The Development of Technology in Taiwanese Agriculture

Richard Grabowski*
Ronald L. Tracy
and
Onesimo Sanchez

I. Introduction

This paper is basically concerned with determining the bias[1] of technical innovation in Taiwan's agricultural sector during the period 1911 to 1964. This is an important topic for a number of reasons. First, in the literature on the theory of induced innovation it has been argued that during Taiwan's colonial period land saving agricultural technology was transferred from Japan. In addition, following this period it has also been argued that the policies followed by the Taiwanese government fostered the further development of land saving technical innovation. However, no actual empirical determination of bias or its cause has been undertaken. Second, Taiwan's agricultural sector has grown very rapidly and as a result has played an important role in the overall development process. Hence an understanding of the process is useful historically and also possibly to today's developing countries. Finally, in the determination of the bias we will apply a relatively new form of production function.

Section two of this paper will discuss, from a historical perspective, the process of development in Taiwanese agriculture.

* The authors are respectively Associate Professor of Economics at Southern Illinois University-Carbondale, Associate Professor of Economics at Oakland University, and graduate student at Southern Illinois University-Carbondale.

[1] The definition of bias used here will be presented and discussed later in this paper.

this significantly exceeded the rate of growth of the rural population. Thus there was a significant increase in the per capita availability of food.

Agricultural development in Taiwan can be divided into two time periods: colonial and post colonial. From the time Taiwan became a Japanese colony the Japanese made significant efforts to develop and apply scientific knowledge to agriculture in Taiwan. As early as 1899 the colonial government allocated funds to operate agricultural experiment stations and in 1903 the Taiwan Agricultural Research Institute was established in Taipei, with agricultural improvement stations in strategic farming districts. At first these research organizations were only loosely related, but after 1921 they were all brought under the supervision of the Central Research Institute (Ho, p. 58).

The 1920s also marked the beginning of rapid growth in Taiwanese agriculture. From 1905 until the late 1920s agricultural growth was relatively slow and seems to have been the result of increases in the utilization of land, labor, working capital, and fixed capital. The technology was traditional in nature in that very few nonagricultural inputs were used and technological change, when it occurred, was based primarily on personal knowledge and experiences (Ho, pp. 56-58). In contrast, from the early 1930s to the 1940s agricultural output grew very rapidly, despite the fact that the land to labor ratio deteriorated.[2] This growth was the result of the rapid technological innovation that began to take place in the early 1920's and was in large part due to the application of agricultural science.

It was in the early 1920s that new high yielding varieties of rice were developed and introduced. Until that time the main improvements in yields stemmed from eliminating inferior natural varieties of rice, but these improvements were not great. The breakthrough came with the successful introduction of the higher yielding Japonica varieties of rice, commonly called ponlai rice. The rapid adoption of the new varieties helped to raise the average rice yield in Taiwan from 1,379 kilograms per hectare in

[2]There has been some controversy on this point. Over the time period under consideration labor did grow faster than arable land. However multiple croping also increased. This has led some observers to argue that the effective land to man ratio remained unchanged.

duction in Taiwan and also brought an end to Japanese colonialization. By 1951 agricultural output had reattained the prewar peak. From 1952 to the late 1960s agricultural output grew at between 4 and 5 percent a year. Much of this growth was again due to the development and application of new seed varieties and the increased application of commercially produced fertilizers. The government invested heavily in the development and operation of a number of research and experimental institutions. In 1960 the number of agricultural research workers per 100,000 people active in agriculture was 29 in Taiwan. By comparison it was 60 in Japan, 4.7 in Thailand, 1.6 in the Philippines, and 1.2 in India. (Ho, pp. 177-178).

Beginning in the 1960s an increasing number of farm workers moved to other occupations and this generally involved moving to urban areas. This resulted in a labor shortage in the agricultural sector in the latter half of the 1960s. As a result, agricultural wages began to rise significantly (Lee and Chen, p. 43). Farmers responded by using such labor saving devices as power tillers, power sprayers, power thrashers, etc (Shen and Wang, pp. 366-416). In other words, agricultural production became increasingly mechanized and labor saving.

Significant change in the structural organization of agriculture also occurred in the postwar period. An extensive land reform program was carried out between 1949 and 1953. The reform was carried out in three stages: compulsory rent reduction, the sale of public land to actual tillers and the compulsory sale of private land to actual tillers. The land reform significantly reduced the degree of inequality in the rural areas, however the basic operational size of farm units remained about the same (Ho, pp. 159-165).

This brief review of conditions in Taiwanese agriculture allows us to develop a hypothesis concerning the bias of technical innovation. Agricultural technology is usually divided into two types: mechanical and biochemical. Mechanical technology generally allows for the substitution of capital for labor, does not generally increase land productivity, and is characterized by significant economies of scale. Biochemical technologies usually involve the development of new seed varieties which are highly responsive to increased application of fertilizer and water, are yield increasing in nature, and are generally scale neutral. It is often argued that substitution) are allowed.[4] This difference is due to using the constraint that $(X_1 - \Upsilon X_2)$ and $(X_2 - \delta X_1) > 0$ (or equivalently $\gamma^{-1} > X_2/X_1 > \delta$) instead of the more usual constraint that $((1-\alpha) + \gamma\alpha\delta)/\gamma > X_2/X_1 > (\alpha \div \delta(1-\alpha)\gamma)/\delta$. However, this modification has the advantage of providing a simple test for input congestion (if the marginal product of an input is negative, congestion is indicated).

The modified VES function used in this paper is, as are all VES functions, weakly disposable[5]. Weak disposability is indicated by the parameters γ and δ being greater than zero. This characteristic means that if both inputs increase proportionately, ceteris paribus, output will not decrease, and if one input increases, ceteris paribus, output may decline. This is in contrast to a strongly disposable function where if both inputs increase proportionately, ceteris paribus, output will increase, and if one input increases, ceteris paribus, output will not decrease. Clearly if the parameters γ and δ are both equal to zero, then the VES function reduces to the traditional strongly disposable Cobb-Douglas function. Figure 1 illustrates this point using unit isoquants. The dotted isoquant GH is strongly disposable, i.e., if X_1 is increased then, ceteris paribus, output will not decrease. Thus the marginal products only asymptotically approach zero. In contrast, the weakly disposable isoquant IJ (solid line) is asymptotic to the rays OA and OB (not a vertical or horizontal line) and hence have marginal products that are zero and within the range set by the rays OA and OB become negative. The slope of ray OB is δ and the slope of ray OA is γ^{-1}.

Two brief digressions seem appropriate. First, in allowing for weak disposability it is important to remember that what is being modeled is not the desired relations between inputs and output but the observed relation. Hence, if production in the area of negative marginal products is detected (above point C or to the right of point D) there should be no inference that this is of the producers' choice, but only that congestion has occurred (it

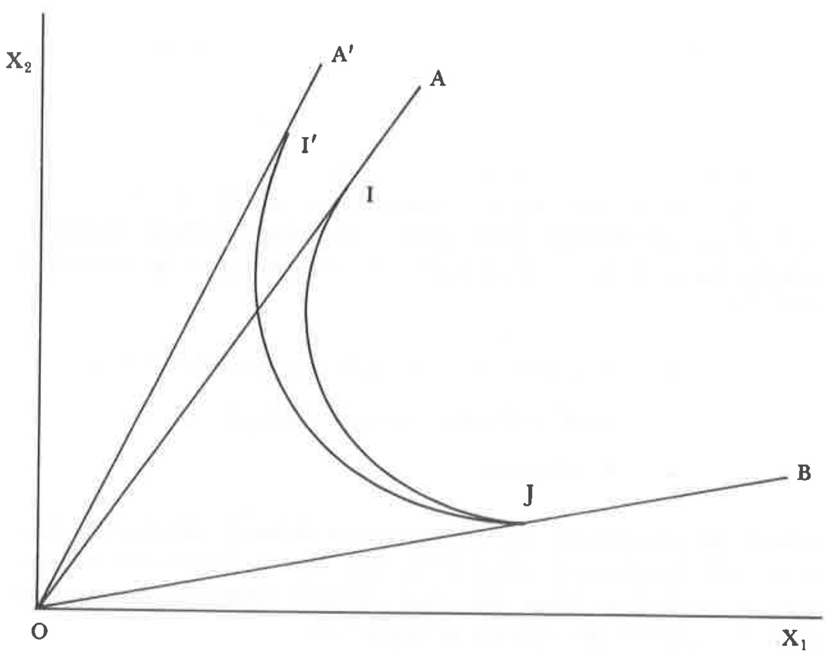
[4]The elasticity of substitution can as a result also become negative. However, since the marginal product of both inputs cannot be negative at the same time, a positive elasticity of substitution implies that one is operating in the efficient portion of the isoquant.

[5]For a good discussion of weak disposability and a proof that the VES function is weakly disposable.

where t denotes time, exp is the exponential function, and η and ν should be less than zero. In order to understand this modified function assume for the moment that ν equals zero and refer to Figure Two. Since η is negative as time increases exp (ηt) becomes smaller. Since the slope of ray OA for model (2) is $(\gamma \exp(\eta t))^{-1}$ (recall that it was γ^{-1} for model 1), the slope of ray OA has increased (become steeper) to OA′ (in Figure 2). Hence, the unit isoquant shifts out to be asymptotic to OA′ (from IJ to I′J).[6] Hence, if t is used as a proxy for technical innovation (as it would occur over time) $\eta < 0$ would indicate that technical innovation allows greater possibilities of substituting input X_1 for input X_2. A similar analysis can be done if $\delta < 0$.

Figure 2

TECHNOLOGICAL CHANGE



6 This shifting of the unit isoquant can be seen by taking the partial derivative of equation (2) with respect to X_2. Since $\eta \lesseqgtr 0$ the marginal product of X_2 increases, ceteris paribus, as t increases.

substitution between land and labor ($MRTS_{LN}\ \frac{\partial Y}{\partial N} \Big/ \frac{\partial Y}{\partial L}$) decreases, ceteris paribus. Similarly it would be classified as labor using (land saving) if $MRTS_{LN}$ increases, ceteris paribus. As a result, by taking the derivative of $MRTS_{LN}$ with respect to t and evaluating the derivative at any point in time, the type of technological progress being observed at that point in time can be ascertained. For example if $\partial\, MRTS_{LN}/\ \partial t > 0$ this implies that $MRTS_{LN}$ is rising due to the passage of time and thus technical change is labor using (land saving). The reverse holds when $\partial\, MRTS_{LN}/\ \partial t < 0$. Since it has been suggested earlier in this paper (bottom of page six) that within Taiwan (from 1911-1964) working capital was substituted for land and increased the need for labor, the direction of technological progress should be of the land saving (labor and working capital using) type. Thus we would expect to find that $\partial\, MRTS_{LN}/\ \partial t > 0$ and $\partial\, MRTS_{LK}/\partial t > 0$. This is the hypothesis that will be tested.

One further comment is necessary concerning the use of the modified weakly disposable VES production function to test the direction of technological progress. The most common method of measuring the direction of technological progress is to use the translog production function. A useful by-product of that analysis is the ability to test for the convexity of the cost function (or production function). Unfortunately to easily estimate the translog production function requires either the expenditure share (for the production function) or the price (for the cost function) of each input. Often, as in the case of Taiwan from 1911 to 1964, neither of these are available. Although the translog function can be estimated directly this involves the joint estimation of 15 parameters (May and Denny, pp. 759-774) (whey symmetry is imposed) which may lead to a severe multicollinearity problems. In these cases the alternate method being proposed and used in this paper should prove extremely useful. In addition, much as the translog technique gave the useful by-product of being able to test for the convexity of the cost function, the modified weakly disposable VES production function allows one to test for input congestion.

were not extensively applied until the early 1930s. Prior to that time much of the agricultural growth in Taiwan stemmed from additional applications of working capital and growth was rather slow. Our results show that by the late 1920s Taiwan had reached the limit in using this approach to agricultural growth, i.e. the marginal product to increased applications of working capital became negative. However, as the new varieties rice were extensively applied, the marginal product of capital (which includes seed) once again became positive in the early 1930s.

The results of evaluating the derivatives of the various marginal rates of technical substitution with respect to time are given in Table 2. These results show that from 1911 to 1964 technological change in Taiwan has been labor using (land saving), since $\partial \text{ MRTS}_{LN} / \partial t > 0$ for all years, i.e., $\frac{\partial Y}{\partial N} \Big/ \frac{\partial Y}{\partial L}$ has been rising throughout the period. In addition, it is interesting to note that technical change became increasingly labor using, land saving from the early 1920's until the mid 1930's. Then the degree to which technical innovation was labor using/land saving begins to steadily decline. This is likely due to the fact that beginning in the early 1920's arable land per worker actually fell, meaning that the land constraint on agricultural growth was becoming quite severe. Of course after World War II and the recovery the land constraint became less and less of a problem and labor shortages begin to develop. Thus one might suspect that technical innovation would become less land saving/labor using and it indeed has. In fact, after 1964 one might hypothesize that technical change may have become land using and labor saving (this would be reflected in a negative sign for $\partial \text{ MRTS}_{LN} / \partial t$). This is a topic for future research.

Examining Table 2 again, one finds that $\partial \text{ MARTS}_{LK} / \partial t$ and $\partial \text{ MRTS}_{NK} / \partial t$ are both positive throughout the period. Thus both $\frac{\partial Y}{\partial K} \Big/ \frac{\partial Y}{\partial L}$ and $\frac{\partial Y}{\partial K} \Big/ \frac{\partial Y}{\partial N}$ were rising. This implies that technical progress was working capital using with respect to both land and labor. The extent to which technical innovation was working capital using and labor saving rose dramatically from the mid 1920's to the early 1930's, but declines steadily for the rest of the period. The rise in the mid 1920's through the mid 1930's was likely due to the fact during this period commercially produced

However, the extent to which it did so steadily decreased throughout the period, i.e., the size of $\partial \, MRTS_{NK} / \partial t$ declines. This most likely reflects the fact that land was becoming less and less of a constraint on the growth process in agriculture.

V. Conclusion

In this short paper a brief review of the agricultural experience of Taiwan for the period 1911 to 1964 was presented. As a result of this review, it was hypothesized that technical innovation during this time period was labor using relative to land and capital using relative to labor and land. In order to test this hypothesis a weakly disposable VES production function incorporating technical change was estimated using nonlinear least squares. The results confirm the hypothesis made in the paper. In addition, it seems that 1964 represents an important turning point in Taiwan's agricultural development. More specifically, although up until that point in time technical innovation was labor using, land saving, it was becoming increasingly less so. This seems to correspond to the point in time when labor was becoming the relatively scarce input in Taiwan. However, additional research concerning this post 1964 period is necessary to confirm this proposition.

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