent. The same holds for new production techniques etc.* In Kennedy's framework the benefit of efficiency gains is in the augmentation of the factors. But the cost is in some real investment activity. Any businessman or economist could not answer apriori the question of which economic activity or

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*A good example is a new seed variety. The efficiency gain is embodied in the new seeds. Unless you have the new seeds there is no access to the efficiency gain. But not only the augmentation coefficients of the seeds will be altered, but also the augmentation coefficients of all cooperating factors, and probably in various degrees.

investment leads to labor augmenting technical change. And unless we know, that, there is no way in which useful policy guidelines can come out of a factor augmenting induced innovation hypothesis.

The task of building an investment model will be further complicated by the presence of externalities in most activities which lead to efficiency gains.

With respect to development policy the conclusion of this paper strengthens the conclusions of Schultz (1964) because optimal technology is clearly shown to be location specific. Unless less developed countries are able to set up institutions which are capable of responding to local factor scarcities in developing and distributing modern production inputs they will not be able to achieve growth. Also factor prices should be such that producers are given the incentives to adopt these locally developed production methods. Some imitation of production methods of more advanced countries is of course possible and desirable. But the countries will be more successful if they copy methods from countries which have had similar factor endowments to their own ones rather than from the western countries which are rich in physical and human capital.

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APPENDIX

Indices of biases, data on factor shares and data on prices used to derive the series of biases

Table 1. U.S. Factor shares adjusted for factor price influence: Indices of biases in technical change.

	Numerical values, as percent of total expenditures				
Year	Land	Labor	Mach.	Fert.	Other
1912	21.0	38.3	10.9	1.9	28.0
1916	21.2	36.7	11.6	1.8	28.7
1920	19.6	39.3	9.3	2.1	29.7
1924	20.0	39.7	10.3	2.2	27.8
1928	18.1	41.4	10.4	2.7	27.4
1932	18.8	40.3	14.3	2.7	24.0
1936	18.9	32.5	16.3	3.0	29.3
1940	16.8	34.3	17.6	3.9	27.5
1944	16.5	38.4	16.1	4.8	24.2
1948	17.1	37.2	13.9	5.1	26.7
1952	16.5	29.8	19.7	5.7	28.3
1956	16.3	30.6	23.1	6.5	23.4
1960	17.1	27.2	23.4	6.1	26.1
1964	17.8	25.8	22.4	6.7	27.3
1968	19.1	25.3	23.1	7.2	25.3

	Standardized, as percent of their 1910-1912 value				
1912	100	100	100	100	100
1916	101.1	95.8	106.8	96.5	102.6
1920	93.5	102.6	85.6	113.4	106.1
1924	95.4	103.7	94.8	113.9	99.4
1928	86.3	108.1	95.8	144.0	97.9
1932	89.7	105.2	131.7	142.4	85.4
1936	90.1	84.9	150.1	159.8	104.7
1940	80.1	89.6	162.1	204.1	98.3
1944	78.7	100.3	148.3	253.2	86.5
1948	81.5	97.2	128.0	267.9	95.4
1952	78.7	77.9	181.4	298.0	101.1
1956	77.7	79.9	212.7	341.8	83.6
1960	81.5	71.0	215.5	323.3	93.3
1964	84.9	67.4	206.3	354.4	97.6
1968	91.1	66.1	212.7	379.9	90.4

Table 2. Development of actual shares, U.S.

Year	Land	Labor	Mach.	Fert.	Other
	Numerical values, as percent of total expenditures				
1912	21.0	38.3	10.9	1.9	28.0
1916	21.6	36.5	11.6	1.9	28.4
1920	17.3	40.5	10.1	2.0	30.1
1924	19.7	38.5	10.3	1.7	29.7
1928	15.9	40.9	10.2	1.9	31.1
1932	18.6	37.6	12.6	1.6	29.7
1936	14.9	34.7	14.5	2.2	33.7
1940	12.0	35.3	15.1	2.3	35.2
1944	8.5	39.5	14.0	2.3	35.6
1948	9.4	37.7	12.2	2.4	38.3
1952	9.8	29.7	17.5	3.0	40.0
1956	11.5	27.4	20.1	3.3	37.8
1960	15.6	21.3	19.8	2.9	40.4
1964	17.5	18.3	18.5	3.3	42.3
1968	20.4	15.3	19.1	3.6	41.1

Table 3. U.S. input price/output price ratio indexes

Year	Land	Labor	Mach.	Fert.	Other
	1910-12 = 100				
1912	100	100	100	100	100
1916	113.3	106.8	110.0	105.7	103.8
1920	79.0	104.3	81.3	85.7	105.0
1924	119.0	134.5	111.7	93.1	106.6
1928	104.8	154.1	128.5	90.0	118.9
1932	160.8	194.7	231.5	128.6	101.5
1936	69.4	113.4	189.2	99.6	110.9
1940	87.3	179.0	288.8	103.4	160.1
1944	65.2	217.2	244.2	63.0	211.7
1948	73.0	247.8	226.6	50.4	222.8
1952	91.3	274.3	301.1	53.6	214.6
1956	145.8	407.9	423.7	65.9	229.6
1960	254.1	502.7	550.3	63.0	241.5
1964	338.1	610.0	651.2	63.2	270.9
1968	481.0	766.9	735.8	58.2	280.4

[a] For construction of the series and the data sources, see Binswanger 1973.

Table 4. Japanese factor shares adjusted for factor price influence: Indices of biases in technical change

	Numerical values, percent of total expenditures				
Year	Land	Labor	Mach.	Fert.	Other
1893	31.6	38.0	10.9	2.9	16.6
1896	31.2	39.4	9.4	2.8	17.3
1900	28.6	43.5	9.2	3.2	15.7
1904	29.6	43.0	9.1	3.8	14.5
1908	30.1	42.3	8.2	4.7	14.7
1912	30.8	42.9	7.4	5.8	13.0
1916	29.3	42.4	8.3	7.0	13.0
1920	30.6	41.1	7.8	8.2	12.3
1924	27.7	48.9	6.2	7.0	10.2
1928	26.4	51.4	6.1	8.4	7.7
1932	26.4	50.4	6.4	8.3	8.4
1936	29.2	43.1	7.1	8.8	11.8
1940	28.7	41.5	7.2	9.3	13.3
1954	23.1	40.3	7.8	9.3	19.5
1958	26.5	37.4	5.6	8.1	22.4
1962	26.2	38.5	4.9	7.5	23.0
	Standardized, as a percent of 1910-1912 value				
1893	102.6	88.6	147.3	50.0	127.7
1896	101.3	91.8	127.0	48.3	133.1
1900	92.9	101.4	124.3	55.2	121.0
1904	99.1	100.2	123.0	65.5	111.5
1908	97.7	98.6	110.8	81.0	113.1
1912	100.0	100.0	100.0	100.0	100.0
1916	95.1	98.8	112.1	120.7	100.0
1920	99.4	95.8	105.4	141.4	94.6
1924	89.9	114.0	83.8	120.7	78.4
1928	85.7	120.0	82.4	144.3	59.2
1932	85.7	117.5	86.5	143.1	64.6
1936	94.8	100.5	95.1	151.7	90.8
1940	93.2	96.7	97.2	160.3	102.3
1954	75.0	93.9	105.4	160.3	150.0
1958	86.0	87.1	75.7	139.7	172.3
1962	84.4	89.7	66.2	129.3	176.9

Table 5. Development of actual shares, Japan

	Numerical values, percent of total expenditures				
Year	Land	Labor	Mach.	Fert.	Other
1893	31.6	38.0	10.9	2.9	16.6
1896	30.1	40.0	9.9	2.7	17.2
1900	25.8	44.2	9.7	2.6	17.7
1904	27.5	43.0	9.5	3.1	16.9
1908	27.6	42.7	9.1	4.1	16.6
1912	28.4	42.6	8.5	5.0	15.5
1916	25.9	42.7	9.2	6.1	16.1
1920	28.0	40.6	8.7	7.1	15.5
1924	22.7	48.5	7.8	5.3	15.7
1928	21.4	50.1	7.5	6.4	14.6
1932	20.8	49.8	8.0	6.3	15.2
1936	25.2	43.2	8.8	7.4	15.3
1940	24.0	42.2	9.1	8.2	16.5
1954	11.6	44.7	10.8	7.9	22.0
1958	20.1	41.5	9.3	7.0	22.1
1962	20.1	40.4	9.2	6.0	24.4

[a]For construction of the series and the data sources, see Binswanger 1973.

Table 6. Japanese input price/output price ratio indexes

Year	Land	Labor	Mach.	Fert.	Other
		1910-12 = 100			
1893	120.6	80.5	143.6	190.8	113.0
1896	112.9	85.4	129.4	165.2	115.9
1900	94.4	94.9	124.0	148.7	112.9
1904	99.0	93.7	120.5	127.9	104.8
1908	97.6	94.6	110.2	118.2	106.1
1912	100.0	100.0	100.0	100.0	100.0
1916	97.7	111.0	113.7	116.1	113.4
1920	99.2	105.0	102.8	93.8	99.2
1924	92.7	141.1	96.3	74.6	107.7
1928	93.6	153.7	93.6	71.9	104.2
1932	100.3	172.5	105.1	73.7	118.7
1936	96.4	122.4	88.8	62.6	101.1
1940	87.4	117.1	84.4	79.1	105.6
1954	44.0	113.9	82.5	38.2	122.7
1958	97.2	138.1	73.6	32.9	126.0
1962	109.1	170.5	60.9	27.6	116.3

[a] For construction of the series and the data sources see Binswanger 1973.