Journal of Rural Development 3 (April 1980): 1–10

A PARTIAL ANALYSIS OF TECHNICAL EFFICIENCY AND RETURN TO SCALE IN KOREAN RICE PRODUDTION

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I. Introduction

Rice production in Korea has been characterized by small landholdings and labor intensive technologies for centuries. Rice is the single most important crop and source of about 60 percent of farmers' agricultural income. Rapid economic growth since the 1960s and subsequent internationalization of the economy have brought significant changes in the resource employment structure of the traditional agricultural sector. A shortage of agricultural labor is becoming a particularly serious management bottleneck in rice production.

Due to shortages of labor, the agricultural wage rate has increased more rapidly than agricultural product prices in recent years. Therefore, the capital labor ratio has shown an increasing trend. Capital input for agricultural production, measured at 1970 constant prices, shows a marked increase: from 2.4 percent of annual average growth rate for the period of 1955–1964 to 10.5 percent for the period of 1965–1978 (Kim 1979), whereas labor input has continued to decrease at an annual rate of about 2.7 percent since the mid 1960s.

Substitution of capital for labor, nevertheless, has been limited to the extent of greater applications of chemical fertilizers, herbicides, pesticides, fungicides and some mechanization of the land tilling and spraying processes. Important manual operations such as rice planting and harvesting, which comprise about 40 percent of the total labor requirement of rice production, are not yet mechanized.

In the face of this changing resource employment structure, farm-size composition has changed significantly. The number of subsistence farms defined as those cultivating less than 0.5 ha of land decreased by 31 percent during the 1967–1978 period. Large farms those cultivating more than 2.0 ha of land, decreased by about 28 percent during the

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same period. Although the number of small- to medium-sized farms also shrank, the rate was much slower, resulting in an increased share of the small- and medium-sized farms in the total composition.

Decreased subsistence farming may be explained partly by urban mirgation for new job opportunities and partly by movement into higher brackets by leasing more land. Fewer large farms may be the result of increasing wage rates and technical difficulties in balanced labor-capital substitution. Large farms in Korea are not large enough to employ modern technologies to save labor and thus still have to heavily rely upon hired labor. The changing farm-size structure strongly indicates there may be significant differences in technical and economic efficiencies of rice production among various scales of operation. Thus, the objectives of this study are: 1) to compare relative technical efficiency in rice production between farms of various sizes; 2) to delineate some clues on factors affecting economies or diseconomies of scale in rice production.

II. Method of Analysis

Farrell's model is to observe various combinations of inputs needed to produce a unit of ouput and to find the minimum of such combinations over existing combinations (Farrell 1957; Farrell and Fieldhouse 1962). In this approach there is no prior specification of an algebraic form of the production function. The best observed performance in practice is accepted as a basis for efficiency measurement. Differences in scale and technology are handled by estimating efficient unit isoquants for each scale or technology and making comparisons between them.

Consider, as Farrell does, some product by n farms, each of which uses two inputs in amounts X_{1j} and X_{2j}, where j indexes the farms. Each farm's production function can be written generally as

$$q_j = f_j(X_{1j}, X_{2j}), \quad j=1, \ldots, n$$

We wish to consider the production function in the form of an isoquant, in particular a unit output isoquant. Thus, the arguments X_{ij} are replaced by the average product inverse.

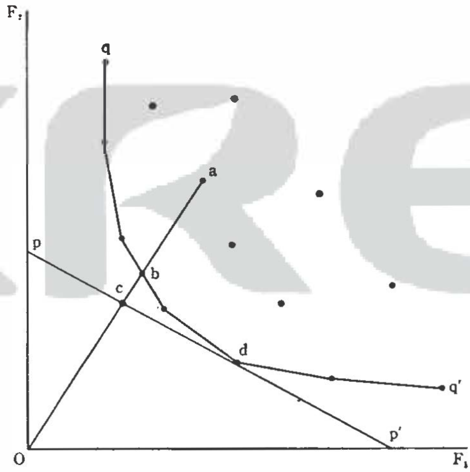
$$F_{1j} = X_{1j}/q_j \text{ and } F_{2j} = X_{2j}/q_j$$

In Figure 1, values of X_{1j} are plotted against the two input planes F_1 and F_2. Each point represents the input combination used by farm j to produce on unit of output.

An estimate of the minimum input quantities necessary to produce one unit of output can be made by taking an a locus of points indicating the minimum quantities of the production factors with varying factor proportions. The resulting envelope of the observed points labeled qq' is Farrell's efficient unit isoquant.

Farms represented by points inside the envelope curve can be said to be using whatever factor combinations they do use less efficiently than they might, given current technology. With any given factor proportions —say that represented by the ray O_a in Figure 1—one unit of output can be produced from input levels at point b. Thus the amount of factors used by the farm from which we observed are larger than necessary. A measure of the degree of efficiency is the ratio O_b/O_a—the ratio between the input combination necessary to efficiently produce one unit with the given factor proportions, and that actually observed. This ratio is defined by Farrell as the technical efficiency (TE) rating of point a.

FIGURE 1 Efficient Unit Isoquant



Even a farm using a technically efficient input combination may not be producting optimally, depending upon prevailing factor prices. Given factor prices as pp' line in Figure 1, only a farm producing at point d is economically (technically and price) efficient, for it is the least factor combination. The farm at point b is only technically efficient. The optimal factor combination given by point d has the same total costs as point c, which represents the same factor proportions as the farm at point a.

Thus the price efficiency (PE) of the input combination represented by the ray O_a is given by O_c/O_b—the ratio between total costs of producing one unit using actual factor proportions in a technically efficient manner and total costs of producing one unit using optimal factor proportions in a technically efficient manner.

Finally, the product of technical efficiency and price efficiency indices yields overall or economic efficiency (EE). This is intended to relate the costs per unit of output of the optimal input combination, to that of actual combination, Algebraically.

$$EE = (TE) \cdot (PE)$$
$$= \frac{O_b}{O_a} \cdot \frac{O_c}{O_b}$$
$$= \frac{O_c}{O_a}$$

The essential point of the method is not so much the construction of an isoquant, but rather the comparison of efficiencies of existing farms with real or hypothetically efficient farms. If a technically efficient farm exists with the same factor proportions as those of the farm for which an efficiency index is desired, the comparison can be made directly. If not, then a hypothetical farm is constructed as a weighted combination of farms using factor proportions in the neighborhood of the subject farm. The efficiency comparison can be made between the exisitng farm and the hypothetical but technically efficient farm(Moncur 1973).

Given the estimated values of technical efficiency for each farm in the sample, the relative efficienty of alternative scales of operation can also be determined.[1] That is, several different unit isoquants can be derived from the given sets of technically efficient farms data by introducing scale factors. Among the several unit isoquants, the inside unit isoquant toward an origin which represents a particular size of operation, or scale, is more efficient than the other isoquants or scales.

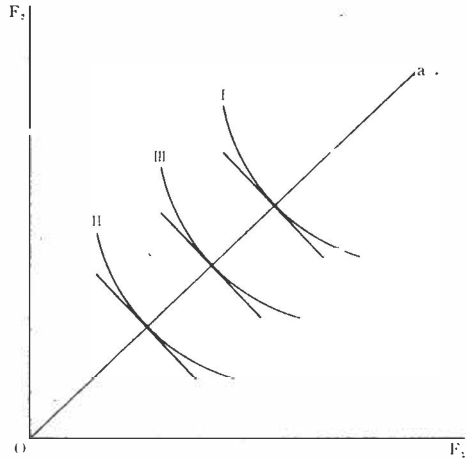
Figure 2 shows a map of hypothetical efficient unit isoquants for various scale of operations or size of farms assuming a production function with a straight-line expansion path from the origin. Curves I, II, and III represent the efficient unit isoquants for the smallest to the largest scale farms, respectively.

The map of the unit isoquants I to II indicates increasing return to scale or economies of scale, since input per unit of output decreases as scale increases and a further increase of scale to isoquant III evidences diseconomies of scale because input per unit of output increase.[2]

[1] A method of estimating frontier production function allowing economies and diseconomies of scale was developed by Seitz and others. For full discussion of technical efficiency given scale and technical scale efficiency index of alternative scale activity, see Wesley D. Seitz, 1970, "The Measurement of Efficiency Relative to a Frontier Production Function," *American Journal of Agricultural Economics,* 52(Dec.): 505–511.

[2] When scale has non-neutral effect on production function the efficient unit isoquants for different scales may intersect. In this case,explanation and measurement of efficiencies are more complex. For full information, see; Wesley D. Seitz, op. cit.

FIGURE 2 Efficient Unit Isoquants for Various Farm Scales



The graphical method suggested by Farrell is not appropriate for measuring the technical efficiency index when more than two inputs and outputs are to be considered. Farrell, however, indicated that there is a similarity between the description of the unit isoquants and a linear programming minimization procedure. Boles later developed computer routines for more up-to-date IBM equipment, solving the linear programming problems and calculating the resulting technical efficiency indices.[3]

Bole's computer programs provide a numerical description of the isoquant hypersurface by enumerating the coordinates of each fact. But this description is hard to visualize and interpret meaningfully. Therefore, the programs also compute coordinates of two dimensional cuts of the hypersurfaces. For these partial isoquants, the level of output is specified at one unit and levels of all inputs except the two to be considered are fixed at average levels within the range of data. The resulting partial unit isoquants show the transformation between any two inputs, with levels of the other inputs and of the scale factor entering parametrically.

III. Data

The data used in this study are 1977 rice production costs survey data compiled by the Ministry of Agriculture and Fisheries(MAF 1978) A total of 2,812 rice farms was selected by a three-stage stratified random

[3] For the mathematical formulation of the procedure, see Jame N. Boles, 1971, "The 1130 Farrell Efficiency System-Multiple Products, Multiple Factors," Gianni Foundation of Agricultural Economics, University of California, Agricultural Experiment Station.

sampling method. The sample covers the entire country. The input and output data of the sample farm households regarding rice production were aggregated into four parts for this study; output, land, labor, and capital. Each is defined as follows.

Output: Total rice production was measured by physical unit, kg. The rice production represents the total harvest amount during 1977 crop year.

Land: Land is measured in Pyong, and includes rice paddy and upland. Only the harvested acreage of the total land was considered. On the average about 60 percent of the cultivated land is used for rice production.

Labor: Labor used in rice production only was considered. Agricultural activities for rice production such as preparing seed beds, the preparation of land, plowing, replanting, weeding, pest and disease control, irrigation, the application of fertilizer, harvest, and drying work are included for both family and hired labor. Labor is measured by working hour.

Capital: This variable represents the sum of depreciation charges for buildings and machines, interest charges, repairing and maintenance costs, fuel costs, fertilizer, chemicals and other cash expenses used for rice production. The capital also includes taxes and other fees. Capital is measured in value terms by won.

Technical scale efficiency refers to the technical efficiency of a farm given the level of scale at which it operates. The other indices such as price and economic efficiencies would require factor price data on a farm-by-farm basis, which are not available. Thus, only technical scale efficiency is considered to compare relative efficiency among the different scales of operation in rice production. The amount of rice production was used as the scale factor.

IV. Results

Figures 3, 4, and 5 show sets of isoquant maps derived from 137 rice farms which are technically efficient. Seven different rice production levels were used as a scale factor in order to represent sizes of operation.

Scales of operation which are expressed in terms of rice production may be roughly converted into the average size of land held per farm as shown in Table 1.

Figure 3 shows unit isoquants of rice production using two factors of production, land and capital, holding labor input constant at the average level. The unit isoquant is shifting downward to the origin as scale increases. This indicates smaller input amounts are used to produce a unit of rice as scales increase, implying the existence of economies of scale. However, if scale increases further, from 6 to 7, diseconomies of scale

FIGURE 3 Partial Isoquants by Scale of Operation (Land and Capital)

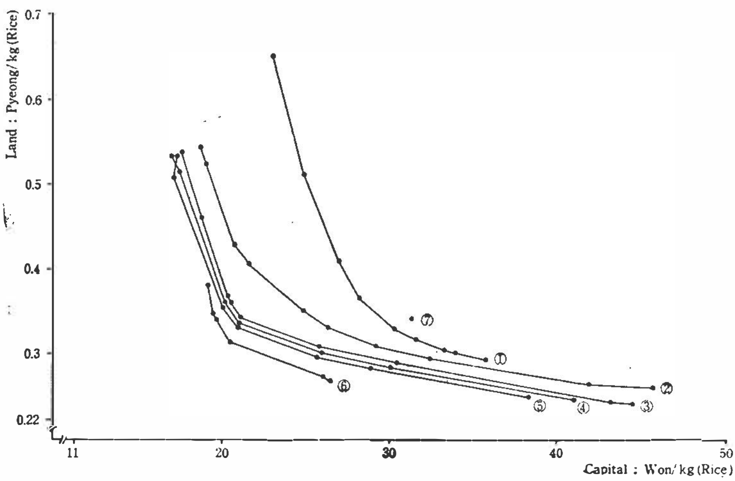
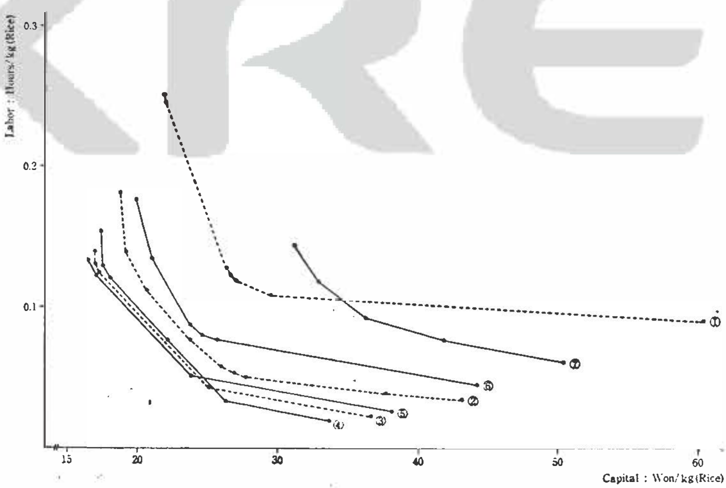


FIGURE 4 Partial Unit Isoquants by Scale of Operation (Labor and Capital)



appears. The farm size of about 4.3 ha is considered to be the most efficient when land and capital inputs are varied. Also, as shown from the highest partial unit isoquant, the production process seems to use a relatively larger amount of capital as scale rises.

Figure 4 illustrates the relationship between labor and capital. The partial unit isoquants shift toward origin and the shift backward as the scale of operation increases. This exhibits an existence of economies of scale to a certain level of scale and thereafter diseconomies of scale. The

FIGURE 5 PARTIAL UNIT ISOQUANTS BY SCALE OF OPERATION (LABOR AND LAND)

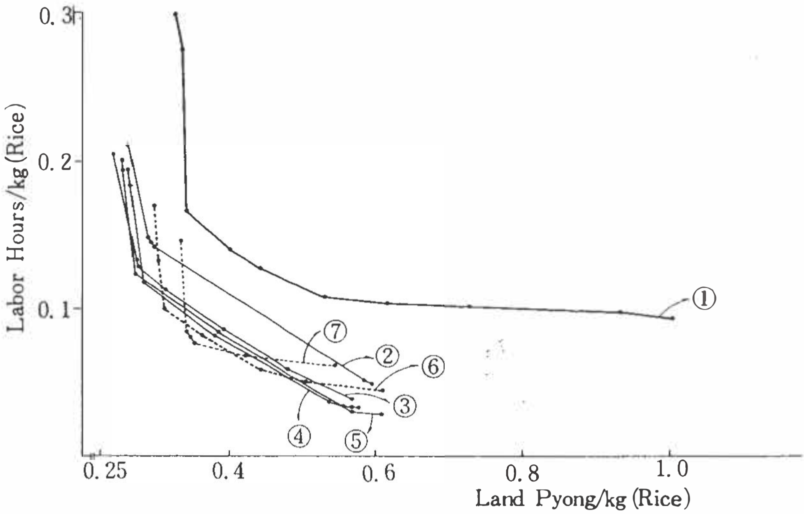


TABLE 1 RELATIONSHIP BETWEEN SCALE OF OPERATION AND AVERAGE SIZE OF HOLDING

Scale (Rice Production)	Average Size of Holding	Identification Number of Unit Isoquant
1,000 kg	0.4 ha	1
3,000	1.1	2
6,000	2.1	3
7,000	2.5	4
8,000	2.9	5
12,000	4.3	6
16,000	5.7	7

movement of isoquants from 1 to 3 or 4 show a similar shape of isoquant indicating same shape, at a given capital-labor ratio. It means a neutral technological progress exists in the span of economies of scale.

However, when isoquants are shifting backward the marginal rate of technical substitution of capital for land declines at a constant capital labor ratio. This depicts a shifting production function characterized by capital-biased technological changes. Increasing lumpiness of capital equipments to replace a unit of labor may prevail until the operation size reaches a larger scale which is not observed in the data. The existence of diseconomies of scale appears to have a close relationship with capital-biased technological change as the size of operation increases. Also, small and large farms may face different markets for inputs. For the small farms,with relatively more family labor and less capital, may face different factor price ratios than large farms to which hired labor is relatively more expensive than capital. Nonpaid family labor of small and large farms may different opportunity costs.

Figure 5, the partial unit isoquants between labor and land, gives a bit less clear-cut interpretation. The isoquants shift toward origin as scale increases, but intersect thereafter regardless of scale increase. It is difficult to tell which scale is the most efficient due to frequent intersecting and overlapping of the isoquants. Also, curvatures of the isoquants do not significantly differ from each other except for the larger scales of 6 and 7. This appears to indicate rather neutral economies of scale, or constant to return scale, when labor and land inputs are considered holding eapital constant. In the case of larger farms with more than 4–5 ha, substitution between land and labor becomrs more difficult, indicating machinery may be a better substitute.

V. Conclusion

This study has examined the relative technical efficiency in rice production for various sizes of operation. The Farrell and Fieldhouse unit isoquant approach was employed to evaluate if there are economies of scale in Korean-style rice production. The results indicate the medium-size farm is technically more efficient than subsistence or large farms. As scales of operation increase beyond a certain sizes diseconomies of scale present themselves. Diseconomies of scale are evident with respect to the relationship between labor and capital inputs. The marginal rate of technical substitution of capital for land and the direction of movement of the isoquants between small and large farms do differ significantly. This implies the underlying production functions may not be the same, or that small and large farms face different factor prices.

Due to shortages of labor, agricultural wages rates have increased very rapidly in recent years. Despite the increasing degree of substitution of capital for labor, important manual tasks such as rice planting and harvesting, which give rise to peak labor demand have not yet been replaced by machines. Increasing wage rates appear to more significantly affect large farms, which have to rely heavily upon hired labor. Besides, the difficulties of balanced capital-labor substitution beyond a certain scale, and the progressive nature of land tax (tax is included in the capital data and the land tax base is the amount of production) seem to cause diseconomies of scale as the size of operation increases. For a detailed and full explanation, price information on factor markets for small and large farms is needed.

However, the input relationship between land and capital reveals there are fairly good economies of scale. If critical manual tasks such as rice planting and harvesting can be mechainzed with the proper combination of land, there would be a good chance of economies of scale appearing in rice production.

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