Research Journal of Agricultural and Environmental Management Vol. 2(2), pp. 033-043, February, 2013
Available online at http://www.apexjournal.org
ISSN 2315-8719© 2013 Apex Journal International

Full Length Research Paper

Total factor Productivity and Efficiency in Iranian Crop Production: A None Parametric Approach

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Accepted 20 December, 2013

Productivity growth is a major source of economic growth and welfare improvement and works for obtaining economic goals. On the other hand, because of its basic role in providing strategic products and food security, Iranian Agronomy Sub-Sector has an excessive importance in agriculture sector as a main and important sector in Iranian economy. In this research, technical, allocative and economic efficiency, total factor productivity and optimum values for cost minimizing are calculated for strategic agronomy products including wheat, barley, rice, cotton and sugar beet in 15 years during 1995 to 2009 by Malmquist index and data envelopment analysis (DEA) method. Results show that productivity for these products has generally risen in this period. Technical efficiencies are in high levels but allocative and economic efficiencies are in lower levels. Economic efficiency and consequently farmers' income can increase by optimizing value of inputs and employing more advanced technology and improving agricultural extension.

Key words: Total factor productivity (TFP), efficiency, Malmquist index, data envelopment analysis (DEA), crop production.

INTRODUCTION

Productivity growth is of interest to economists and policymakers; because, it is a major source of economic growth and welfare improvement. In the economics literature, aggregate productivity refers to the amount of output obtained from given levels of inputs in an economy or in a sector. In Iran, agriculture sector produces more than 20 percent of GNP and a main part of non-oil export; so, this sector should be pondered more specifically in order to increase productivity in Iranian economy. In addition, Agronomy has the highest share in added value of Agriculture Sector (60% in recent 30 years) (IAM, 2004), playing the basic role in providing strategic products and food security; so, the necessity of investigating on Agronomy Sub-sector is obvious.

The purpose of this paper is to investigate total factor productivity (TFP), technical, allocative, and economic efficiency and cost-minimizing input values for strategic products including wheat, barley, rice, cotton and sugar beet (that produce almost half of value in Agronomy Sub-sector) over a 15-year period of 1995 to 2009.

The methodology is based on ideas from measurement of efficiency by (Farrell, 1957) and from measurement of productivity as expressed by (Caves et al., 1982). In his classic article, "The Measurement of Productive Efficiency,". Farrell introduced a framework for efficiency determining in which overall efficiency can be decomposed into the two component measures: allocative and technical efficiency. Technical efficiency is the reciprocal of the (Shephard, 1981) and (Malmquist, 1953) distance function. Caves et al. 1982 defined the input-based Malmquist productivity index as the ratio of two input distance functions. They developed Malmquist output and input productivity indices for multiple-input, multiple-output technologies that are valid for any returns to scale. The output- (input-) oriented index is based on an output (input) distance function and reflects changes in maximum output (minimum input requirements) given inputs (outputs). Caves et al. (1982) stated that unless some functional form is specified for a parametric production frontier, these indices cannot be computed. As an index number alternative, the Translog structure of production, an (output) input index can be constructed as a geometric mean of two Malmquist output (input) indices using data on prices and quantities, without the

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knowledge of the translong parameters defining the production frontier.

Färe et al. (1994) extended the work of Caves et al. (1982) in two important ways. First, they showed how to compute Malmquist indices relative to a nonparametric specification of production frontier. They did so by using the nonparametric, linear programming techniques of data envelopment analysis (DEA) to fit distance functions to data on input and output quantities. They directly calculated productivity as a geometric mean of two Malmquist indices, without price data and without using a translog functional form. Second, Färe et al. (1994) generalized the pervious approach by decomposing productivity index into technological change and efficiency change. However, whereas their approach is nonparametric, it imposes a constant return to scale (CRS) restriction on the frontier technology. They used a variable return to scale (VRS) technology only for the purpose of further decomposing efficiency change. There are some cases that have used macro-economic data for estimating efficiency and productivity.

Bravo-Ureta and Evenson (1994) calculated the efficiency in agricultural production of peasant farmers in eastern Paraguay. They suggested that improving efficiency is a good substitute for increasing under-culture land. Kumbhakar (1994) studied the efficiency of India farmers and used stochastic sampling to reach needed data and then estimated a translog product function and frontier product function by maximum likelihood estimation (MLE).

Chavas (2001) provided an international analysis of agricultural productivity. The paper relies on non-parametric methods to estimate a representation of technology. The analysis uses FAO annual data on agricultural inputs and outputs for 12 countries between 1960 and 1994. Productivity indices are estimated using non-parametric methods. They show the evolution of agricultural productivity both ever time and across countries. The empirical results illustrate the usefulness of the methodology as well as limitation of current data. Färe et al. (2001) analyzed productivity growth in 16 of Taiwan's manufacturing industries during 1978 to 1992. The non-parametric DEA approach is used to compute Malmquist productivity indices. Empirical results indicate that the sector's TFP increased at a rate of 2.89% per annum, which could be ascribed to a technical progress 2.56% and an efficiency improvement 0.33%. Managi and Karemera (2004) applied data envelopment analysis (DEA) techniques to a state-level data set in order to measure the total factor productivity (TFP) in US agriculture over 1960 to 1996. TFP is decomposed into input and output biased technological change, efficiency change, and scale change, under both constant return to scale (CRS) and variable return to scale (VRS). Assumption of Hick neutral technological change is discussed. Technological change is found to be the result of efficient use of inputs much more than the effects of output capability increase. Bailey et al. (2004b) calculated productivity growth in agricultural sector of England by Tornquist-Theil index. In this study, disadvantages of common indices for calculating productivity (like as Divisia index) are mentioned and then Tornquist-Theil index is identified as the best index for calculating productivity in agricultural sector of England. Bailey et al. 2004a) applied maximum entropy (ME) techniques to jointly estimate the share equations of a multi-output restricted profit function and the impact of technology and policy biases in post-war UK agriculture. The model provides evidence of factor saving biases for Land, Labor and Feed inputs and output augmentation for Crop and Horticultural products. They conclude that recent agricultural policy changes appear to have had a significant biasing impact on profit shares. However, early attempts at partial decoupling appear to have fallen short of expectations. Kwon and Lee (2004) estimated parametric and non-parametric production frontiers and compared with estimated productivity, using panel data on Korean rice production. Both approaches reveal that the main sources of growth in Korean rice farming have been technical change and productivity improvements in regions of the country that have been associated with low efficiency.

Chauhan et al. (2006) used a data envelopment analysis (DEA) approach to determine the efficiencies of farmers with regard to energy use in rice production activities in the alluvial zone in the state of West Bengal in India. Their study helped to segregate efficient farmers from inefficient ones, identify wasteful uses of energy from different sources by inefficient farmers and to suggest reasonable savings in energy uses from different sources.

Ramanathan (2006) used a DEA approach to study the comparative performance of selected Middle East and North Africa countries. Kumar (2006) examined conventional and environmentally sensitive TFP in 41 developed and developing countries over the period of 1971 to 1992. He used directional distance function to derive Malmquist–Luenberger (ML) productivity index.

METHODOLOGY

Farrell (1957) suggested economic efficiency as the degree of accomplishment of a unit in minimizing cost of a given value of product. He separated economic efficiency into allocative efficiency and technical efficiency and believed that allocative efficiency is achieved by optimizing input values. If inputs are allocated optimally regarding to their prices, the profit will be maximized and allocative efficiency will be achieved. On the other side, a unit is technically efficient if maximum available product is achieved by using a given value of products. Productivity involves goals and values. It increases input return achieved by increasing economic efficiency and using proper and more advanced technology.

Malmquist total factor productivity index

Malmquist index and efficiency values measured by DEA method are used for defining Productivity. Charnes et al. (1978) suggested practical measuring of efficiency by linear programming. This method now is known as Data Envelopment Analysis, because it envelopes all data. It is used to calculate distance functions and to construct productivity measures. This method is a set of nonparametric mathematical programming techniques for estimating the relative efficiency of production units and for identifying best practice frontiers. Like the distance function formulation, DEA is not conditioned on the assumption of optimizing behavior on the part of each individual observation, nor does DEA impose any particular functional form on production technology.

Maintained hypotheses may be an advantage, particularly for micro-level analyses that extend over a long time series, where assumptions of technological efficiency of every production unit in all time periods might be suspect. In this method, productivity is measured by Malmquist Index for each unit and TFP is divided into efficiency change and technological change. Furthermore, this method measures productivity and efficiency for multi-product units. Malmquist index also separates total productivity into two main part involving technological change and efficiency change. Färe et al. (1992) suggested that if product qt is achievable by using technology Ft and input xt over the period t=1, 2, …, T; and Ft={(xt,qt): xt can produce qt} Therefore Malmquist index is defined based on Distance Function:

If real assumption of existing non-efficient units in industry is considered, Malmquist Productivity Index is defined with four distance functions that are reversed values of efficiencies defined by Farrell:

$$M_i^{t+1}(q^{t+1}, x^{t+1}, q^t, x^t) = \frac{D_i^{t+1}(q^{t+1}, x^{t+1})}{D_i^t(q^t, x^t)}\left[\frac{D_i^t(q^{t+1}, x^{t+1})}{D_i^{t+1}(q^{t+1}, x^{t+1})}\frac{D_i^t(q^t, x^t)}{D_i^{t+1}(q^t, x^t)}\right]^{1/2} = E_i^{t+1} \times T_i^{t+1}$$

where E_i^{t+1} is efficiency change and T_i^{t+1} is technological change (with shifting frontier product function between period t and t+1, $M_i^{t+1}(q^{t+1}, x^{t+1}, q^t, x^t)$ = efficiency change × technological change, TFP change = pure technical (managerial) efficiency change × scale efficiency change × technological change.

A key advantage of the distance function approach is that it provides a convenient way to describe a multi-input, multi-output production technology without the need to specify functional forms or behavioral objectives, such as cost-minimization or profit-maximization.

Measuring total productivity

Total productivity and its parts can be measured by DEA like linear programming method and using pooled data. In order to measure TFP change, Färe et al. (1994) assumed a constant return to scale (CRS) technology in their analysis. The required linear programs are:

$[d_0^t(Y_t, X_t)]^{-1} = \max\varphi$ St: $-\varphi Y_{it} + Y_t\lambda >= 0$ $X_{it} - X_t\lambda >= 0$ $\lambda >= 0$	$[d_0^s(Y_s, X_s)]^{-1} = \max\varphi$ St: $-\varphi Y_{is} + Y_s\lambda >= 0$ $X_{is} - X_s\lambda >= 0$ $\lambda >= 0$	$[d_0^t(Y_s, X_s)]^{-1} = \max\varphi$ St: $-\varphi Y_{is} + Y_t\lambda >= 0$ $X_{is} - X_t\lambda >= 0$ $\lambda >= 0$	$[d_0^s(Y_t, X_t)]^{-1} = \max\varphi$ St: $-\varphi Y_{it} + Y_s\lambda >= 0$ $X_{it} - X_s\lambda >= 0$ $\lambda >= 0$

If price data are available and units are cost-minimizers or revenue-maximizers, allocative efficiency can be measured. Thus linear programming problems are needed, one for measuring technical efficiency and the other for measuring allocative efficiency.

RESULTS

In order to measure efficiency and TFP of strategic products in Iranian crops production; namely, wheat, barley, rice, cotton and sugar beet, we used production cost data published by Agriculture Ministry by considering the cost of inputs such as seed, chemical fertilizer, anti-pest, labor and land.

Average of efficiency and productivity for different products

Table 1 shows average of productivity, technical, a locative and economic efficiency for different products.
Productivity of different agricultural products generally increased over mentioned period. Productivity of cotton

Table 1. Average of productivity, technical, a locative and economic efficiency (1995-2009).

Crops	Productivity index	Technical efficiency	Allocative efficiency	Economic efficiency
Irrigated wheat	1.011	0.94	0.897	0.842
Rain fed wheat	1.024	0.835	0.896	0.745
Irrigated barley	1.001	0.948	0.798	0.753
Rain fed barley	1.018	0.86	0.897	0.774
Rice	1.012	0.942	0.829	0.78
Irrigated cotton	1.076	0.935	0.699	0.657
Rain fed cotton	1.069	0.835	0.485	0.418
Sugar beet	1.066	0.932	0.858	0.797

Reference: research results.

has risen more than other products and irrigated barley has the least productivity increase. Technical efficiencies are generally high but allocative and economic efficiencies are in lower levels. Irrigated barley and rice have the highest technical efficiency while the lowest technical efficiency belongs to rainfed wheat and rainfed cotton. Irrigated wheat has the highest allocative and economic efficiency whereas the lowest allocative and economic efficiency belongs to rainfed cotton.

Irrigated wheat

Values of Malmquist TFP index for irrigated wheat is shown in Figure 1. Malmquist index of irrigated wheat has fluctuated over time and increased slightly. TFP includes all categories of productivity change, which can be decomposed into two components: (1) technological change (shifts in the production frontier) and (2) efficiency change (movement of inefficient production units relative to the frontier) (Fare et al., 1994). Results show that TFP was affected by technological change rather than efficiency change; that is, technical efficiency part was almost constant. Consistent improvement of productivity over 1997 to 2001 was found. It is concluded that technological change was the principal factor responsible for productivity increase since efficiency amounts keep relatively constant.

Technological change improved over the period due to innovating new genetically-refined seeds and extension new fertilizers. Moreover, some of productivity changes can be proved by amount of precipitation in different years. The average of precipitation in Iran is shown in Table 2. Drought led productivity to decrease in 2004 and 2005 but Malmquist index has increased after 2006 due to improving climate condition. Average of Malmquist index is 1.011 that shows that productivity of irrigated wheat has grown a little over the period.

Figure 2 shows technical, allocative and economic efficiency for irrigated wheat. Technical, allocative and consequently economic efficiency of irrigated wheat are in high levels, illustrating that farmers did effectively in culturing this crop. Averages of technical, allocative and economic efficiency are 0.94, 0.897 and 0.842 respectively. Results show that allocative efficiency increased at last years of the period but technical efficiency reduced slightly.

Rainfed wheat

A Malmquist TFP index of rainfed wheat is shown in Figure 3. Malmquist index of rainfed wheat has fluctuated excessively over the period. Results show that Malmquist index doesn’t have any regular trend over the period, in some years it has increased intensively; but, in some other years, it has decreased a lot. In addition, results show that TFP was affected by technological change rather than efficiency change; to be precise, the share of technical efficiency was almost constant. Therefore, cyclical fluctuations in productivity are maybe because of fluctuations in precipitation and other weather conditions. Productivity increased during rainy years; in contrast, it decreased during dry years. Average of Malmquist index is 1.024, showing that productivity of rainfed wheat has grown a little during the period.

Figure 4 shows technical, allocative and economic efficiency for rainfed wheat. Allocative and technical efficiency of rainfed wheat are high; but, economic efficiency is relatively lower than them. Averages of technical, allocative and economic efficiency are respectively 0.835, 0.895 and 0.745. Results show that technical efficiency fluctuated more than allocative efficiency did over the period.

Irrigated barley

Values of Malmquist TFP index for irrigated barley is shown in Figure 5. Malmquist index of irrigated barley fluctuated a little over the period. Moreover, results show that TFP was affected by technological change rather than efficiency change; on the other words, the share of technical efficiency was practically constant. Constance

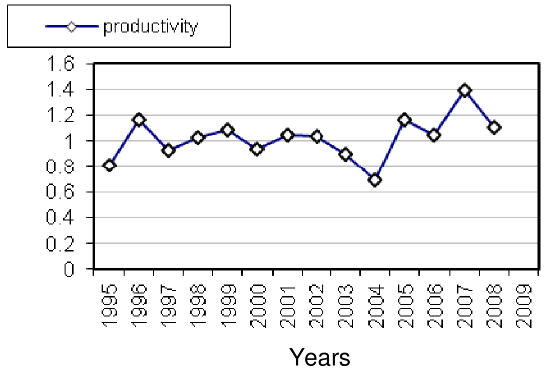

Figure 1. TFP for irrigated wheat.

Table 2. Average of precipitation in Iran.

Year	2003	2004	2005	2006	2007	2008	2009	Average of recent 30 years
precipitation (mm)	262.31	171.88	195.98	232.40	254.95	301.48	271.34	247.19

Reference: Meteorological Organization of Iran.

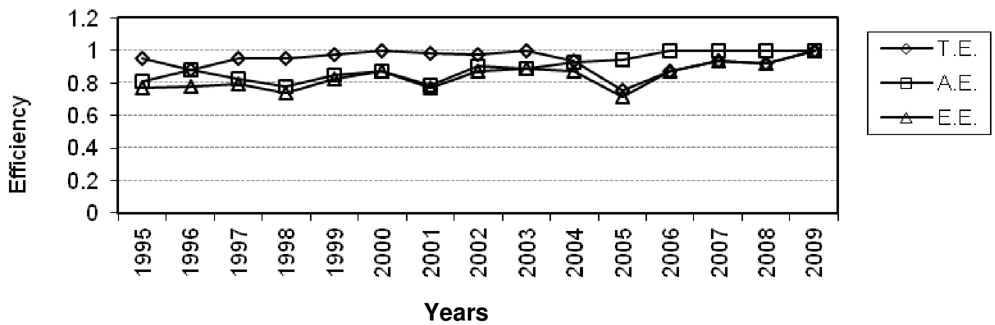

Figure 2. Technical, allocative and economic efficiency for irrigated wheat.

of technical efficiency caused TFP to be affected by technological change rather than efficiency change. It is concluded that technological change was the principal factor responsible for productivity increase since efficiency amounts keep relatively constant. Drought led productivity to decrease in 2004 and 2005; but, Malmquist index increased after these 2 years because of improving weather condition. Average of Malmquist index is 1.001 during the period, showing that productivity of irrigated barley has been constant over the period.

Figure 6 shows technical, allocative and economic efficiency for irrigated barley. Technical efficiency of irrigated barley is high level; precisely, farmers cultured this crop in an effective manner; on the contrary, allocative efficiency and consequently economic efficiency are in lower levels than technical efficiency. Averages of technical, allocative and economic efficiency are 0.948, 0.798 and 0.753 respectively. Results show that allocative efficiency increased over last years of the period; but, technical efficiency reduced firstly and then increased.

Rainfed barley

Values of Malmquist TFP index for rainfed barley are demonstrated in Figure 7. Malmquist index of rainfed barley fluctuated a lot over the period. Results show that Malmquist index does not have any regular trend over the period; in some years, it increased a lot; but, it has a decreasing trend in some other years. Additionally, results show that TFP was affected by technological change rather than efficiency change; namely, technical efficiency share was almost constant. It is concluded that

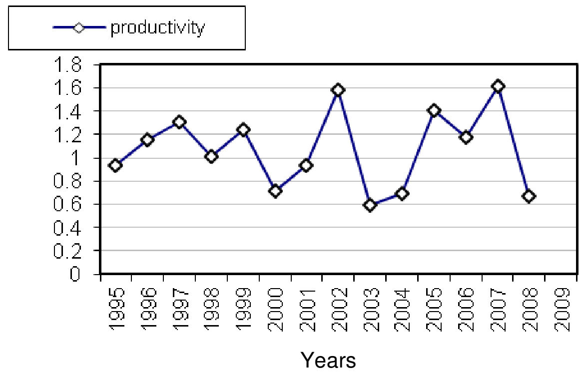

Figure 3. TFP change for rainfed wheat.

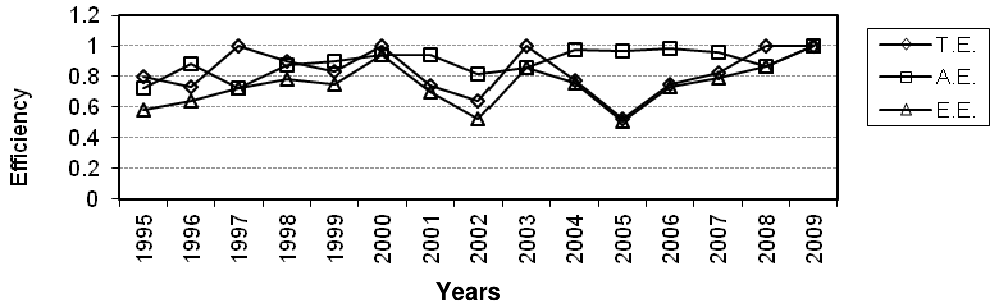

Figure 4. Technical, allocative and economic efficiency for rainfed wheat.

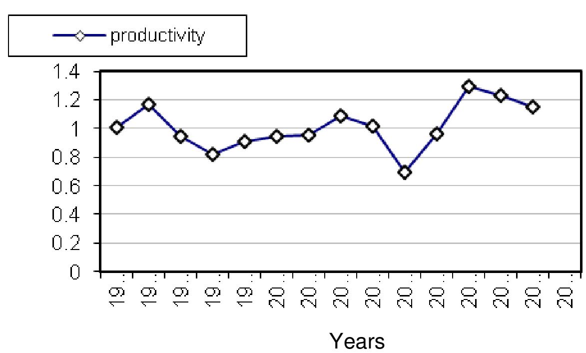

Figure 5. TFP change for irrigated barley.

cyclical fluctuations in productivity are probably because of fluctuations in precipitation and other weather conditions. Productivity has increased in rainy years and decreased in dry years. Average of Malmquist index was 1.018 that shows that productivity of rainfed barley has grown a little over the period.

Figure 8 shows technical, allocative and economic efficiency of dry barley. Allocative efficiency of dry barley is in high level; while, technical efficiency and economic efficiency are in lower levels than allocative efficiency. Averages of technical, allocative and economic efficiency are 0.86, 0.897 and 0.774 respectively. Results show that fluctuation in technical efficiency is more than allocative efficiency.

Rice

Values of Malmquist TFP index of rice is shown in Figure 9. Malmquist index of rice fluctuated slightly over the

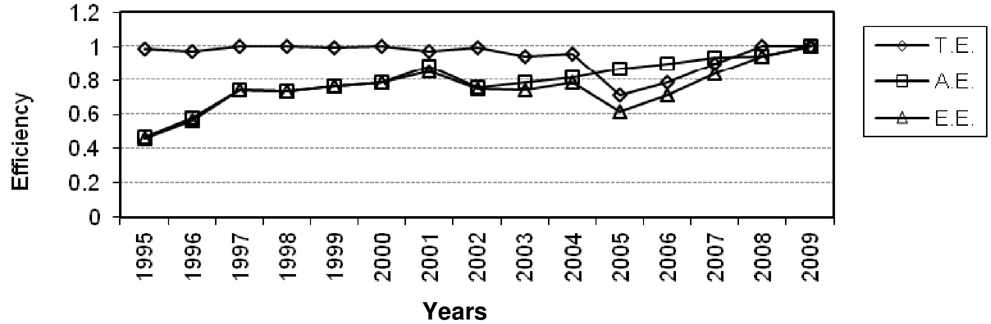

Figure 6. Technical, allocative and economic efficiency for irrigated barley.

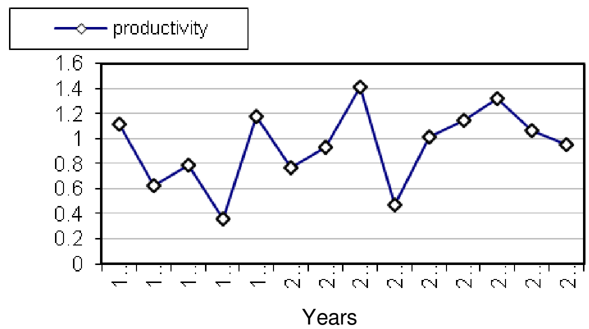

Figure 7. TFP change for rainfed barley.

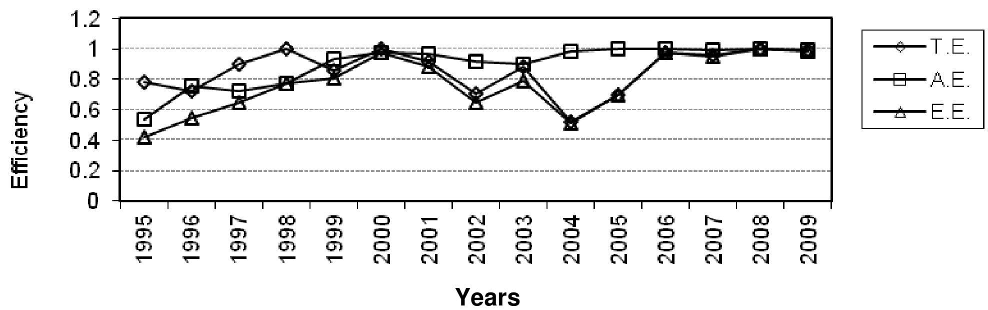

Figure 8. Technical, allocative and economic efficiency for rainfed barley

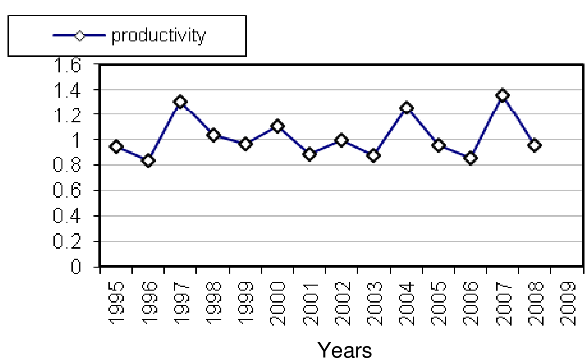

Figure 9. TFP change for rice.

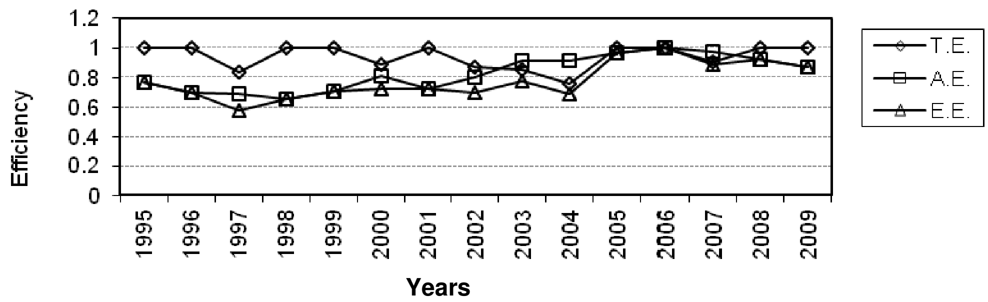

Figure 10. Technical, allocative and economic efficiency for rice.

period. Furthermore, results show that TFP was affected by technological change rather than efficiency change; to be precise, the share of technical efficiency was almost constant. Constance of technical efficiency led TFP to be affected by technological change rather than efficiency change. It is concluded that technological change was the principal factor responsible for productivity increase; since, efficiency amounts keep relatively constant. Productivity decreased in 2006, 2007 and 2009; while, Malmquist index increased in 2008. Average of Malmquist index is 1.012 during the period, showing that productivity of rice has grown to some extent over the period.

Figure 10 shows technical, allocative and economic efficiency of rice. As technical efficiency of rice is high, it is concluded that farmers carried out effectively in culturing rice. Allocative efficiency and consequently economic efficiency are relatively desirable. Averages of technical, allocative and economic efficiency are 0.942, 0.829 and 0.78 respectively. Allocative efficiency increased at last years of the period; while, technical efficiency had a nearly constant trend after 2004.

Irrigated cotton

Values of Malmquist TFP index for irrigated cotton is demonstrated in Figure 11. Malmquist index of irrigated cotton fluctuated a little over the period. Additionally, results show that TFP was affected by technological change rather than efficiency change; on the other words, technical efficiency share was almost constant. Constance of technical efficiency caused TFP to be affected by technological change rather than efficiency change. Drought led productivity to decrease in 2005; while, Malmquist index increased after 2005 because of improving weather condition. Average of Malmquist index during the period is 1.076, illustrating that productivity of irrigated cotton has grown over the period.

Figure 12 shows technical, allocative and economic efficiency of irrigated cotton. Technical efficiency of irrigated cotton is high during the period except of 2002; namely, farmers were effective in culturing this crop; whereas, allocative efficiency and consequently economic efficiency are in relatively low levels. Averages of technical, allocative and economic efficiency are 0.935, 0.699 and 0.657 respectively. Allocative efficiency increased at last years of the period but technical efficiency reduced firstly and then had a constant trend.

Rainfed cotton

Values of Malmquist TFP index for rainfed cotton is shown in Figure 13. Malmquist index of rainfed cotton fluctuated significantly over the first years of period; but, it had an increasing trend from 2003. Moreover; results show that TFP was affected by technological change rather than efficiency change; on the other words, technical efficiency share was almost constant. Average of Malmquist index was 1.069, showing that productivity of rainfed cotton has grown over the period.

Figure 14 shows technical, allocative and economic efficiency for rainfed cotton. Technical efficiency of rainfed cotton is high; but, allocative efficiency and consequently economic efficiency are in low levels. Averages of technical, allocative and economic efficiency are 0.835, 0.485 and 0.418 respectively. Moreover, technical efficiency decreased in 2004, 2005 and 2006; but, increased after 2006.

Sugar beet

Values of Malmquist TFP index for sugar beet is shown in Figure 15. Malmquist index of sugar beet has fluctuated a little over the period. Additionally, results show that TFP was affected by technological change rather than efficiency change; precisely, technical efficiency share was almost constant. Constance of technical efficiency led TFP to be affected by technological change rather than efficiency change. Productivity was constant on 2003 and 2007; but, Malmquist index increased in 2008 and then decreased in 2009. Average of Malmquist index was 1.066, showing that productivity of sugar beet has grown over the period.

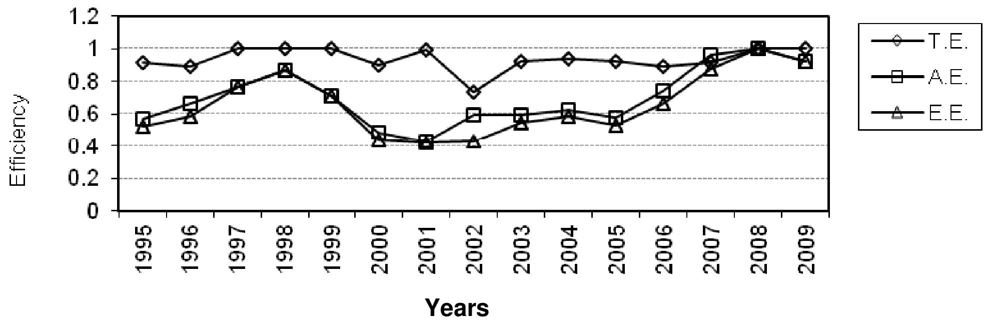

Figure 12. Technical, allocative and economic efficiency for irrigated cotton.

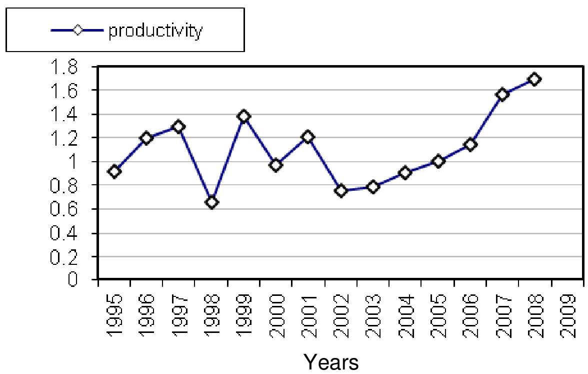

Figure 13. TFP change for rainfed cotton.

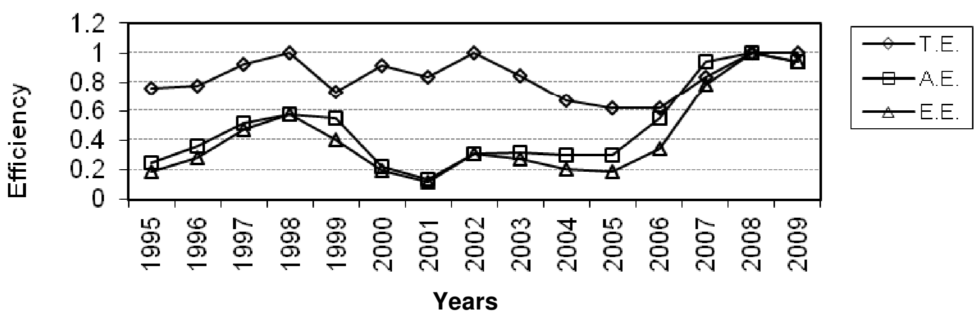

Figure 14. Technical, allocative and economic efficiency for rainfed cotton.

Technical, allocative and economic efficiency for sugar beet are shown in Figure 16. Technical efficiency of sugar beet is high; precisely, farmers cultured this crop effectively. Allocative and consequently economic efficiency are also in relatively high levels. Averages of technical, allocative and economic efficiency are 0.932, 0.858 and 0.797 respectively.

Optimum values for cost minimizing

If production inputs of different crops are used at the cost-minimizing optimum values, the quality and quantity of outputs will increase and the economic cost of production process will decrease. Cost-minimizing optimum values of production inputs for different crops are shown in Table 3.

As mentioned before, values of technical efficiencies are in high levels; in contrast, values of allocative efficiencies are in lower levels; it shows that farmers consider optimal technical amounts of inputs; but, they do not observe optimum cost-minimizing amounts; so, higher income can be obtained if they observe optimum cost-minimizing amounts. On the other words, farmers can obtain higher income in a given production amount, because of improving allocative efficiency.

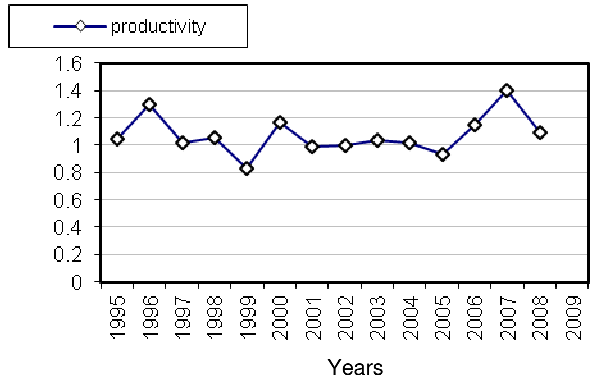

Figure 15. TFP change for sugar beet.

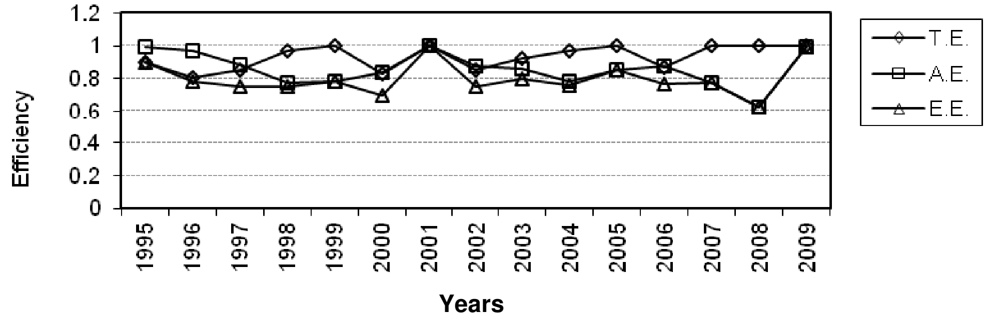

Figure 16. Technical, allocative and economic efficiency for sugar beet.

Table 3. Cost-minimizing values of production inputs.

Crops	land (hectare)	labor (worker-equivalent in hectare)	chemical fertilizer (kg in hectare)	antipest (kg in hectare)	seed (kg in hectare)
Irrigated wheat	2547632	43	374.13	0.835	236.76
Rainfed wheat	4057688	22	107.28	0.532	122.67
Irrigated barley	597494	45	308.44	0.215	200.12
Rainfed barley	988621	34	96.816	0.123	124.62
rice	532766	126.26	387.711	4.724	100
Irrigated cotton	145444	95.873	464.506	1.265	106.397
Rainfed cotton	7699	56.104	307.916	2.785	49.944
Sugar beet	154409	77.555	583.515	4.967	22.695

Reference: Research results.

Conclusion

In this research, technical, allocative and economic efficiency, TFP and optimum cost-minimizing amounts are calculated for strategic products including wheat, barley, rice, cotton and sugar beet in a 15-year period during 1995-2009 by Malmquist index and DEA method. Results show that productivity of these products has generally risen over this period. Technology improved during the period; while, efficiency was constant over this period; illustrating that TFP was affected by technological change rather than efficiency change; precisely, technical efficiency share was almost constant. Slight improvements of productivity over the period were found. Technological change is the principal factor responsible for productivity increase; since, efficiency amounts keep relatively constant. Technological change improved over the period because of innovating new genetically-refined seeds, improving agricultural extension and using new fertilizers; so, it is recommended that these new methods are developed more and more in order to improve technological change and consequently productivity in agronomy sector. In the recent years, more attention is paid to researches, focusing on such fields, causing productivity improvement, specifically; Biotechnology Research Department, working on new technologies for improving the quantity and quality of production, was set up in 2004. However, most of research founding is not yet applied in practice. Such organizations must be supported by government and their research founding should be used in practice. In order to improve their knowledge and skillfulness, farmers should be consulted and educated in such way that new technologies are accepted by them easily. More attention should be paid on investment on research, innovation and extension of new technologies. Allocative and economic efficiency can be increased by extension and educating farmers to use optimum cost-minimizing amounts of production inputs so that farmers' income increase. Furthermore, using new technologies is recommended if authorities plan to improve basic and proper extension as well as farmers' education and knowledge.

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