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Non-parametric Environmental Adjusted Productivity [EAP] Measures: Nebraska Agriculture Sector[1]

by

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Abstract

Traditional total factor productivity [TFP] misrepresents the true change in agricultural productivity to the extent that environmental bads jointly produced with desirable outputs are unaccounted. Nonparametric productivity measures incorporating environmental bads are evaluated for Nebraska agriculture. The results indicate that prior to the 1980's the traditional TFP measures overstate productivity growth while it is underestimated afterwards, reflecting peak use of chemicals.

Non-parametric Environmentally Adjusted Productivity [EAP] Measures: Nebraska Agriculture Sector

Agriculture, one of the most successful sector in terms of productivity growth, had more than compensated for the rapid growth in demand for the past few decades but with a hidden cost. Agriculture has important effects on the natural environment: it can generate pollutants [undesirable outputs jointly produced with desirable outputs] that reduce the value of the environment for others; and the allocation of resources to agriculture generally excludes their use for recreational and other purposes. Because these "uses" of the environment may not be either paid for or priced in the market, the associated values are not included in our normal social accounting of the net benefits from agricultural production. To the extent that unpriced natural resource degradation results from agricultural production, traditional empirical measurement of productivity change misrepresents the true change in productivity [or for that matter, the true value to society from technological advance].

An environmentally adjusted productivity index [EAP] could be based on the Divisia index by adding extra output(s) or input(s) representing the value of the environmental bads, adjusting the revenue or cost shares accordingly. As the prices of environmental bads are seldom available, the index approach is difficult to implement. However, Pittman(1983) showed that this shortcoming can be overcome to some extent by estimation of shadow prices, but to obtain these prices is not a trivial exercise.

Non-parametric data envelopment approaches to measuring productivity are an alternative to the indexing method. They impose little a priori structural functional form, handle multi-output and multi-input cases, compute productivity without the need for price data and accommodate both weak and strong disposability properties. Nonparametric productivity measures include output, input and graph models based on the distance function developed by Malmquist(1953) in a consumer context and Shephard(1953) in a producer context. The output distance function used to calculate productivity can be defined as the maximum simultaneous multiple increase of desirable output [with strong disposability] and contraction of environmental bads [with weak disposability] for given input quantities that is feasible in a subsequent period as compared to an earlier period. A graph measure of productivity is defined as a similar multiple increase in output and decrease in both bads and inputs.

The following section specifies non-parametric output and graph measures of productivity to adjust the productivity for environmental bads. Next is a brief description of Nebraska output and input indexes as well as the computed environmental bads data. Finally, the empirical results are presented, examining EAP measures for the Nebraska agriculture sector.

Non-parametric Output and Graph Models

The technology that transforms inputs $x = (x_1.......x_I) \quad \mathbb{R}^I_+$ into desirable outputs [crop and livestock production] $y_g = (y_{g1}.......y_{gG}) \quad \mathbb{R}^G_+$ and environmental bads [nitrogen, pesticide contamination and wetland losses] $y_b = (y_{b1}.......y_{bB}) \quad \mathbb{R}^B_+$, can be represented by output and graph sets. These sets can be effectively utilized to compute productivity measures.

Following Fare, Grosskopf and Lovell (1994 pp 97), the output reference set satisfying constant returns to scale and strong disposability of outputs can be defined as:

$$P^T(x) = \{ y_g : x \text{ can produce } y_g \text{ in year } T \; ; x \in \mathbb{R}^I_+ \} \qquad (1)$$

In a time series of observations on a single economic unit (such as the state of Nebraska), a Malmquist output-based measure of productivity in year *t* relative to the final year *T* can be represented as follows. Consider the multiple of year *t* output that is revealed to be possible relative to the set of all observations up to and including year *T*, using the year *t* bundle of inputs. If outputs could be doubled (the multiple is 2.0), then the productivity at time *t* is the inverse of this multiple, or 0.5. This concept can be represented by an output distance function evaluated for any year *t* using a reference production possibilities set *T* , as:

$$\begin{array}{l} D_0^T(x^t, y_g^t)^{-1} = \max\{\theta : \theta\, y_g^t \in P^T(x^t)\} \\ \qquad\qquad\qquad or \\ \max\limits_{\theta, z}\ \theta \quad subject\ to{:}\ \theta y_g^t \quad Y_g z \\ \qquad\qquad\qquad\qquad\quad x^t \quad Xz \\ \qquad\qquad\qquad\qquad\quad z \quad 0\ , \\ where\ \ Y_g = (y_g^1\ y_g^2 \ldots y_g^T)\ . \end{array} \qquad (2)$$

Here, the second expression identifies the linear program that is used to calculate the distance function, with the *z*'s being a *Tx1* vector of intensity variables that identify the boundaries of the reference set.

The output-based Malmquist productivity index relative to time *T* technology is thus represented as:

$$M_O^T TFP(t) = D_0^T(x^t, y_g^t) \qquad (3)$$

To accommodate environmental bads, one definition of productivity is the multiple by which year *t* output can be increased and year *t* bads simultaneously decreased at a later point in time, using the year *t* bundle of inputs. Following Fare, Grosskopf, Lovell and Pasurka(1989 pp 92-93), the weak disposal reference set satisfying constant returns to scale, strong disposability of desirable outputs, and weak disposability of environmental bads can be defined as:

$$\begin{aligned} &P_w^T(x) = \{(y_g,y_b) : x \textit{ can produce } (y_g,y_b) \textit{ in year } T \text{ ,} \\ &\mathbf{0} \quad \theta \quad \mathbf{1} \textit{ implies } \theta(y_g,y_b) \in P_w^T(x) \textit{ and } y_g' < y_g \qquad \theta(y_g,y_b) \in P_w^T(x)\} \end{aligned} \qquad \mathbf{(4)}$$

The distance function and linear programming problem[1] used to calculate this hyperbolic output measure can be evaluated for each year *t* as:

$$\begin{aligned} &D_0^T(x^t,y_g^t,y_b^t)^{-1} = \max \{\theta : (\theta y_g^t, \theta^{-1} y_g^t) \in P_w^T(x^t)\} \\ &\qquad\qquad \textit{or} \\ &\max_{\theta,z} \theta \quad \textit{subject to: } \theta y_g^t \quad Y_g z \\ &\qquad\qquad (2-\theta) y_b^t = Y_b z \\ &\qquad\qquad x^t \quad Xz \\ &\qquad\qquad z \quad \mathbf{0} \text{ ,} \\ &\textit{where } Y_g = (y_g^1 \; y_g^2 \ldots y_g^T) \text{ .} \end{aligned} \qquad \mathbf{(5)}$$

A hyperbolic output Malmquist environmentally adjusted productivity can therefore be represented as:

$$M_h^T EAP(t) = D_h^T(x^t, y_g^t y_b^t) \qquad \mathbf{(6)}$$

Finally, the above measure can be further modified by shrinking the input set as well as

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[1] This result uses the Fare, Grosskopf, Lovell and Pasurka linearization of the θ^{-1} nonlinear constraint. Using a first order Talyor series expansion, $f(X) = f(X_0) + f\,'(X_0)\,(X-X_0)$, let $f(\theta) = \theta^{-1}$ and if θ is approximated around 1 then $Y_b z \quad \theta^{-1} y_b$ would be $Y_b z \quad (2 - \theta)\, y_b$

the bads. That is, let this graph measure of productivity be the multiple by which year *t* good outputs can be expanded and both bad outputs and inputs diminished, relative to the reference technology. Following Fare, Grosskopf and Lovell(1994 pp 197-198) the graph reference set satisfying constant returns to scale, strong disposability of desirable outputs and weak disposability of environmental bads can be defined as:

$$\begin{gathered}\{GR^{T} = (x,y_g,y_b) \;:\; (y_g,y_b) \in P_w^{T}(x) \;; \\ 0 \quad \theta \quad 1 \;\textit{implies}\; \theta(x,y_g,y_b) \in GR^{T} \;\textit{and}\; y_g^{/} < y_g \qquad \theta(x,y_g^{/},y_b) \in GR^{T}\}\end{gathered} \qquad \textbf{(7)}$$

A graph measure of productivity for year *t* can thus be based on the following distance function or the equivalent linear programing problem:

$$\begin{array}{l} D_g^{T}(x^{t},y_g^{t},y_b^{t})^{-1} = \max\,\{\theta \;:\; (\theta y_g^{t},\, \theta^{-1} y_g^{t},\, \theta^{-1} x^{t}) \in GR^{T}\} \\ \qquad\qquad\qquad\qquad\qquad \textit{or} \\ \qquad\qquad \underset{\theta,z}{\max\,\theta} \quad \textit{subject to}\text{:}\; \theta y_g^{t} \quad Y_g z \\ \qquad\qquad\qquad\qquad\qquad (2-\theta) y_b^{t} = Y_b z \\ \qquad\qquad\qquad\qquad\qquad (2-\theta) x_i^{t} \quad Xz \\ \qquad\qquad\qquad\qquad\qquad\qquad z \quad 0 \;, \\ \textit{where}\; Y_g = (y_g^{1}\; y_g^{2} \ldots y_g^{T}) \;. \end{array} \qquad \textbf{(8)}$$

The graph Malmquist environmentally adjusted productivity index [$\mathrm{M}^{\mathrm{T}}_{\mathrm{O}}$EAP(t)] is therefore represented as:

$$M_g^{T}EAP(t) = D_g^{T}(x^{t},y_g^{t}y_b^{t}) \qquad \textbf{(9)}$$

Output, Input and Environmental Bads Data

The input and output quantity indexes for Nebraska aagriculture have been constructed by accounting for quantity and quality changes, the details of which are present in Shaik(1998). The input, output and environmental data span a period of 59 years, from 1936 to 1994.

Outputs

The outputs aggregates were food grains, feed grains, vegetable and oil crops, meat animals, poultry, other livestock including milk, honey and wool production. Annual data on crop production [yield per acre times total harvested acres for each crop] and prices received by the farmers were used in the construction of output Theil-Tornquist quantity indexs. Similarly for livestock commodities the quantity estimates [pounds of meat produced] and average prices per pound were used in the construction of livestock quantity indexes.

Inputs

In regards to inputs particular emphasis was given in the construction of farm equipment, farms real estate, breeding livestock, intermediate inputs and farm labor with different methods needed in the construction of indexes for each group in accounting for quantity and quality changes. In the case of farm equipment the perpetual inventory method was used in the construction of capital stock for four assets to account quantity changes, and rental values were used to construct a Theil-Tornquist quantity index. In the case of breeding livestock, the number of breeding livestock on 1st January was used as a measure of capital stock. The rental value was used to construct shares, with a depreciation rate of zero [as the value of the heifer entering the breeding stock value is approximately the same as that of the cull cow sent for slaughter at the end of the life period, so depreciation is assumed zero since the farmer has neither gained nor lost]. Farm real estate consists of land, disaggregated into three types [non-irrigated, irrigated and pastures], plus buildings and structures. The acres of land and stock value of the structures, used as quantity was aggregated by state-level cash rents and constructed rental value was used as shares respectively to obtain a farm real estate quantity index.

An implicit quantity index [logarithmic difference between the rate of change in expenditures and price index] for intermediate inputs constructed as share weighted by the expenditure shares was used in the construction of an index. To account for quantity changes in agriculture labor's contribution to agriculture production, data was compiled on hours worked for hired labor and unpaid and family labor and wage rate for hired labor. Wage compensation was used to construct shares in the aggregation to a farm labor quantity index.

Environmental Bads Data

Excess nitrogen from agriculture is calculated as difference between nitrogen inputs [commercial fertilizer, animal manure and legume fixation] and nitrogen removed by harvested crops. Evidence [Exner and Spalding, 1990: Muller et al, 1995] based on sampling of wells in Nebraska indicates a positive correlation between high levels of nitrate contamination in irrigation wells and fertilizer and animal manure application and accumulation in the soil. This offers some support for using nitrogen surplus as a proxy for environmental bads produced due to agriculture.

Information on the extent of pesticide use in pounds is available only for survey years. Utilizing these point data, a time series data on quantity of an active pesticide ingredient was generated based on the rate of change of implicit pesticide quantity index for Nebraska. A pesticide leaching loss potential [PLLP] index of pesticides is computed by using pounds of pesticide as shares for the survey years to aggregate PLLP value for each pesticide. A time series PLLP index was computed by interpolation between the survey years. An implicit damage quantity index is formed by deflating the pesticide use by PLLP index.

Wetland loss is computed as the difference in wetland inventory. A wetland inventory is computed based on unpublished wetland data [Ralph Heimlich, 1997] for Nebraska and Gersib et al [1992] data for rainwater basin and Natural Resource Commission[1993] for sandhills. Utilizing these data, a times series is constructed by adding acreage drained for conservation farming.

Empirical Application and Results

Traditional Theil-Tornquist total factor productivity (TFP), the Malmquist total factor productivity [M^TTFP] and Malmquist environmental adjusted productivity [M^TEAP] measures were computed for Nebraska using SHAZAM(1993). The annual growth rates of the variables used in the computation are presented in Table 1.

Table 1. Annual growth rates of Outputs, Inputs and Environmental bads

Outputs		Inputs		Environmental Bads	
Aggregate Output	2.8114	Aggregate Input	1.4040	Excess Nitrogen	2.1574
Crops	4.2070	Capital	0.2395	Pesticide contamination	8.3968
Food grains	0.6226	Farm equipment	0.5807	Wetland losses	2.4298
Feed grains	4.8966	Farm real estate	0.2527		
Vegetables,Oil	5.8993	Breeding LS	-0.3343		
Livestock	1.7336	Farm labor	-1.3463		
Meat animals	2.1439	Intermediate	2.8030		
Poultry	0.3523				
Other livestock	-1.4405				
TFP	1.3928				

The output, graph M^TTFP and M^TEAP measures for aggregate and disaggregate models are presented in Table 2. The $M^{T}TFP^{D}$ and $M^{T}EAP^{D}$ measures for the disaggregate models did not pick up any technical/productivity change. If the multiple outputs and inputs are collapsed into aggregate output and input by using prices as weights the models do express technical change close to Theil-Tornquist productivity [TFP] index.

When data are aggregated to single outputs and inputs, the average annual EAP output measures were 1.9213(considering excess nitrogen as a bad), 1.1750(pesticide contamination) and 2.2250(wetland losses), lower than the traditional TFP of 2.2553. A similar pattern is shown by graph measures.

Table 2 Average Annual Malmquist Productivity Measures, 1936-94 [2]

	6 Outputs, 5 Inputs	2 Outputs, 1 Input	1 Output & 3 Inputs	1 Output & 5 Inputs	1 Output & 1 Inputs
Output Malmquist Productivity Measures					
TFP					2.2553
M^{T}_{O}TFP	0	1.2069	1.1074	1.1037	2.2557
M^{T}_{O}EAP					
Excess Nitrogen[N]	0	1.1558	0	0	1.9213
Pesticide leaching [P]	0	0	1.0518	1.0518	1.1750
Wetland losses [W]	0	1.2012	1.1035	1.1035	2.2250
ALL [NPW]	0	0	0	0	0
Graph Malmquist Productivity Measures					
M^{T}_{g}TFP	0	1.1963	1.1045	1.1010	1.9202
M^{T}_{g}EAP					
Excess Nitrogen[N]	0	1.1638	0	0	1.8530
Pesticide leaching [P]	0	0	1.0690	1.0691	1.2766
Wetland losses [W]	0	1.1922	1.0935	1.0876	1.9137
ALL [NPW]	0	0	0	0	0

An interesting result supporting the hypothesis that prior [after] to 1980's the productivity

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[2] Other Disaggregate models involving 2 outputs, 3 inputs and 2 outputs, 5 inputs for Output, Input and Graph measures were also computed but did not pick up any technical change/productivity as in 6 outputs, 5 inputs case. Only the traditional TFP showed a technical change of 2.11 in the first case of 2 outputs and 3 inputs. The combinations of three environmental bads was also estimated but did not pick technical change hence not reported.

growth rate is overstated [understated], truly reflecting the peak use of fertilizer and pesticide in the early 1980's. The annual growth rate of 1.31 for $M^{T}TFP^{A}$ measure prior to 1980 is higher compared to $M^{T}EAP^{A}$ growth rate of 0.54 (excess nitrogen), 0.12 (pesticide contamination) and 1.17 (wetland losses) indicating that it has been over estimated. The $M^{T}TFP^{A}$ growth rate of 1.38 for the period after 1980's was under estimated compared to $M^{T}EAP^{A}$ growth rate of 2.23 (excess nitrogen) and 1.89 (wetland losses) with the exception of pesticide contamination with $M^{T}EAP^{A}$ growth rate of 0.57. The annual growth rate of pesticide contamination was way higher than all other variables used in the analysis, masking the effect.

The results confirm that TFP measures overestimate/underestimate productivity growth if environmental cost/benefits are accounted.

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