# Off-Farm Labor and the Structure of U.S. Agriculture:
# The Case of Corn/Soybean Farms

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***Abstract***

While the growing importance of off-farm earnings suggests large benefits accrue to farmers from efforts to expand off-farm income opportunities, survival still depends on greater efficiency. To comprehensively gauge the economic health of farm operator households we interpret off-farm income as an output along with corn, soybeans, livestock, and other crops. To accomplish this task we use two related methodologies. First, using 2000 data, we setup a multiactivity cost function to analyze labor allocation decisions within the farm operator household and also to estimate returns to scale and scope. Second, using 1996-2000 data , we follow an input distance function approach to estimate returns to scale, technical progress, cost economies, and technical efficiency--and compare the relative performance of farm operator households with and without off-farm wages and salaries. Our preliminary results suggest that over our sample period, scale economies are a primary factor driving up farm operator household size and decreasing the competitiveness of small farm operator households in the base farm operator household model where off-farm income is constrained to zero. But small farm operator households appear to achieve efficiency levels more comparable to larger farm operator households when off-farm income is accommodated. The evidence therefore suggests that while short-falls in these productivity components are decreasing the competitiveness of small farm operator households as agricultural structure changes, corn/soybean farm operator households have partially adapted to such pressures by increasing off-farm income and, therefore, achieving economies of scope.

**Off-Farm Labor and the Structure of U.S. Agriculture: The Case of Corn/Soybean Farms***

**Introduction**

While the growing importance of off-farm earnings suggests large benefits accrue to farmers from efforts to expand off-farm income opportunities, survival still depends on greater efficiency (USDA 2001). To comprehensively gauge the economic health of farm operator households[1] we interpret off-farm income as an output along with corn, soybeans, livestock, and other crops. To accomplish this task we use two related methodologies. First, using 2000 data, we setup a multiactivity cost function to analyze labor allocation decisions within the farm operator household and also to estimate returns to scale and scope. Second, using 1996-2000 data , we follow an input distance function approach to estimate returns to scale, technical progress, cost economies, and technical efficiency--and compare the relative performance of farm operator households with and without off-farm wages and salaries. The role of off-farm income in analyses of farm structure and economic performance has been largely neglected .

Off-farm income and non-farm business opportunities have become increasingly important in many agricultural areas in recent years. As noted in USDA (2001), most rural communities that are dominated by small farms are no longer "anchored" by farming, and in fact non-farm income sources have dominated net farm income in the U.S for many years.[2] The Economic Research Service (ERS) has developed a farm typology (Hoppe, Perry, and Banker) that groups farms based on the sales, occupation of operator, farm assets, and total household income (Table 1). Using these groupings Table 2 identifies off-farm income by typology group for the U.S. for 1993 to 1999. The table shows that for all family farms, mean (per farm) and aggregate off-farm income grew dramatically in the short time between 1993 and 1999, almost twice as fast as the mean U.S. household income. While off farm income is clearly concentrated in the residential farms, it is also important in smaller and intermediate commercial farms. Among large and very large family farms off-farm income is less important relative to on farm income, but , nonetheless, represents a sizeable income stream as shown by the 2000 data in Table 2.

**The Methodologies for Analysis**

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* The opinions and conclusions expressed here are those of the authors and do not represent the views of the U.S. Department of Agriculture.

1 For purposes of our analysis farm operator household income includes income from farm activities and wages and salaries that the operator and all other household members received from off-farm sources. For our base farm operator household model we constrain all such off-farm income to zero.

2 Income from farming in the U.S., measured by net-farm cash income, was $55.7 billion in 1999, as compared to income from off-farm sources of $124 billion (USDA 2001b).

*Cost Function Approach*

The well-developed restricted cost function (Diewert; Lau) is used to estimate theoretically consistent demand and cost equations. Consider n outputs, m variable inputs, and s fixed inputs and other exogenous factors such as location or weather proxies, $\boldsymbol{Y} = (Y_1,...Y_n)'$ denotes the vector of outputs, $\boldsymbol{X} = (X_1,...X_m)'$ denotes the vector of variable inputs, $\mathbf{Z} = (Z_1,...Z_s)'$ is the vector of nonnegative quasi-fixed inputs and other (exogenous) factors, and $\boldsymbol{W} = (W_1,...W_m)'$ denotes the price vector of variable inputs. The restricted profit function is defined by:

$$(1) \qquad C(W,Y,Z) \;=\; Min\,[\,W'\,X \,:\, X \in T\,]\,.$$

The production possibilities set T is assumed to be nonempty, closed, bounded, and convex. Under these assumptions on the technology, the restricted cost function is well defined and satisfies the usual regularity conditions (Diewert). In particular, with some of the inputs fixed, *C* is homogeneous of degree one in variable input prices and quasi-fixed input quantities. Using the Shephard lemma, the per acre input demand functions are given by the following equation:

$$(2) \qquad X \;=\; \frac{\partial\, C\,(W,Y,Z\,)}{\partial\, W}$$

**The Empirical Model**

The empirical model uses a normalized quadratic variable cost function, which can be viewed as a second-order Taylor series approximation to the true cost function (Diewert). With symmetry imposed by sharing parameters and linear homogeneity imposed by normalization, this functional form may be expressed as:

$$(3) \qquad C(W,Y,Z) \;=\; a_0 \;+\; (a'\,b'\,c')\begin{bmatrix} W \\ Y \\ Z \end{bmatrix} \;+\; 1/2(W'\,Y'\,Z'\,)\begin{bmatrix} H & G & F \\ G' & B & E \\ F' & E' & C \end{bmatrix}\begin{bmatrix} W \\ Y \\ Z \end{bmatrix}$$

where $\boldsymbol{W}$ is a vector of normalized variable input prices, $a_0$ is a scalar parameter, while $\boldsymbol{a}$, $\boldsymbol{b}$, and $\boldsymbol{c}$ are vectors of constants of the same dimension as $\boldsymbol{W}$, $\boldsymbol{Y}$ and $\boldsymbol{Z}$. The parameter matrices $\boldsymbol{B}$, $\boldsymbol{C}$, and $\boldsymbol{H}$ are symmetric and of the appropriate dimensions. Similarly $\boldsymbol{E}$, $\boldsymbol{F}$, and $\boldsymbol{G}$ are matrices of unknown parameters.

Using equations (2) and (3), the per acre demand function for variable inputs is:

$$(4) \qquad X(P,W,Z) \;=\; \Delta_W\, C(W,Y,Z) \;=\; b \;+\; G'\,P \;+ B\,W \;+\; E\,Z$$

Considering the case of a five outputs (corn, soybeans, other crops, livestock, and operator and spouse off-farm labor), four inputs (hired labor, operator labor, spouse labor, miscellaneous inputs, and pesticides), using the pesticides price as the numeraire, and appending disturbance terms, the per acre demand functions and the cost function become

$$(5)\quad X_1 = a_1 + B_{11}W_1 + B_{12}W_2 + B_{13}W_3 + B_{14}W_4 + E_{11}Y_1 + E_{12}Y_2 + E_{13}Y_3 + E_{14}Y_4 + E_{15}Y_5 + F_{11}Z_1 + F_{12}Z_2 + \varepsilon_1$$

$$(6)\quad X_2 = a_2 + B_{12}W_1 + B_{22}W_2 + B_{23}W_3 + B_{24}W_4 + E_{21}Y_1 + E_{22}Y_2 + E_{23}Y_3 + E_{24}Y_4 + E_{25}Y_5 + F_{21}Z_1 + F_{22}Z_2 + \varepsilon_2$$

$$(7)\quad X_3 = a_3 + B_{13}W_1 + B_{23}W_2 + B_{33}W_3 + B_{34}W_4 + E_{31}Y_1 + E_{32}Y_2 + E_{33}Y_3 + E_{34}Y_4 + E_{35}Y_5 + F_{31}Z_1 + F_{32}Z_2 + \varepsilon_3$$

$$(8)\quad X_4 = a_4 + B_{14}W_1 + B_{24}W_2 + B_{34}W_3 + B_{44}W_4 + E_{41}Y_1 + E_{42}Y_2 + E_{43}Y_3 + E_{44}Y_4 + E_{45}Y_5 + F_{31}Z_1 + F_{32}Z_2 + \varepsilon_4$$

$$(9)\quad \begin{aligned} C = {} & a_0 + \sum_j a_j W_j + \sum_k b_k Y_k + \sum_l b_l Z_l + \sum_j G_{1i} P W_j + 0.5 \sum_j \sum_i B_{ij} W_i W_j \\ & + \sum_j \sum_k E_{jk} W_j Y_k + 0.5 \sum_i \sum_k C_{ik} Y_i Y_k + \sum_k \sum_l G_{kl} W_k Y_l + 0.5 \sum_i \sum_l D_{il} Z_i Z_l + \varepsilon_C \end{aligned}$$

*Input Distance Function Approach*

Following Morrison Paul et.al. the analysis of production structure and performance requires representing the underlying multi-dimensional (-input and -output) production technology. This may be formalized by specifying a transformation function, $\boldsymbol{T(X,Y,R)=0}$, which summarizes the production frontier in terms of an input vector **X**, an output vector ***Y***, and a vector of external production determinants ***R***. This information on the production technology can equivalently be characterized via an input set, $L(\boldsymbol{Y},\boldsymbol{R})$, representing the set of all ***X*** vectors that can produce ***Y*,** given the exogenous factors ***R***.

An input distance function (denoted by superscript I) identifies the least input use possible for producing the given output vector, defined according to $L(\boldsymbol{Y},\boldsymbol{R})$:

(10) $D^I(\boldsymbol{X},\boldsymbol{Y},\boldsymbol{R}) = max\{\rho: (x/\rho) \in L(\boldsymbol{Y},\boldsymbol{R})\}$ .

It is therefore essentially a multi-input, input-requirement function, allowing for deviations from the frontier. It is also conceptually similar to a cost function, if allocative efficiency is assumed, in the sense that it implies minimum input or resource use for production of a given output vector (and thus implicitly costs). However, it does so in a primal or technical optimization or efficiency context with no economic optimization implied.

For our preliminary treatment, the ***Y*** vector contains $Y_1$ = crops (Corn, soybeans, and other crops), $Y_2$=livestock (A, animal), and, for our off-farm comparison model, $Y_1$ * = crops and livestock (c, animal), and $Y_2$*=off-farm income (I), as farm "outputs". With $Y_2$* included one might think of ***Y*** as a multi-activity rather than a multi-output vector. For our base model with just $Y_1$ and $Y_2$ distinguished we will call our "constrained farm operator household" model, where off-farm income is set to zero, and the model with $Y_2$* included will be denoted our "farm operator household" model. The components of ***X*** are defined as $X_1$ = land (LD), $X_2$ = hired labor (L), $X_3$ = operator labor (including hours worked off-farm), (K), $X_4$=spouse labor (including hours worked off-farm), (E), $X_5$ = capital (F), and $X_6$ = materials (M).

A time trend, t, is the only ***R*** component. We wish to establish patterns of measured productivity growth across space, size and farm/farmer characteristics, rather than attempt to explain all variation in the initial step by including all potential driving forces of the production process in the functional specification.

The deterministic and stochastic efficiency models used for our analysis are based on characterizing the input distance function, given these definitions of ***Y***, ***X*** and ***R***, alternatively using linear programming and econometric methods. Estimation of (10) by either method is designed to represent the "distance" from the frontier, or technical inefficiency, assuming a radial contraction of inputs to the frontier (constant input composition). This ratio of estimated potential efficient input use compared to the actual observed use will be denoted TE (for technical efficiency). In addition, with the time dimension explicitly incorporated in the model, we can separately identify shifts in the frontier over time (t) due to technical progress, or TP. And if variable returns to scale are allowed for, variations in the input/output ratio at different scale levels may be identified, which we will call SE (scale economies). CE (cost economies) will therefore signify the combined scale and scope economy measure.

*The Nonparametric (DEA) Approach*

Functional relationships representing production processes, such as the distance function discussed above, only loosely represent a foundation for deterministic programming-based data envelopment analysis (DEA) procedures. Such an input-oriented linear programming problem may formally be written as:

$$\text{Min}_{\theta z,\lambda}\ \theta_i,\ s.t.\ -Y_i + Y\lambda \geq 0,\ \theta X_i - X\lambda \geq 0,\ Nl'\lambda = 1 \text{ and } l \geq 0,$$

where $\theta_i$ is a scalar representing the efficiency score for the ith firm, $\lambda$ is an Nx1 vector of constants, $Nl$ is a Nx1 vector of ones, and the $Nl'\lambda = 1$ convexity constraint allows for variable returns to scale (VRS).[3] For our empirical implementation, the solutions to this problem were computed using Tim Coelli's DEAP program.

The results from this DEA framework may be used not only to determine the efficiency scores for each observation, by establishing measures of $\theta_i$ representing the deviation from the existing technical **frontier, but also** to compute measures of technical progress (TP), or shifts in the frontier between time periods. Returns to scale or scale economy (SE) measures may also be derived from associated measures of "scale inefficiency", combined with information from the DEAP program on whether increasing or decreasing returns to scale are implied by the estimates. These measures are computed within the DEAP program used for analysis, and reported as SECH, TechCH, and PECH.

In the DEA context, therefore, our technical progress measure TP = TechCH indicates positive technical change from period $t_0$ to $t_1$ – an inward shift of the input requirement function – if TP > 1, and the deviation from one shows the proportional change.

Measuring scale economies – $\varepsilon(t)$– involves characterizing the efficiency scores from a CRS (constant returns to scale) as compared to a VRS model. Such a measure, $TE_{CRS}/TE_{VRS}$, will fall short of 1 if either increasing (IRS) or decreasing (DRS) returns to scale exist, since the CRS frontier will always envelope the VRS frontier. Comparing measured $TE_{VRS}$ to a corresponding measure constrained to non-increasing returns to scale, however, shows whether increasing or decreasing returns are implied. We can thus define our returns to scale or scale economy measure as SE = $TE_{CRS}/TE_{VRS}$ if IRS prevails, and SE = $TE_{VRS}/TE_{CRS}$ for DRS. SE<1 then implies increasing returns to scale, since it indicates the proportion input use must increase to generate a 1 percent increase in outputs.

In turn, to establish efficiency levels, or the distance from the frontier by observation, we wish to measure $D^I_{t1}(\boldsymbol{Y}_{t1},\boldsymbol{X}_{t1})$ and $D^I_{t0}(\boldsymbol{Y}_{t0},\boldsymbol{X}_{to})$, respectively, for time periods $t_1$ and $t_0$, rather than their ratio. These efficiency "scores", allowing for VRS, are presented in the DEAP program as VRS TE; we will call such a measure $TE_{VRS}$, or simply TE. The shortfall of this index from one indicates the proportional deviation from full technical efficiency in that time period; that is, $\theta_t$ indicates the proportion by which inputs could contract and maintain the same output level.

*The Parametric (SPF) Approach*

3 See Coelli et al. (1998) for an overview of these procedures and extensive references to more rigorous treatments.

As described in Morrison et.al. stochastic production frontier (SPF) measurement involves econometric estimation of the input distance function $D_I(\boldsymbol{X},\boldsymbol{Y},\boldsymbol{R})$, after adapting for theoretically required regularity conditions, making a functional form assumption, and specifying a stochastic structure allowing for both a white noise error and a one-sided error representing deviations from the production frontier.

The first of these tasks requires imposing the condition that an input-oriented distance function be homogeneous of degree one in the inputs. Analogous to the output distance function case described by Lovell et al. (1994), this constraint can be imposed on the input distance function through normalization by one input. This is based on the definition of linear homogeneity, $D^I(\omega\boldsymbol{X},\boldsymbol{Y},t) = \omega D^I(\boldsymbol{X},\boldsymbol{Y},t)$ for any $\omega>0$; so if $\omega$ is set arbitrarily at $1/X_1$, we obtain $D^I(\boldsymbol{X},\boldsymbol{Y},t)/X_1 = D^I(\boldsymbol{X}/X_1,\boldsymbol{Y},t) = D^I(\boldsymbol{X^*},\boldsymbol{Y},t)$ (where t is the only component of the **R** vector and **X*** represents a vector of input ratios normalized by input $X_1$). Writing the distance function accordingly, assuming it can be approximated by a translog functional form to limit *a priori* restrictions on the relationships among arguments of the function, we obtain:

$$\text{(10a)}\ ln\ D^I_{it}/X_{1,it} = \alpha_0 + \alpha_t\, t + \alpha_{tt}\, t^2 + \Sigma_m\, \alpha_m\, ln\ X^*_{mit} + .5\ \Sigma_m\, \Sigma_n\, \beta_{mn}\, ln\ X^*_{mit}\, ln\ X^*_{nit} + \Sigma_m\, \gamma_{mt}\, ln\ X^*_{mit}\, t$$
$$+ \Sigma_k\, \alpha_k\, ln\ Y_{kit} + \Sigma_k\, \gamma_{kt}\, ln\ Y_{kit}\, t + .5\ \Sigma_k\, \Sigma_l\, \beta_{kl}\, ln\ Y_{kit}\, ln\ Y_{lit} + \Sigma_k\, \Sigma_m\, \beta_{km}\, ln\ Y_{kit}\, ln\ X^*_{mit}\ , \text{ or}$$
$$\text{(10b)}\ \text{-}ln\ X_{1,it} = \alpha_0 + \alpha_t\, t + \alpha_{tt}\, t^2 + \Sigma_m\, \alpha_m\, ln\ X^*_{mit} + .5\ \Sigma_m\, \Sigma_n\, \beta_{mn}\, ln\ X^*_{mit}\, ln\ X^*_{nit} + \Sigma_m\, \gamma_{mt}\, ln\ X^*_{mit}\, t$$
$$+ \Sigma_k\, \alpha_k\, ln\ Y_{kit} + \Sigma_k\, \gamma_{kt}\, ln\ Y_{kit}\, t + .5\ \Sigma_k\, \Sigma_l\, \beta_{kl}\, ln\ Y_{kit}\, ln\ Y_{lit} + \Sigma_k\, \Sigma_m\, \beta_{km}\, ln\ Y_{kit}\, ln\ X^*_{mit} - ln\ D^I_{it}\ ,$$

where i denotes farm and t time period. This functional relationship, which embodies a full set of interactions among the **X**, **Y** and t arguments of the distance function, can more succinctly be written as $-ln\ X_{1,it} = TL(\boldsymbol{X}/X_1,\boldsymbol{Y},t) = TL(\boldsymbol{X}^*,\boldsymbol{Y},t)$. If $X_1$ is taken to be land, therefore, the function is essentially specified on a per-land-mass basis, which is consistent with much of the literature on farm production and productivity in terms of yields.

The resulting $-ln\ X_1 = TL(\boldsymbol{X}^*,\boldsymbol{Y},t) + v - u$ function (with the sub-scripts suppressed for notational simplicity) may be estimated by maximum likelihood (ML) methods, to impute the TE measures as the distance from the frontier. We have used Tim Coelli's FRONTER program, based on the error components model of Battese and Coelli (1992), for this purpose (see also Aigner et.al. and Meeusen and van den Broeck). For the SPF model -u thus represents inefficiency; the efficiency scores generated by FRONTIER essentially measure $exp^u = D^I(\boldsymbol{X}^*,\boldsymbol{Y},t)$. This is therefore our measure of TE.

In turn, the parameter estimates from the model may be used directly to construct our technical progress measure, based on the distance function elasticity $\varepsilon_{DIt} = \partial ln\ D^I(\mathbf{X},\mathbf{Y},t)/\partial t$ – or more explicitly in terms of input requirements and the estimating equation as $\varepsilon_{X1t} = -\partial ln\ X_1/\partial t$ (which we have done using PC-TSP). This measure, expressed in terms of growth rates, reflects the potential overall contraction in inputs over time, for a given input composition (since the **X*** ratios are held constant by definition). Technical progress therefore implies $ln\ TP = \varepsilon_{X1t} > 0$, or $TP = exp(\varepsilon_{X1t}) > 1$. So the proportion by which TP exceeds (falls short of) 1 indicates the extent of technical progress (regress).[4]

The SPF-based scale economy measure may also be computed from the estimated model via derivatives or scale elasticities: $-\varepsilon_{DIY} = -\Sigma_m \partial ln\ D^I(\mathbf{X},\mathbf{Y},t)/\partial ln\ Y_m = \varepsilon_{X1Y}$ for M outputs $Y_m$ (similarly to the treatment in Baumol, Panzar and Willig, 1982 for a multiple-output cost model, and consistent with the output distance function formula in Färe and Primont, 1995). However, our inverse measure is more comparable to the cost literature, where the extent of increasing returns or scale economies are implied by the short-fall of the measure from 1. Again, this measure is based on evaluation of (scale) expansion from a given input composition base.

Finally, note that this measure actually embodies both scale and scope economies, since the cross-terms among the outputs, which comprise the basis of a scope economy measure, are imbedded in the scale (input use or "cost") elasticity. Setting these cross-terms to zero results in a measure reflecting only scale economies; the remainder of the estimated $\varepsilon_{X1Y}$ measure can be attributed to scope economies. Thus, we will define total cost economies as $CE = \varepsilon_{X1Y}$, and "pure" scale economies SE as $\varepsilon_{X1Y}$ computed with the $\beta_{kl}$ terms set to zero.

**Multiproduct Economies of Scale and Scope**

When a firm produces more than one output, there is a qualitative change in the production structure that makes the concept of economies of scale developed for a single output insufficient. For multiproduct firms, production economies may arise not only because the size of the firm is increased but also due to advantages derived from producing several outputs together rather than separately. Thus, more than one measure is necessary to capture the economies (or diseconomies) related to the scale of operation (volume of output) and the economies related to the scope of the operation (composition of output or product mix). The concepts of economies of scale and scope for multiproduct firms have been developed by Panzar and Willig (1977, 1981) and Baumol, Panzar and Willig and have been used is agriculture by Akridge and Hertel (1986) and

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4 This measure does not fully reflect potential input substitution, however, since by construction of the model, and the requirement of linear homogeneity, this is a radial measure holding input ratios constant.

Fernandez-Cornejo et al. (1992).

Scope and scale economies play an important role in the analysis of market structure. In fact they determine the viability of perfect competition (Baumol). Perfect competition is likely to prevail if an industry is such that economies of scale and scope are exhausted at an output level, which is a small fraction of the market. Otherwise some form of oligopoly with industry conglomerates or a conglomerate monopolist is the likely outcome.

The measure of scale economies for the multiproduct case is an extension of the concept used by Hanoch in the single-output situation. It is called by Baumol, Panzar and Willig (BPW) degree of multiproduct scale economies S(Y), defined as:

$$S(Y) = C(Y) / \sum_{i=1}^{n} Y_i C_i(Y) \tag{11}$$

where $Y_i$ is the ith component of the output vector $Y$ and $C_i(Y)$ is the partial derivative of $C(Y)$ with respect to $Y_i$. Equation (11) may be interpreted as the inverse of the sum of the cost elasticities by writing $S(Y) = (\Sigma Y_i\, C_i(Y)/C(Y)]^{-1} = [\Sigma\, \partial C(Y)\, \partial Yi \cdot Yi/C(Y)]^{-1}$. In addition, since output is not usually expanded proportionately in a multiproduct firm, another concept, the degree of product-specific economies of scale is defined as the ratio of the average incremental cost to the marginal cost of a particular output.

The effect of multi-output production upon costs is captured by the concept of economies of scope, which measures the cost savings due to simultaneous production relative to the cost of separate production.

For example, for two outputs A and B (with cost functions $C(Y_A)$ and $C(Y_B)$ static scope economies (SC) will arise when $SC = [C(Y_A)+C(Y_B)-C(Y)]/C(Y)]$ is positive. In general, scope economies are related to the notion of strict subadditivity of costs, which occurs when the cost of producing all products together is smaller than producing them separately.

Formally, consider a partition of the output set N into two (disjoint) groups T and N-T. Let $Y_T$, $Y_{N-T}$ be the output quantity (subvector) of each of the two groups and $Y_N$ (or simply $Y$) the output vector, which consists of all the outputs. The respective cost functions $C(Y_T)$, $C(Y_{N-T})$ give the minimum of the present value of costs of providing the two output groups separately and $C(Y_N)$ denotes the minimum present value of the costs of providing them together. The degree of economies of scope (SC) relative to the (output) set T is defined as

(12) $$SC = [\ C(Y_T\ ) + C(Y_{N\text{-}T}\ ) - C(Y_N\ )\ ]\ /\ C\ (Y_N\ )$$

where SC will be positive if there are economies of scope and negative if there are diseconomies of scope. In our case we will consider the first subset of the partition to include the first four outputs (corn, soybeans, other crops, and livestock): N={1,2,3,4} and the second subset the last output (off farm labor) N-T={5}.

**The U.S. Agricultural Sector Panel Data**

The U.S. farm level data used to construct our panel data are from the 1996, 1997, 1998, 1999, and 2000 Agricultural Resources Management Study (ARMS) Phase III survey. This is an annual survey covering U.S. farms in the 48 contiguous states, conducted by the National Agricultural Statistics Service, USDA, in cooperation with the Economic Research Service.

Ten corn/soybean-states are distinguished in the data: IL, IN, IA, MI, MN, MO, NE , OH, SD, and WI. The states straddle traditional regions, but may be categorized in terms of recent USDA regional distinctions documented in Figure 1 as parts of the Heartland-IL, IN, IA, MO, and OH ; the Northern Plains-SD ; the Prairie Gateway-NE ; the Northern Crescent or Lake states – MI, MN, and WI.

Farm labor is a critical input in agricultural production and one of the focuses of our cost function analysis. In the corn/soybean states analyzed, farm operators, household members and their spouses provide more than 80 percent of all labor hours in agriculture. A significant proportion of the labor hours worked on corn/soybean farms are not valued directly in the market place. Previous studies have estimated opportunity costs of labor by imputing predicted off-farm wage rates to serve as proxies for operators' opportunity cost of unpaid labor for the entire United States, by region, by size of farm, and by farm type (El-Osta and Ahearn). A useful, more current approximation of the predicted opportunity costs derived in the El-Osta and Ahearn study, based on 1988 data, can be computed from the ARMS given the availability of off-farm income and hours for both operators and spouses by dividing off-farm income by total hours worked off farm5 (Table 3). It is interesting to note that nominal opportunity costs for operators and spouses do not appear to have increased in the time period analyzed.

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5 Total hours worked off-farm were computed by multiplying total weeks worked off-farm times the number of hours worked off-farm. Spouse data for 1997 was not collected. Hence we imputed data for 1997 based on cohort averages for 1996.

To support empirical production studies using panel data, the temporal pattern of a given farm's production behavior must be established. In the absence of genuine panel data, repeated cross-sections of data across farm typologies may be used to construct a pseudo panel data (see Deaton, Heshmati and Kumbhakar, Verbeek and Nijman) The pseudo panels are created by grouping the individual observations into a number of homogeneous cohorts, demarcated on the basis of their common observable time-invariant characteristics, such as geographic location, quality of land, size of land, and scope of agricultural activities relative to off-farm activities. The subsequent economic analysis then uses the cohort means rather than the individual farm-level observations.

The recent development at the ERS of farm typology groups, described in Table 1, allows us to assign farm-level data to cohorts by typology, and sub typology, by state, by year for the corn-producing states. The data in typologies 1 through 3 (limited resource, retirement, and residential) is relatively limited compared to the traditional farm data in typologies 4 through 7 – particularly cohorts 1 and 2. Hence, typologies 1 through 3 were grouped into three cohorts by level of agricultural sales in both regions. Similarly, the data in typologies 4 and 6 were used to form three cohorts, while data in typologies 5 and 7 were grouped into two cohorts each. These categories are summarized in Table 4, and are documented in our results tables, although we will focus in our discussion on a more aggregated breakdown into (i) residential cohorts (cohorts 1-3); (ii) small family farms (cohorts 4-5); (iii) larger family farms (cohorts 6-10); and (d) very large family farms and non-family operations (cohorts 11-13).

The resulting panel data set consists of 13 cohorts by state, for 1996-2000, measured as the weighted mean values of the variables to be analyzed. In total we have 650 annual observations (130 per year, a balanced panel), summarizing the activities of 1934 farms in 1996, 3890 in 1997, 2311 in 1998, 3201 in 1999, and 2394 in 2000 .

Agricultural output is measured as bushels of corn, bushels of soybeans, tons of other crops and cwts[6] of livestock. Off-farm output (I) is based on the wages and salaries, and hours of operator and spouse labor reported in the ARMS survey. For the (variable) inputs, hired labor (L) is annual hours per-farm of hired labor used[7]; operator labor (OP) is the annual hours of operator labor used (and operator labor employed off-farm in the off-farm model); spouse labor (SL) is the annual hours of spouse labor used (and operator labor employed off-farm in the off-farm model);

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6 We constructed the state-level weighted average price for cattle, hogs, and milk, using data from ERS state-level productivity files. and divided livestock revenues from ARMS by this price to get an implicit quantity.
7 Calculated as the some of unpaid worker hours (such as partners, family members, etc) plus the implicit quantity of all other paid farm and ranch labor divided by the hired wage rate. This aggregation is likely to be reasonable in the states analyzed. An analysis including significant migrant labor would more reasonably disagregate hired labor.

materials (M) is tons of miscellaneous inputs (miscellaneous expenditures divided by the weighted price of feed, fertilizer, fuel, and pesticides)[8]. Capital machinery (K) is measured as the sum of depreciation and repairs . Our base land variable (LD), is constructed as an annuity based on a 20-year life and a 10 percent rate of interest, and an annualized flow of quality-adjusted services from land. State-level price data used to derive implicit quantities for corn and soybeans were obtained from Ag Statistics. State-level price data used to derive implicit quantities for other crops, livestock, and miscellaneous inputs were based on information from ERS state-level productivity files. To translate nominal values into real terms, all expenditure variables are deflated by the estimated increase or decrease in cost of production in 1997-2000 compared to 1996 (in terms of agricultural prices).

A summary of the sample data used in the cost function is presented in Table 5. The price data are normalized on the pesticide input. A summary of the sample data used in the input distance function estimations is presented in Table 6. The average farm size varies from 151 acres in the limited resource typology to 2,168 acres in the industrial farm typology. Off-farm income is highest, in aggregate and per acre, in the residential typology, and is lowest per acre in the large family farms and industrial farm typologies. Operator labor off-farm is highest for residential farms, averaging twice the mean of 1,030 annually ; for spouses off-farm labor is also highest for residential farms, but only 40 percent higher than the mean of the sample of 873. Operator hours worked on farm average 1,498 annually, about 4 times the annual hours for spouse and hired labor (the sum of unpaid hours for partners, family members, etc plus the implicit number of all other paid farm and ranch labor—annual totals for 1996-1999 tend to be significantly higher than for 2000) in 2000. The average age of farmers is highest in retirement and low sales typologies, and lower in the residential and higher sales farm typologies. The farmer education average of 2.5 is between a high school diploma (2) and some college (3), and tends to be slightly greater in the high sales typologies.

**The Results**

*Cost Function Results*

Our preliminary cost function results are for 2000 only. The normalized quadratic variable cost function (9) and the four cost share equations (6-8) are estimated in an iterated seemingly unrelated regression (ITSUR)framework with symmetry imposed by sharing parameters and linear homogeneity imposed by normalization are reported in table 7. The $R^2$'s were 0.99 for the quadratic cost function, but only 0.26 for the hired labor input, 0.21 for the operator labor

8 The weighted average price of feed, fertilizer, fuel, and pesticides was calculated using data from ERS state-level

equation, 0.30 for the spouse labor equation, and 0.60 for the miscellaneous labor equation. However, we find that 48 percent of coefficients for the joint estimates are significant at the 10 percent level or better, and 56 percent of coefficients are significant at the 20 percent level or better.

The own price effects for the inputs exhibit the expected negative signs. We find that the own price effect for hired labor is significant at the 10 percent level, while the own price effects for operator labor and spouse labor are not significant in this cross-section . The own price elasticity of demand for hire labor, computed as B11*(price of hire labor/quantity of hire labor)--((-.55*(2.29)/.48))---is highly elastic with a value of -2.62. These results are not directly comparable with cost function studies in the literature (Ray reports an own price elasticity of demand of -0.83) but their relative significance, provides preliminary evidence that operator and spouse labor can be satisfactorily included as factors of production in a multi-activity model.

There are substantial economies of scope (SC=0.238) for the pair traditional farm products (corn, soybeans, other crops, livestock) and off farm labor. This means, for example, that on average, by the operators working off farm in addition to producing the traditional farm outputs, farm operator households have a cost savings of 24 percent, compared to the base farm operator household were off-farm wages and salaries are constrained to zero. Traditionally, separate production is associated with the term output- specialization and the presence of scope economies is a condition of output-diversified firms. In general, holding everything else constant - including transaction costs, the higher the scope economies the more likely that the firm is diversified. The degree of multiproduct scale economies S(Y) at the means of the data is equal to 0.908, meaning that the average farm is exhibiting increasing returns to scale.

*Input Distance Function Results*

The constrained farm operator household model may be compared with the farm operator household model. The farm operator household estimates, presented in Table 9 for the DEA and SPF models, show significant differences compared to the constrained farm operator household estimates presented in Table 8. For the DEA specification somewhat higher scale economies, greater technical progress and slightly higher efficiency scores are evident for the farm operator model compared to the constrained farm operator household model. For the SPF specification this pattern is mirrored; RTS is significantly higher, TP is somewhat higher, and TE is significantly higher and cost (scope) economies are lower. Regional differences also arise, with significantly higher efficiency levels for the farm operator

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productivity files.

household estimates in Indiana, Michigan, and Ohio in both the DEA and SPF results, but less change elsewhere, except Wisconsin—down in DEA and up slightly in SPF. This impact on the performance estimates, particularly for efficiency, appears to support the suggestion in USDA (2001) that off-farm income benefits do accrue to all farmers who work off the farm, at least for this sample of corn/soybean states.

The most obvious differences revealed by these numbers is a much smaller rise in SE through the cohorts for the farm operator household estimates compared to the constrained farm operator household estimates, especially for the DEA specification. The highest cohort levels appear similar, but the lower levels indicate much less potential scale economies. For scope economies on the other hand small cohorts fall proportionately more than for larger cohorts, suggesting an even greater role for scope economies when off-farm income (here scope economies are interpreted as the difference between SE—pure scale economies and CE–ie CE includes scale and scope economies), and thus expanded output composition, is accommodated. This supports the USDA (2001) observation that off-farm income has very little impact on larger commercial farms, but is used by small farms as a diversification mechanism. The recognition of the strong and increasing tendency of small farmers to seek off-farm income correspondingly smoothes the size patterns in the cost economy estimates. Note, however, that the small farm cohorts – especially C4 and C5 – still face some of the greatest unexploited cost economies.

**Summary and Conclusions**

The past few decades have seen increased evidence of, and concern about, the impacts of the structural transformation of agriculture on the economic health of farm operator households. To explore the potential of these farmers to exploit off-farm opportunities in a multi-activity sense in order to survive in such a rapidly changing environment, this study examines labor allocation decisions and the productivity and efficiency of farm operator households at the state level. We use a cost function and frontier methods to measure and evaluate factor underlying price elasticities, technical change, efficiency, and scale economies of corn/soybean farms, based on annual 1996 to 2000 USDA surveys. We examine such indicators for corn/soybean states as a whole, and compare them across time, farm typology, and alternative estimation methodologies. Our preliminary results suggest that over our sample period scale economies are a primary factor driving up farm size and decreasing the competitiveness of small farms in the constrained farm operator household model. But small farms appear to achieve efficiency levels more comparable to larger farms when off-farm income is accommodated. The evidence therefore suggests that, while short-falls in these productivity components are decreasing the competitiveness of small farms as agricultural structure changes, corn/soybean farms have partially adapted to such pressures by increasing off-farm income and, therefore, achieving economies of scope. The cost function results also suggest that off-farm outputs and inputs can be modeled in a multi-activity framework and that this is a useful tool to analyze labor allocation decisions and to identify not only economies of size but of scope.

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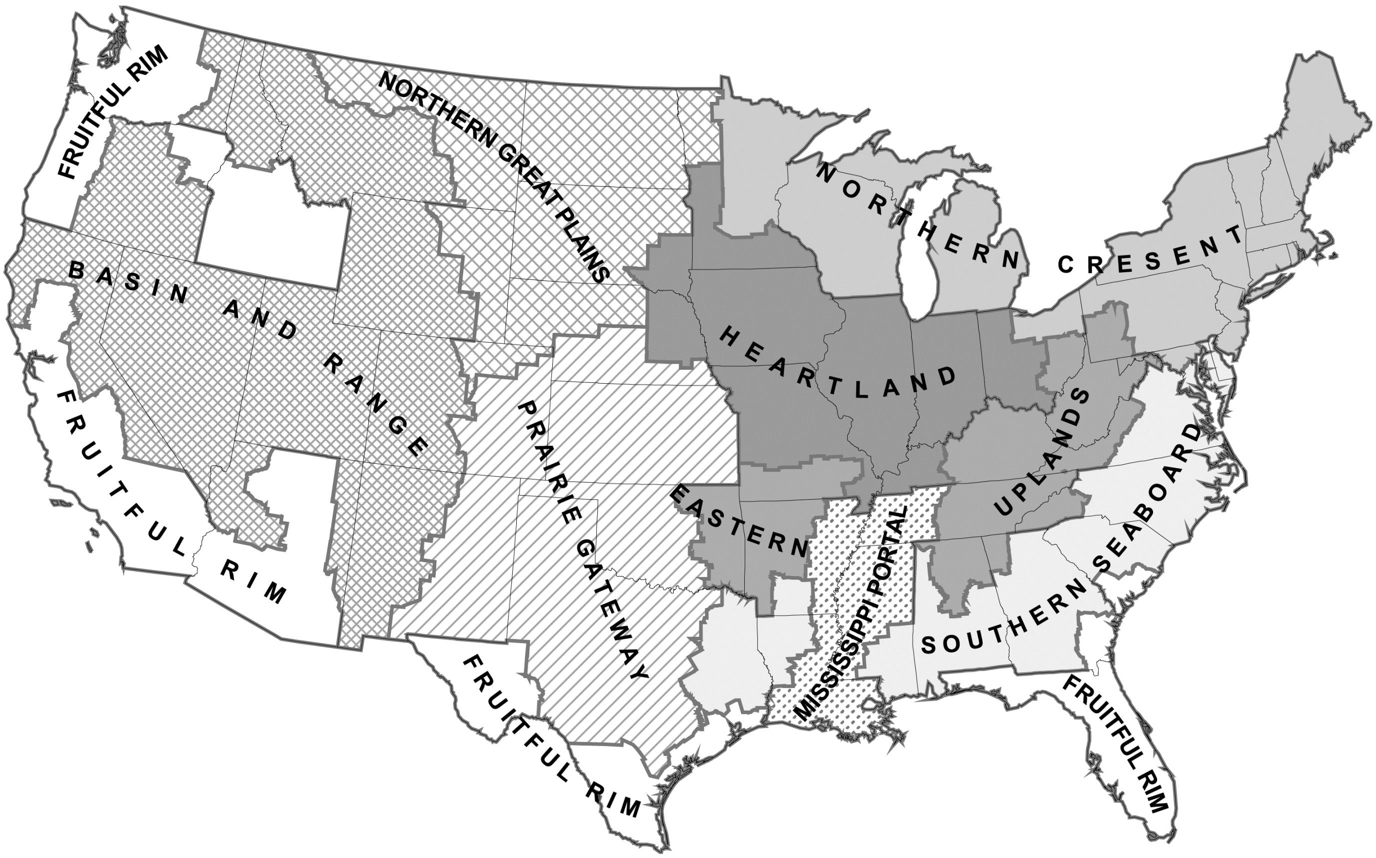
**Figure 1. Farm Resource Regions**




Source: U.S. Department of Agriculture, Economic Research Service

**Table 1. Farm Typology Groupings**

**Small Family Farms (sales less than $250,000)**

**1. Limited-resource.** Any small farm with: gross sales less than $100,000, total farm assets less $150,000, and total operator household income less than $20,000. Limited-resource farmers may report farming, a nonfarm occupation, or retirement as their major occupation

**2. Retirement.** Small farms whose operators report they are retired (excludes limited-resource farms operated by retired farmers).

**3. Residential/lifestyle.** Small farms whose operators report a major occupation other than farming (excludes limited-resource farms with operators reporting a nonfarm major occupation).

**4. Farming occupation/lower-sales.** Small farms with sales less than $100,000 whose operators report farming as their major occupation (excludes limited-resource farms whose operators report farming as their major occupation).

**5. Farming occupation/higher-sales.** Small farms with sales between $100,000 and $249,999 whose operators report farming as their major occupation.

**Other Farms**

**6. Large family farms.** Sales between $250,000 and $499,999.

**7. Very large family farms.** Sales of $500,000 or more

**Nonfamily farms.** Farms organized as nonfamily corporations or cooperatives, as well as farms operated by hired managers

Source: U.S. Department of Agriculture, Economic Research Service

**Table 2. Off-Farm Income, by year, and farm typology**

| Typology Class | Aggregate Off-farm Income billion dollars | | Share of Aggregate Off-farm Income percent | | Mean Off-farm Income billion dollars | | Share of Income from off-farm sources |
|---|---|---|---|---|---|---|---|
| | 1993 | 1999 | 1993 | 1999 | 1993 | 1999 | 2000 |
| Limited Resouce | 3.657 | 1.664 | 4.9 | 1.3 | 12,398 | 13,114 | 127.1 |
| Retirement | 8.078 | 12.495 | 11.2 | 10.0 | 34,273 | 41,991 | 103.8 |
| Residential | 40.792 | 81.787 | 56.6 | 65.7 | 59,216 | 87,796 | 107.6 |
| Farming/low sales | 12.950 | 19.166 | 13.9 | 15.4 | 25,489 | 39,892 | 105.8 |
| Farming/high sales | 3.597 | 4.669 | 5.0 | 3.7 | 17,286 | 26,621 | 69.3 |
| Large family farms | 1.738 | 2.675 | 2.4 | 2.1 | 25,487 | 34,598 | 47.2 |
| Very Lrg family farms | 1.358 | 2.078 | 1.9 | 1.7 | 32,840 | 35,572 | 21.7 |
| All op households | 72.080 | 124.534 | 100.0 | 100.0 | 35,408 | 57,988 | 95.5 |

*Source*: ERS estimates and Hoppe (2001).

**Table 3. Opportunity costs of farm operators and spouses, 1996-2000 and hire wage rate in dollars per hour**

| Year | Operator | Spouse | Hired |
|---|---|---|---|
| 1996 | 22.88 | 17.87 | 7.42 |
| 1997 | 26.72 | 19.06 | 8.01 |
| 1998 | 22.14 | 18.77 | 8.30 |
| 1999 | 22.19 | 17.96 | 8.67 |
| 2000 | 21.07 | 17.47 | 8.99 |

ERS estimates for corn/soybean states analyzed

**Table 4: Final Cohort Definitions**

| *Small farms* | | | *Large farms* | | |
|---|---|---|---|---|---|
| *Cohort* | *Typology* | *GV Sales* | *Cohort* | *Typology* | *GV Sales* |
| COH1 | 1-3 | <2,499 | COH9 | 6 | 250,000-330,000 |
| COH2 | 1-3 | 2,500-29,999 | COH10 | 6 | 330,000-410,000 |
| COH3 | 1-3 | >30,000 | COH11 | 6 | >410,000 |
| COH4 | 4 | <10,000 | COH12 | 7 | <1,000,000 |
| COH5 | 4 | 10,000-29,999 | COH13 | 7 | >1,000,000 |
| COH6 | 4 | >30,000 | | | |
| COH7 | 5 | 100,000-174,999 | | | |
| COH8 | 5 | 175,000-249,999 | | | |

**Table 5. Data used in cost Function, normalized by Pesticide price:2000**

| **Variable** | **Unit** | **Mean** | **Std Dev** | **Minimum** | **Maximum** |
|---|---|---|---|---|---|
| **Prices** | | | | | |
| Hire labor | $/hour | 2.290 | 0.560 | 1.571 | 2.985 |
| Operator labor | $/hour | 5.476 | 1.876 | 2.938 | 14.816 |
| Spouse labor | $/hour | 4.446 | 1.390 | 2.054 | 12.879 |
| Misc inputs | $/ton | 26.559 | 7.479 | 17.675 | 37.510 |
| Pesticides | $/pound | 1.000 | 0 | 1.000 | 1.000 |
| **Input quantities** | | | | | |
| Hire labor | hours | 0.483 | 0.619 | 0 | 6.233 |
| Operator labor | hours | 3.922 | 1.073 | 1.031 | 6.622 |
| Spouse labor | hours | 1.223 | 0.522 | 0 | 2.695 |
| Misc inputs | tons | 1.458 | 7.479 | 0 | 19.545 |
| Pesticides | pounds | 3.723 | 0 | 0 | 30.288 |
| **Output quantities** | | | | | |
| Corn | tons | 25.382 | 30.022 | 0 | 158.205 |
| Soybeans | tons | 9.047 | 11.001 | 0 | 56.844 |
| Other crops | tons | 0.967 | 3.734 | 0 | 38.260 |
| Livestock | cwts | 6.237 | 15.586 | 0 | 109.151 |
| Off farm | hours | 1.370 | 0.892 | 0 | 3.798 |
| N | 130 | | | | |

**Table 6: Summary Statistics for Selected Variables in Corn States, 2000**

| Type | Farms (%) | Area (%) | Corn bu | Soybeans bu | op hours off-farm | op hours on-farm | sp hours off-farm | sp hours on-farm | hired labor | Off-farm income | Acres (Fm) | Age | Ed |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | --------------------hours | | | | ---------------------------- | ($1000) | | | |
| Limited Resource | 4.4 | 1.4 | 1625.9 | 563.7 | 484.3 | 1082.4 | 138.4 | 194.7 | 115.0 | 6.5 | 151 | 56.9 | 2.1 |
| Retirement | 11.4 | 4.0 | 649.7 | 268.9 | 132.8 | 753.7 | 392.4 | 119.3 | 106.9 | 10.1 | 137 | 70.4 | 2.3 |
| Residental/ lifestyle | 38.35 | 14.8 | 2271.5 | 1053.2 | 2062.4 | 898.8 | 1252.2 | 210.0 | 160.0 | 58.2 | 152 | 48.8 | 2.8 |
| Farming/ lower sales | 23.5 | 21.3 | 5156.9 | 1973.2 | 486.3 | 1926.7 | 672.1 | 405.3 | 312.5 | 15.7 | 338 | 58.4 | 2.2 |
| Farming/ higher sales | 12.5 | 25.1 | 25595.9 | 7869.1 | 391.9 | 2722.5 | 903.0 | 552.6 | 521.2 | 20.1 | 768 | 48.8 | 2.5 |
| Large family farms | 5.0 | 15.2 | 49046.7 | 14544.1 | 288.2 | 2864.6 | 818.2 | 700.0 | 899.5 | 17.7 | 1300 | 49.2 | 2.7 |
| Very Large Family Farms | 2.8 | 15.6 | 82228.4 | 24232.7 | 128.6 | 2969.6 | 785.9 | 685.5 | 2464.5 | 19.6 | 2160 | 48.5 | 2.8 |
| Nonfamily Farms | 2.0 | 2.7 | 12182.8 | 5011.5 | 0.0 | 1126.1 | 0.0 | 97.2 | 800.5 | 0.0 | 1064 | 49.7 | 3.0 |
| All Farms | 100.0 | 100.0 | 10278.9 | 3369.0 | 1030.9 | 1498.3 | 873.1 | 319.0 | 343.6 | 32.0 | 398 | 53.9 | 2.5 |

**Table 7. Estimation Results of the Normalized Quadratic Variable Cost Function:2000.**

| Equation | Model | DF Error | DF SSE | MSE | Root MSE | R-Square | Adj R-Sq |
|---|---|---|---|---|---|---|---|
| COST | 64 | 66 | 7131.8 | 108.1 | 10.3951 | 0.9929 | 0.9860 |
| X1 | 6 | 124 | 33.7157 | 0.2719 | 0.5214 | 0.3189 | 0.2915 |
| X2 | 6 | 124 | 47.6642 | 0.3844 | 0.6200 | 0.2432 | 0.2127 |
| X3 | 6 | 124 | 23.6513 | 0.1907 | 0.4367 | 0.3283 | 0.3013 |
| X4 | 6 | 124 | 426.9 | 3.4427 | 1.8555 | 0.6144 | 0.5988 |

| Parameter | Estimate | Approx Std Err | t Value | Approx Pr > \|t\| |
|---|---|---|---|---|
| A0 | -5.91909 | 15.3703 | -0.39 | 0.7014 |
| A1 | 0.57348 | 0.2985 | 1.92 | 0.0577 |
| A2 | 1.63815 | 0.4173 | 3.93 | 0.0002 |
| A3 | 0.42640 | 0.3618 | 1.18 | 0.2415 |
| A4 | 0.70689 | 1.0471 | 0.68 | 0.5012 |
| B1 | 1.19012 | 0.6414 | 1.86 | 0.0680 |
| B2 | -1.50652 | 2.0600 | -0.73 | 0.4672 |
| B3 | 3.62794 | 7.8031 | 0.46 | 0.6435 |
| B4 | 6.00878 | 1.9587 | 3.07 | 0.0031 |
| B5 | -0.22876 | 5.3364 | -0.04 | 0.9659 |
| C1 | -1.80851 | 0.6001 | -3.01 | 0.0037 |
| C2 | 0.10548 | 0.1254 | 0.84 | 0.4034 |
| C3 | 7.21504 | 13.935 | 0.52 | 0.6063 |
| B11 | -0.54945 | 0.2771 | -1.98 | 0.0503 |
| B12 | 0.07197 | 0.0409 | 1.76 | 0.0811 |
| B13 | -0.08764 | 0.0546 | -1.60 | 0.1116 |
| B14 | 0.03642 | 0.0226 | 1.61 | 0.1098 |
| B22 | -0.03697 | 0.0628 | -0.59 | 0.5577 |
| B23 | 0.01596 | 0.0528 | 0.30 | 0.7632 |
| B24 | 0.00294 | 0.0167 | 0.18 | 0.8602 |
| B33 | -0.03717 | 0.0799 | -0.47 | 0.6428 |
| B34 | 0.01473 | 0.0155 | 0.95 | 0.3426 |
| B44 | -0.04352 | 0.0363 | -1.20 | 0.2338 |
| E11 | -0.00569 | 0.0036 | -1.60 | 0.1126 |
| E12 | 0.01628 | 0.0114 | 1.43 | 0.1553 |
| E13 | -0.06335 | 0.0212 | -2.98 | 0.0036 |
| E14 | -0.02668 | 0.0072 | -3.71 | 0.0004 |
| E15 | -0.02001 | 0.0597 | -0.34 | 0.7382 |
| E21 | -0.00392 | 0.0058 | -0.68 | 0.5007 |
| E22 | -0.03443 | 0.0184 | -1.88 | 0.0637 |
| E23 | -0.09527 | 0.0341 | -2.80 | 0.0062 |
| E24 | -0.04952 | 0.0114 | -4.33 | <.0001 |
| E25 | 0.30965 | 0.0970 | 3.19 | 0.0019 |
| E31 | 0.00059 | 0.0051 | 0.12 | 0.9081 |
| E32 | -0.00998 | 0.0152 | -0.66 | 0.5140 |
| E33 | -0.04212 | 0.0284 | -1.48 | 0.1410 |
| E34 | -0.01249 | 0.00997 | -1.25 | 0.2134 |
| E35 | 0.32645 | 0.0874 | 3.74 | 0.0003 |
| E41 | -0.00600 | 0.0108 | -0.55 | 0.5807 |
| E42 | -0.06257 | 0.0431 | -1.45 | 0.1503 |
| E43 | -0.04382 | 0.0980 | -0.45 | 0.6558 |

**Table 7. Estimation Results of the Normalized Quadratic Variable Cost Function: 2000 (continued).**

| Parameter | Estimate | Approx Std Err | t Value | Approx Pr > \|t\| |
|---|---|---|---|---|
| E44 | -0.01714 | 0.0259 | -0.66 | 0.5096 |
| E45 | 0.13130 | 0.1384 | 0.95 | 0.3451 |
| F11 | 0.01763 | 0.0042 | 4.15 | <.0001 |
| F12 | -0.00121 | 0.0014 | -0.85 | 0.3989 |
| F13 | -0.23837 | 0.1469 | -1.62 | 0.1080 |
| F21 | 0.02679 | 0.0069 | 3.89 | 0.0002 |
| F22 | 0.00390 | 0.0023 | 1.67 | 0.0975 |
| F23 | -0.00092 | 0.2331 | -0.00 | 0.9969 |
| F31 | 0.01041 | 0.0061 | 1.72 | 0.0888 |
| F32 | 0.00049 | 0.0020 | 0.24 | 0.8103 |
| F33 | 0.01214 | 0.2004 | 0.06 | 0.9518 |
| F41 | 0.05379 | 0.0136 | 3.96 | 0.0001 |
| F42 | 0.00699 | 0.0029 | 2.43 | 0.0172 |
| F43 | -0.36245 | 0.5422 | -0.67 | 0.5055 |
| G11 | 0.01104 | 0.0114 | 0.97 | 0.3348 |
| G12 | 0.01097 | 0.0030 | 3.66 | 0.0005 |
| G13 | -0.70638 | 0.3562 | -1.98 | 0.0515 |
| G21 | 0.17955 | 0.0377 | 4.77 | <.0001 |
| G22 | -0.00139 | 0.0068 | -0.21 | 0.8374 |
| G23 | 2.42658 | 0.8286 | 2.93 | 0.0047 |
| G31 | 0.48500 | 0.1186 | 4.09 | 0.0001 |
| G32 | -0.04546 | 0.0551 | -0.82 | 0.4125 |
| G33 | 8.68232 | 3.9654 | 2.19 | 0.0321 |
| G41 | 0.01248 | 0.0209 | 0.60 | 0.5518 |
| G42 | 0.02200 | 0.0114 | 1.92 | 0.0587 |
| G43 | 1.18184 | 1.3573 | 0.87 | 0.3871 |
| G51 | 0.48648 | 0.2605 | 1.87 | 0.0663 |
| G52 | -0.04805 | 0.0568 | -0.85 | 0.4010 |
| G53 | -0.54472 | 2.8306 | -0.19 | 0.8480 |
| C11 | -0.02077 | 0.0166 | -1.25 | 0.2152 |
| C12 | -0.07320 | 0.0194 | -3.78 | 0.0003 |
| C13 | 0.17419 | 0.1159 | 1.50 | 0.1378 |
| C14 | -0.08082 | 0.0269 | -3.00 | 0.0038 |
| C15 | -0.47864 | 0.2602 | -1.84 | 0.0704 |
| C22 | -0.21733 | 0.0783 | -2.77 | 0.0072 |
| C23 | 0.17542 | 0.2281 | 0.77 | 0.4446 |
| C24 | -0.13766 | 0.0983 | -1.40 | 0.1662 |
| C25 | 1.44979 | 0.8204 | 1.77 | 0.0818 |
| C33 | -1.29684 | 0.9628 | -1.35 | 0.1826 |
| C34 | -1.71761 | 0.3526 | -4.87 | <.0001 |
| C35 | -13.23010 | 5.7065 | -2.32 | 0.0235 |
| C44 | 0.07357 | 0.0403 | 1.82 | 0.0725 |
| C45 | -0.42080 | 1.0512 | -0.40 | 0.6902 |
| C55 | -1.31377 | 0.9543 | -1.38 | 0.1733 |
| D11 | -0.03028 | 0.0148 | -2.05 | 0.0441 |
| D12 | -0.01096 | 0.0039 | -2.84 | 0.0060 |
| D22 | -0.00095 | 0.0009 | | |

**Table 8: DEA and SPF, 2-Output, Constrained Farm Operator Farm Operator Household Model***

| | *DEA* | | | *SPF* | | | |
|---|---|---|---|---|---|---|---|
| | SE | TP | TE | SE | CE | TP | TE |
| **Total** | 0.848 | 1.118 | 0.726 | 0.659 | 0.531 | 0.956 | 0.913 |
| **1996** | 0.876 | 0.000 | 0.667 | 0.647 | 0.524 | 1.071 | 0.855 |
| **1997** | 0.853 | 0.942 | 0.795 | 0.665 | 0.539 | 0.971 | 0.892 |
| **1998** | 0.896 | 1.240 | 0.825 | 0.692 | 0.556 | 0.956 | 0.920 |
| **1999** | 0.788 | 0.911 | 0.688 | 0.644 | 0.518 | 0.910 | 0.942 |
| **2000** | 0.829 | 1.380 | 0.653 | 0.647 | 0.511 | 0.872 | 0.958 |
| **IL** | 0.832 | 1.193 | 0.732 | 0.652 | 0.523 | 0.948 | 0.919 |
| **IN** | 0.835 | 1.270 | 0.671 | 0.648 | 0.537 | 0.944 | 0.892 |
| **IA** | 0.846 | 1.079 | 0.723 | 0.665 | 0.525 | 0.949 | 0.926 |
| **MI** | 0.833 | 1.144 | 0.678 | 0.653 | 0.547 | 0.962 | 0.917 |
| **MN** | 0.830 | 1.085 | 0.720 | 0.677 | 0.514 | 0.962 | 0.927 |
| **MO** | 0.847 | 1.012 | 0.770 | 0.639 | 0.554 | 0.958 | 0.888 |
| **NE** | 0.871 | 1.177 | 0.752 | 0.686 | 0.554 | 0.954 | 0.907 |
| **OH** | 0.868 | 1.079 | 0.648 | 0.647 | 0.521 | 0.955 | 0.896 |
| **SD** | 0.866 | 1.072 | 0.780 | 0.662 | 0.536 | 0.961 | 0.937 |
| **WI** | 0.856 | 1.070 | 0.766 | 0.660 | 0.532 | 0.966 | 0.923 |
| **C1** | 0.299 | 1.210 | 0.872 | 0.349 | 0.313 | 0.893 | 0.928 |
| **C2** | 0.669 | 1.042 | 0.629 | 0.500 | 0.419 | 0.939 | 0.956 |
| **C3** | 0.908 | 1.112 | 0.612 | 0.639 | 0.518 | 0.951 | 0.952 |
| **C4** | 0.575 | 1.160 | 0.727 | 0.440 | 0.375 | 0.925 | 0.848 |
| **C5** | 0.838 | 0.992 | 0.612 | 0.585 | 0.485 | 0.950 | 0.872 |
| **C6** | 0.946 | 1.079 | 0.590 | 0.662 | 0.542 | 0.955 | 0.900 |
| **C7** | 0.968 | 1.128 | 0.692 | 0.730 | 0.589 | 0.969 | 0.916 |
| **C8** | 0.968 | 1.121 | 0.691 | 0.746 | 0.596 | 0.968 | 0.911 |
| **C9** | 0.969 | 1.193 | 0.742 | 0.767 | 0.610 | 0.980 | 0.920 |
| **C10** | 0.970 | 1.239 | 0.781 | 0.777 | 0.618 | 0.977 | 0.899 |
| **C11** | 0.966 | 1.081 | 0.782 | 0.780 | 0.615 | 0.978 | 0.920 |
| **C12** | 0.962 | 1.090 | 0.747 | 0.776 | 0.609 | 0.972 | 0.936 |
| **C13** | 0.992 | 1.089 | 0.954 | 0.815 | 0.621 | 0.968 | 0.917 |
| **C1-3** | 0.625 | 1.121 | 0.704 | 0.496 | 0.417 | 0.928 | 0.945 |
| **C4-6** | 0.789 | 1.080 | 0.655 | 0.564 | 0.467 | 0.943 | 0.873 |
| **C7-10** | 0.969 | 1.170 | 0.727 | 0.755 | 0.603 | 0.974 | 0.912 |
| **C11-13** | 0.973 | 1.087 | 0.861 | 0.790 | 0.615 | 0.973 | 0.924 |

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*SE=scale efficiency, TP=technical progress, TE=technical efficiency, CE=cost economies, Scope Economies=SE-CE

**Table 9: DEA and SPF, 2-Output, Farm Operator Household Model***

| | *DEA* | | | *SPF* | | | |
|---|---|---|---|---|---|---|---|
| | SE | TP | TE | SE | CE | TP | TE |
| **Total** | 0.870 | 1.214 | 0.729 | 0.827 | 0.417 | 0.978 | 0.951 |
| | | | | | | | |
| **1996** | 0.913 | 0.000 | 0.700 | 0.893 | 0.474 | 1.116 | 0.923 |
| **1997** | 0.941 | 1.334 | 0.719 | 0.793 | 0.378 | 1.008 | 0.941 |
| **1998** | 0.936 | 0.938 | 0.831 | 0.877 | 0.441 | 0.981 | 0.954 |
| **1999** | 0.794 | 0.986 | 0.741 | 0.791 | 0.366 | 0.923 | 0.965 |
| **2000** | 0.767 | 1.597 | 0.656 | 0.782 | 0.363 | 0.865 | 0.973 |
| | | | | | | | |
| **IL** | 0.842 | 1.255 | 0.753 | 0.864 | 0.440 | 0.972 | 0.958 |
| **IN** | 0.871 | 1.252 | 0.724 | 0.842 | 0.417 | 0.971 | 0.949 |
| **IA** | 0.885 | 1.210 | 0.737 | 0.851 | 0.423 | 0.970 | 0.952 |
| **MI** | 0.882 | 1.138 | 0.713 | 0.805 | 0.378 | 0.991 | 0.955 |
| **MN** | 0.860 | 1.178 | 0.699 | 0.806 | 0.379 | 0.985 | 0.953 |
| **MO** | 0.836 | 1.190 | 0.741 | 0.825 | 0.408 | 0.977 | 0.950 |
| **NE** | 0.891 | 1.381 | 0.742 | 0.846 | 0.420 | 0.953 | 0.944 |
| **OH** | 0.874 | 1.179 | 0.687 | 0.830 | 0.403 | 0.980 | 0.946 |
| **SD** | 0.887 | 1.185 | 0.771 | 0.825 | 0.413 | 0.976 | 0.957 |
| **WI** | 0.874 | 1.170 | 0.728 | 0.776 | 0.361 | 0.988 | 0.949 |
| | | | | | | | |
| **C1** | 0.884 | 1.664 | 0.970 | 0.570 | 0.230 | 0.923 | 0.951 |
| **C2** | 0.832 | 1.074 | 0.754 | 0.673 | 0.289 | 0.966 | 0.957 |
| **C3** | 0.916 | 1.048 | 0.721 | 0.784 | 0.344 | 0.988 | 0.954 |
| **C4** | 0.631 | 1.152 | 0.843 | 0.679 | 0.350 | 0.944 | 0.948 |
| **C5** | 0.696 | 1.092 | 0.718 | 0.717 | 0.348 | 0.970 | 0.952 |
| **C6** | 0.817 | 1.175 | 0.575 | 0.808 | 0.390 | 0.985 | 0.951 |
| **C7** | 0.907 | 1.239 | 0.645 | 0.871 | 0.431 | 0.996 | 0.951 |
| **C8** | 0.921 | 1.232 | 0.627 | 0.895 | 0.444 | 0.994 | 0.950 |
| **C9** | 0.939 | 1.216 | 0.646 | 0.930 | 0.469 | 1.001 | 0.949 |
| **C10** | 0.943 | 1.274 | 0.683 | 0.950 | 0.494 | 0.998 | 0.946 |
| **C11** | 0.946 | 1.203 | 0.708 | 0.954 | 0.490 | 0.953 | 0.949 |
| **C12** | 0.897 | 1.187 | 0.713 | 0.938 | 0.486 | 0.984 | 0.957 |
| **C13** | 0.985 | 1.224 | 0.879 | 0.984 | 0.492 | 0.977 | 0.951 |
| | | | | | | | |
| **C1-3** | 0.877 | 1.262 | 0.815 | 0.675 | 0.287 | 0.959 | 0.955 |
| **C4-6** | 0.715 | 1.140 | 0.712 | 0.734 | 0.362 | 0.966 | 0.951 |
| **C7-10** | 0.928 | 1.240 | 0.650 | 0.911 | 0.460 | 0.997 | 0.949 |
| **C11-13** | 0.943 | 1.205 | 0.767 | 0.959 | 0.489 | 0.985 | 0.953 |

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*SE=scale efficiency, TP=technical progress, TE=technical efficiency, CE=cost economies, Scope Economies=SE-CE