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Input and output technical efficiencies of wheat production in Kerman, Iran

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Abstract

The Iranian government encourages farmers to produce wheat (a common agricultural enterprise) by increasing farm productivity and efficiency. In this paper, using a Cobb–Douglas frontier production function, a simple relationship between a farm-level output-based technical efficiency measure (the Timmer index) and an input-based measure (the Kopp index) is first developed. Then, using 1995 data from 164 farms in Kerman province, Iran, the average Timmer and Kopp indexes were estimated at 0.93 and 0.91, respectively, and were found to be similarly affected by farm size (positively up to about 9 ha) and by input ratios, though with rather small explanatory power. Thus, there seems some but limited scope to increase the profitability of Iranian wheat production either by increasing the product, given input levels, or by decreasing inputs for the current level of wheat production. However, since wheat producers may be able to adapt their production process more easily and quickly by implementing new techniques, i.e. by more efficient combination of inputs, than by adopting new technology, correction of input over-use can be regarded as a policy with speedy if limited effect in this case.

Keywords: Technical efficiency; Timmer index; Kopp index; Wheat; Iran

1. Introduction

In light of its general objective of attaining national self-sufficiency in agricultural products, the Iranian government has sought strategies that would lead to higher levels of production given current inputs particularly of land and water, and has paid considerably more attention to the production of wheat than to other crops. However, Iranian farmers have preferred to move to more profitable enterprises, and, although the production of wheat has been increased during recent years, a substantial share of consumption, e.g. a little over 20% in 1995, is imported into Iran each year (Table 1).

In terms of economic efficiency, inputs seem not to be economically used in wheat production in Iran. Bakhshoodeh (1995) found that the value marginal product (VMP) of wheat-growing land was less than the rent paid in the Kerman province of the country, a finding which implies over-use of this input. Moreover, while seed and phosphate fertiliser were also over-used, labour, water and urea fertilisers were under-used. Wheat production has increased through changing the traditional patterns of production structure and cultivation, and by increasing the use of machinery, high-yielding varieties and pumped groundwater (Iranian Ministry of Agriculture, 1992). However, further reallocation and more efficient use

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Table 1
Wheat production, imports and consumption, Iran, 1965–1995[a]

Year	Harvested area (×1000 ha)	Yield (kg/ha)	Production (×1000 t)
1961	3600	797	2870
1965	4700	776	3650
1970	5330	800	4260
1975	5990	919	5510
1980	5950	982	5850
1985	6190	1070	6630
1990	6280	1276	8010
1995	6570	1710	11230
Rate of growth (% per year)	1.6	2.2	3.8

[a] Source: FAO, http://apps.fao.org.

of resources should enable higher private and/or social profits (Iranian Ministry of Agriculture, 1995).

In this paper, an output-based measure of technical efficiency of individual farms as well as that of an input-based measure is estimated. Given the scarcity of available inputs in Iran, the production of wheat can only be increased by making farms more efficient than they are. A study of production efficiency can provide some of the information needed for policy makers to improve the productivity of wheat inputs. More detailed information can be obtained by determining the sources of inefficiency, which may relate to either inputs or output, and in particular by investigating the effects of farm size and input ratios.

2. Methodological framework

Efficiency can be defined in terms of producing a maximum amount of output, given a set of inputs; or producing a given level of output using a minimum level of inputs; or a mixture of both. Efficient farms either use less input than others to produce a given quantity of output, or for a given set of inputs they generate a greater output.

The output-based Timmer (1971) index of technical efficiency TE_T is simply the ratio of the observed level of output to the potential (frontier) output, given a set of inputs. The input-based Kopp (1981) index of efficiency TE_K is defined as the ratio of frontier input (cost) to the observed level of input (cost), given the level of output. According to Llewelyn and Williams (1996), these two indices are not necessarily the same, because input efficiency does not focus on the same aspects of production as those of output efficiency. According to Fare and Lovell (1978), a unique measure of these two indexes cannot be calculated in the case of non-homothetic technology. Homotheticity — for which homogeneity is sufficient but not necessary (Laidler and Estrin, 1989) — implies that all the isoquants have the same slope on a ray through the origin in the input space.

In this paper, these relationships are illustrated using the Cobb–Douglas production function

$$Y = A\prod_{i=1}^{N} X_i^{B_i}\, e^{-\mu+\nu} \tag{1}$$

where Y is the observed level of output, X_i (i=1, ..., N) are the observed levels of the i inputs, A and B_i are unobservable parameters indicating the efficiency parameter and the output elasticity coefficients, respectively, and the error term is decomposed into an inefficiency component μ and the usual random noise ν. The degree of homogeneity is equal to its sum of the B_i coefficients.

Then the Timmer index for an individual farm is the ratio of observed output Y to frontier output Y_f, defined for μ=0

$$TE_T = \frac{Y}{Y_f} = \frac{\left(A\prod_{i=1}^{N} X_i^{B_i}\, e^{-\mu+\nu}\right)}{\left(A\prod_{i=1}^{N} X_i^{B_i}\, e^{\nu}\right)} = e^{-\mu} \tag{2}$$

and following Russell and Young (1983) the Kopp index may be formulated (for any j) as

$$TE_K = \frac{X_{fj}}{X_j} = \left(e^{-\mu}\right)^{1/\sum B_i} = (TE_T)^{1/\sum B_i} \tag{3}$$

where X_{fj} and X_j are the frontier (μ=0) and observed levels of the jth input, respectively.

Given the inefficiency component μ, both indices may be calculated simply and directly. In the case of constant returns to scale, ΣB_i=1, the Kopp index equals the Timmer index, while the Kopp index is greater (less) than the Timmer index in the case of increasing (diminishing) returns to scale, ΣB_i >1 (<1) (Fig. 1).

The expected value of farm-specific inefficiency term μ_j is defined by Jondrow et al. (1982) as the conditional mean of μ_j, given $\varepsilon_j=-\mu_j+\nu_j$ and assuming a normal distribution for ν and a half-normal distribution for μ

$$E(\mu_j|\varepsilon_j) = \sigma_* \left[\frac{f(\cdot)}{1-F(\cdot)} - \frac{\varepsilon_j \lambda}{\sigma} \right] = \hat{\mu}_j \qquad (4)$$

where σ, σ_μ, and σ_ν are the standard errors of ε, μ, and ν, respectively, $\sigma_*^2 = \sigma_\mu^2\sigma_\nu^2/\sigma^2$, $\lambda = \sigma_\mu/\sigma_\nu$, and $\sigma = \sqrt{\sigma_\mu^2+\sigma_\nu^2}$, and $f(\cdot)$ and $F(\cdot)$ are the standard Gaussian density function and the cumulative distribution function, respectively, both evaluated at ε_j/σ.

In the absence of other farm-level data (e.g. farmer education, technical assistance) which may represent the sources of inefficiency, the effect of farm size alone may be examined by means of a simple quadratic function. The potential efficiency gains, i.e. the rise in the level of output that could be gained ($G_T=1-TE_T$) or the share of input that could be saved ($G_K=1-TE_K$) if the farmer were 100% efficient, may be defined as a function of the input ratios.

3. Data and empirical model

To estimate the Timmer and Kopp indexes of inefficiency in the production of wheat, a random sample of 164 farmers was interviewed in Kerman province of Iran in 1995. The variables in the Cobb–Douglas production frontier function (1) are defined as

Y	total production of wheat per farm (t)
X_1	cultivated land (ha)
X_2	seed (kg per farm)
X_3	fertiliser (phosphate) (kg)
X_4	fertiliser (urea) (kg)
X_5	irrigation (number of irrigations per year)
X_6	labour in worker-equivalents

Table 2
Basic statistics of wheat production, Kerman, Iran, 1995[a]

Statistics	Mean	S.D.	Minimum	Maximum
Y wheat (t)	11.27	12.52	1.18	55.00
X_1 cultivated land (ha)	3.54	4.31	0.25	22.00
X_2 seed (kg)	216.58	31.53	120.00	300.00
X_3 phosphorus fertiliser (kg)	185.95	57.70	100.00	350.00
X_4 urea fertiliser (kg)	178.81	50.94	100.00	250.00
X_5 irrigations (no.)	10.29	1.83	8.00	18.00
X_6 labour (h/ha)	12.96	1.44	9.00	16.00

[a] Number of observations=164.

The mean, standard deviation, minimum and maximum levels of total product and inputs are shown in Table 2. As can be seen, on average each farmer cultivated 3.5 ha of land for wheat, used a total of 365 kg/ha of fertiliser, and produced 11 t of wheat. Each farmer irrigated his or her land 13 times (each time using around 1000 m^3 of water), generally by flood irrigation under individual or small-group control.

4. Results and analysis

4.1. *The frontier production function*

Table 3 shows the estimated coefficients of the production function and their corresponding levels of statistical significance. Five out of the six variables are significant (all except labour, and also the intercept) and explain 94% of the variation in the total production of wheat. OLS estimates of coefficients

Table 3
Maximum likelihood estimate of the frontier function coefficients[a]

	Estimated parameter	Standard deviation	*t*-statistic
A	−0.036	1.219	−0.030
B_1	0.999	0.026	39.171
B_2	0.586	0.150	3.907
B_3	−0.213	0.089	−2.378
B_4	0.059	0.104	0.568
B_5	−0.325	0.157	−2.068
B_6	−0.278	0.193	−1.441
σ	0.387	0.040	9.662
λ	−4.092	1.810	2.261

[a] Log-likelihood value=7.373.

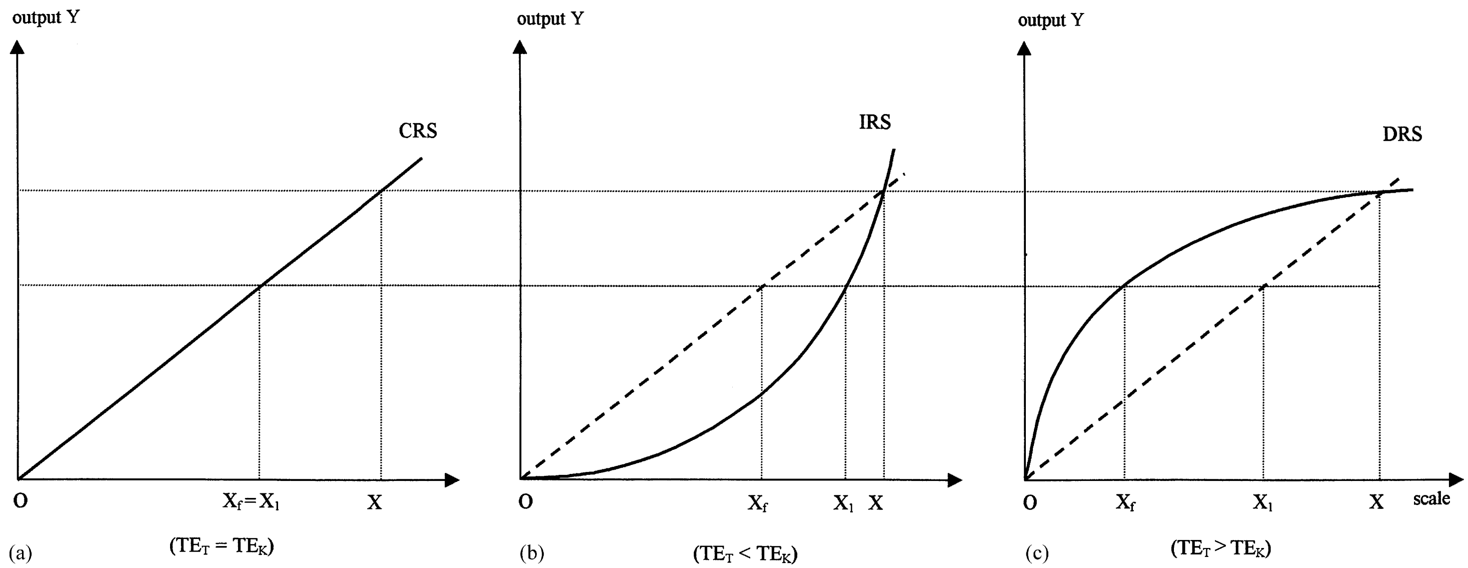

Fig. 1. TE indexes with: (a) constant returns to scale (CRS); (b) increasing returns to scale (IRS) and (c) decreasing returns to scale (DRS).

Table 4
Frequency distribution of Timmer and Kopp TE indices

	Efficiency index		Frequency		Percentage		Cumulative frequency		Cumulative percentage	
	TE_T	TE_K	TE_T	TE_K	TE_T	TE_K	TE_T	TE_K	TE_T	TE_K
	0.6–0.7		0	7	0.0	4.3	0	7	0.0	4.3
	0.7–0.8		17	23	10.4	14.0	17	30	10.4	18.3
	0.8–0.9		32	33	19.5	20.1	49	63	29.9	38.4
	0.9–1.0		125	101	70.1	61.6	164	164	100.0	100.0
Mean	0.93	0.91								
S.D.	0.07	0.08								
Minimum	0.73	0.67								
Maximum	0.99	0.99								

were taken as the starting values for the maximum likelihood (ML) estimation of the frontier function (1) where B_1–B_6 are related to the variables X_1–X_6, and σ and $\lambda=\delta_\mu/\delta_\nu$ are the coefficients of the log-likelihood function. As indicated in Table 3, six out of the eight coefficients of the frontier function are statistically significant at the 95% confidence level.

4.2. The Timmer and Kopp TE indices

Using the values of μ_j, Eq. (2) was estimated for individual farms as a basis for the TE_T and TE_K inefficiency indices, whose frequency distributions are shown in Table 4. The mean value of TE_T is estimated to be 0.93, with a range from 0.73 to 0.99, while the average TE_K is found to be 0.91 (range 0.67–0.99). The mean values indicate that either output can be increased on average by 7% with the same amount of inputs as before, or the current level of output can be produced using 9% less inputs on average than are applied by farmers. A quarter of the observations were under 90% efficient for the TE_T and under 87% efficient for the TE_K. At least one wheat producer could gain over 30% by input reallocation or over 25% by output maximisation. The frequency of the Timmer and Kopp indexes among the farms indicates that 125 farms (70%) had an output-based efficiency level of 0.90 or above and 101 farms (62%) an input-based efficiency in that range. About 4% of farms were in an input-based inefficiency range below 0.70. In summary, most farms are recognised to be more than 90% efficient on both measures, but there is a 'tail' of farms over 20% inefficient on either measure.

4.3. Causes of inefficiency

As mentioned above, farm-level data on the sources of inefficiency are not available for Iranian wheat farmers, although it may be conjectured that these sources include the difficulty of acquiring inputs such as chemical fertiliser. In the absence of such evidence, farm size, and input ratios, which differ from large to small farms, are considered as determinants of the potential efficiency gains G_T and G_K.

The relation between both TE indices and farm size (as measured by land area, X_1) was examined by an estimated quadratic equation (standard errors of coefficients in parentheses)

$$G_T = \underset{(0.0094)}{0.051} + \underset{(0.0038)}{0.011}*X_1 - \underset{(0.0002)}{0.0006}*X_1^2 \qquad (5)$$

$$G_K = \underset{(0.0110)}{0.061} + \underset{(0.0044)}{0.013}*X_1 - \underset{(0.0002)}{0.0007}*X_1^2 \qquad (6)$$

As signs of the (very similar) coefficient estimates suggest, the potential efficiency gains G_T and G_K increase up to a certain point (around 9 ha) and decrease again with larger farm sizes. Therefore, in terms of general objective of attaining self-sufficiency in agricultural products and raising the level of wheat production, policies for improving efficiency should be directed towards the medium-sized farms. The average yield of wheat in these farms (4.1 t/ha) is higher than that of large and small farms (3.2 t/ha), and their lower level of efficiency implies a higher potential output. A comparison of mean efficiency gains among the farms with different sizes (Table 5) shows that the efficiency gain for the medium-sized

Table 5
Mean efficiency gains G_T sand G_K by farm size[a]

	Size	No. of farms	G_T	G_K
Large	>9 ha	16	0.078 (0.017)	0.093 (0.020)
Medium	6–9 ha	9	0.109 (0.022)	0.130 (0.027)
Small	3–5 ha	41	0.079 (0.011)	0.095 (0.012)
Very small	<3 ha	48	0.004 (0.007)	0.076 (0.008)

[a] Standard errors in parentheses.

farms is significantly higher than that for very small farms. Such differences could be due to the technologies applied at different sizes, and to the economies of scope related to the degree of on-farm diversification.

The input ratios were found to affect the farm-specific inefficiency levels. The effect of the ratios on the potential efficiency gain G_T is indicated in Table 6. As shown, the ratios can explain only 12% of the changes in G_T, which means there are other factors influencing the level of inefficiency. However, it can be concluded that inputs are not optimally combined in the production of wheat, and a reallocation of inputs results in some improvement in the farm level inefficiency.

The coefficients of four out of seven ratios, i.e. water/seed, phosphate fertiliser/seed, urea fertiliser/seed, and the ratio of fertilisers, were significantly different from zero. As the coefficients in Table 6 show, an increase in each of these ratios (except urea/seed) causes the potential gain G_T to decrease, which is equivalent to an increase in the efficiency level of farms. The level of efficiency will decrease either by using more urea fertiliser, given the current amount of seed, or by decreasing seed while the amount of urea is constant.

Table 6
OLS estimation of the Timmer efficiency equation

Variables	Estimated coefficient	Standard error	*t*-statistic
Constant	0.099	0.096	1.037
Land/labour	−0.079	0.581	−0.136
Water/seed	−2.856	1.140	−2.505
Phosphate/seed	−0.127	0.051	−2.470
Urea/seed	0.328	0.092	3.554
Phosphate/urea	−0.181	0.052	−3.509
Water/phosphate	1.640	1.029	1.593
Water/urea	0.566	1.241	0.456
R^2	0.123		
F	3.128		

5. Summary and conclusions

In this paper, Timmer and Kopp indexes of technical inefficiency were estimated for 164 farms in Kerman province, Iran, using a Cobb–Douglas frontier production function with a composite error term, and a developed relationship between these two indices. The results show that the mean values of the Timmer and Kopp TE indices were over 0.90, but one quarter of the farms were below 0.90 for the Timmer index and below 0.87 for the Kopp index. The level of inefficiency was found to be related to farm size: small and large farms were shown to be more technically efficient than medium-sized farms, and efficiency was found to be affected by some input ratios such as the ratio of fertiliser to seed. With the given inputs, the production of wheat could be increased by 7.2% on average through making all farms 100% efficient. Alternatively, inputs could be reduced by 9% on average to produce the same amount of wheat output.

Examining the distribution of results, wheat producers in Kerman appear somewhat more inefficient in their use of inputs than in maximising production levels. There are farmers who can gain over 30% by a reduction in the inputs for the same level of output. Changing the combination of inputs, e.g. the fertiliser ratio, could increase the farm level of efficiency.

Farmers can improve the level of inefficiency either by applying a new technique of production that is a different combination of inputs, or by adopting technological progress. They may accept more easily and quickly a new combination of inputs to reduce the total cost of production, i.e. to increase the profit per ha, than a new technology. So, encouraging more efficient techniques can be regarded as a policy with relatively speedy effects to increase the profitability of wheat production, and to release surplus inputs to be used in the production of an extra amount of either wheat or other products.

The lower level of efficiency but higher yield in the medium-sized farms means that more wheat can potentially be produced in these farms. So, as far as the general policy of attending self-sufficiency in wheat is concerned, applying improved input management on these farms can be recommended alongside appropriate new technologies. Further studies to investigate sources of inefficiency such as diversification versus specialisation, and availability and suitability of new technologies, and to determine the level of other indices of inefficiency such as profit efficiency, are recommended in order to develop more productive and profitable techniques of wheat production in Iran.

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