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Environmentally Adjusted Productivity Measurement of the Iranian Agricultural Sector

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Abstract

In this study, the conventional and environmentally adjusted productivity and the efficiency and technical changes of the Iranian agricultural sector are measured, using the Malmquist-Luinberger index and the panel data from 28 provinces over the period 2000-2008. Results show that the annual average of nitrogen balance index, as a proxy of nitrogen pollution, is 32.7 kilograms per hectare of agricultural land and nitrogen use efficiency is 62%. On average, the conventional total factor productivity, efficiency and technical change indices are 0.9687, 0.9610 and 1.008, respectively, while the environmentally adjusted counterpart indices are 0.9716, 0.9738 and 0.9977. Hence, by ignoring pollution, conventional measurements of productivity tend either to overestimate or to underestimate the true productivity of the agricultural sector.

Key words: Directional distance function, Malmquist-Luenberger index, Nitrogen pollution, Iran.

اندازه‌گیری بهره‌وری زیست‌محیطی بخش کشاورزی ایران

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چکیده

دراین مطالعه بهره وری، کارایی و تغییر تکنولوژی متداول و زیست محیطی در بخش کشاورزی کشور با استفاده از شاخص مالم کوئیست لونبرگر و داده های تابلویی ۲۸ استان و طی دوره زمانی ۸۷-۱۳۷۹ محاسبه گردید. نتایج نشان می دهد میانگین سالانه شاخص موازنه نیتروژن به عنوان تقریبی از آلودگی نیتروژن، ۳۲,۷ کیلوگرم در هکتار و میانگین کارایی مصرف نیتروژن در کشور ۶۲ درصد بوده است. به طور میانگین شاخصهای بهره وری، کارایی و تغییر تکنولوژی متداول برابر با ۰,۹۶۸۷، ۰,۹۶۱۰ و ۱,۰۰۸ بوده و شاخصهای متناظر زیست محیطی آنها به ترتیب ۰,۹۷۱۶، ۰,۹۷۳۸ و ۰,۹۹۷۷ بوده است. بنابراین نادیده گرفتن آلودگی در محاسبه شاخصهای بهره وری منجر به برآورد بیش از حد یا کمتر ازحد مقدار واقعی آنها می شود.

کلمات کلیدی: تابع فاصله جهت دار، شاخص مالم کوئیست لونبرگر، آلودگی نیتروژن، ایران.

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1. Introduction

Over the past three decades, the agriculture sector of Iran has experienced sharp growth. For example, the production of wheat, barley and rice has risen from 6.88 million tons in 1981 to 16.1 million tons in 2006. Simultaneously, consumption of chemical fertilizers has increased significantly from 1.64 to 3.4 million tons during this period [22]. An adequate supply of nutrients such as nitrogen is necessary in the soil for crop growth but surplus nutrients in excess of crop needs can be a source of environmental pollution and damage to surface water, groundwater and atmosphere. Nutrient runoff into rivers, lakes and coastal waters can accelerate the process of eutrophication, reduce the quality of drinking water and damage their usefulness for fishing and recreational purposes. Contaminated groundwater can be harmful for human health and air pollution can lead to greenhouse gas emissions through the volatilization of ammonia [19]. Although increased outputs have provided significant economic welfare, environmental pollution resulting from excessive use of chemical fertilizers has implicitly reduced social welfare.

Productivity has been considered by policymakers in Iran as a significant engine for growth. According to the 5th National Development Plan Law, one-third of economic growth must be achieved annually through productivity growth [25]. In many studies, conventional productivity growth has been measured in the agriculture sector of Iran while pollution has been ignored [2, 3, 20, 14, 23, 4]. Pollution control may reduce productivity while more inputs may need to produce the same level of output. Thus, the conventional productivity index that ignores environmental impacts can present an incomplete picture of productivity growth. Ball *et al.* [5] showed that productivity measurement of the US agricultural sector differs when pesticide pollution of groundwater and surface water are accounted for. Furthermore, Nanere *et al.* [17] writing on the Australian agriculture sector, Murtry *et al.* [16] on the Indian sugar industry, Aiken and Pasurka [1] and Färe *et al.* [9] on the US manufacturing sector, all indicated that including pollution has a measurable effect on the productivity measurement.

The measurement of productivity growth traditionally requires data on prices of outputs and inputs, whereas price data of non-marketed pollution does not exist. This problem can be resolved using Malmquist's productivity index, where only quantitative information is required in its computation. However, Malmquist's productivity index is based on the Shephard distance function, which expands desirable and undesirable outputs to the production frontier. Chung *et al.* [6] defined the Malmquist-Luenberger (ML) index based on the directional distance function. This function allows the simultaneous increase of desirable outputs and decrease of undesirable outputs. In several studies the directional distance function has been used to calculate the shadow price of pollution abatement [for example, 12, 8, 10, 24] or the total factor productivity index [for example, 9, 7, 11, 13].

This study employs the ML index to incorporate the environmental impacts of nitrogen pollution into the measurement of productivity growth in the agriculture sector of Iran. In the next section the directional output distance function, the ML index and empirical model are explained. Then, data and estimates of conventional and environmentally adjusted productivity are presented. The conclusions are provided in the final section.

2. Materials and Methods

To model the joint production of desirable and undesirable outputs, $y \in R_+^M$ are desirable outputs, $b \in R_+^I$ are undesirable outputs and $x \in R_+^N$ are inputs [7, 8, 10]. Also, suppose that the feasible output set, P(x), represents the set of (y,b) that can be jointly produced from inputs x as follows:

$$P(x) = \{(y, b): \text{ x can produce } (y, b)\} \quad (1)$$

It is assumed that desirable output is strongly disposable:

$$\text{If } (y,b) \in P(x) \text{ and } y' \leq y \text{ then } (y', b) \in P(x) \quad (2)$$

Strong or free disposability implies that desirable outputs can be reduced without any reduction in undesirable outputs. In contrast, the reduction of undesirable outputs is costly and requires the reallocation of inputs from the production of desirable outputs to mitigation of undesirable outputs. In other words, desirable and undesirable outputs are together weakly disposable:

$$\text{If } (y,b) \in P(x) \text{ and } 0 \leq \theta \leq 1 \text{ then } (\theta y, \theta b) \in P(x) \quad (3)$$

Finally, it is assumed that desirable and undesirable outputs are null-joint. This means that it is not possible to produce a desirable output without producing an undesirable output:

$$\text{If } (y,b) \in P(x) \text{ and } b = 0 \text{ then } y = 0 \quad (4)$$

A data envelopment analysis (DEA) model can be constructed to satisfy the above conditions [9]. In this model, the output set is defined as:

$$P^t(x^t) = \left\{ (y^t, b^t) : \sum_{k=1}^{K} z_k^t y_{km}^t \geq y_m^t \quad m=1, \ldots, M \right.$$

$$\sum_{k=1}^{K} z_k^t b_{ki}^t = b_i^t \quad i=1, \ldots, I$$

$$\sum_{k=1}^{K} z_k^t x_{kn}^t \leq x_n^t \quad n=1, \ldots, N$$

$$\left. z_k^t \geq 0 \quad k=1, \ldots, K \right\} \quad (5)$$

Where k=1, …, K denotes observations of inputs and outputs, t= 1, …, T denotes the time period and Z_k^t are intensity variables or weights used to form the production possibility frontier. The first constraints imply strong disposability of desirable outputs. The first and second constraints together imply weak disposability of desirable and undesirable outputs. The final constraint imposes the constant return to scale of technology. To satisfy the null-joint character of desirable and undesirable outputs, the following constraints must be imposed:

$$\sum_{k=1}^{K} b_{ki}^t \succ 0 \quad i=1, \ldots, I \quad (6)$$

$$\sum_{i=1}^{I} b_{ki}^t \succ 0 \quad k=1, \ldots, K \quad (7)$$

According to constraint (6), each undesirable output is produced by at least one firm. The next inequity implies that each province produces at least one undesirable output. The directional output distance function can be used as a computable function to represent the production possibility frontier. Suppose g=(g_y ,-g_b) is a direction vector, then the directional output distance function is defined as:

$$\vec{D}_0(x, y, b; g) = \sup\{\beta : (y + \beta g_y, b - \beta g_b) \in P(x)\} \quad (8)$$

This function depicts the output vector (y,b) in the direction (g_y ,-g_b) on the boundary of p(x). The direction (y,-b) seeks, simultaneously, the maximum increase in desirable outputs and reduction in undesirable outputs. As shown in Fig. 1 the shepherd output distance function expands desirable and undesirable outputs simultaneously and depicts the output vector M on the frontier at point N, while the directional output distance function takes place at the point on the P point where the maximum feasible expansion of the desirable output and reduction of the undesirable outputs are obtained [8, 11].

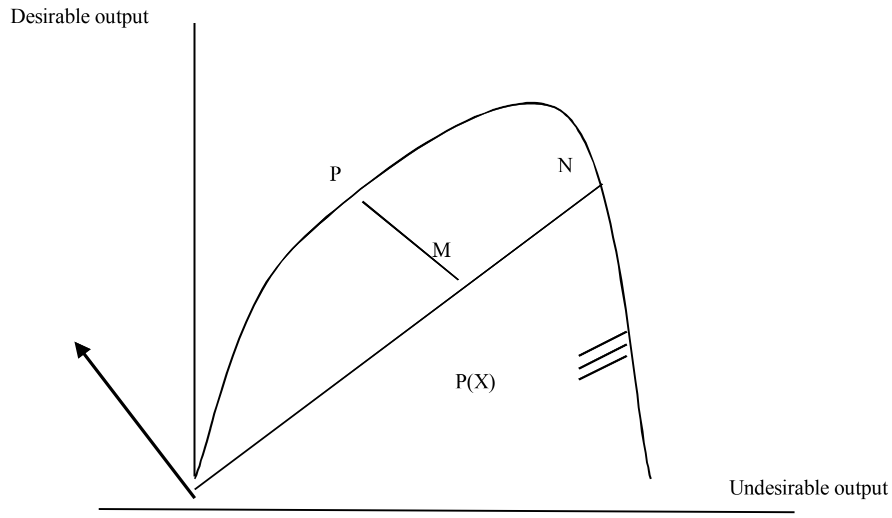

Figure1. Shephard and directional output distance functions.

The ML productivity index between period t and t+1 is defined as [6]:

$$ML_t^{t+1} = \left[\frac{(1+\vec{D}_0^t(y^t, b^t, x^t; y^t, -b^t))}{(1+\vec{D}_0^t(y^{t+1}, b^{t+1}, x^{t+1}; y^{t+1}, -b^{t+1}))} \times \frac{(1+\vec{D}_0^{t+1}(y^t, b^t, x^t; y^t, -b^t))}{(1+\vec{D}_0^{t+1}(y^{t+1}, b^{t+1}, x^{t+1}; y^{t+1}, -b^{t+1}))} \right]^{1/2} \quad (9)$$

Where $\vec{D}_0^{t+1}(y^t, b^t, x^t; y^t, -b^t)$ measures the distance of observations in period t from the frontier in period t+1 and $\vec{D}_0^t(y^{t+1}, b^{t+1}, x^{t+1}; y^{t+1}, -b^{t+1})$ measures the distance of observations in period t+1 from the frontier in period t. This index can be decomposed into two component measures:

$$MLEFFCH_t^{t+1} = \frac{(1+\vec{D}_0^t(y^t, b^t, x^t; y^t, -b^t))}{(1+\vec{D}_0^{t+1}(y^{t+1}, b^{t+1}, x^{t+1}; y^{t+1}, -b^{t+1}))} \quad (10)$$

$$MLTECH_t^{t+1} = \left[\frac{(1+\vec{D}_0^{t+1}(y^{t+1}, b^{t+1}, x^{t+1}; y^{t+1}, -b^{t+1}))}{(1+\vec{D}_0^t(y^t, b^t, x^t; y^t, -b^t))} \times \frac{(1+\vec{D}_0^{t+1}(y^t, b^t, x^t; y^t, -b^t))}{(1+\vec{D}_0^t(y^{t+1}, b^{t+1}, x^{t+1}; y^{t+1}, -b^{t+1}))} \right]^{1/2} \quad (11)$$

Where $MLEFFCH_t^{t+1}$ and $MLTECH_t^{t+1}$ are, respectively, the index of efficiency change and technological change. The ML productivity index equals the multiplication of these indices:

$$ML_t^{t+1} = MLEFFCH_t^{t+1} \times MLTECH_t^{t+1} \quad (12)$$

Values of ML_t^{t+1} that are greater or less than one indicate, respectively, an increase or decrease in productivity. The $MLTECH_t^{t+1}$ index depicts the position of the production possibility frontier over time. Values of greater than one imply that the production possibility frontier has shifted in the direction of more desirable outputs and fewer undesirable outputs. On the contrary, values of $MLTECH_t^{t+1}$ that are less than one indicate that a more undesirable output and less desirable output are attainable over period t+1 compared to period t. Finally, the $MLEFFCH_t^{t+1}$ index shows the position of observation with respect to their frontier over time. Values of $MLEFFCH_t^{t+1}$ that are greater or less than one indicate, respectively, that an observation is either closer or further from the production possibility frontier in period t+1 compared to period t [9].

In this study four linear programming (LP) models are used to calculate the required directional distance measures for the ML index. Two LP models are constructed to compute the directional distance of observation k in period t and t+1 from frontier in the same period. The LP model for period t can be formulated as follows:

$$\vec{D}_0^t(y^t, b^t, x^t; y^t, -b^t) = \max \beta$$

St.

$$\sum_{k=1}^{K} z_k^t y_{km}^t \geq (1+\beta) y_{k'm}^t \qquad m=1, \ldots, M$$

$$\sum_{k=1}^{K} z_k^t b_{ki}^t = (1-\beta) b_{k'i}^t \qquad i=1, \ldots, I$$

$$\sum_{k=1}^{K} z_k^t x_{kn}^t \leq x_{k'n}^t \qquad n=1, \ldots, N$$

$$z_k^t \geq 0 \qquad k=1, \ldots, K \qquad (13)$$

Two other models mix the period and yield directional distance of observation in period t from the frontier in period t+1, and vice versa.

The mixed period LP models may be unfeasible, as observed data for period t (or t+1) may not belong to the output set in period t+1 (or t). To reduce this problem following Färe *et al.* [9] and Kumar [11], all of the production possibilities frontiers would be calculated using observations from each year and the two previous years.

3. Results and Discussion

In this study panel data from 28 provinces over the period 2000-2008 were used to calculate the directional distance function and ML index, using Lingo 8 software. The variables include one aggregate output (aggregate of irrigated and dry wheat, irrigated and dry barely, corn, sugar beet, potato, tomato, watermelon, cucumber, paddy and onion) as a desirable output and five inputs (land, labour, machinery, water and seed). Furthermore, following Shaik *et al.* [21], the nitrogen balance (NB) index is also used.

The NB index namely measures the difference between nitrogen inputs (fertilizers and animal manure) and nitrogen removed by harvested crops, which is calculated as a proxy of nitrogen pollution[1]. Output and input data were collected from the website of the Ministry of Agricultural Jihad. Data on crop nitrogen content were obtained from the website of Natural Resources Conservation Service (NRCS). Descriptive statistics of variables are shown in Table 1. Fars produced the most crops and also used the most machinery, seed, fertilizers and manure in 2007 and labour in 2004. Khorasan had the most land in 2007 while Bushehr used the least machinery and seed in 2000. Qom produced the least crops in 2008 and used the least fertilizers and manure in 2002 as well as the least labour in 2003. Kohgiluyeh and Boyer-Ahmad in 2000 and Yazd in 2001 used the least water and land, respectively.

Average annual estimation of N inputs, N removal and NB index in Iran is reported in Table 2. During 2000-2008, only 51-67% of total N inputs were removed from soil through harvested crops and

Table 1. Descriptive statistics of the variables (28 provinces, 9 years, 2000-2008)

Variables	Mean	Standard deviation	Minimum (province-year)	Maximum (province-year)
Crops (103 * ton)	1350.7	1219.9	79.0 (Qom, 2008)	6107.4 (Fars, 2007)
NB (103 * ton)	10.7	11.5	-6.0 (Ardabil, 2003)	60.8 (Fars, 2007)
Inputs:				
Land (103 *ha)	329.0	249.4	29.7 (Yazd, 2001)	1112.7 (Khorasan, 2007)
Labour (106 *individual-day)	10.5	8.1	0.7 (Qom, 2003)	42.9 (Fars, 2004)
Water cost (109*Rials)	13.2	18.5	Kohgiluyeh and Boyer-Ahmad	109.4 (Khorasan, 2008)
Machinery cost (109*Rials)	30.1	26.9	1.1 (Bushehr, 2000)	159.5 (Fars, 2007)
Seed (103 * ton)	66.0	52.8	2.8 (Bushehr, 2000)	233.2 (Fars, 2007)
Fertilizers and manure (103 * ton)	277.7	244.2	18.2 (Qom, 2002)	1558.2 (Fars, 2007)

the remaining have had the potential for surface water or groundwater contamination. Annually, the average of nitrogen balance is 298,200 tons, while the average value of nitrogen balance per hectare of agricultural land and nitrogen use efficiency are 32.7 kg/ha and 62%, respectively. The nitrogen balance estimates reveal that Fars, with 51,200 tons, and Bushehr, with 1,200 tons, experience the greatest and least average annual value of nitrogen balance, respectively (Table 3). Nitrogen balance exceeds the average at the country level in Fars, Hamadan, Isfahan, Kerman, Kermanshah, Khorasan, Khuzestan, Lorestan and Mazandaran Provinces. The most and least nitrogen balance per hectare are observed in Isfahan (119.4 kg/ha) and Ardabil (3.3 kg/ha) Provinces, respectively, where Chahar Mahaal and Bakhtiari, Fars, Gilan, Hamadan, Hormozgan, Isfahan, Kerman, Markazi, Mazandaran,

Qom, Semnan, Tehran and Yazd Provinces have higher value than the country level. Also, Ardabil with 92% and Isfahan with 41.1% have, respectively, the most and least nitrogen use efficiency in Iran.

In this study, conventional and environmentally adjusted productivity indices are computed, using the ML index. Table 4 shows average annual productivity and technical and efficiency changes for 28 provinces. As already mentioned, data for each year and the two previous years are used to reduce the likelihood of a lack of feasibility in the mixed period linear programming model. In spite of this, the problem still exists for some provinces. In column 3, the values in parenthesis show the number of years that is unfeasible for at least one of the mixed period models. As the ML index is a geometric mean, the annual average growth rate represents geometric means from the years for which this index is computable. Kerman Province experienced the highest growth (10.29%) in conventional total factor productivity, while Kohgiluyeh and Boyer-Ahmad Province experienced the steepest decline (23.24%). In the study period, the average value of the conventional ML index is 0.9687, which means that conventional productivity decreased annually by 3.13% in Iran. Furthermore, an efficiency regression of 3.9% and a technical progression of 0.80% per year are experienced at the country level, when only desirable output is considered.

On average, the environmentally adjusted ML index decreases by 2.84% per year due to a 2.62% decline in efficiency change and a 0.23% decline in technical change. Ardabil and Ilam Provinces

Table 2. Average annual estimation of nitrogen balance (NB) in Iran (10^3 * ton)

Year	N inputs			N removal	NB	NB (kg/ha)	Nitrogen efficiency (%)
	Fertilizer	Manure	Total				
2000	480.9	96.8	577.7	334.3	243.4	32.2	57.9
2001	547.6	121.2	668.8	390.6	278.2	33.1	58.4
2002	634.4	108.6	743.0	495.4	247.6	26.4	66.7
2003	673.6	107.5	781.1	521.1	260.0	27.6	66.7
2004	717.0	105.5	822.5	552.5	270.0	27.8	67.2
2005	762.4	128.8	891.2	563.8	327.4	32.2	63.3
2006	805.2	130.5	935.7	592.0	343.7	33.5	63.3
2007	809.2	161.2	970.4	610.6	359.8	34.7	62.9
2008	610.8	116.6	727.4	372.9	354.5	46.5	51.3
Average	671.2	119.6	790.8	492.6	298.2	32.7	62.0

experience, respectively, the highest progression and regression in the environmentally adjusted ML index. The ML index (which accounts for undesirable outputs) has a higher value in comparison to the conventional ML index (which accounts only for desirable outputs) for Ardabil, Azerbaijan West, Bushehr, Gilan, Hamadan, Hormozgan, Khorasan, Khuzestan, Kohgiluyeh and Boyer-Ahmad, Mazandaran, Qazvin, Qom, Semnan and Zanjan Provinces. The relative growth rates of the conventional and environmentally adjusted productivity index depend on the relative growth rates of both desirable and undesirable outputs [9]. For a given input vector, when the percentage increase in desirable output is higher (less) than the absolute value of the percentage decrease in the undesirable output, then the growth rate of the conventional productivity index is higher (less) than the growth rate of the environmentally adjusted productivity index.

As Table 4 shows, East Azerbaijan, Fars, Golestan, Isfahan, Kerman, Kurdistan, Markazi and Sistan and Baluchistan Provinces have a lower efficiency change index when nitrogen pollution is accounted for in comparison to the situation when only the desirable output is accounted for. In addition, East Azerbaijan, West Azerbaijan, Bushehr, Gilan, Hormozgan, Kohgiluyeh and Boyer-Ahmad, Kurdistan, Mazandaran, Qazvin and Zanjan Provinces experience a higher average value of technical change index when pollution is included.

In Table 4, the annual average of conventional and adjusted productivity index is reported at the country level. Environmentally adjusted productivity growth was less than its conventional counterpart in

Table 3. Average annual estimation of nitrogen balance (NB) (10^3 * ton) at the provincial level (2003-2008).

Province	N inputs			N removal	NB	NB (kg/ha)	Nitrogen efficiency (%)
	Fertilizer	Manure	Total				
Ardabil	15.7	3.1	18.8	17.3	1.5	3.3	92.0
Azerbaijan, East	21.8	5.3	27.1	20.6	6.5	12.4	76.0
Azerbaijan,West	16.8	5.0	21.8	19.1	2.7	6.8	87.6
Bushehr	5.0	2.6	7.6	6.4	1.2	6.2	84.2
Chahar Mahaal and Bakhtiari	7.8	2.2	10.0	5.1	4.9	45.1	51.0
Fars	113.9	10.9	124.8	73.6	51.2	62.7	59.0
Gilan	18.4	1.6	20.0	10.1	9.9	45.1	50.5
Golestan	36.0	1.1	37.1	29.2	7.9	15.6	78.7
Hamadan	32.6	10.7	43.3	22.5	20.8	40.9	52.0
Hormozgan	6.3	2.5	8.8	5.4	3.4	69.6	61.4
Ilam	10.3	1.4	11.7	7.0	4.7	26.7	59.8
Isfahan	34.7	9.3	44.0	18.1	25.9	119.4	41.1
Kerman	29.1	10.1	39.2	20.8	18.4	91.0	53.1
Kermanshah	35.1	3.8	38.9	25.1	13.8	25.4	64.5
Khorasan	64.1	2.8	66.9	49.9	17.0	22.9	74.6
Khuzestan	65.8	13.0	78.8	50.4	28.4	30.1	64.0
Kohgiluyeh and Boyer-Ahmad	8.6	1.7	10.3	5.9	4.4	25.9	57.3
Kurdistan	16.2	6.4	22.6	12.3	10.3	20.3	54.4
Lorestan	23.9	5.6	29.5	16.4	13.1	28.3	55.6
Markazi	16.2	4.5	20.7	11.8	8.9	33.7	57.0
Mazandaran	27.4	0.9	28.3	15.2	13.1	48.3	53.7
Qazvin	15.5	3.5	19.0	12.8	6.2	32.9	67.4
Qom	4.5	0.9	5.4	2.4	3.0	85.7	44.4
Semnan	7.6	1.4	9.0	5.4	3.6	50.3	60.0
Sistan and Baluchistan	7.2	1.3	8.5	6.1	2.4	25.0	71.8
Tehran	12.3	4.8	17.1	11.9	5.2	47.6	69.6
Yazd	5.3	0.7	6.0	3.4	2.6	70.5	56.7
Zanjan	13.1	2.5	15.6	8.3	7.3	17.9	53.2
Average	24.0	4.3	28.2	17.6	10.7	32.7	62.0

2003, 2004 and 2007 and was higher for the rest of the years. Furthermore, in 2003, 2004, 2006 and 2007, efficiency change was less when nitrogen pollution is considered. The environmentally adjusted technical change index was less than the conventional index in 2004, 2007 and 2008.

Table 4. Annual average of productivity, efficiency and technical changes at the provincial level (2003-2008).

Province	Total Productivity Change			Efficiency Change			Technical Change		
	Con.	Env.	Difference	Con.	Env.	Difference	Con.	Env.	Difference
Ardabil	1.0639	1.0981(2)	-0.0342	0.9864	1.0225	-0.0361	1.0785	1.074	0.0045
Azerbaijan, East	0.9427	0.9322	0.0105	0.9524	0.936	0.0164	0.9898	0.9959	-0.0061
Azerbaijan,West	1.0154	1.041(1)	-0.0256	0.984	0.9885	-0.0045	1.0318	1.0531	-0.0213
Bushehr	0.969	1.0074	-0.0384	1.0049	1.0344	-0.0295	0.9642	0.9739	-0.0097
Chahar Mahaal and Bakhtiari	0.9231	0.8817(2)	0.0414	0.944	0.9834	-0.0394	0.9779	0.8966	0.0813
Fars	1.0097	0.9582	0.0515	0.9765	0.9383	0.0382	1.034	1.0212	0.0128
Gilan	0.9161	0.9357(2)	-0.0196	0.8958	0.899	-0.0032	1.0227	1.0408	-0.0181
Golestan	1.0437	1.0389(1)	0.0048	1.0323	1.0277	0.0046	1.011	1.0109	1E-04
Hamadan	0.9664	0.9767	-0.0103	0.9434	0.9739	-0.0305	1.0243	1.0028	0.0215
Hormozgan	1.0172	1.024(3)	-0.0068	1	1	0	1.0172	1.024	-0.0068
Ilam	0.8466	0.8236(3)	0.023	0.7949	0.8645	-0.0696	1.065	0.9527	0.1123
Isfahan	1.0014	0.9646	0.0368	1.0033	1.0025	0.0008	0.9982	0.9622	0.036
Kerman	1.1029	1.0628(2)	0.0401	1.0646	1.0552	0.0094	1.036	1.0072	0.0288
Kermanshah	0.9299	0.8975(4)	0.0324	0.9027	0.9111	-0.0084	1.0301	0.9851	0.045
Khorasan	0.9416	0.9593	-0.0177	0.9272	0.9507	-0.0235	1.0155	1.0091	0.0064
Khuzestan	0.9855	1.0409(2)	-0.0554	0.9824	1.0075	-0.0251	1.0031	1.0331	-0.03
Kohgiluyeh and Boyer-Ahmad	0.7676	0.8399(1)	-0.0723	0.8133	0.8747	-0.0614	0.9438	0.9601	-0.0163
Kurdistan	1.0931	1.0879(1)	0.0052	1.1774	1.1578	0.0196	0.9284	0.9396	-0.0112
Lorestan	0.8953	0.8601	0.0352	0.9289	0.9296	-0.0007	0.9638	0.9252	0.0386
Markazi	1.0527	1.0299	0.0228	1.0301	1.0256	0.0045	1.022	1.0042	0.0178
Mazandaran	1.0335	1.0381(4)	-0.0046	1	1	0	1.0335	1.0381	-0.0046
Qazvin	1.057	1.0639(1)	-0.0069	1.0371	1.0402	-0.0031	1.0192	1.0228	-0.0036
Qom	0.8598	0.8718(1)	-0.012	0.8403	0.8742	-0.0339	1.0232	0.9972	0.026
Semnan	1.0087	1.0109	-0.0022	0.9842	0.9958	-0.0116	1.0249	1.0151	0.0098
Sistan and Baluchistan	0.947	0.9333	0.0137	0.9339	0.9231	0.0108	1.0139	1.0111	0.0028
Tehran	1.002	0.9923	0.0097	0.993	0.9953	-0.0023	1.0091	0.9969	0.0122
Yazd	1.0292	1.0004	0.0288	0.9823	1.005	-0.0227	1.0478	0.9954	0.0524
Zanjan	0.8918	0.9202	-0.0284	0.8881	0.8901	-0.002	1.0042	1.0337	-0.0295

Env.: Environmentally adjusted measure; Con.: Conventional measure

Table 5. Annual average of productivity, efficiency and technical changes at the country level.

year	Total Productivity Change			Efficiency Change			Technical Change		
	Con.	Env.	Difference	Con.	Env.	Difference	Con.	Env.	Difference
2003	0.9973	0.988	0.0093	1.0026	0.9914	0.0112	0.9948	0.9966	-0.0018
2004	1.0408	0.9553	0.0855	0.9908	0.9539	0.0369	1.0504	1.0015	0.0489
2005	0.9544	0.9677	-0.0133	0.9664	0.9793	-0.0129	0.9876	0.9881	-0.0005
2006	1.0127	1.016	-0.0033	1.0092	1.0026	0.0066	1.0035	1.0134	-0.0099
2007	1.0281	1.012	0.0161	1.0157	1.0117	0.004	1.0122	1.0003	0.0119
2008	0.8009	0.8957	-0.0948	0.8005	0.9078	-0.1073	1.0005	0.9867	0.0138
Average	0.9687	0.9716	-0.0029	0.961	0.9738	-0.0128	1.008	0.9977	0.0103

Env.: Environmentally adjusted measure; Con.: Conventional measure

4. Conclusion

In this study the ML index, based on the directional output distance function, was used to incorporate environmental impacts of nitrogen pollution to the measurement of productivity. The non-parametric approach is used to calculate the directional distance function. Results show that the annual average score of the environmentally adjusted ML index is less than the conventional ML index in three years and for 14 provinces. Furthermore, the value of efficiency and technical change (which accounts for pollution) is less than the conventional measurement in 10 and 18 provinces, respectively. Therefore, the traditional measure of productivity and its components can lead to an overestimation or underestimation of these indices in the agricultural sector and is not reliable when environmental issues are important for policymakers.

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Nots:

1. Data on nitrogen inputs from biological N fixation and N mineralized from previous crop residues and N outputs in the form of gaseous losses (through denitrification and ammonium volatilization) to the atmosphere were not available.

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