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A REVIEW OF THE THEORY OF TECHNOLOGICAL CHANGE IN AGRICULTURE: BIASES AND SUBSTITUTABILITY

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Introduction

Farm resource migration basically depends upon the differential structure of opporuntity cost between farm and non-farm sectors. However, the degree to which resources will migrate out of the farm sector against a differential of opportunity cost and the amount of farm production that will be lost in the migration depend upon the structure of factor substitutability and technological change biases in agriculture. And it is by now a well-established notion in economics that inter-sectoral migration of resources plays a role in economic growth equally as important as technological progress within individual industries.

As the significance of factor substitutability and biases came to be realized, the factors which guide the evolution of the changes came to be of greater concern in economics. Initially, the theory of induced innovation emerged as an epoch-making theme. The basic idea of the theory is that the direction of technological change is determined endogeneously in the economic system and influenced substantially by economic variables. If endogeneity of technological change is the case, any policy with respect to farm technology should be made to match given economic conditions and we have to draw particular attention to the fact that current economic variables and economic policies have a significant meaning for the complexion of future technology.

The objective of this paper is to present a theoretical mechanism of the endogeneity of technological change. However, we begin by defining more precisely what we mean by technology and the production function. Particular importance is ascribed to the definitions since they have often implied a variety of concepts. This does not mean that we will be engaged in metaphysical reasoning about the substance of technology. Rather, the ultimate purpose of the discussion is to indicate the conceptual framework within which the economic reasoning to be followed can be

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executed without any conceptual confusion.

Next, a theoretical mechanism of technological change is formulated in terms of the indicated conceptual framework. The induced bias hypothesis by Hicks is taken as the basic idea. After a brief critical review of Hicks' idea and its proponents' revision, the induced bias hypothesis is reformulated drawing on three common places—learning-by-doing, localized technical progress, and putty-(semi) clay structure. Futhermore, our reformulation is extended to take into account invention lag, the effect of output price, endogeneity of factor prices, multi-factor relations, and changes in factor-to-factor relationships.

I. Conceptual Basis

We start with distinguishing the concept of technology from that of technique.[1] A technique is a specific method of production, and thus a change in technique implies an alternation of the specification of inputs and the mode of operation. On the other hand, technology implies the state of productive arts which are currently utilized in an industry,[2] and technological change is an advance in the state of productive arts.

Empirical observation tells us that firms utilize different shapes of inputs in different modes of operation, and that a variety of techniques coexist side by side.[3] We can then regard the assortment of current techniques as representing the technological level of the industry in the sense that it defines the scope of available processes when choosing a new technique and determines the total output of the industry together with its frequency distribution.[4]

Figure 1 depicts the conceptual relation diagramatically. A technique is abstracted by an ex-post poduction function which shows the scope of ex-post factor substitution. It is easily conceivable that substitution is very limited along the ex-post function. If we assume fixed input coefficients in the ex-post relation, a technique is represented by a L-shaped isoquant as shown in Figure 1. And the group of L-shaped isoquants implies the assortment of current techniques. We then may take the liberty of approximating the state of the productive arts in the industry by two al-

1 This conceptual discrimination relies on Mansfield (1968, pp. 10–12).

2 Some authors extended the concept of technology to include the potential techniques which can be developed with current scientific knowledge. However, such extension makes the concept somewhat ambiguous and too ideal to have any empirical sense.

3 Empirical examples are illustrated in Salter (1960, pp. 48–50) and Mansfield (1968, pp. 24–27). And the reasons why such an assortment of techniques exists is masterly depicted by Sato (1975, pp. 103–114), Johansen (1972, pp. 29–34) and Salter (1960, pp. 52–64 and pp. 66–73).

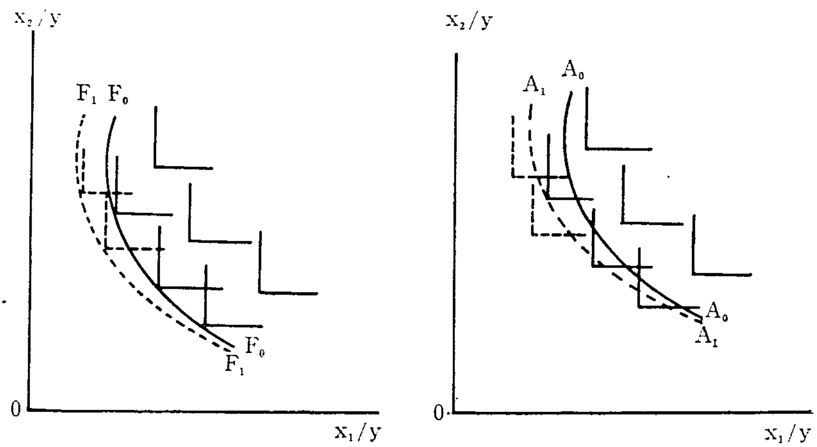
4 Mathematical development is presented in Johansen (1972, pp. 34–39) and Sato (1975, pp. 17–20).

ternative concepts

The first is the frontier concept represented by the envelope curve F_0F_0 of the most efficient techniques, in Farrell's sense.[5] The other is the average concept depicted by the curve A_0A_0 which passes through the center of gravity of each ray of factor ratio. In other words, frontier technology describes the maximum output while average technology indicates the expected output from a given bundle of inputs in the industry at a particular moment in time. These curves are designated as the efficient ex-ante production function and the average ex-ante production function respectively.[6,7]

By definition, technological change implies a change in the assortment of techniques currently utilized; the change may come from a flow of new tecniques (innovation) or from a change in the frequency of existing techniques (diffusion) as is shown in Figure 1. If new techniques, which are represented by the broken ex-post isoquants in Figure 1, are adopted by firms in the industry, the frontier curve will shift to F_1F_1 and the average to A_1A_1. It is quite conceivable that the same shift of the average curve may result when some firms change to new techniques from among existing techniques. We thus realize that individual technical choices give rise to technological change, which is then reflected in a shift of the ex-ante production function. If the ex-ante production function

FIGURE 1 THE ASSORTMENT OF TECHNIQUES, TECHNOLOGY, AND TECHNOLOGICAL CHANGE



(a) Frontier Concept (b) Average Concept

[5] See Farrell (1957).

[6] These may correspond to Aigner and Chu's efficient industrial production function and average industrial production function (Aigner and Chu, 1968).

[7] The estimation method of the frontier function has not been developed yet in spite of many trials. See Farrell (1957), Timmer (1970), Aigner *et. al.* (1976), and others.

were observable over time, a comparison of the production function between two periods would provide us with a measure of the effect of technological change between the two periods. The preceding reasoning leads us to the conclusion that technological change, if present, can be measured only if we have the time-series of micro cross-sectional data on input and output.[8]

II. Three Characteristics of Technological Change

Technological change is characterized by three features which are of economic interest: the realized rate of advance in production efficiency, biases toward uneven factor-saving, and changes in factor-to-factor relationships. The first characteristic is the rate of movement of the production function. The rate of movement indicates the degree of improvement in production efficiency in the sense that more output can be produced with the same bundle of inputs.

The second feature of technological change relates to the direction of the shift of the isoquants. The significance of the direction is reflected in a change in the ratio of the marginal productivities at a given factor combination. If we concentrate on two factors, for example, labor and land, we can classify technological change as land-using, neutral and land-saving according to whether the initial effects are to increase, leave constant, or diminish the ratio of the marginal productivity of land to that of labor.[9]

The third characteristic of technological change is a change in the curvature of the isoquants. The curvature of isoquants indicates a change in factor ratios against a change in factor prices. Thus a change in factor-to-factor relationships may accelerate or decelerate the change in factor demand (price) against a change in factor prices (quantities).

III. Simple Version of the Direction of Technological Change

The previous section was devoted to presenting the concept and characteristics of technological change. Our next subject is to investigate the factors which lead technological change, if at all present, to its resulting course. Our basic hypothesis is that the characteristics of technological change are determined within the economic system and influenced substantially by economic variables.

8 Nelson (1973) presents this point in the conventional neoclassical framework. And Johansen (1972, pp. 185–223) and Sato (1975, pp. 117–127) discuss the relation between the data and the sense of the production function estimated from it.

9 See Hicks (1963, p. 124).

Review

Hicks was the first proponent of the endogeneity of technological change. He argues that a change in factor price induces biased inventions which save the progressively more expensive factor. This idea has been explored and improved further with respect to its theoretical exposition by Fellner (1961), Kennedy (1964), and Ahmad (1966). Further, the idea has been empirically supported by Hayami and Ruttan (1970), Fellner (1971), Binswanger (1974), and Le (1978). In spite of such sophisticated exposition and empirical conviction, the idea is not yet rid of some ambiguity and poor economic causality.

The most ambiguous point, in the context of our conceptual framework, is whether the idea is concerned with the ex-post technical relation or with the ex-ante technological relation. If the idea is concerned with the former relation, it is open to objection. An increase in labor price, for example, relative to other factor prices does not necessarily draw entrepreneurs' attention exclusively to labor-saving techniques, since they are interested in reducing the cost in total no matter which specific cost is reduced. In addition, new techniques are often invented and supplied by other industries. There is no obvious reason why the inventors and suppliers would concentrate their attention on the development of specific factor-saving techniques.

To furnish Hicks' idea with a microeconomic mechanism, Ahmad (1966) and Kennedy (1964) postulated the existence of a confined range of new techniques which entrepreneurs expect to develop with the use of the available amount of knowledge. Then cost-minimizing behavior could come into play in choosing a particular technique out of the various processes which belong to the range of feasible new techniques. However, we are safe in saying that such postualtion is too ideal to be conceived with any empirical consideration. Furthermore, little is said as to what determines the characteristics of the range of new techniques. If it is a technical or laboratory matter, there remains too little to be attributed to economic variables.

On the contrary, if the idea is concerned with the ex-ante technological relation, it is not clear how individual behavior regarding technological choice and innovation results in biased change in the state of productive arts utilized in the industry.

Reformulation

Here are we engaged in reformulating the factor-price-inducement mechanism within our conceptual framework.[10] Our reformulation depends on three emprical commonplaces together with the long-run cost

[10] This reformulation follows in principle David's idea of technical choice (David, 1975).

minimization postulation: learning-by-doing by Arrow (1962), localized technical progress by Atkinson and Stiglitz (1969) and the putty-(semi) clay structure by Johansen (1959) and Salter (1960).

The first commonplace is that learning-from-experience results in an endogeneous generation of efficiency-increasing designs and new modes of operation.[11] The second, localized technical progress, implies that each technical innovation is usually very specific: the effect of an innovation is localized to a confined spectrum of technique.[12] The third implies that the ex-post range of factor substitution is much smaller than the ex-ante.[13] Thus entrepreneurs, when choosing a technique, have to pay attention to future relative factor prices as well as to current prices[14] because factor combination in the future is partly determined in advance by the current choice of technique.

Figure 2 shows on the simple plane of two inputs how technological change bias is realized in an industry. For convenience sake, fixed input coefficients are assumed in the ex-post relation and the group of L-shaped isoquants stands for a variety of techniques currently utilized in an industry. By way of illustration, only a few techniques are shown explicitly: The α-technique is the best-practice technique at current relative factor prices, represented by P_0P_0, and the β-technique stands for the most frequent technique utilized.

If it is supposed in the figure that the relative factor prices change as shown by the change in the price-line from P_0P_0 to P_1P_1, the δ-technique becomes the new best-practice technique and, thus, entrepreneurs tend to adopt the new best-practice when designing or reforming their production methods. As the δ-technique is diffused into the industry, learning-by-doing advances at a progressive rate to improve the production methods adjoining the δ-technique. At the same time, the demand naturally increases for the specified inputs embodying the δ- and adjoinning techniques, and thus learning-by-doing is also stimulated on the supplier side so as to produce better inputs embodying δ- and adjoinning techniques.

So far, we have disregarded the effect of the entrepreneurs' expec-

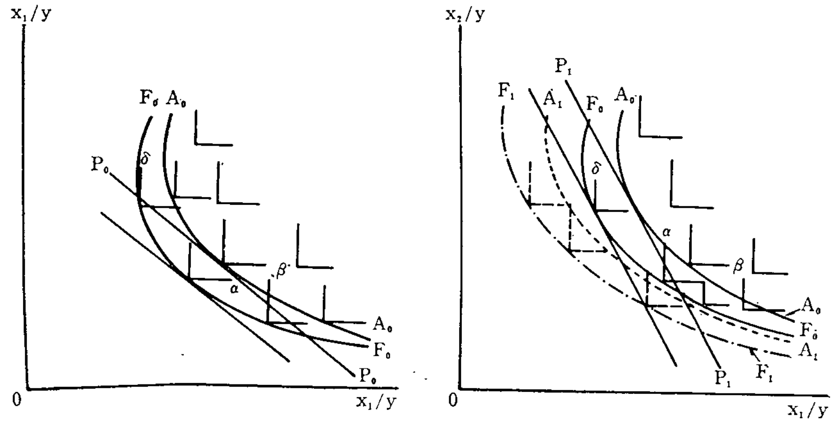
[11] The improving processes of the power tiller, transplanting machine, and harvesting machine in Japan provide good illustrations of how both farmers and suppliers have taken advantage of learning from experience for making better machines and for performing better operations (Nihon 1971, vol. I, pp. 1029–1041, pp. 1056–1062, and pp. 1084–1094). For an econometric study see David (1975, Chapters 2 and 3).

[12] For example the development of the wheel-type power tiller from the caterpillar-type makes no sense for cattle plowing and the invention of the mat-type rice nursery makes no sense for hand transplanting.

[13] For a sophisticated empirical test see Fuss (1977).

[14] Salter (1960, pp. 48–65) and Sato (1975, pp. 104–110) show this point with an analytical development. Egaitsu (1978) tried an empirical test in the context of postwar Japanese rice farming in Y. Kato and N. Egaitsu, ed. (1978).

FIGURE 2 A New Formulation of Biased Technological Change



(a) Prior to a Change in Factor Price (b) After a Change in Factor Price

tations for the future. Our reformulation is completed by taking into account the entrepreneurs' expectations for future factor prices. Let us assume the wage rate to increase by a rate w while the purchase price of one unit of capital equipment is constant at R. The discounted value of wage payment for one unit of labor during the lifetime (T) of the plant is thus given as $W = \sum_{t}^{T} W_0(1 + w/1 + i)^t$, where W_0 stands for the wage rate at the time of technical choice and i for the interest rate. The wage-capital price ratio will then be given as W/R, which is greater than the current price ratio W_0/R_0 if $w > 0$. The wage rate usually increases at a positive rate in a growing economy and, therefore, the wage-capital price ratio relevant for investment decisions is higher in the case of putty-(semi) clay than in the case of putty-putty in a growing economy. It follows from this reasoning that entrepreneurs tend to choose a technique more labor-saving than the current best-practice, and learning-by-doing spreads over the technique spectrum more labor-saving than current best-practice. If the relative price of labor continues to rise, the same process will be repeated. As the result, the frontier curve F_0F_0 shifts to F_1F_1 and the average A_0A_0 to A_1A_1.

IV. A More Complex Version

The discussion of the preceding section has been insulated from the complexities of reality in order to abstract the basic mechanism of biased technological change in a simplified version. The subject of this section is to take into account some complexities in order to draw out testable hypotheses with respect to technological change in the real world.

First, the simple version of the preceding section did not mentioned anything about the time elapsed between a change in relative factor prices and an innovation induced by it. The time comprises four distinguishable processes inducement—research and development (R & D)—invention—innovation. Economists have found all these processes are lagged and time consuming activities. Invention is an activity characterized by such a great uncertainty that the initiation of an R & D project is often delayed. R&D itself is very expensive and time-consuming. It often takes more than ten years to reach an intended invention.[15] Furthermore, an invention is not followed by an innovation immediately. An innovation often lags behind the invention by more than five years.[16] This consideration lets us anticipate that technological change biases are often realized a few years after relevant inducement (a change in relative prices) was in effect.

Second, the simplified version of technological change has assumed all factor prices to be exogeneous. This is not always relevant in an industrial analysis. If a factor price is very responsive to technological change, that is, if a factor price is substantially endogeneous, the factor price and technological change bias would be in a parallel motion. In most growing economies, however, the non-agricultural labor market has dominated the farm labor market and farm wages. Also, farm machinery, fertilizer, and pesticide have been supplied by monopolisti or oligopolistic non-agricultural industries. Hence, the price of labor, machinery, and other industrial supplies can be regarded as largely exogeneous to agriculture. On the other hand, the price of the farm land input (rent) must have been largely endogeneous since both the supply of and demand for farm land inputs are primarily associated with farm production.

Third, the simplified version of the preceding section has postulated output price to be trivial in determining the direction of biases. However, output price may play an important role in determining biases, particularly when adjustment to a change in factor prices is substantially retarded due to a lag in invention or other constraints. Figure 3 illustrates the way output price can affect the direction of bias. Let us assume that only two factors, x_1 and x_2, are required for producing output y. F_0F_0 denotes the ex-ante unit-isoquant curve and P_0P_0 the zero-profit-line at a given output price. Then the firms in the segment between the unit-isoquant and the zero-profit-line obtain a positive profit. Now suppose that the relative price of the input x_1 has risen and output price has increased to shift the zero-profit-line to P_1P_1. In addition, suppose that, despite the change in factor prices, the invention of an x_2-using technique lags behind. In such a situation, the x_1-using technique would be utilized

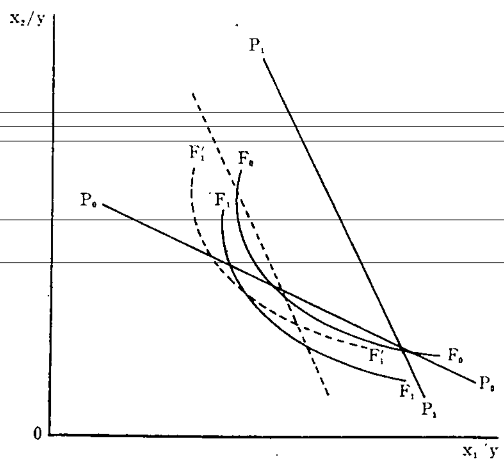
[15] See Mansfield (1968, pp. 43–52).

[16] See Mansfield (1968, pp. 99–106).

persistently making a positive profit, while learning-by-doing advanc(along the spectrum of x_1-using techniques. Thus, technological chang results in x_2-saving bias despite the rise of x_1-price.

Fourth, the simplified version was developed in the world of two facto inputs. The scene of induced biases becomes much more complicated i the multi-factor case. The complication comes first from the fact the techniques are not completely malleable and the terms "saving" an "using" are defined in a relative sense.[17] By way of illustration, let us sup pose that the relative price of labor has become significantly expensiv and that the land price has risen moderately. Suppose also that the rela tive prices of the other factors have declined. Then one may expect tha technological change would be factor-saving with respect to land and labc and factor-using with respect to the other factor. However, if labor-savin techniques are strongly linked with land-using characteristics, a lanc using bias might develop in spite of the moderate rise of land price. Insteac for the other factors, technological change would be measured as "neutral or even as "saving" because the terms "saving" and "using" are define in relative terms. Therefore, we have to realize that all factors are nc necessarily consistent with what the induced bias hypothesis would expec Rather, we have to try to find which is the dominant factor in the tech nological change of the period. Further complications may derive als from the indivisibilities of the equipment embodying the labor-savin techniques and the inelastic supply of land.[18] If the labor-saving techniqu is embodied in large and indivisible machinery, the adoption of such

FIGURE 3 THE EFFECT OF OUTPUT PRICE ON BIASES OF TECHNOLOGICAL CHANGE



[17] Refer to Lee (1980 b).

[18] For an empirical example see David (1975, Chapter 4).

echnique is apt to be hindered in small size farms due to a too low utiliza-ion rate. Farm land size is thus an important factor affecting the rate and irection of technological change biases.

Finally, the simplified version in the preceding section says nothing bout a change in factor-to-factor relationships. Hicks (1963, pp. 127–28) put forward a hypothesis with respect to this subject as follows:

> "In the first case, where inventions of all kinds are almost wholly absent, ... It is conceivable that in an early stage these may be sufficient to keep the elasticity of substitution greater than unity. . . . . But as capital continues to grow, it is certain that the more advantageous application will be used up: the elasticity of substitution must fall, ... It is impossible to say how soon this stage will set in, but it must set in sooner or later. . . . .
>
> In the other case, where invention is very active, the elasticity of substitution will be high and will remain high."

Also, Sato and Hoffman (1968) suggest that factor substitutability ay increase over time saying:[19]

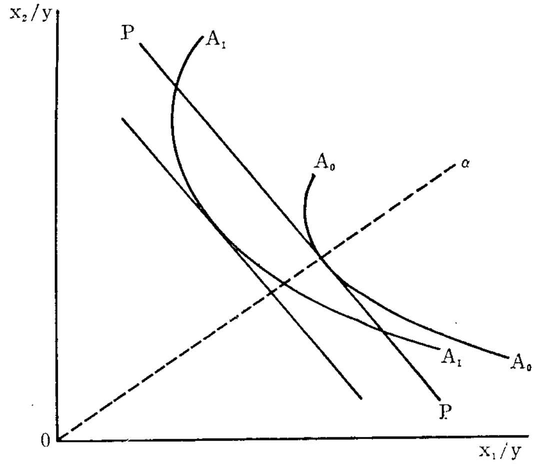
> "The basic idea here is that as time passes, technology advances and results in the enhancement of opportunities for factor substitution."

Figure 4 shows how technological change maintains the elasticity of ıbstitution high. This is nothing but a diagrammatic representation of icks' idea. Given the state of technology represented by the ex-ante nit-isoquant A_0A_0, factor substitutability substantially declines as the ıpital-labor ratio comes higher than α. Now, supposing that the isoquant ıifts to A_1A_1 maintaining the global shape of the isoquant, factor sub-tutability at a high capital-labor ratio increases and factor demand would ecome sensitive to a change in relative factor prices. Consequently, chnological change may sometimes be regarded as clearing a bar to ırther factor substitution and reviving the price-response of factor emand.[20]

[19] For empirical examples, see also Takayama (1974) and Sato (1970).

[20] Yotopoulos and Nugent (1976, p. 151) seem to set forth adverse opinions: "the elasticity of substitution (between labor and capital) is considerably larger in agriculture than in industry," "the adoption of modern technology of the Green Revolution variety has lowered the elasticity of substitution in agriculture," "(the elasticity of substitution in industry) secularly declines as modern technology replaces traditional technology."

FIGURE 4 Change in Factor-to-Factor Relationships



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