8-11-1999

The Role of Non-parametric Approach in Adjusting Productivity Measures for Environmental Impacts

Saleem Shaik
Montana State University, Bozeman, MT

Richard K. Perrin
University of Nebraska-Lincoln, rperrin@unl.edu

Shaik, Saleem and Perrin, Richard K., "The Role of Non-parametric Approach in Adjusting Productivity Measures for Environmental Impacts" (1999). *Presentations, Working Papers, and Gray Literature: Agricultural Economics*. 30.
https://digitalcommons.unl.edu/ageconworkpap/30

The Role of Non-parametric Approach in Adjusting Productivity Measures for Environmental Impacts[1]

Saleem Shaik
207 A Linfield Hall
Dept of Agricultural Economics and Economics
Montana State University, Bozeman, MT-59717
Phone: (406) 994 5634; Fax: (406) 994 4838
E-mail: saleem@montana.edu

and

Richard Perrin
314 A Filley Hall
Dept of Agricultural Economics
University of Nebraska, Lincoln, NE-68583
Phone: (402) 472 9818; Fax: (402) 472 3460
E-mail: rperrin@unl.edu

Abstract

This paper addresses the role of non-parametric analysis in adjusting agricultural productivity measures for environmental impacts. The modified Tornquist-Theil index computed using shadow prices derived from the programming procedures is compared and contrasted with a non-parametric hyperbolic Malmquist index for the case of Nebraska agriculture.

[1] Selected Paper, American Agricultural Economics Association Meetings, Nashville, Tennessee, August 8-11, 1999.

The Role of Non-parametric Approach in Adjusting Productivity Measures for Environmental Impacts

Saleem Shaik and Richard Perrin[1]

An increase in productivity is generally defined as an increase in output obtained from a given set of inputs. Because a productivity increase implies that more goods can be consumed from a given resource base, it implies that human welfare can be increased. Measurement of productivity is therefore important, but it is not an unambiguous task, especially when unpriced (or poorly-priced) inputs or outputs are involved. Among the sectors of the U.S. economy, measured productivity gains in agriculture during the twentieth century have been among the highest, but it is also a sector for which environmental impacts may be important, but unmeasured, component of productivity. This study examines the role of non-parametric analysis in making environmental adjustments to productivity measurement in agriculture, with particular reference to the Nebraska agricultural sector. The study quantifies three environmental damage variables due to agriculture in the state of Nebraska, potential environmental nitrate production, potential environmental pesticide impact, and wetland reduction.

We directly estimate productivity changes non-parametrically using data envelopment analysis (DEA), and we also recover shadow prices of environmental impacts from this approach to modify the traditional indexing measure of productivity changes. We find that direct non-

---

[1] Post-doctoral research associate at Montana State University, and Professor at the University of Nebraska-Lincoln, respectively.

parametric productivity methods provide unrealistic measurement of environmentally-adjusted productivity gains, but do offer shadow prices that seem to be plausible values for adjusting the standard productivity index approach.

Index measures of productivity change

First consider the index approach to measuring productivity change. Denote inputs by the vector $x=(x_1, \ldots, x_n)$ and outputs by $y=(y_1, \ldots, y_m)$, with corresponding price vectors $w=(w_1, \ldots, w_n)$ and $p=(p_1, \ldots, p_m)$. The Tornquist-Theil index of productivity change between year t and year T is the share-weighted logarithmic change in outputs minus the share-weighted logarithmic change in inputs (average revenue shares for outputs and average cost shares for outputs), or

$$\text{(1)} \quad \ln \mathrm{TFP}_{T,t} = \sum\nolimits_j \tfrac{1}{2}(\mathrm{RS}_{j,T} + \mathrm{RS}_{j,t}) \ln \frac{y_{j,T}}{y_{j,t}} - \sum\nolimits_i \tfrac{1}{2}(\mathrm{CS}_{i,T} + \mathrm{CS}_{i,t}) \ln \frac{x_{i,T}}{x_{i,t}}$$

where $\mathrm{RS}_{j,t}$ is the share of output j in year t revenue and $\mathrm{CS}_{i,t}$ is the share of input i in year t costs. This and related index measures have a theoretical basis as a proxy for consumer welfare, but they also owe much to Solow residual concept - residual output changes that are not accounted for by changes in inputs must be due to technical progress. Further discussion of these antecedent ideas can be found in Antle and Capalbo and Caves, Christensen and Diewert.

Typical applications of productivity indexes do not include non-market inputs or outputs such as polluting emissions or other environmental impacts. There is no conceptual problem in doing so. A flow of chemicals into surface waters, for example, could be included as an undesirable output with a negative price reflecting its marginal disutility to recipients of the externality, or equivalently as an input with a positive price[2]. As a practical matter, not only are the quantities of such flows more difficult to measure than market goods (there are no markets in which to monitor quantities), the marginal disutility value is often even more difficult to measure. Since these values are not directly observable, they are often referred to as shadow prices.

There are two distinct notions of shadow prices that have been considered in environmental accounting efforts. One notion is the value of the marginal disutility to the recipients of the non-market output(s), or consumers' shadow price, which can be thought of as the slope of a consumer's indifference curve between the non-market output and purchasable goods. If the purpose of the productivity index is to measure progress in terms of human welfare, this is the appropriate shadow price for the index (Smith, 1998). An alternative notion is the opportunity cost of increasing or decreasing the non-market output, or production shadow price, which can be thought of as the slope of a production possibilities curve for the non-market output versus other outputs. Under perfect markets, these two shadow prices are equal, but for the non-market outputs we are considering that is unlikely.

Although consumer shadow prices are needed to adjust productivity indexes, they are difficult to estimate (Smith, 1997). Production shadow prices, on the other hand, are more readily inferred from estimation of production technologies (Färe and Grosskopf, 1998), and in the present study we will utilize such production shadow prices in the index approach adjusting productivity measurements for environmental impacts.

---

[2] Treatment of the externality as an output or an input will not necessarily be equivalent if total revenue does not equal total costs, because the share of the externality might then differ depending on where it is placed.

Non-parametric estimation of productivity change and shadow prices

The past decade has witnessed a surge in the application of non-parametric techniques to productivity measurement, much of which is summarized by Lovell (1996). In general these methods are distance function approaches that compare the production plans that were available at time *T* with those that were available at time *t*. The productivity change over the interval is typically measured as the proportional increase in output that was achievable at *T* from year *T* inputs, relative to what would have been achievable at *t* from year *T* inputs[3]. Implicit in the estimation procedure is estimation of the piece-wise linear convex production hull that envelops the set of production plans available at time *t*. The production shadow prices of environmental outputs are measured as the relevant gradients of this production technology, an issue considered further below.

The particular non-parametric productivity measure considered here is derived from the hyperbolic graph efficiency measures pioneered by Färe and described in Färe, Grosskopf and Lovell, Chapter 8 section 3. In this approach, productivity gain between time *t* and time *T* is defined as the proportion by which good outputs could have been increased, and "bad" outputs simultaneously decreased, in year *T* as compared to year *t*, using reduced level of inputs available in year *t*. To formally represent this measure, first partition the output vector into good outputs and bad outputs, y = (y_g, y_b) and define the technology using the graph reference set satisfying constant returns to scale, strong disposability of good outputs and weak disposability of bad outputs:

$$(2)\qquad \begin{array}{l} GR^T = \{ (x, y_g, y_b) : x \text{ can produce } (y_g y_b) \text{ in year } T; \\ 0 \le \theta \le 1 \text{ implies } \theta(x, y_g, y_b) \in GR^T \;\; y'_g < y_g \Rightarrow \theta\, (x, y'_g, y_b) \in GR^T(x)\} \end{array}$$

A direct measure of productivity gain from year t to T can then be defined as the hyperbolic graph distance function, or its equivalent linearized programming problem, as

$$
\begin{array}{lll}
 & H^T(x^t,y_g^t,y_b^t)^{-1} = \max\limits_{\Theta,\,z} & \{\theta : (\theta y_g^t, \theta^{-1} y_b^t, \theta^{-1} x^t) \in GR^T(x^t)\} \\
 & \qquad\qquad\qquad\quad \text{or} & \\
 & \qquad\qquad\qquad\quad \max\limits_{\Theta,\,z} \theta & \text{s.t.}\ \ \theta\, y_g^t \le Y_g\, z \\
 & & \quad (2-\theta)\, y_b^t = Y_b\, z \\
(3) & & \quad (2-\theta)\, x^t \ge X z \\
 & & \qquad\quad z \ge 0 \\
 & \qquad\qquad\qquad\quad \text{where} & Y_g = (y_g^1, y_g^2, \ldots\ldots, y_g^T) \\
 & & Y_b = (y_b^1, y_b^2, \ldots\ldots, y_b^T), \text{and} \\
 & & X\ = (x^1, x^2, \ldots\ldots, x^T)
\end{array}
$$

Thus, examining the year *t* production plan compared with the production possibilities revealed to be available through some future year T, a solution value of *è*=1.2 would indicate that 20% more good outputs could be produced with 20% less bad outputs and 20% less inputs than were observed in year *t*. Hence the interpretation that the productivity increase between year *t* and year *T* was .20, or 20%.

Estimation of the above productivity measure includes estimation of the piecewise linear technology available at time *T*, with the estimated facets consisting of linear combinations of previously observed production plans. For a particular year *t*, the optimal values of *z* are the linear combinations of other years' plans that identify the frontier production facet to which the year t production point is projected (along a hyperbolic arc identified by (èy_g, è$^{-1}y_b$, and è$^{-1}$x)). The producer shadow price of a bad output $y_{b\,j}$ in terms of a good output $y_{g\,j}$ that must be given up, is the gradient of the technology frontier facet at the relevant point. That gradient is measured

---

[3] There are many variations on this theme, such as the analogous proportional reduction in inputs required in time *T* versus time *t* , or the geometric average of the proportional increase in output in time *T* relative to that achievable in *t*, divided by the proportional fraction of output in time *t* of what could have been achieved in time *t*.

as the ratio of the relevant shadow prices of the constraint row for the bad output in the programming problem and the constraint row for the good output, or

$$(4) \qquad r_{b_j,g_j} = \frac{\lambda_{y_{b_j}}}{\lambda_{y_{g_j}}}$$

where λ_k *is the dual value of row k in the programming solution above*

Observations that form the vertexes of the year *T* technology hull will have multiple values of the shadow prices, and observations interior to the hull may be projected to different facets of the hull with different shadow prices.

In the study reported here, good outputs are measured as a Tornquist-Theil index. To convert a shadow price from units of index per unit of bad output to dollars per unit of bad output, we multiply the above-defined shadow price by the value of output for the year in question. These prices we then use to calculate shadow shares to modify Tornquist-Theil productivity indexes as an alternative to the direct non-parametric productivity indexes derived from the programming approach.

Output, Input and Environmental Data

Nebraska agriculture sector data span a period of 59 years from 1936-94. The details of the methodology and sources of data used in the construction of output, input and environmental damage variables are presented in Shaik (1998). An aggregate output Tornquist-Theil index is constructed by share weighting the changes in the crop and livestock production by the price the farmers received. The outputs are food grains, feed crops, vegetable and oil crops, meat animals, poultry and other livestock including milk, honey and wool production.

Similarly an aggregate input quantity index was constructed based on the quantity changes of farm equipment, breeding livestock capital stock, farm real estate, farm labor and intermediate inputs. In case of farm equipment, breeding livestock rental values are used as shares. State-level cash rents in the case of farmland, expenditures in the case of intermediate inputs and wage compensation in the case of farm labor are used as shares in the aggregation of the input quantity index.

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 with fertilizer and animal manure accumulation in the soil. This offers some support for using nitrogen surplus as a proxy for potential environmental nitrate production due to agriculture. Excess nitrogen from agriculture is calculated as difference between nitrogen inputs [commercial fertilizer, animal manure and legume fixation] and nitrogen removed by harvested crops.

A pesticide leaching loss potential [PLLP] index of all the pesticides is computed by using pounds of pesticide as shares for the survey years. A time series PLLP index was computed by interpolation between the survey years. Deflating the pesticide use by PLLP index gives potential environmental pesticide damage quantity 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 time series is constructed by adding acreage drained for conservation farming.

Results for Nebraska agriculture

Traditional Tornquist-Theil total factor productivity (TFP), the non-parametric graph total factor productivity (GTFP), environmental adjusted productivity (EAP) and modified Tornquist-Theil total factor productivity (MTFP) measures were computed for Nebraska agriculture sector using SHAZAM (1997). The annual growth rates of the variables used in the computation of the productivity measures are presented in Table 1.

Table 1. Annual growth rates of Aggregate Output, Input and Environmental Damage

Variables	***Average Annual Growth Rate***
Aggregate Output	2.9768
Aggregate Input	2.0955
Potential Environmental Nitrate Pollution	2.1574
Potential Environmental Pesticide Impact	8.3968
Wetland Reduction	2.4298

To overcome the limitations of non-parametric productivity measurement in accounting for multiple environmental damage, we derive shadow prices to modify the Tornquist-Theil productivity index. Implicit in the shadow price estimates (dual values) is the influence of the programming method (involves estimation of the piecewise linear convex production hull that envelops the set of production plans). Table 2 presents the ratio of the dual LP slopes relevant to the constraint row in the programming problem and shadow price of potential environmental nitrate production, potential environmental pesticide impact, and wetland reduction in dollars per unit of bad. The per unit shadow price of \$5.00, \$1.73 and \$21.16 for potential environmental nitrate production, potential environmental pesticide impact, and wetland reduction respectively was high during 1981-94 time period compared to the shadow price prior to 1980 (\$2.5, \$0.13 and \$9.77).

These shadow prices are thereupon used as shares to obtain the modified TFP indexes as an alternative to the direct non-parametric productivity indexes (GTFP and EAP) derived from the programming method. The Nebraska agriculture sector TFP, GTFP, EAP and MTFP measures for potential environmental damage variables are presented in Table 3 for specified years. This is also represented graphically in Figures 1 and 2. The non-parametric graph total factor productivity measure would be less than the TFP index due to the assumption of simultaneous increase in good output and decrease in bad output and input.

The annual growth rate of non-parametric graph EAP measures are 1.845 (potential environmental nitrate pollution), 1.270 (potential environmental pesticide impact) and 1.905 (wetland reduction), lower than the GTFP measure of 1.911 and TFP measure of 2.385. The annual growth rate of GTFP measure prior to 1980 is higher compared to EAP growth rate indicating that it has been over estimated. The GTFP growth rate for the period after 1980 was under estimated compared to EAP growth rate. The MTFP measures indicate 2.497, 2.405 and 2.385 average annual productivity growth rate accounted for potential nitrate pollution, potential pesticide impact and wetland reduction respectively which is higher than the GTFP measure of 1.911 and TFP of 2.385.

The environmentally adjusted productivity measures would be less than the non-parametric graph productivity measures which seems consistent with the notion that accounting for environmental damage lowers productivity. In contrast the modified Tornquist-Theil productivity measures indicate higher or equal productivity change between 1936-94. The results confirm that the traditional Tornquist-Theil total factor productivity measure overestimate/underestimate productivity growth if environmental cost/benefits are accounted.

References:

Antle, J., and S. Capalbo. "An Introduction to Recent Developments in Production Theory and Productivity Measurement." *Agricultural Productivity: Measurement and Explanation.* S. Capalbo and J. Antle, eds., pp17-95. Washington: Resources for the Future, 1988.

Caves, D., L. Christensen, W. Diewert. "The Economic Theory of Index Numbers and the Measurement of Input, Output, and Productivity. *Econometrica* 50(November 1982):1393-1414.

Exner, Mary E., and R. F. Spalding. "Occurrence of pesticides and nitrate in Nebraska's ground water." Nebraska Water Resources Center, Lincoln: Water Center, Institute of Agriculture and Natural Resources, The University of Nebraska, 1990.

Färe R. and S. Grosskopf. "Shadow Pricing of Good and Bad Commodities." *Amer. J. Agr. Econ*. 80(August 1998):584-590.

Fare, R ., S. Grosskopf and C. A. K. Lovell. *Production Frontiers*. Cambridge: Cambridge University Press, 1994.

Lovell, C. "Applying Efficiency Measurement Techniques to the Measurement of Productivity Change." *Journal of Productivity Analysis* 7(July, 1996): 329-340.

Shaik Saleem. "*Environmentally Adjusted Productivity [EAP] Measures for Nebraska Agriculture Sector" Dissertation*, Dept. of Agriculture Economics, University of Nebraska-Lincoln, May 1998.

SHAZAM *User's Reference Manual Version 8.0,* McGraw-Hill, 1997.

Smith, V. K. "Pricing What is Priceless: A Status Report on Non-Market Valuation of Environmental Resources." *International Yearbook of Environmental and Resource Economics 1997/1998.* H. Folmer and T. Tietenberg, eds., Chapter 6. Brookfield Vt, Elgar, 1997.

Smith, V. K. "Should Pollution Reductions Count as Productivity Gains for Agriculture?" *Amer. J. Agr. Econ.* 80(August 1998):591-594.

Table 2. Ratio of Dual LP slopes and Shadow Price of Environmental damage

	Potential Nitrate Pollution	*Pesticide Contamination*	*Wetland Losses*
	Hyperbolic Graph Distance Function		
Ratio of Dual LP Slopes			
1936-80	0.334	0.016	1.337
1981-94	0.326	0.118	1.374
1936-94	0.332	0.040	1.346
$ / per total bads			
1936-80	2.50	0.13	9.77
1981-94	5.00	1.73	21.16
1936-94	3.10	0.51	12.48

Where the units of shadow prices are $/ lb Nitrogen, $/ lb pesticide and $ / acre of wetland

Table 3. Nebraska Agriculture Sector TFP, Non-parametric and Modified Productivity Measures for Potential Environmental damage

	Non-parametric Graph Productivity Measures				Tornquist-Theil TFP	Modified Tornquist-Theil Productivity Index		
	GTFP	EAP_n	EAP_p	EAP_w	TFP	MTFP_n	MTFP_p	MTFP_w
1936	1	1	1	1	1	1	1	1
1940	1.148	1.145	1.127	1.148	1.043	1.346	1.043	1.043
1950	1.504	1.075	1.450	1.426	1.290	2.186	1.290	1.290
1960	1.429	1.122	1.098	1.384	1.473	1.175	1.473	1.473
1970	1.500	1.153	1.061	1.446	1.537	0.535	1.536	1.537
1980	1.651	1.119	1.057	1.425	1.472	5.178	1.465	1.473
1981	1.690	1.272	1.086	1.354	1.737	1.977	1.728	1.737
1982	1.663	1.071	1.053	1.266	1.705	2.557	1.696	1.706
1983	1.823	1.405	1.192	1	1.555	1.569	1.547	1.555
1984	1.688	1.210	1.068	1.066	1.780	2.527	1.771	1.780
1985	1.670	1.066	1.052	1.397	1.945	2.896	1.935	1.945
1986	1.673	1.256	1.055	1.665	1.995	3.529	1.985	1.995
1987	1.632	1.223	1	1.623	1.929	3.699	1.911	1.929
1988	1.610	1	1	1.602	1.813	1.630	1.829	1.813
1989	1.743	1.332	1.120	1.736	1.913	1.686	1.929	1.914
1990	1.894	1.648	1.259	1.887	2.035	2.121	2.052	2.035
1991	1.810	1.610	1.184	1.803	2.093	2.121	2.110	2.093
1992	1.753	1.373	1.130	1.747	2.237	2.571	2.256	2.238
1993	1.845	1.626	1.210	1.839	2.018	1.523	2.035	2.019
1994	1.911	1.845	1.270	1.905	2.385	2.497	2.405	2.385

Where GTFP is the graph measures of total factor productivity, EAP is the environmentally adjusted productivity measures for potential environmental nitrate production (n), potential environmental pesticide impact (p) and wetland reduction (w). The MTFP represents the modified total factor productivity measures accounting for potential environmental damage (n, p, w).

Figure 1. Nebraska Agriculture Sector
Tornquist-Theil TFP and Nonparametric TFP and EAP

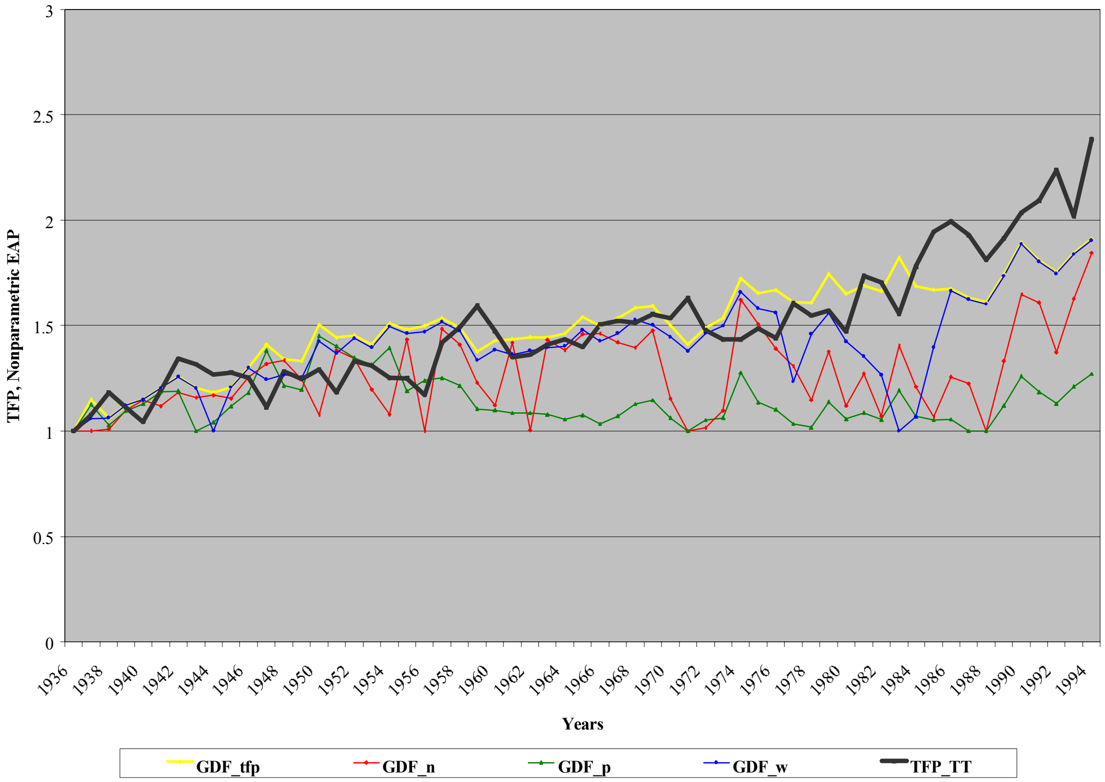

Figure 2. Nebraska Agriculture Sector
TFP, Nonparametric GDF and Modified TFP