AJAE APPENDIX: DYNAMIC EFFICIENCY MEASUREMENT: THEORY AND APPLICATION

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2007

Abstract:

Nonparametric dynamic measures of production efficiency are developed in the context of an adjustment-cost technology and intertemporal cost minimization. Bounds on each efficiency measure are derived for each firm using a nonparametric revealed preference approach. Long-run efficiency measures indicate the relative efficiency of both variable and dynamic factors while short-run measures of efficiency indicate whether variable inputs are employed efficiently in the production process. The efficiency measures are temporal in nature by describing the degree of efficiency of the firm at a particular point along its adjustment path. The empirical implementation is illustrated for a balanced panel of Pennsylvania dairy operators during 1986-1992.

Keywords: economic dynamics, efficiency measurement, nonparametric production analysis

Running Head: Dynamic Efficiency Measurement

JEL: C61, D61, D21, D91, Q12

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Propositions

Proposition 1: The functions $F_{gtb}(y^i_t, x^i_t, I^i_t, k^i_t)$, $b=l,u$, satisfy the following properties for each observation

F_g.1 $0 < F_{gtb}(y^i_t, x^i_t, I^i_t, k^i_t) \leq 1$, $b=l,u$.

F_g.2 $(x^i_t, I^i_t) \in Isoq\ V_B(y^i_t: k^i_t) \Leftrightarrow F_{gtb}(y^i_t, x^i_t, I^i_t, k^i_t) = 1$, $B=O$ and $b=l$ or $B=I$ and $b=u$.

F_g.3 $F_{gtb}(y^i_t, \theta x^i_t, \theta^{-1} I^i_t, k^i_t) = \theta^{-1} F_{gtb}(y^i_t, x^i_t, I^i_t, k^i_t)$, $\theta > 0$, $b=l,u$.

F_g.4 $F_{gtb}(y^i_t, x^i_t, I^i_t, k^i_t)$ is independent of the unit of measurement, $b=l,u$.

Proof:

F_g.1 This property follows from the definition of $F_{gtu}(y^i_t, x^i_t, I^i_t, k^i_t)$ in (15) and the fact that $(x^i_t, I^i_t) \in V_I(y^i_t: k^i_t)$, $i=1,\ldots,n$, $t=1,\ldots,T$. The proof is similar for $F_{gtl}(y^i_t, x^i_t, I^i_t, k^i_t)$.

F_g.2 Assume $F_{gtu}(y^i_t, x^i_t, I^i_t, k^i_t) = 1$. From definition (15), $(F_{gtu}(.)x^i_t, F_{gtu}(.)^{-1} I^i_t) \in V_I(y^i_t: k^i_t)$. If $(F_{gtu}(.)x^i_t, F_{gtu}(.)^{-1} I^i_t) \notin Isoq\ V_I(y^i_t: k^i_t)$, then $\exists\ 0<\delta<1$ such that $(\delta F_{gtu}(.)x^i_t, \delta^{-1} F_{gtu}(.)^{-1} I^i_t) \in V_I(y^i_t: k^i_t)$. Thus, $F_{gtu}(y^i_t, x^i_t, I^i_t, k^i_t) = 1$ is not a minimum. This contradiction establishes that $(F_{gtu}(.)x^i_t, F_{gtu}(.)^{-1} I^i_t) = (x^i_t, I^i_t) \in V_I(y^i_t: k^i_t)$. Conversely, let's assume $(x^i_t, I^i_t) \in Isoq\ V_I(y^i_t: k^i_t)$. By the definition of *Isoq* and the properties of positive monotonicity and negative monotonicity of $V_I(y^i_t: k^i_t)$ in x and I, respectively, $(\delta x^i_t, \delta^{-1} I^i_t) \notin V_I(y^i_t: k^i_t)$, $0<\delta<1$. Thus, the optimal solution of problem (15) is $F_{gtu}(y^i_t, x^i_t, I^i_t, k^i_t) = 1$. The proof is similar for $F_{gtl}(.)$.

F_g.3

$$\begin{aligned} F_{gtu}(y^i_t, \theta x^i_t, \theta^{-1} I^i_t, k^i_t) &= \min\{\gamma^i_{gtu} : (\gamma^i_{gtu}\theta x^i_t, {\gamma^i_{gtu}}^{-1}\theta^{-1} I^i_t)) \in V_I(y^i_t : k^i_t)\} \\ &= \theta^{-1} \min\{\theta\gamma^i_{gtu} : (\gamma^i_{gtu}\theta x^i_t, (\gamma^i_{gtu}\theta)^{-1} I^i_t) \in V_I(y^i_t : k^i_t)\} \\ &= \theta^{-1} F_{gtu}(y^i_t, x^i_t, I^i_t, k^i_t) \end{aligned}$$

for $\theta > 0$. The proof is similar for $F_{gtl}(.)$.

F_g.4 Consider the constraints on variable inputs, $\sum_j \lambda_t^j x_t^j \leq \gamma_{gtu}^i x_t^i$, and on gross investments, $\sum_j \lambda_t^j I_t^j \geq \gamma_{gtu}^{i\ -1} I_t^i$, in the minimization problem in (16). If we change $X^j = \mu x_t^j$ and $\bar{I}_t^j = \alpha I_t^j$, μ, α > 0, the optimal λ_t and the optimal $\gamma_{gtu}{}^i$ are not affected. Thus, $F_{gtu}(y^i{}_t, x^i{}_t, I^i{}_t, k^i{}_t)$ is independent of the unit of measurement. Consider the function $F_{gtl}(y^i{}_t, x^i{}_t, I^i{}_t, k^i{}_t)$ and the minimization problem in (18). If we change $X^j = \mu x_t^j$ and $\bar{I}_t^j = \alpha I_t^j$, μ, α > 0, then $\nu_t^j = \mu^{-1} w_t^j$ and $\overline{W}_{kt}^{bj} = \alpha^{-1} W_{kt}^{bj}$. Thus, the optimal $\gamma_{gtl}{}^i$ is not affected.

Proposition 2: The economic efficiency measure is related with the minimum shadow cost as follows: $rW(w_t, c_t, y_t, k_t) = w_t' E_g(.) x_t + c_t' k_t + W_k(.)'(E_g(.)^{-1} I_t - \delta k_t)$.

Proof:

Assume that $(x_t^o, I_t^o) \in H_g^-(y_t, E_g(.)x_t, E_g(.)^{-1} I_t, k_t, w_t, c_t) \cap V(y_t : k_t)$. Then, $(x_t^0, I_t^0) \in V(y_t : k_t)$ and given $E_g(.)$ is a minimum,

$$w_t' x_t^o + c_t' k_t + W_k(.)'(I_t^o - \delta k_t) = w_t' E_g(.) x_t + c_t' k_t + W_k(.)(E_g(.)^{-1} I_t - \delta k_t).$$

By way of contradiction, let's consider the following two cases:

(i) If $w_t' x_t^0 + c_t' k_t + W_k(.)'(I_t^0 - \delta k_t) < rW(w_t, c_t, y_t, k_t)$, then $(x_t^0, I_t^0) \notin V(y_t : k_t)$.

(ii) If $w_t' x_t^0 + c_t' k_t + W_k(.)'(I_t^0 - \delta k_t) > rW(w_t, c_t, y_t, k_t)$, then $E_g(.)$ is not a minimum.

From (i)-(ii), $w_t' x_t^0 + c_t' k_t + W_k(.)'(I_t^0 - \delta k_t) = rW(w_t, c_t, y_t, k_t)$. Thus,

$$rW(w_t, c_t, y_t, k_t) = w_t' E_g(.) x_t + c_t' k_t + W_k(.)'(E_g(.)^{-1} I_t - \delta k_t).$$

Proposition 3: The functions $E_{gtb}(y^i_t,x^i_t,I^i_t,k^i_t,w^i_t,c^i_t)$, $b=l,u$, satisfy the following properties for each observation

E_g.1 $0 < E_{gtb}(y^i_t,x^i_t,I^i_t,k^i_t,w^i_t,c^i_t) \leq 1$, $b=l,u$.

E_g.2 (x^i_t,I^i_t) solves problem (5) ((7)) $\Leftrightarrow$ $E_{gtu}(y^i_t,x^i_t,I^i_t,k^i_t,w^i_t,c^i_t)=1$ $(E_{gtl}(y^i_t,x^i_t,I^i_t,k^i_t,w^i_t,c^i_t)=1)$.

E_g.3 $E_{gtb}(y^i_t,\theta x^i_t, \theta^{-1}I^i_t,k^i_t,w^i_t,c^i_t) = \theta^{-1} E_{gtb}(y^i_t,x^i_t,I^i_t,k^i_t,w^i_t,c^i_t)$, $\theta > 0$, $b=l,u$.

E_g.4 $E_{gtb}(y^i_t,x^i_t,I^i_t,k^i_t,\theta w^i_t,\theta c^i_t) = E_{gtb}(y^i_t,x^i_t,I^i_t,k^i_t,w^i_t,c^i_t)$, $\theta > 0$, $b=l,u$.

E_g.5 $E_{gtb}(y^i_t,x^i_t,I^i_t,k^i_t,w^i_t,c^i_t)$ is independent of the unit of measurement, $b=l,u$.

Proof:

E_g.1 This property follows from the definition of $E_{gtu}(y^i_t,x^i_t,I^i_t,k^i_t,w^i_t,c^i_t)$ in (22) and the fact that $(x^i_t,I^i_t) \in V_I(y^i_t: k^i_t)$, $i=1,\ldots,n$, $t=1,\ldots,T$. The proof is similar for $E_{gtl}(y^i_t,x^i_t,I^i_t,k^i_t,w^i_t,c^i_t)$.

E_g.2 Assume $E_{gtu}(y^i_t,x^i_t,I^i_t,k^i_t,w^i_t,c^i_t) = 1$. Then, by proposition 2,

$$rW(w_t,c_t,y_t,k_t) = w_t' E_g(.)x_t + c_t' k_t + W_k(.)'(E_g(.)^{-1} I_t - \delta k_t).$$

Conversely, if (x^i_t,I^i_t) solves problem (5), by proposition 2, $E_{gtu}(y^i_t,x^i_t,I^i_t,k^i_t,w^i_t,c^i_t) = 1$. The proof is similar for $E_{gtl}(y^i_t,x^i_t,I^i_t,k^i_t,w^i_t,c^i_t)$.

E_g.3

$$\begin{aligned} E_{gtu}(y^i_t,\theta x^i_t,\theta^{-1}I^i_t,k^i_t,w^i_t,c^i_t) &= \min\{e_{gtu} : H_g^-(y^i_t,e_{gtu}\theta x^i_t,e_{gtu}^{-1}\theta^{-1}I^i_t,k^i_t,w^i_t,c^i_t) \\ &\qquad \cap V_I(y^i_t : k^i_t) \neq \varnothing\} \\ &= \theta^{-1}\min\{\theta e_{gtu} : H_g^-(y^i_t,e_{gtu}\theta x^i_t,e_{gtu}^{-1}\theta^{-1}I^i_t,k^i_t,w^i_t,c^i_t) \\ &\qquad \cap V_I(y^i_t : k^i_t) \neq \varnothing\} \\ &= \theta^{-1}E_{gtu}(y^i_t,x^i_t,I^i_t,k^i_t,w^i_t,c^i_t) \end{aligned}$$

for $\theta > 0$. The proof is similar for $E_{gtl}(y^i_t,x^i_t,I^i_t,k^i_t,w^i_t,c^i_t)$.

E_g.4 This follows from the property of homogeneity of degree zero in the market input prices w_t and c_t of the lower halfspace defined in (20).

E_g.5 This follows from problems (22) and (24).

Proposition 4: The functions $A_{gtj}(y^i_t,x^i_t,I^i_t,k^i_t,w^i_t,c^i_t)$, j=1,...,4, satisfy the following properties for each observation

A_g.1 $0 < A_{gtj}(y^i_t,x^i_t,I^i_t,k^i_t,w^i_t,c^i_t) \leq 1$, j=1,...,3.

A_g.2 $\exists$ α $\in$ (0,1] such that $(\alpha x^i_t, \alpha^{-1} I^i_t)$ solves problem (5) ((7)) $\Leftrightarrow$

$A_{gt2}(y^i_t,x^i_t,I^i_t,k^i_t,w^i_t,c^i_t) = 1$, $(A_{gt1}(y^i_t,x^i_t,I^i_t,k^i_t,w^i_t,c^i_t) = 1)$.

A_g.3 $A_{gtj}(y^i_t,\theta x^i_t,\theta^{-1}I^i_t,k^i_t,w^i_t,c^i_t) = A_{gtj}(y^i_t,x^i_t,I^i_t,k^i_t,w^i_t,c^i_t)$, $\theta > 0$, j=1,...,4.

A_g.4 $A_{gtj}(y^i_t,x^i_t,I^i_t,k^i_t,\theta w^i_t,\theta c^i_t) = A_{gtj}(y^i_t,x^i_t,I^i_t,k^i_t,w^i_t,c^i_t)$, $\theta > 0$, j=1,...,4.

A_g.5 $A_{gtj}(y^i_t,x^i_t,I^i_t,k^i_t,w^i_t,c^i_t)$ is independent of the unit of measurement, j=1,...,4.

Proof:

A_g.1 From F_g.2, $(x^i_t,I^i_t) \in Isoq\ V_B(y^i_t: k^i_t) \Leftrightarrow F_{gtb}(y^i_t,x^i_t,I^i_t,k^i_t) = 1$, $B=O$ and $b=l$ or $B=I$ and $b=u$. If $(x^i_t,I^i_t) \in Isoq\ V_B(y^i_t: k^i_t)$, then $0 < E_{gtb}(y^i_t,x^i_t,I^i_t,k^i_t,w^i_t,c^i_t) \leq 1$, $B=O$ and $b=l$, $B=I$ and $b=u$. Furthermore, if $E_{gtl}(y^i_t,x^i_t,I^i_t,k^i_t,w^i_t,c^i_t) = 1$ $(E_{gtu}(y^i_t,x^i_t,I^i_t,k^i_t,w^i_t,c^i_t) = 1)$, $F_{gtl}(y^i_t,x^i_t,I^i_t,k^i_t) = 1$ $(F_{gtu}(y^i_t,x^i_t,I^i_t,k^i_t) = 1)$. Thus, $0 < A_{gtj}(y^i_t,x^i_t,I^i_t,k^i_t,w^i_t,c^i_t) \leq 1$, j =1,2. Since $A_{gt3}(y^i_t,x^i_t,I^i_t,k^i_t,w^i_t,c^i_t) \leq A_{gtj}(y^i_t,x^i_t,I^i_t,k^i_t,w^i_t,c^i_t)$, j =1,2, also $A_{gt3}(y^i_t,x^i_t,I^i_t,k^i_t,w^i_t,c^i_t) \leq$ 1.

A_g.2 Assume $(\alpha x^i_t, \alpha^{-1} I^i_t)$, α $\in$ (0,1], solves problem (5) ((7)). From proposition 2, $E_{gtu}(y^i_t,x^i_t,I^i_t,k^i_t,w^i_t,c^i_t) = \alpha$ $(E_{gtl}(y^i_t,x^i_t,I^i_t,k^i_t,w^i_t,c^i_t) = \alpha)$ and $(\alpha x^i_t, \alpha^{-1} I^i_t) \in Isoq\ V_I(y^i_t:k^i_t)$ $((\alpha x^i_t, \alpha^{-1} I^i_t) \in Isoq\ V_O(y^i_t:k^i_t))$. Also, $(F_{gtu}(y^i_t,x^i_t,I^i_t,k^i_t)\ x^i_t,\ I^i_t/(F_{gtu}(y^i_t,x^i_t,I^i_t,k^i_t)) \in Isoq\ V_I(y^i_t:k^i_t)$ $((F_{gtl}(y^i_t,x^i_t,I^i_t,k^i_t)x^i_t,\ I^i_t/(F_{gtl}(y^i_t,x^i_t,I^i_t,k^i_t)) \in Isoq\ V_O(y^i_t:k^i_t))$. Thus, $E_{gtu}(y^i_t,x^i_t,I^i_t,k^i_t,w^i_t,c^i_t) = F_{gtu}(y^i_t,x^i_t,I^i_t,k^i_t)$ $(E_{gtl}(y^i_t,x^i_t,I^i_t,k^i_t,w^i_t,c^i_t) = F_{gtl}(y^i_t,x^i_t,I^i_t,k^i_t))$. Therefore,

$A_{gt2}(y^i{}_t,x^i{}_t\,,I^i{}_t,k^i{}_t,w^i{}_t,c^i{}_t) = 1$ ($A_{gt1}(y^i{}_t,x^i{}_t\,,I^i{}_t,k^i{}_t,w^i{}_t,c^i{}_t) = 1$). Conversely, assume $A_{gt2}(y^i{}_t,x^i{}_t\,,I^i{}_t,k^i{}_t,w^i{}_t,c^i{}_t) = 1$ ($A_{gt1}(y^i{}_t,x^i{}_t\,,I^i{}_t,k^i{}_t,w^i{}_t,c^i{}_t) = 1$). Then, $E_{gtu}(y^i{}_t,x^i{}_t\,,I^i{}_t,k^i{}_t,w^i{}_t,c^i{}_t) = F_{gtu}(y^i{}_t,x^i{}_t\,,I^i{}_t,k^i{}_t)$ ($E_{gtl}(y^i{}_t,x^i{}_t,I^i{}_t,k^i{}_t,w^i{}_t,c^i{}_t) = F_{gtl}(y^i{}_t,x^i{}_t,I^i{}_t,k^i{}_t)$). Since $F_{gtu}(y^i{}_t,x^i{}_t,I^i{}_t,k^i{}_t) \in (0,1]$ ($F_{gtl}(y^i{}_t,x^i{}_t\,,I^i{}_t,k^i{}_t) \in (0,1]$) and from proposition 2, $A_g.2$ holds.

$A_g.3$ This follows from properties $F_g.3$ and $E_g.3$ and definitions in (28).

$A_g.4$ This follows from property $E_g.4$.

$A_g.5$ This follows from properties $F_g.5$ and $E_g.5$.

Proposition 5: The functions $F_{xtb}(y^i{}_t,x^i{}_t\,,I^i{}_t,k^i{}_t)$, $b=l,u$, satisfy the following properties for each observation

$F_x.1$ $0 \leq F_{xtb}(y^i{}_t,x^i{}_t\,,I^i{}_t,k^i{}_t) \leq 1$, $b=l,u$.

$F_x.2$ $F_{xtb}(y^i{}_t,x^i{}_t\,,I^i{}_t,k^i{}_t) \Rightarrow (x^i{}_t\,,I^i{}_t) \in Isoq\ V_B(y^i{}_t\!: k^i{}_t)$ or on the boundary of $\Re^{m+o}_+$, $B=O$ and $b=l$ or $B=I$ and $b=u$.

$F_x.3$ $F_{xtb}(y^i{}_t,\theta x^i{}_t\,,\theta^{-1}I^i{}_t,k^i{}_t) = \theta^{-1}\ F_{xtb}(y^i{}_t,x^i{}_t\,,I^i{}_t,k^i{}_t)$, $\theta > 0$, $b=l,u$.

$F_x.4$ $F_{xtb}(y^i{}_t,x^i{}_t\,,I^i{}_t,k^i{}_t)$ is independent of the unit of measurement, $b=l,u$.

Proof: The proof is similar to the proof of proposition 1.

Proposition 6: The functions $E_{xtb}(y^i{}_t,x^i{}_t\,,I^i{}_t,k^i{}_t,w^i{}_t)$, $b=l,u$, satisfy the following properties for each observation

$E_x.1$ $0 < E_{xtb}(y^i{}_t,x^i{}_t\,,I^i{}_t,k^i{}_t,w^i{}_t) \leq 1$, $b=l,u$.

$E_x.2$ $(x^i{}_t\,,I^i{}_t)$ solves problem (9) ((12)) $\Leftrightarrow$ $E_{xtu}(y^i{}_t,x^i{}_t\,,I^i{}_t,k^i{}_t,w^i{}_t)=1$ ($E_{xtl}(y^i{}_t,x^i{}_t\,,I^i{}_t,k^i{}_t,w^i{}_t) =1$).

$E_x.3$ $E_{gtb}(y^i{}_t,\theta x^i{}_t\,,\theta^{-1}I^i{}_t\,k^i{}_t,w^i{}_t) = \theta^{-1}\ E_{xtb}(y^i{}_t,x^i{}_t\,,I^i{}_t,k^i{}_t,w^i{}_t)$, $\theta >0$, $b=l,u$.

$E_x.4$ $E_{xtb}(y^i{}_t,x^i{}_t\,,I^i{}_t,k^i{}_t,\theta w^i{}_t) = E_{xtb}(y^i{}_t,x^i{}_t\,,I^i{}_t,k^i{}_t,w^i{}_t)$, $\theta >0$, $b=l,u$.

$E_x.5$ $E_{xtb}(y^i{}_t,x^i{}_t\,,I^i{}_t,k^i{}_t,w^i{}_t)$ is independent of the unit of measurement, $b=l,u$.

Proof: The proof is similar to the proof of proposition 3.

Proposition 7: The functions $A_{xtj}(y^i_t, x^i_t, I^i_t, k^i_t, w^i_t)$, j=1,...,4, satisfy the following properties for each observation

A_x.1 $0 < A_{xtj}(y^i_t, x^i_t, I^i_t, k^i_t, w^i_t) \leq 1$, j=1,...,3.

A_x.2 $\exists\, \alpha \in (0,1]$ such that αx^i_t solves problem (9) ((12)) $\Leftrightarrow$ $A_{xt2}(y^i_t, x^i_t, I^i_t, k^i_t, w^i_t)=1$, ($A_{xt1}(y^i_t, x^i_t, I^i_t, k^i_t, w^i_t) = 1$).

A_x.3 $A_{xtj}(y^i_t, \theta x^i_t, I^i_t, k^i_t, w^i_t) = A_{xtj}(y^i_t, x^i_t, I^i_t, k^i_t, w^i_t)$, $\theta > 0$, j=1,...,4.

A_x.4 $A_{xtj}(y^i_t, x^i_t, I^i_t, k^i_t, \theta w^i_t) = A_{xtj}(y^i_t, x^i_t, I^i_t, k^i_t, w^i_t)$, $\theta > 0$, j=1,...,4.

A_x.5 $A_{xtj}(y^i_t, x^i_t, I^i_t, k^i_t, w^i_t)$ is independent of the unit of measurement, j=1,...,4.

Proof: The proof is similar to the proof of proposition 4.

Appendix Table 1. Variable Factors Lower Bounds

	Technical Efficiency						Allocative Efficiency					
Farm No.	1987	1988	1989	1990	1991	1992	1987	1988	1989	1990	1991	1992
1	1	1	0.9646	1	0.9424	1	1	1	0.2894	0.3167	0.303905	1
2	1	1	1	1	1	1	1	1	1	1	1	0.6376
3	1	1	1	1	1	1	1	1	1	1	1	1
4	0.743	1	1	1	1	1	0.6705	1	1	1	1	1
5	1	1	1	1	1	1	1	1	1	1	1	1
6	1	1	1	1	1	1	0.7332	0.7857	0.6731	0.8795	1	0.8833
7	1	0.9128	0.7148	0.7601	1	1	1	0.8343	0.680775	0.4153	1	1
8	1	1	1	1	1	1	1	0.7354	1	0.9544	1	1
9	1	1	1	1	1	1	1	1	1	1	0.9488	1
10	1	1	1	0.6385	1	0.6482	1	1	1	0.528	1	1
11	1	1	1	1	1	1	1	1	1	1	1	1
12	1	1	1	1	0.86	1	1	1	1	1	1	1
13	1	1	1	1	1	1	1	1	1	1	1	1
14	1	1	1	1	1	1	1	1	1	1	1	1
15	1	1	1	1	1	1	1	1	1	1	0.7117	0.9493
16	1	1	1	1	0.8791	1	1	1	1	1	0.981696	1
17	0.583	1	1	1	0.7299	1	0.461942	1	1	1	0.585504	0.6025
18	1	1	1	1	1	1	1	1	1	1	1	1
19	1	0.549	1	1	0.987	1	0.8736	0.549	1	1	1	1
20	0.90	1	0.9993	1	1	1	0.6879	1	0.997436	1	1	1
21	1	0.7199	1	1	1	1	1	0.719882	1	1	1	1
22	1	1	0.6534	1	1	1	1	1	0.665312	1	1	1
23	1	1	1	1	1	1	1	1	1	1	1	1

Appendix Table 1. Variable Factors Lower Bounds (continued)

	Technical Efficiency						Allocative Efficiency					
Farm No.	1987	1988	1989	1990	1991	1992	1987	1988	1989	1990	1991	1992
24	0.798	1	1	1	1	1	0.6181	1	1	1	1	1
25	1	1	1	1	1	1	1	1	1	1	0.6634	1
26	0.892	0.8335	1	1	1	1	0.8393	0.6697	1	0.7047	1	1
27	1	1	1	1	1	1	1	0.5309	1	1	1	1
28	1	1	1	0.9259	1	1	1	1	1	0.7208	1	1
29	1	1	1	1	1	1	1	1	1	1	1	1
36	1	1	1	1	1	1	1	1	1	1	1	1
37	1	1	1	1	1	1	1	1	1	1	0.9556	1
38	1	1	1	1	1	1	1	1	1	1	1	1
39	0.6482	1	1	1	1	1	0.6482	1	1	1	1	0.9625
40	0.7077	1	1	1	1	1	0.6368	1	1	1	1	1
41	1	1	1	1	1	1	1	1	1	1	1	1
42	1	1	1	1	1	1	1	1	1	1	0.7727	1
43	1	1	1	1	1	1	1	1	1	1	1	1
44	1	1	1	1	1	1	1	1	1	1	1	1
45	1	1	1	1	1	1	1	1	1	1	1	1
46	1	1	1	1	1	1	1	1	1	1	1	1
47	1	1	1	1	1	1	1	1	1	1	1	1
48	1	1	1	1	1	1	1	1	1	1	1	1
49	1	1	1	1	1	1	1	1	1	1	1	1
50	1	1	0.8734	1	1	1	0.8247	1	0.8607	0.93	1	1
51	1	1	0.801	0.9168	1	0.7989	1	0.8739	0.469599	0.1851	1	0.5955

Appendix Table 1. Variable Factors Lower Bounds (continued)

	Technical Efficiency						Allocative Efficiency					
Farm No.	1987	1988	1989	1990	1991	1992	1987	1988	1989	1990	1991	1992
52	0.8835	1	1	1	1	1	0.2607	0.6474	1	1	1	1
53	1	1	1	1	1	1	1	0.7833	1	1	0.7917	1
54	1	1	1	1	1	1	1	1	1	1	1	1
55	1	1	1	1	1	1	1	1	1	1	1	1
56	1	1	1	1	1	1	1	1	1	1	1	1
57	1	1	1	1	1	1	1	0.8571	1	1	1	1
58	1	1	1	1	1	1	1	1	1	1	1	1
59	0.9929	1	0.6095	1	1	1	0.944	1	0.6095	1	1	1
60	1	1	0.7472	1	1	1	1	0.9857	0.7472	1	1	1
61	0.9337	0.6534	1	1	1	1	0.9337	0.6534	1	1	0.8556	1

Appendix Table 2. Variable Factors Upper Bounds

	Technical Efficiency						Allocative Efficiency					
Farm No.	1987	1988	1989	1990	1991	1992	1987	1988	1989	1990	1991	1992
1	1	1	1	1	1	1	1	1	0.743832	1	0.3132	1
2	1	1	1	1	1	0.9845	1	1	1	1	1	0.9358
3	1	1	1	1	1	1	1	1	1	1	1	1
4	1	1	1	1	1	1	1	1	1	1	1	0.7802
5	1	1	1	1	1	1	1	1	1	1	1	1
6	1	1	1	1	1	1	1	1	0.9517	1	0.8625	1
7	1	1	0.7844	1	1	1	1	0.90206	1	1	1	1
8	1	1	1	1	1	1	1	1	1	1	0.9037	1
9	1	1	1	1	1	1	1	1	1	1	1	1
10	1	1	1	1	1	1	0.8992	1	1	1	1	0.9759
11	1	1	1	1	1	1	1	1	1	1	1	1
12	1	1	1	1	1	1	1	1	1	1	0.9713	1
13	1	1	1	1	1	1	1	1	1	1	1	1
14	1	1	1	1	1	1	1	1	1	1	1	1
15	1	1	1	1	0.855	1	1	1	1	1	1	0.774
16	1	1	1	1	0.8791	1	1	1	1	1	1	1
17	0.7436	1	1	1	0.7754	1	0.919568	1	1	0.7903	0.7983	1
18	1	1	1	1	1	1	1	1	1	1	1	1
19	1	1	0.652	1	1	1	0.7929	1	0.6422	1	0.6206	1
20	1	1	0.9752	1	1	1	1	1	0.88612	1	1	1
21	1	0.845	1	1	1	1	1	0.89443	1	1	1	1
22	1	1	0.9597	1	1	1	1	1	1	1	1	1
23	1	1	0.9993	1	1	1	1	1	0.8412	1	1	1

Appendix Table 2. Variable Factors Upper Bounds (continued)

	Technical Efficiency						Allocative Efficiency					
Farm No.	1987	1988	1989	1990	1991	1992	1987	1988	1989	1990	1991	1992
24	1	1	1	1	1	1	1	1	1	1	1	1
25	1	1	1	1	1	1	1	1	1	1	1	1
26	1	1	1	1	1	1	1	1	1	0.6218	1	0.9957
27	1	1	1	1	1	1	1	1	1	1	1	1
28	1	1	1	1	1	1	1	1	1	1	1	1
29	1	1	1	1	1	1	1	1	1	1	1	1
36	1	1	1	1	1	1	1	1	1	1	1	1
37	1	1	1	1	1	0.8785	1	1	1	1	1	1
38	1	1	1	1	1	1	1	1	1	1	1	1
39	1	1	1	1	1	1	1	1	1	1	1	0.866
40	1	1	1	1	1	1	1	1	1	1	1	1
41	1	0.9673	1	1	0.778	1	1	0.9664	1	1	0.9654	0.794
42	1	1	1	1	1	1	1	1	1	1	1	1
43	1	1	1	1	1	1	1	1	0.9239	1	1	1
44	1	1	1	1	1	1	1	1	1	1	1	1
45	1	1	1	1	1	1	1	1	0.9539	1	1	1
46	1	1	1	1	1	1	1	1	1	1	1	1
47	1	1	1	1	1	1	1	1	1	1	1	1
48	1	1	1	1	1	1	1	1	1	1	1	1
49	1	1	1	1	1	1	1	1	1	1	1	1
50	1	1	1	1	1	1	1	1	1	1	1	1
51	1	1	1	1	1	1	1	1	1	1	1	1

Appendix Table 2. Variable Factors Upper Bounds (continued)

	Technical Efficiency						Allocative Efficiency					
Farm No.	1987	1988	1989	1990	1991	1992	1987	1988	1989	1990	1991	1992
52	1	1	1	1	1	1	0.5511036	0.6338	1	1	1	0.8679
53	1	1	1	1	1	1	1	1	1	1	1	1
54	1	1	1	1	1	1	1	1	1	1	1	1
55	1	1	1	1	1	1	1	1	1	1	1	1
56	1	1	1	1	1	1	1	1	1	1	1	1
57	1	1	1	1	1	1	1	1	1	1	1	1
58	1	1	1	1	1	1	1	1	1	1	1	1
59	1	1	1	1	1	1	1	1	1	1	1	1
60	1	1	1	1	1	1	1	1	1	1	1	1
61	1	1	1	1	1	1	1	1	0.8514	1	1	1

Appendix Table 3. All Factors Lower Bounds

	Technical Efficiency						Allocative Efficiency					
Farm No.	1987	1988	1989	1990	1991	1992	1987	1988	1989	1990	1991	1992
1	0.789	1	0.8717	0.8391	0.7507	0.9274	0.1649	0.5457	0.2813	0.1924	0.2204161	0.3828
2	0.6678	0.7717	1	1	0.9347	0.7675	0.5710512	0.7221568	0.8954	0.8686	0.4963	0.1712493
3	0.5881	0.6711	0.6298	0.7249	0.6409	0.6952	0.6357897	0.8332685	0.613702	0.7904241	0.7324982	0.7664049
4	0.4854	0.5108	0.6136	0.6471	0.5948	0.5276	0.6060061	0.7153545	0.5813604	0.7938012	0.5176853	0.1574429
5	0.7188	0.6194	0.5959	0.7067	0.7377	0.6638	0.54	0.3245	0.4790142	0.1028	0.1561	0.1953
6	0.6266	0.707	0.7728	0.8738	0.7336	0.7131	0.563	0.6637	0.6328	0.6076	0.6767	0.7131
7	0.6035	0.6466	0.5651	0.6622	0.7472	0.9886	0.4831474	0.7701225	0.6536358	0.6351943	0.709341	0.7877
8	0.5369	0.5537	0.7253	0.6802	0.6563	0.6542	0.5269867	0.7045273	0.4844	0.695281	0.834094	0.6274458
9	0.9016	0.6811	0.6715	0.9498	0.8499	1	0.88	0.6536	0.6265	0.5868	0.6925	0.8278
10	0.7177	0.8415	0.8047	0.6884	0.6877	0.6672	0.7318724	0.6105	0.6871862	0.577709	0.6941577	0.5837996
11	0.6432	0.9378	1	0.7036	0.5016	0.7007	0.572	0.6806	0.7009	0.7258405	0.7151188	0.8273372
12	0.9353	0.7256	1	0.9238	0.8578	0.6946	0.9201	0.9092827	0.9657	0.8242834	0.8713457	0.203418
13	0.7935	0.7198	0.8456	0.8594	0.9065	0.8318	0.7949068	0.9261496	0.7501073	0.9293409	0.6945	0.8313293
14	0.9453	1	0.8788	1	1	1	0.8228	0.8898	0.6932	0.86	0.9932	0.7587
15	0.8064	1	0.9959	0.9101	0.5159	0.9846	0.7714	0.8865	0.7759	0.5694	0.6243756	0.7686
16	0.9615	1	1	0.9857	0.7529	1	0.9627888	1	0.9917	0.8286689	0.9886394	0.7442
17	0.471	0.8489	0.6619	0.6406	0.5272	0.6954	0.4747752	0.7528	0.6694335	0.662869	0.4743788	0.4247653
18	0.7364	0.7659	0.6765	0.6749	0.5972	0.7691	0.3102516	0.3967831	0.2265057	0.3171987	0.2811998	0.0553902
19	0.6366	0.5806	0.6098	0.6254	0.63	0.7309	0.5896933	0.7162879	0.4886849	0.3946	0.5387	0.7309
20	0.8298	0.791	0.6566	0.684	0.6438	0.8232	0.6692974	0.7814916	0.7516849	0.9486824	0.6081547	0.6095388
21	0.5588	0.6393	0.6699	0.749	1	0.7541	0.3979925	0.5048077	0.4693194	0.6971624	0.6163	0.6236
22	0.7634	0.7759	0.5771	0.7954	0.7598	1	0.8317087	0.7143	0.2965774	0.9504395	0.8590176	0.859
23	0.5864	0.9372	0.6889	0.6762	1	1	0.7059406	0.7731	0.8148488	0.7781445	0.7549	0.9116

Appendix Table 3. All Factors Lower Bounds (continued)

	Technical Efficiency						Allocative Efficiency					
Farm No.	1987	1988	1989	1990	1991	1992	1987	1988	1989	1990	1991	1992
24	0.5899	0.6756	0.6407	0.7587	0.6478	0.6802	0.3758213	0.7132889	0.6933999	0.7306068	0.8227425	0.7707687
25	0.7725	0.8108	0.645	0.8056	0.7568	0.7758	0.6466927	0.3398173	0.2987864	0.6789066	0.4000485	0.4848375
26	0.5778	0.7322	0.7276	0.6567	0.7727	0.6951	0.53463	0.5532043	0.5799775	0.5675336	0.6270488	0.0846174
27	0.6806	0.6988	0.6398	0.6475	0.7436	0.8521	0.29827	0.5558373	0.4996338	0.4829202	0.4029718	0.3730624
28	0.6191	0.6523	1	0.6966	0.6093	0.7103	0.6278227	0.7644725	0.8683	0.7963623	0.5858289	0.7006478
29	0.5775	0.7156	0.7212	0.6811	0.6732	0.6901	0.3179859	0.5543734	0.5740222	0.6111179	0.5221374	0.3829843
36	0.5813	0.7604	0.7855	0.847	0.8228	0.8286	0.6556772	0.8393986	0.8467823	0.7480112	0.7733	0.8536803
37	0.5615	0.7308	0.7528	0.6966	0.9391	0.7091	0.4928768	0.4212	0.6607	0.5820878	0.4638	0.2169623
38	0.6658	0.5913	0.6944	0.7176	0.641	0.7523	0.7034483	0.6374502	0.6992624	0.7070925	0.6370139	0.3821311
39	0.6143	0.6251	0.9258	0.8799	0.7374	0.6961	0.7410133	0.6855374	0.813	0.6218309	0.686706	0.6961
40	0.6234	0.9214	1	0.7936	0.7249	0.867	0.6234	0.7991	0.8735	0.5777416	0.8141184	0.867
41	0.5523	0.7208	0.8033	0.6801	0.5311	0.6769	0.7310523	0.8661093	0.7375	0.7947075	0.6645061	0.9271174
42	1	1	0.7683	1	0.972	1	1	0.9886	0.7721024	1	0.9477	0.9999
43	1	1	0.7515	0.7859	0.8035	0.8022	0.8769	0.9162	0.6632892	0.6702	0.9251096	0.7640644
44	0.591	0.5611	0.5029	0.6329	0.6712	0.6972	0.3659	0.349	0.5282631	0.582683	0.5984	0.7325931
45	0.6223	0.8965	0.7362	0.6548	0.9852	0.6278	0.6369144	0.567	0.7213632	0.6331029	0.7955	0.710391
46	0.6507	0.6276	0.6502	0.6736	0.8987	0.6462	0.6302	0.5131	0.6461	0.5991	0.7649	0.5343
47	0.516	0.6208	0.7715	0.5987	0.7327	0.7181	0.2130584	0.2243679	0.3905	0.2409867	0.3762934	0.233341
48	0.8128	0.6041	0.6505	0.5861	0.6076	0.5632	0.8974274	0.7720041	0.7071471	0.4485008	0.5989235	0.6778931
49	0.6216	0.8618	0.5712	0.839	0.5823	0.6352	0.7875295	0.6359	0.8337469	0.633809	0.8440354	0.9069103
50	0.6905	0.7569	0.6037	0.828	0.66	0.4891	0.9050073	0.5349495	0.8536447	0.6628649	0.7576209	0.6974879
51	0.8914	0.8188	0.733	0.7435	0.7878	0.9159	0.6521	0.803	0.5201449	0.7277143	0.7333	0.4968

Appendix Table 3. All Factors Lower Bounds (continued)

	Technical Efficiency						Allocative Efficiency					
Farm No.	1987	1988	1989	1990	1991	1992	1987	1988	1989	1990	1991	1992
52	0.7476	0.7041	0.7446	0.5896	0.6918	0.7263	0.2567991	0.4206145	0.529654	0.3878611	0.3941109	0.7161833
53	0.4841	0.7464	0.694	0.9509	0.4934	0.5621	0.5593765	0.6443914	0.7156468	0.5489	0.660185	0.7644266
54	0.4803	0.5429	0.6072	0.568	0.622	1	0.4405331	0.54097	0.5200216	0.4928299	0.574711	0.7284
55	0.7454	0.729	0.8392	0.8776	0.8872	0.8156	0.3094155	0.1664347	0.3218599	0.3021122	0.2370041	0.2046336
56	0.5454	0.7264	0.5303	0.6054	0.5795	0.7221	0.3871581	0.591719	0.4608282	0.569944	0.5550086	0.3781859
57	0.5836	0.6772	0.7729	0.6142	0.5804	0.8097	0.635247	0.534	0.6149	0.7783476	0.6594644	0.6811
58	0.546	0.7561	0.5325	0.5868	0.7045	0.5941	0.632	0.5879	0.8108795	0.6298157	0.9221277	0.6847246
59	0.6105	0.7355	0.7729	0.9312	1	0.7966	0.3826464	0.6257	0.6279	0.6104	0.6738	0.6901
60	1	0.9411	0.8132	1	0.9716	1	1	0.8191	0.6955	0.9991	0.891	0.9743
61	0.8825	0.698	0.6383	0.6919	0.7527	0.8844	0.8250233	0.7625593	0.5933585	0.5581	0.9493863	0.7507

Appendix Table 4. All Factors Upper Bounds

	Technical Efficiency						Allocative Efficiency					
Farm No.	1987	1988	1989	1990	1991	1992	1987	1988	1989	1990	1991	1992
1	1	1	1	1	0.8797	1	0.27706	1	0.54755	0.33464	0.32063	0.43757
2	0.9085	0.8494	1	1	1	0.8765	1	1	1	1	0.65251	0.78358
3	0.8712	0.7707	0.7269	0.8417	0.8142	0.7894	1	1	0.74802	1	1	0.89917
4	0.7226	0.5881	0.7983	0.7808	0.8312	0.6523	1	1	1	0.9626	0.99697	0.99564
5	1	1	0.9292	1	1	1	0.87869	1	1	0.5288	1	1
6	1	1	1	1	1	1	1	1	1	0.95228	1	1
7	0.8159	0.7591	0.6216	0.7541	0.8725	1	0.95244	1	0.84516	0.65992	0.6966	0.70878
8	0.9727	0.751	1	0.8434	0.745	0.7513	1	1	1	1	1	0.98181
9	1	1	1	1	1	1	1	1	1	0.76342	0.84598	1
10	0.8716	1	0.9958	0.8075	0.8815	0.7864	0.95179	1	0.81919	0.96209	1	0.96493
11	1	1	1	0.8061	0.6859	0.8033	1	1	0.8053	1	1	1
12	1	0.7584	1	0.9908	0.8962	0.6612	0.97038	1	0.9794	0.89294	0.91268	0.69234
13	0.8796	0.7285	0.932	0.8633	1	0.9148	0.88973	1	0.88044	0.96905	0.77209	1
14	1	1	1	1	1	1	0.86756	1	0.25205	0.8804	0.9985	0.7552
15	1	1	1	1	0.8008	1	1	1	0.95542	0.91001	1	0.87172
16	0.9782	1	1	0.9969	0.757	1	0.96443	1	0.73	0.8394	0.99402	0.764
17	0.6561	1	0.759	0.7724	0.7123	0.852	0.84883	1	0.89681	0.70996	0.72458	0.55292
18	0.9618	0.9761	0.8119	0.9524	0.7468	0.8738	0.61325	1	0.53333	0.51667	0.5	0.20895
19	0.8674	0.7349	0.7954	1	1	1	1	1	1	0.86904	1	0.85251
20	0.9123	0.9185	0.7567	0.721	0.8118	0.8869	0.71475	1	0.96863	1	0.77617	0.82507
21	0.8568	0.7488	0.8067	0.8493	1	1	0.73658	1	0.60815	0.48037	0.5435	1
22	0.8925	1	0.6983	0.8192	0.8306	1	0.97236	1	1	0.81619	1	0.8565
23	0.808	1	0.7637	0.8483	1	1	1	1	1	1	0.6661	0.9186

Appendix Table 4. All Factors Upper Bounds (continued)

	Technical Efficiency						Allocative Efficiency					
Farm No.	1987	1988	1989	1990	1991	1992	1987	1988	1989	1990	1991	1992
24	0.761	0.9459	0.7606	0.8289	0.7176	0.8053	0.73962	1	1	0.93555	0.91911	1
25	0.8194	0.8431	0.824	0.8524	0.8249	0.831	0.69696	1	1	0.7531	0.53832	0.59319
26	0.8432	0.8317	0.889	0.7959	0.9945	0.7528	1	1	0.80951	0.50069	0.93982	0.59258
27	0.9364	0.8283	0.8192	0.8109	0.9018	0.9548	0.53218	1	0.69303	0.59228	0.47028	0.44255
28	0.9654	0.8067	1	0.8137	0.748	0.8181	1	1	0.6967	0.93081	0.86394	0.90905
29	0.8818	0.8083	0.8923	0.8221	0.7205	0.764	0.64398	1	0.6919	0.51255	0.4691	0.46341
36	0.8675	0.8381	0.8935	0.9302	1	0.8953	1	1	1	1	1	1
37	0.8704	1	1	0.8698	1	0.8513	0.83598	1	1	0.9021	0.81887	0.48399
38	0.87	0.9036	0.949	0.8361	0.7689	0.8484	1	1	1	0.91388	0.71981	0.39997
39	0.829	0.9044	1	0.9427	0.9997	1	1	1	0.96835	0.85862	1	1
40	1	1	1	0.9821	0.8882	1	1	1	1	0.93889	1	1
41	0.7336	0.7536	1	0.718	0.7097	0.7025	1	1	0.86705	1	1	0.93057
42	1	1	0.8947	1	1	1	1	1	0.9892	1	0.98169	1
43	1	1	0.9376	1	0.8666	0.9261	0.8731	1	0.92136	0.96297	1	0.87397
44	1	1	0.6811	0.8073	1	0.8646	1	1	0.94611	0.94312	1	1
45	0.9243	1	0.9184	0.9256	1	0.8363	1	1	1	1	1	1
46	1	1	1	1	1	1	1	1	1	1	0.91276	1
47	0.7566	0.7871	1	0.8432	0.8698	0.8644	0.50136	1	1	0.53265	0.321	0.46985
48	0.9057	0.7794	0.8465	0.8738	0.7617	0.6265	1	1	1	1	0.92907	0.91282
49	0.7201	1	0.6851	0.9181	0.6899	0.7004	1	1	1	0.75912	1	1
50	0.7569	0.9199	0.7065	0.9557	0.7381	0.6608	1	1	1	0.80628	1	1
51	1	1	0.9109	0.9883	1	1	0.86807	1	0.90723	1	1	0.61349

Appendix Table 4. All Factors Upper Bounds (continued)

	Technical Efficiency						Allocative Efficiency					
Farm No.	1987	1988	1989	1990	1991	1992	1987	1988	1989	1990	1991	1992
52	0.9891	0.8169	0.8498	0.7892	0.866	0.8206	0.47138	0.90016	0.72294	0.61533	0.49205	1
53	0.8084	0.8799	0.8187	1	0.6377	0.6741	1	1	0.96455	0.60395	1	0.95606
54	0.6903	0.8433	0.7392	0.7601	0.7094	1	1	1	0.66156	0.51972	0.55756	1
55	0.8571	0.8622	0.9936	0.9374	0.9907	0.9021	0.41682	1	0.41909	0.45476	0.34806	0.29941
56	0.7896	0.7801	0.6931	0.7506	0.7517	0.8004	0.71104	1	0.66962	0.72514	0.71613	0.5232
57	0.7734	1	1	0.702	0.8701	1	1	1	0.92742	1	1	0.83611
58	0.7125	1	0.5901	0.7164	0.705	0.7679	1	1	1	1	0.97686	1
59	0.7618	1	1	1	1	1	0.59034	1	1	0.80015	0.7715	0.9936
60	1	1	1	1	1	1	1	1	0.95868	1	0.99866	0.9003
61	0.9647	0.8221	0.8462	1	0.7903	1	0.93858	1	1	0.89579	0.99934	0.87743