THE DIRECTION OF TECHNOLOGICAL CHANGE IN JAPANESE AGRICULTURE, 1874–1971

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INTRODUCTION

THE agricultural sector in developing countries plays an important role in the process of economic development. First, this sector is the only source of income to the majority of the people in these countries—the poor. Thus, economic progress in this sector can help reduce poverty. Second, because the agricultural sector is the supplier of food for the industrial-urban sector, its development is crucial in the context of the economy as a whole [9, p. 25].

The purpose of this paper is to investigate the development process of the agricultural sector in Japan. Specifically, the goal is to determine and explain the pattern of technological change in this sector during the period of 1874–1971. The commonly accepted view explains the successful growth of Japanese agriculture[1] as a result of a land-saving, labor-using pattern of technological change.[2] Unlike the supporters of this view, the present study provides evidence in support of the opposite view that Japanese agriculture has followed a labor-saving, land-using pattern of technological change.[3] This conclusion emerges from an application of the weak-disposability-of-inputs (WDI) production function, presented by Färe and Jansson [3], to Japanese agricultural data.[4] In addition, this study also provides evidence regarding the general applicability of the WDI function to the agricultural production process.

The next section briefly reviews the relevant literature related to the issue of technical change, particularly regarding Japanese agriculture. It then specifies the hypothesis regarding the pattern of technological change in this sector. Section II reviews literature regarding the empirical application of the WDI function. Section III specifies the empirical model that will be used to test the hypothesis regarding the pattern of technological change. The section then discusses the results of the statistical tests and their implications. It will be followed by summary and conclusion.

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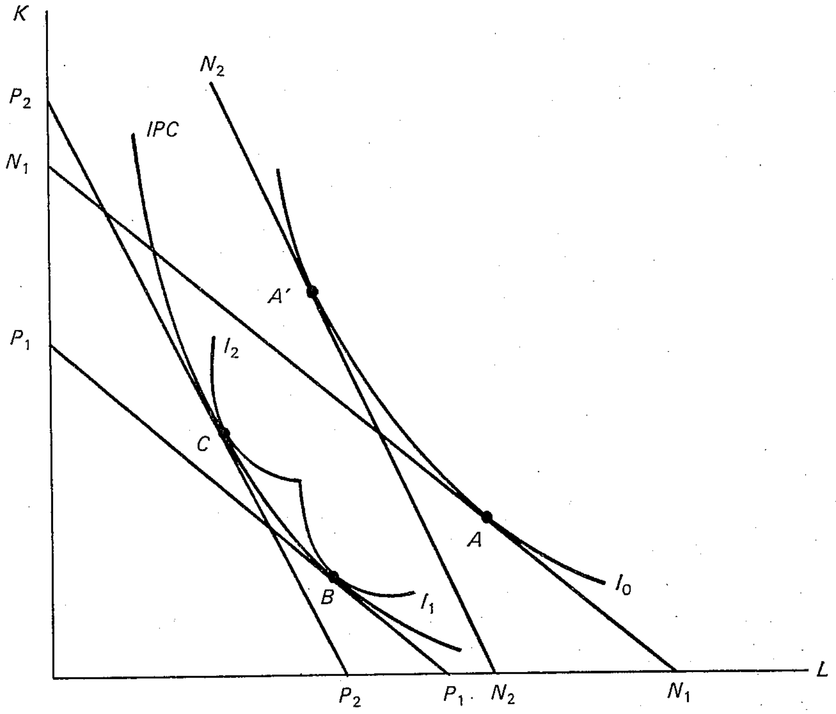
[1] For more details regarding this growth, see [6, p. 43] [15] [18].

[2] This is the chemical-biological technological change discussed by [6, p. 12] [7, p. 1135] [8, p. 238] [9, p. 43] [12, p. 209] [13, p. 58] [18, p. 45].

[3] See, for example, [11, p. 692] [19, p. 256].

[4] The data series for this study were taken from Table J-2 (pp. 250–53) and Table J-4 (pp. 258–61) in [6, Appendix J].

Fig. 1. The Innovation Possibility Curve



I. TECHNOLOGICAL CHANGE AND JAPANESE AGRICULTURE

In order to understand the conventional view regarding the pattern of technological change in Japanese agriculture, one must first examine the induced innovation model developed by Ahmad [1]. A key concept in his approach is the innovation possibility curve (IPC), defined by the existing set of potential production processes the entrepreneur is expected to develop with the use of the available amount of innovating skill. The IPC is the envelope of all the alternative isoquants that represent the potential production processes the entrepreneur might develop. This is represented by the curve IPC in Figure 1.

Suppose, now, a firm is operating at point A on isoquant I_0 and perceives the IPC. Given the input price ratio N_1N_1, the firm will seek to develop the technology given by I_1, which will result in a move from A to B. If the price of factor K falls relative to the price of factor L, i.e., if budget line N_2N_2 prevails, the firm will develop the technology represented by isoquant I_2, saving on the more expensive factor L. This move from A to C is the result of innovation induced by a change in the factor price ratio.

Hayami and Ruttan [5] [7] have modified Ahmad's model in which research was conducted by the private firm, to represent the technical change in the agricultural sector in which research is conducted by public institutions. According to this view, the farmer is induced, by a shift in relative prices, to press public research institutions in order that they develop technology to save the increasingly scarce (more expensive) factor of production. These institutions are assumed to respond to the farmer's needs. This last assumption is realistic, especially if one considers the Japanese research institutions [5, pp. 111–64] [7] [8]. Following this modification, a series of empirical studies of the induced innovation hypothesis and the pattern of technological change were conducted. Those studies concerned with Japanese agriculture concluded that the agricultural sector had developed a chemical-biological technological bias resulting in a labor-using, land-saving pattern of change during the period of 1880–1930's.[5] Their explanation of this result was based on the common conviction that Japanese agriculture contained surplus labor and that land was the relatively scarce factor. This, as the induced innovation theory predicted, led to the labor-using, land-saving technical change [11, pp. 691–92].

However, this conclusion was disputed by Yeung and Roe [19]. Using a factor augmenting CES production function approach they found that the pattern of technological change in Japanese agriculture was of the labor-saving, land-using type. Surprisingly, in another study by Hayami and Ruttan, one finds the following statement:

> ... the introduction of high yielding varieties enhances the substitution of fertilizer and labor for land. On the other hand, commercial fertilizers have significant labor-saving effects as they substitute for self-supplied fertilizers. In Japan, the production of such self-supplied fertilizers as manure, green manure, compost, and night soil has traditionally occupied a significant portion of farmers' work hours. With the increased supply of commercial fertilizers, farmers could divert their labor to the improvement in cultural practices in such forms as better seed bed preparation and weed control. [7, p. 1133]

This would seem to support the view that technical innovation in Japanese agriculture prior to World War II was labor-saving in nature.

The above view finds further support in the work of Nghiep [11, pp. 691–92]. He used a translog cost function from which an expression for changes in factor shares can be derived. In simple terms, the change in a particular factor share can be divided into that resulting from ordinary factor substitution due to changing factor prices and that resulting from technical innovation. If the appropriate elasticity of substitution can be calculated, then time series data on factor prices can be used to calculate the change over time in factor shares due to substitution. Subtracting this from the total change in factor shares leaves a residual which Nghiep attributes to technical change.

Using the factor-share technique, Nghiep finds that technical innovation in Japanese agriculture, from 1903 to 1938, has been labor-saving in nature. However, this approach requires the assumption that the elasticity of substitution between pairs of inputs does not change over time. This is a serious restriction that calls into question the validity of the results.

If the empirical results discussed in the previous three paragraphs are correct,

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[5] See, for example, [6, p. 12] [7, p. 1125] [8, p. 238] [9, p. 43] [12, p. 209].

one is immediately faced with a most perplexing question. Why did labor-saving technological change occur in the Japanese agricultural sector which was, at least during the prewar period, under severe population pressures? Several factors might account for this. Most importantly, a rapid expansion of labor-intensive industries would significantly increase the demand for labor. In fact, Ohkawa [13, pp. 35–38] has shown that throughout the period under investigation the real growth rate of industry was much faster than the real growth rate of agriculture. In addition, Ranis [14, pp. 397–402] has argued that Japanese industrial growth was very labor-intensive in nature. Thus, the rapid, labor-intensive growth of the industrial sector could very well have generated labor shortages in the agricultural sector.

Nghiep provided support to the hypothesis presented above. More specifically, he pointed out that "the sustained high growth rate of labor productivity of the nonagricultural sector induced a continuous stream of off-farm migratory labor which was not totally offset by the growth in the labor force due to the natural increase of rural population" [11, p. 687]. The result was a rise of agricultural wages relative to the prices of other agricultural inputs [11, p. 689]. Under these circumstances, labor-saving technological change in the agricultural sector, such as the substitution of commercial fertilizers for self-supplied fertilizers, is economically sound.

Unfortunately, the available data on the decline in the number of agricultural laborers may actually understate the impact of industrialization on the available supply of labor to agriculture. This is due to the fact that many of the families in rural areas were only part-time farmers [16, p. 327].[6] They allocated part of their time to nonagricultural pursuits, and this may have rapidly increased in the prewar time period. Unfortunately, man-hour data, or data on real labor input is not available for this time period.

The above discussion leads us to the major purposes of this study. The first is to provide additional support to the hypothesis that technological change in Japanese agriculture has been a labor-saving process. The second purpose is to provide an alternative method, the WDI production function, to help determine whether Japanese agriculture has followed a labor-saving pattern, or land-saving pattern of technological change. Unlike the method used by Nghiep, the utilization of the WDI production function, in examining the direction of technical change, does not require that the elasticity of substitution between inputs remain constant.[7] It may, therefore, contribute to the resolution of the conflicting views regarding the pattern of technical change.

II. THE WDI PRODUCTION FUNCTION

The previously-discussed studies all have assumed that the potential technologies

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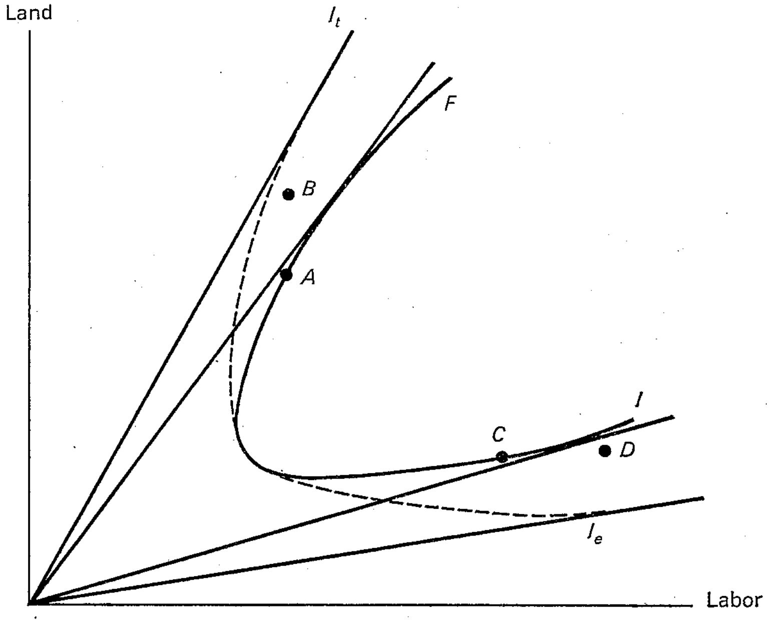
[6] See also [10] for a discussion of a part-time farming in postwar Japan.

[7] Although the WDI approach to determine the direction of technical innovation does not require that elasticities are unchanged, it is faced with the limitation that generally only two inputs can be used. This is said because for more than two inputs the complexity of calculations reduces the attractiveness of the approach.

Fig. 2. The Widening-of-Production-Factor-Combinations Technological Progress



are well known and can be represented by what Ahmad [1] called the IPC. Furthermore, these studies have attempted to distinguish between two effects of a change in the input price ratio. One effect is the input substitution while the other is technological change. The former is the movement along the isoquant, say a movement from A to A', in Figure 1, while the latter is the shift of the isoquant to a new IPC, say a movement from A' to C.

However, it is possible that not all input combinations (i.e., potential technology) are well known [3]. Accepting this view the distinction between the two effects fades, and one may think of technological change as a localized slow process of minor improvements [2, pp. 5–6]. Viewed this way, technological change increases the substitutability of one input for another. This widening-of-production-factor-combinations technological progress is illustrated in Figure 2. Suppose IF is the isoquant that represents the initial state of Japanese agricultural production technology. A technological change of the labor-saving type will extend the isoquant to II_t. Alternatively, a land-saving change will be represented by extension of the isoquant to FI_e. This figure also illustrates the concept of weak disposability of inputs. A production function is weakly disposable if when one input increases, ceteris paribus, output can decrease. An increase in land input from A to B results in fall in output. Similarly, if labor is increased from C to D there would be a fall in output. Thus, the production function illustrated in Figure 2 is weakly disposable in terms of both labor and land. It should be pointed out that this reduction of output when an input rises indicates that the marginal product of the input is negative.

The WDI function was developed by Färe and Jansson [3] to model the production process illustrated in Figure 2. This type of production function can be written as:

$$Q=A[(1-\sigma)(x_1-b_2x_2e^{\beta_2t})^{-l}+\sigma(x_2-b_1x_1e^{\beta_1t})^{-l}]^{-1/l}\,, \qquad (1a)$$

if $(x_1-b_2x_2e^{\beta_2t})\geq 0$ and $(x_2-b_1x_1e^{\beta_1t})\geq 0$.

$$Q=0\,, \qquad (1b)$$

if otherwise.

In equation (1), Q is output, and x_1 and x_2 are two inputs. If β_1 and β_2 are both negative, then widening-of-production-factor-combinations technological change is occurring. Other restrictions are as follows: $A>0$, $\sigma\in(0, 1)$, $b_1\in(0, \infty)$, $b_2\in(0, \infty)$, and $l\in(-1, \infty)$.

Under additional restrictions, this function is easily transformed into a constant-elasticity-of-substitution (CES), or a Cobb-Douglas (CD) production function. Unlike the WDI production function, these are strong-disposability-of-inputs (SDI) functions. That is, an SDI production function is one in which a rise in one input, ceteris paribus, cannot reduce output. An additional problem with this class of functions (i.e., CES and CD) is, as Varian [17, pp. 126–27] pointed out, that the pair-wise elasticities of input substitution must be identical. Alternatively, the WDI production function overcomes these problems.

One variant of the WDI function, equation (1), is of interest for the purpose of this study. By assuming $b_1=0$, and $l\to 0$, it follows that:

$$Q=A'x_2^{\sigma}(x_1-b_2x_2e^{\beta_2t})^{(1-\sigma)}\,, \qquad (2a)$$

if $(x_1-b_2x_2e^{\beta_2t})>0$.

$$Q=0\,, \qquad (2b)$$

if otherwise.

The assumption of constant returns to scale means $0<\sigma<1$. Following Färe and Jansson [3], x_1 is the essential factor of production. Alternatively, it can be said that equation (2) represents a production function that incorporates the x_1-saving, x_2-using pattern of technical change [4].

Färe and Jansson [3] estimated a production function like equation (1) using German data and found a clear labor-saving, capital-using pattern during the period of 1850–1913. Färe, Grabowski, and Yoon [2] examined data for Korean agriculture and used a variant of equation (2). They concluded that Korean agriculture followed a pattern of fertilizer-using, land-saving technological change during the period of 1918–71. Grabowski, Sivan, and Tracy [4] used a variant of equation (1) to determine the pattern of technological change in Taiwan. This function is of the following form:

$$Q=A[x_1-b_2x_2e^{\gamma_1t_1(1-D)+\gamma_2t_2D}]^{\sigma}[x_2-b_1x_1e^{\beta_1t_1(1-D)+\beta_2t_2D}]^{(1-\sigma)}\,, \qquad (3a)$$

if $[x_1-b_2x_2e^{\gamma_1t_1(1-D)+\gamma_2t_2D}]>0$ and $[x_2-b_1x_1e^{\beta_1t_1(1-D)+\beta_2t_2D}]>0$.

$$Q=0\,, \qquad (3b)$$

if otherwise.

In equation (3):

D is 0 for the period 1911–44 and 1 for the period 1945–72;
t_1 is 1 for 1911 through 34 for 1944 and 0 for the period 1945–72;
t_2 is 1 for 1945 through 28 for 1972 and 0 for the period 1911–44;
x_1 is labor measured in man equivalent days/year;
x_2 is land measured in cultivated hectares.

This function divides the time period into colonial and post-colonial subperiods and attempts to determine the bias of technical innovation for each period. They have concluded that the agricultural sector of Taiwan experienced a labor-using, land-saving pattern of technological change throughout the period under investigation, while the land-using variety occurred only in the postwar period.

III. EMPIRICAL ANALYSIS, RESULTS, AND IMPLICATIONS

In analyzing technical innovation in Japanese agriculture, a modified form of equation (3) will be used. This form will allow us to analyze the bias in technical innovation in both the prewar and postwar time periods. In order to do this the variables in equation (3) are to be read as:

D is 0 for the period 1874–1944 and 1 for the period 1946–71;[8]
t_1 is 1 for 1874 through 72 for 1945 and 0 for the period 1946–71;
t_2 is 1 for 1945 through 27 for 1971 and 0 for the period 1874–1944;
x_1 is arable land measured in thousand hectares;
x_2 is labor measured in thousand workers.

It is assumed that $A>0$, and $0<\sigma<1$. It is also hypothesized that this function is weakly disposable in terms of labor and land, or that $b_1>0$, and $b_2>0$. In addition, the hypothesis that technological change has increased the substitutability of land for labor implies that $\beta_1<0$, $\beta_2<0$, $\gamma_1=0$, and $\gamma_2=0$. Being negative, both β_1 and β_2 represent progress (i.e., increases in input substitutability).

The estimation of equation (3) resulted in all parameter values being significant, except the estimates for γ_1 and γ_2.[9] Therefore, γ_1 and γ_2 were assumed to be zero, and thus the following equation was estimated:

$$Q=A[x_1-b_2x_2]^{\sigma}[x_2-b_1x_1e^{\beta_1t_1(1-D)+\beta_2t_2D}]^{(1-\sigma)}, \tag{4a}$$

if $[x_1-b_2x_2]>0$ and $[x_2-b_1x_1^{\beta_1t_1(1-D)+\beta_2t_2D}]>0$.

$$Q=0, \tag{4b}$$

if otherwise.

This equation was then estimated, and the results are presented in Table I.

These results reveal that the signs of the estimated parameters are consistent with the assumed WDI production function. In particular, the fact that $b_2>0$ and $b_1>0$ indicates that the Japanese agricultural sector exhibited a WDI production technology, with weak disposability applying to both land and labor. Since

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[8] For 1945, D does not exist.

[9] These results are available upon request from the authors. As it turns out, they are not significantly different from those reported in Table I.

TABLE I

ESTIMATION OF WDI PRODUCTION FUNCTION FOR JAPANESE AGRICULTURE, 1874–1971

Parameter	Estimate	Asymptotic Standard Error	Asymptotic 97.5% Confidence Intervals*
A	1.422	0.075	0.273, ∞
b_1	2.561	0.142	2.280, ∞
β_1	-0.004	0.0007	$-\infty$, -0.0034
β_2	-0.067	0.018	$-\infty$, -0.032
b_2	0.260	0.0079	0.244, ∞
σ	0.780	0.055	0.670, ∞

Note: $ESS=3.99\times 10^6$, $TSS=978.8\times 10^6$, Corrected $TSS=136.31\times 10^6$, $R^2=0.996$, and $\bar{R}^2=0.9708$.

* One-tail confidence intervals.

TABLE II

ESTIMATION OF WDI PRODUCTION FUNCTION FOR JAPANESE AGRICULTURE, 1874–1939

Parameter	Estimate	Asymptotic Standard Error	Asymptotic 97.5% Confidence Intervals*
A	1.19	0.118	0.954, ∞
b_1	3.138	0.282	2.573, ∞
β_1	-0.0073	0.0016	$-\infty$, -0.0042
b_2	0.224	0.017	0.190, ∞
σ	0.893	0.058	0.777, ∞

Note: $ESS=1.10\times 10^6$, $TSS=396.67\times 10^6$, Corrected $TSS=29.63\times 10^6$, $R^2=0.9975$, and $\bar{R}^2=0.9695$.

* One-tail confidence intervals.

both β_1 and β_2 were negative, technological change tended to increase the degree to which land could be substituted for labor. This is represented in the expansion of the isoquant in Figure 2 from IF to II_t. This type of progress is in line with the studies by Yeung and Roe [19] and Nghiep [11].

These results indicate strong support for the hypothesis that Japanese agriculture experienced labor-saving, land-using technological progress. However, as indicated in Section II,[10] other studies have concluded that in the prewar period the technological change was of the land-saving, labor-using type. Therefore, to strengthen the conclusion that follows from the results in Table I, it would be useful to apply the same method separately to the data for the prewar period. The results from estimating this variant of equation (3) for the prewar period are reported in Table II.[11]

Again, even for the prewar period alone, the hypothesis of this study cannot be rejected. Furthermore, it is important to note that the results for the prewar

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[10] See footnote 5 on page 236.

[11] The period from 1940 to 1945 was excluded because of the destruction caused by World War II.

period are consistent with those for the longer period. One exception to this statement is the estimate for β_1 which is more than one and one-half times its value for the longer period. This could be explained as the result of the exclusion of the war period.[12]

IV. SUMMARY AND CONCLUSION

The most important objective of this study was to determine the pattern of technological change in Japanese agriculture. Its importance lies in the fact that technological change is a determinant of development, and that certain patterns may constrain growth and development. The result of the present study provides support to the view expressed by Nghiep [11] and Yeung and Roe [19] that Japanese agriculture followed a labor-saving pattern of technological change. These results were derived from the estimation of a WDI production function for the entire period (1874 to 1971) as well as separately estimating a WDI function solely for the prewar (1874 to 1939) period. Both estimations indicate that the labor-saving technological progress in Japan was of the widening-of-productive-factor combinations nature.

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[12] The same equation was estimated for the postwar period of 1950–71. The period 1945–49 was characterized as a recovery-reorganizational period, and this was excluded. The resulting estimation provides additional support for the results presented in Table I. The results of estimation are available on request from the authors.

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